ISPSG Project No: IS07/02

First Annual Report

Regional Jurassic-Lower Cretaceous tectono-stratigraphy of the conjugate North Atlantic margins

Yongtai Yang and Patrick M. Shannon

UCD School of Geological Sciences, Science Education and Research Centre, University College Dublin, Belfield, Dublin 4. Ireland

Executive Summary

The overall aim of the project is to provide an improved regional understanding of the Jurassic to Early Cretaceous facies, structure and development in the North Atlantic region. While concentrating initially upon the Porcupine Basin due to the availability of a robust database, it will later expand into a circum-North Atlantic context. The project plays a pivotal role in setting the detailed work of the PhD project of Cedric Bulois (ISPSG Project ISO4/04) in a regional context, while providing critical regional constraints on potential provenance sources and sediment transport pathways being examined in the PhD project of Aine McElhinney (ISO6/09). The main scientific focus of the first year has been on reviewing the available models and data on regional North Atlantic Jurassic to Early Cretaceous development, and on re-interpreting available seismic and well data in order to provide a fresh understanding of the nature, controls, mechanisms of formation and resultant sedimentary facies of the Late Jurassic to Early Jurassic transition.

A data base of 15 key wells and approximately 4000 km of seismic reflection data from the northern half of the Porcupine Basin were examined. While the seismic data quality is variable, making it frequently difficult to map the details of the Jurassic structure, the Base Cretaceous Unconformity is regionally identifiable and mappable. Sufficient details within the Upper Jurassic and Lower Cretaceous successions are imaged to question some long-standing interpretations and to provide new ideas concerning the tectonostratigraphic evolution of this interval, with regional implications for structure and facies development.

While the conventional interpretation of the Jurassic-Lower Cretaceous succession in the Porcupine Basin suggests an extensional setting with progressive deepening of the basin, evidence from the study suggests that compression/transpression, uplift and erosion may have played a role in the shaping of the depositional and structural architecture of the basin. Major structures are mapped, together with structural and stratal geometries that are compatible with a phase of compressional/transpressional tectonism in earliest Cretaceous times. Work is ongoing to test the models and to assess their implications in a regional context.

1. Summary of work

Since Dec. 2008 when Yongtai Yang began his postdoctoral project, the following work has been accomplished:

Regional assessment of Jurassic-Cretaceous of the Atlantic Margin. During the first year of the project, Yang read and evaluated all the relevant published literature and available reports related to the regional North Atlantic Jurassic to Early Cretaceous development, in order to assess the data and regional geological interpretations and models.

Acquiring and loading well and seismic data. Geological data from 27 wells in the Porcupine Basin and eight wells in the Slyne Basin were provided by the Petroleum Affairs Division (PAD). 10 2D seismic surveys in the Porcupine Basin and six 2D and 6 3D seismic surveys in the Slyne Basin were provided by PAD. The 2D seismic surveys (SPEC97, GEOT97, GECO97, NOPC97, HGSW93, HGSD93, MESP81, 85BP34, CHIR80, MARA96) in the Porcupine Basin were loaded on the UCD Marine and Petroleum Geology Charisma workstation.

Well and seismic interpretation. The aim of the tectono-stratigraphy study in the Porcupine Basin is to understand the nature, controls, mechanisms of formation and resultant sedimentary facies of the Late Jurassic to Early Jurassic transition. Data from 15 chosen key wells and approximately 4000 km of seismic reflection data from the northern half of the Porcupine Basin were examined. The Upper Jurassic and the Berriasian strata were mapped in the area.

2. Geological Setting

The Porcupine Basin lies in deep (200 m to more than 2000 m) waters on the continental shelf offshore western Ireland (Figs 1, 2) and contains up to 9 km of Mesozoic and Tertiary sediments (Coker and Shannon, 1987). The Middle Jurassic non-marine to shallow-marine sandstones in the basin are attributed to an onset warp phase in which a general depositional sag occurred, largely devoid of faulting (Sinclair et al., 1994). During the Late Jurassic, the basin experienced a major rifting period, with the development of a range of lithofacies from basin-edge alluvial fans and fluvial strata to deep marine submarine fans (Naylor et al., 2002). Cretaceous and Tertiary sediments represent deposition during regional thermal subsidence following cessation of crustal extension (Croker and Shannon, 1987). However, these were interrupted by phases of Tertiary differential subsidence, sagging and tilting resulting in deltaic to basin floor fan sandstones as well as deep marine siltstones, mudstones and thin limestones (Praeg et al., 2005; Stoker et al., 2005).

Drilling data demonstrate a sedimentation break during the earliest Cretaceous, which lasted from several to tens of million years (Fig. 3). Naylor and Anstey (1987) mapped a widespread, regional Base Cretaceous Unconformity reflecting a major change in tectono-sedimentary architecture. Growth faulting with rapid lateral facies variation was replaced by regionally extensive deep-water mudstones and localised sandstones. Moore (1992) showed that a transition sequence (straddling the late syn-rift to early post-rift development) occurred in isolated areas within the basin during the Berriasian. Tate (1993) attributed a series of conspicuous north-south ridges in northeastern part of the basin to transpressional inversion across the Jurassic-cretaceous boundary. Therefore, the transition from the Late Jurassic rifting phase to the Early Cretaceous thermal subsidence phase was not a simple or sharp boundary.

Tectonism during the earliest Cretaceous has been reported in a number of Irish Atlantic margin basins (Fig. 1). A major unconformity at the base of the Cretaceous succession in the Slyne Basin was attributed by Corcoran and Mecklenburgh (2005) to exhumation and erosion during the

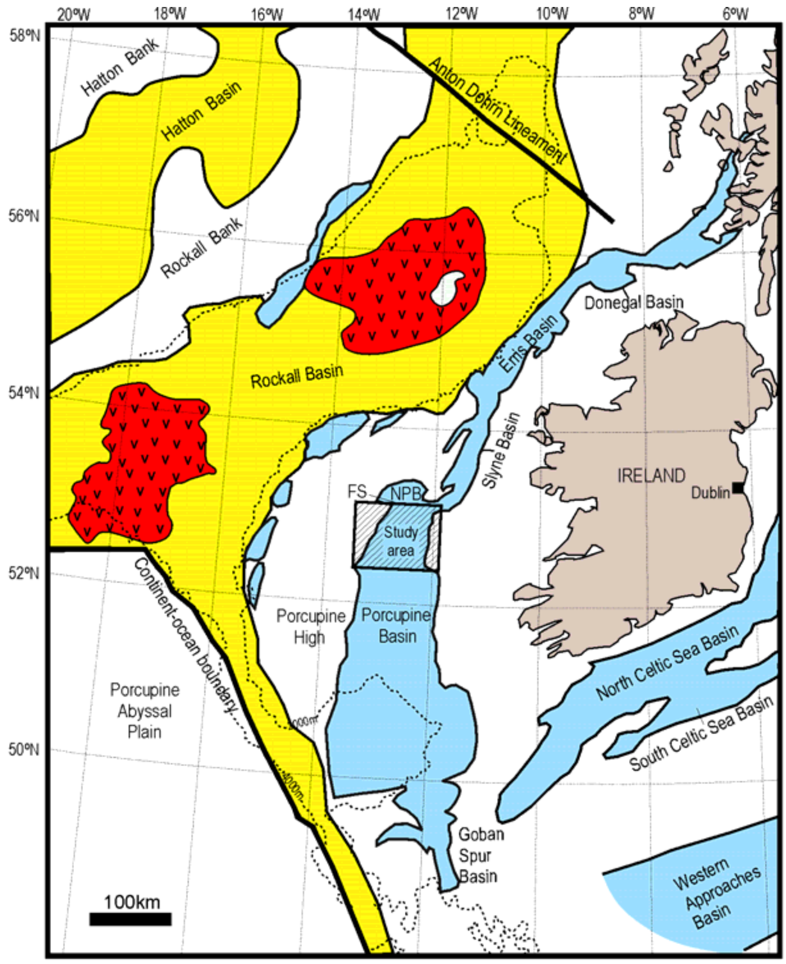

Figure 1. Irish offshore Mesozoic basins (modified from Corfield et al. 1999; Naylor et al., 2002), showing the study area in the northern Porcupine Basin. Blue: Jurassic rifted basin. Yellow: Cretaceous depocenters of the Rockall Basin and Hatton Basin. NPB: North Porcupine Basin. FS: Finnian's Spur. Red areas in the Rockall Basin: Cretaceous and Tertiary igneous rocks.

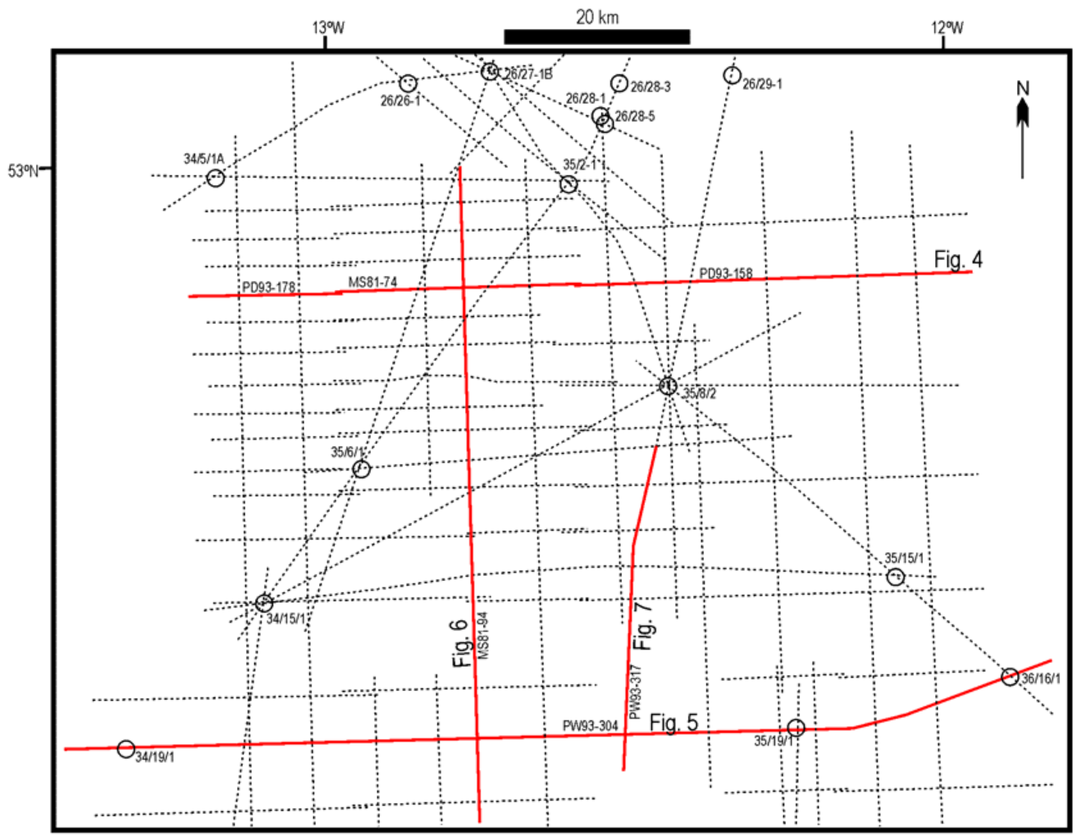

Figure 2. The study area in the northern Porcupine Basin, showing the seismic lines and wells used in this study.

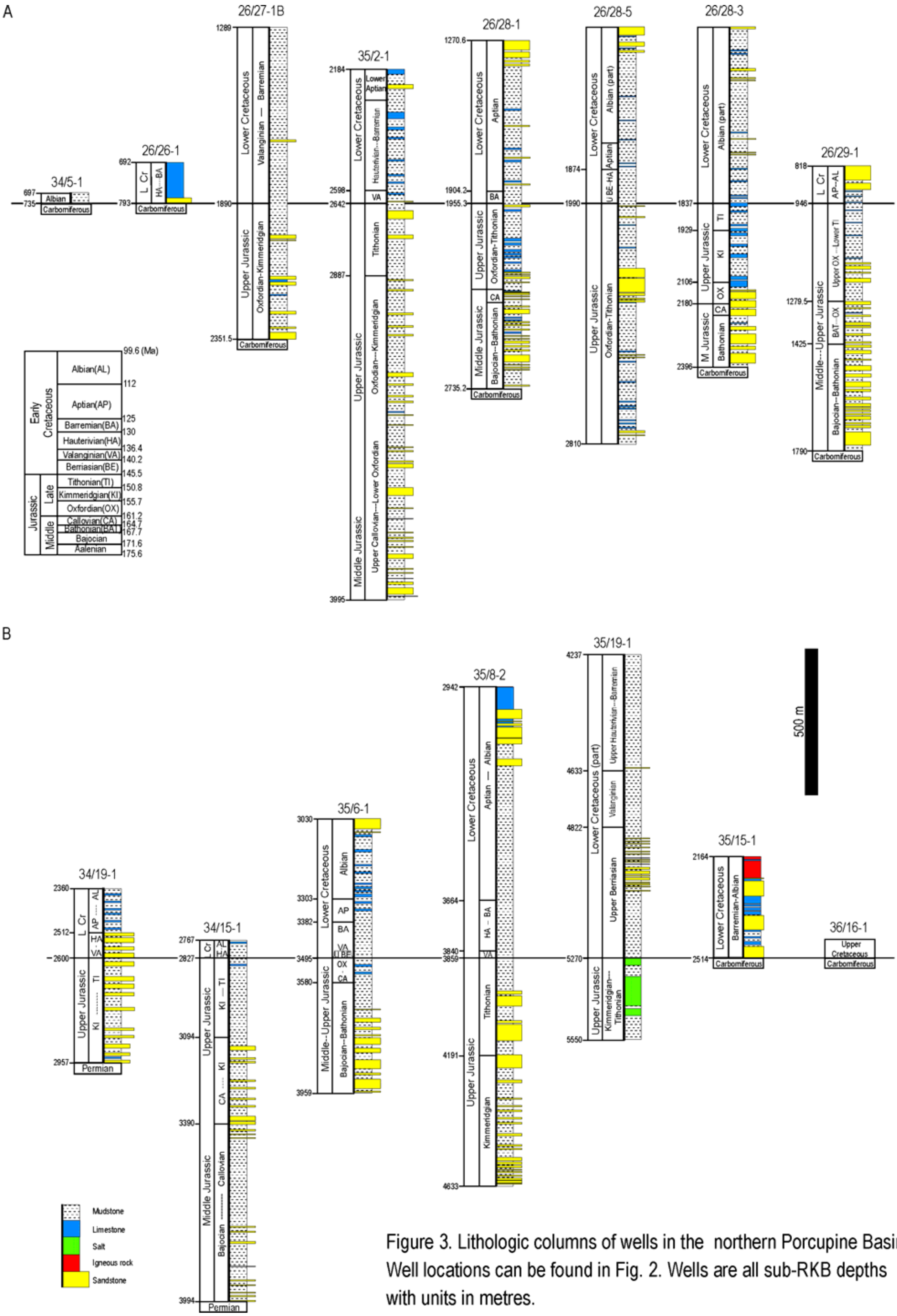

Figure 3. Lithologic columns of wells in the northern Porcupine Basin. Well locations can be found in Fig. 2. Wells are all sub-RKB depths with units in metres.

Berriasian-Valanginian. During the earliest Cretaceous, the western margin of the Erris Basin experienced extensive uplift and consequent erosion (Chapman et al., 1999), attributed by these authors to the effects of rifting and resultant flank uplift in the Rockall Basin.

3. Seismic and well correlation

Approximately 4000 km of seismic reflection data (Fig. 2), with geological constraints from 15 wells (Fig. 3), were examined from the Porcupine Basin in this phase of the project. Six seismic markers, constrained by well data, were mapped (Figs 4-7). The base of the Middle Jurassic (BMJ) and the base of the Upper Jurassic (BUJ) are mainly based on extrapolation from control wells 26/28-1, 26/28-3 and 35/2-1 (Fig. 3). The widespread Base Cretaceous Unconformity (BCU) is an important seismic maker and was encountered in all 15 wells (Fig. 3). The Base Upper Berriasian (BUB) is a surface recognised above the earliest Cretaceous sediments but which is only identified in the isolated synclinal structures (Figs 4-6) and has not been drilled. The sediments between the Base Cretaceous Unconformity (BCU) and the Base Upper Berriasian (BUB) are designated as the Lower Berriasian. The Base Valanginian surface (BVA) is based on well 35/39-1 (Fig. 3). The sediments between the Base Cretaceous Unconformity (BCU) and the Base Valanginian (BVA) are designated as the Berriasian. The Base Upper Cretaceous Chalk (BCH) is an important regional seismic marker in the basin.

4. Major structural style and features

The western boundary of the Jurassic rift basin is controlled by linked faults 1, 2 and 3 (Fig. 8). Fault 1 is a low-angle SE-dipping fault (Figs 4, 6), while the faults 2 and 3 are higher angle SE-dipping faults (Fig. 5). A thick Upper Jurassic growth-fault controlled succession lies in the NNE-trending half-graben to the east of faults 2 and 3. To the east of the half-graben, a NNE-trending structural high (H_1) has a Cretaceous succession resting upon the pre-Jurassic strata (Figs 5, 6, 8). The NW-dipping fault 7 and NE-dipping fault 8 define the northwestern and northern boundaries respectively of H_1. To the east of H_1, fault 9 is an important growth-fault and controlled the deposition in the central part of the study area. Therefore, H_1 was probably a relative structural high area during the Late Jurassic and received thin Upper Jurassic sediments (Fig. 9). Fault 13 is the eastern bounding fault of the Late Jurassic rift basin. It is suggested that this fault was reactivated after the deposition of the Upper Cretaceous Chalk, resulting in a prominent displacement of the base of the chalk succession between the hangingwall and footwall (Figs 4, 5).

A series of folds have been identified in the Jurassic strata (Fig. 10). Most of them have a NNE trend. However, structure S_4 trends in an east-west direction, while the Ruadan High (RH) has a nearly north-south trend. Many of the wells in this part of the basin have been drilled on the structural highs.

The NNE-trending syncline S_1 is located at the northwestern part of the study area and lies between two structural highs (Figs 4, 10). Its formation is suggested to be linked to the inversion of fault 1. During the latest Jurassic-earliest Cretaceous, faults 1 is suggested to have undergone inversion, resulting in the formation of fault-propagation anticline within the Upper Jurassic strata adjacent to the fault.

The NNE-trending syncline S_2 is a large structure and is located at the hangingwall of the major normal fault 9 (Figs 5, 6, 10). The Late Jurassic synrift strata thicken toward the fault 9 across the synclinal axis, showing that folding occurred mainly after the deposition of the Upper Jurassic (Fig. 5). On Figure 6 the folding of the pre-BCU strata is interpreted as a fault-propagation anticline with the north-directed inversion of the hangingwall along fault 9. To the south of the syncline S_2,

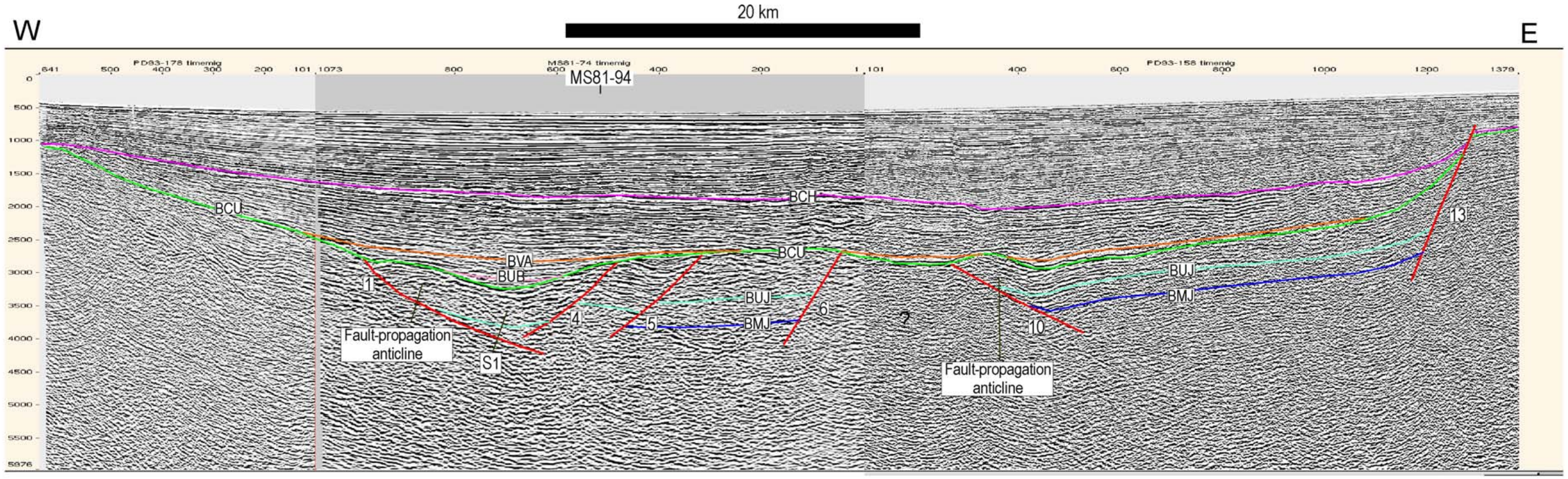

Figure 4. Seismic profile of PD93-178, MS81-74, PD93-158, with location in Fig. 2. BMJ: the base of the Middle Jurassic; BUJ: the base of the Upper Jurassic; BCU: the Base Cretaceous Unconformity; BUB: the base of Upper Berriasian; BVA: the base of Valanginian; BCH: the base of the Upper Cretaceous chalk. The fault number can be found on Fig. 8.

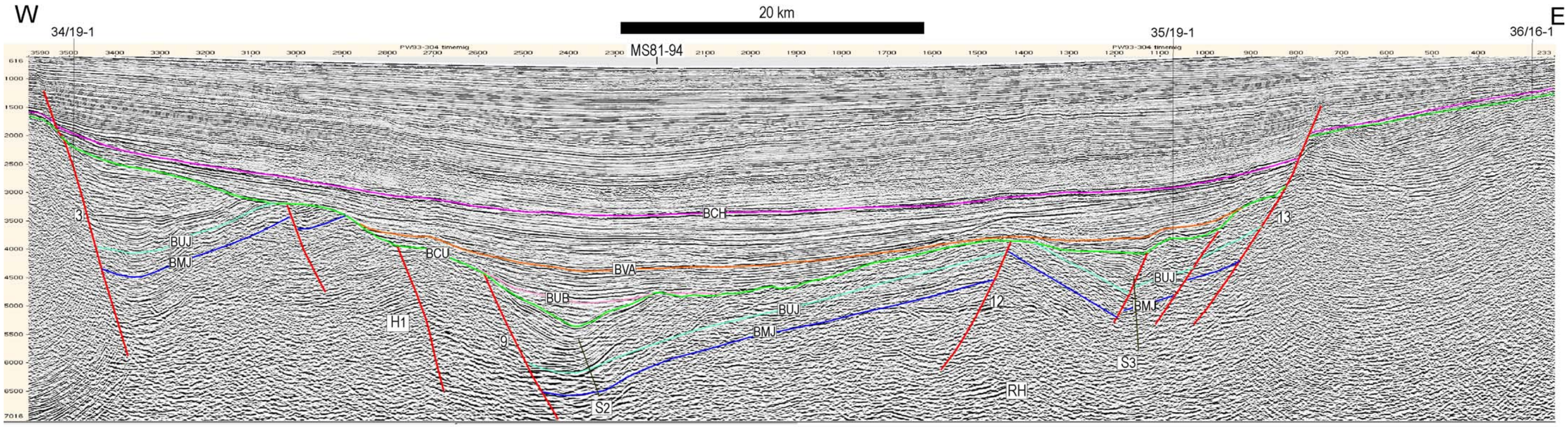

Figure 5. Seismic profile of PW93-304, with location in Fig. 2. BMJ: the base of the Middle Jurassic; BUJ: the base of the Upper Jurassic; BCU: the Base Cretaceous Unconformity; BUB: the base of Upper Berriasian; BVA: the base of Valanginian. BCH: the base of the Upper Cretaceous chalk. The fault number can be found on Fig. 8.

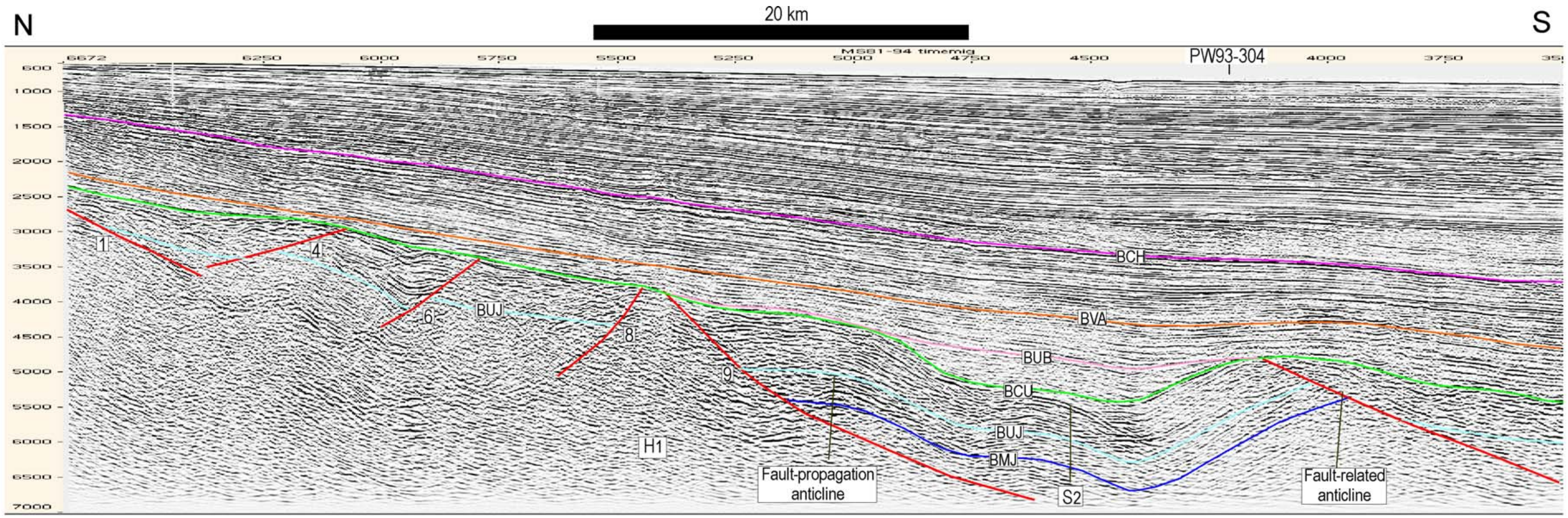

Figure 6. Seismic profile of MS81-94, with location in Fig. 2. BMJ: the base of the Middle Jurassic; BUJ: the base of the Upper Jurassic; BCU: the Base Cretaceous Unconformity; BUB: the base of Upper Berriasian; BVA: the base of Valanginian. BCH: the base of the Upper Cretaceous chalk. The fault number can be found on Fig. 8.

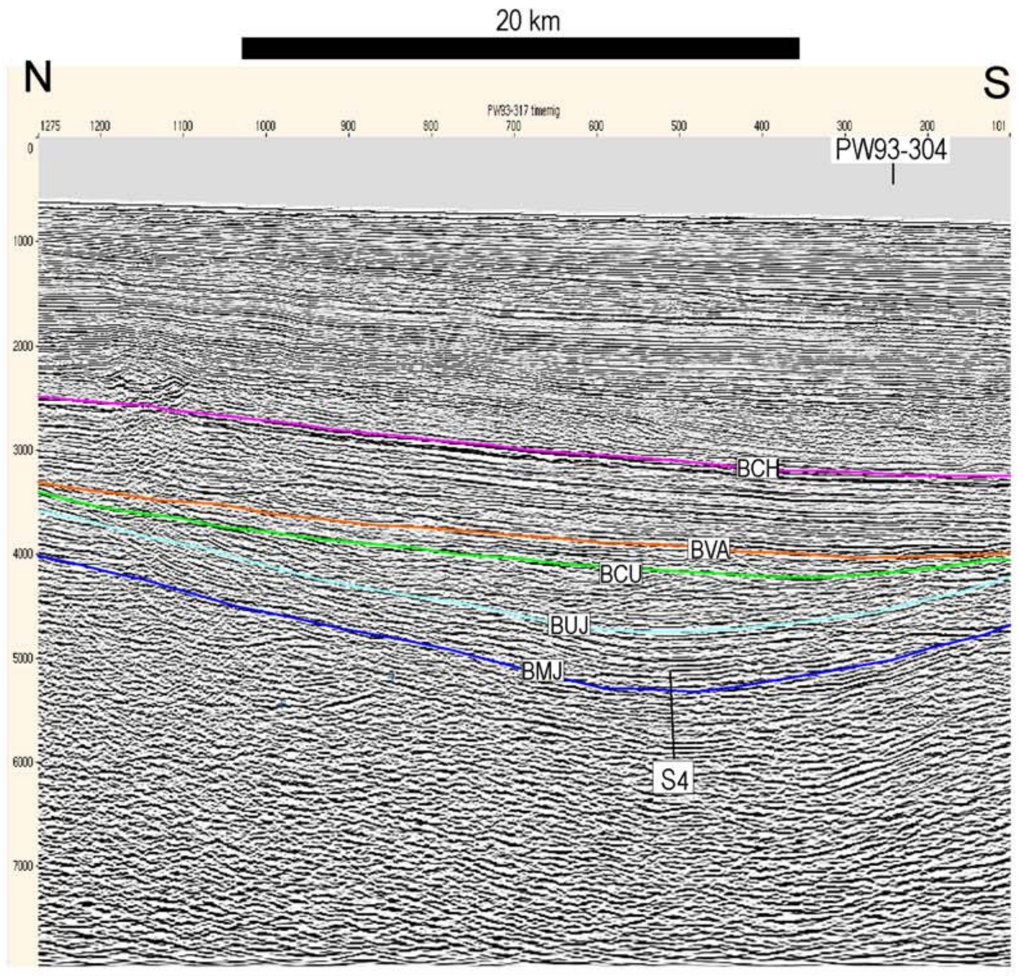

Figure 7. Seismic profile of PW93-317, with location in Fig. 2, mainly showing the syncline S4.

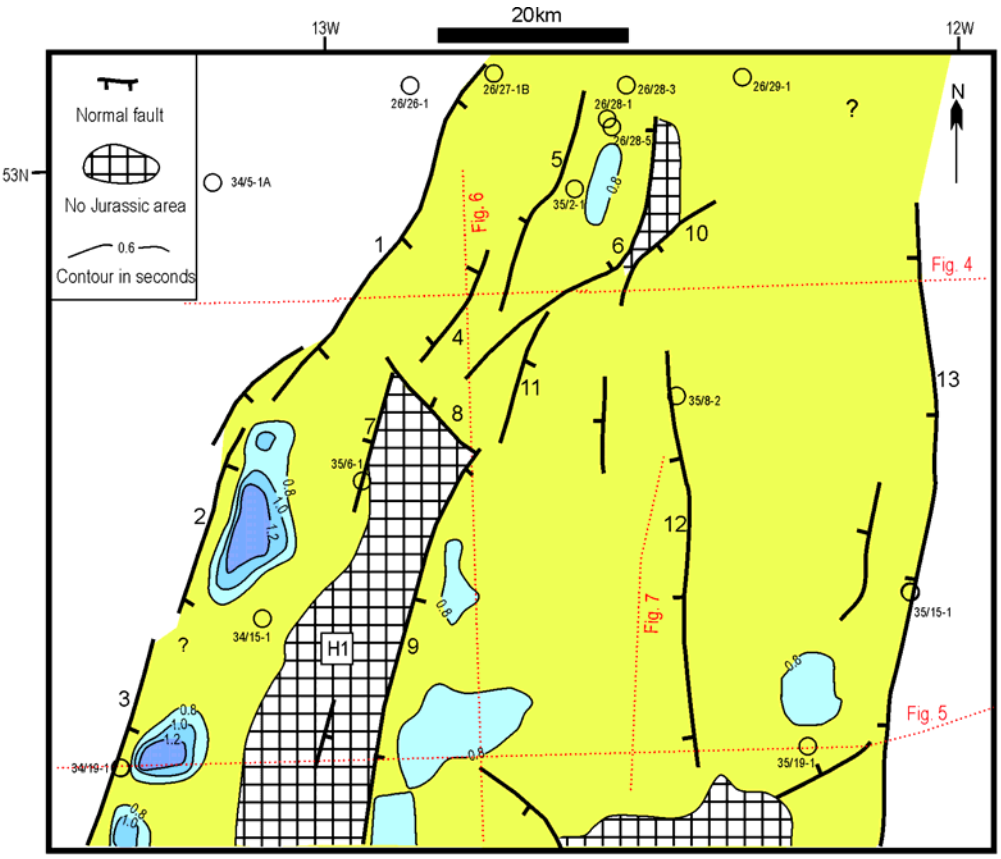

Figure 8. The normal faults formed during the Late Jurassic and the remnant thickness of the Upper Jurassic in the northern Porcupine Basin, showing seismic lines used in figs. 4, 5, 6 and 7.

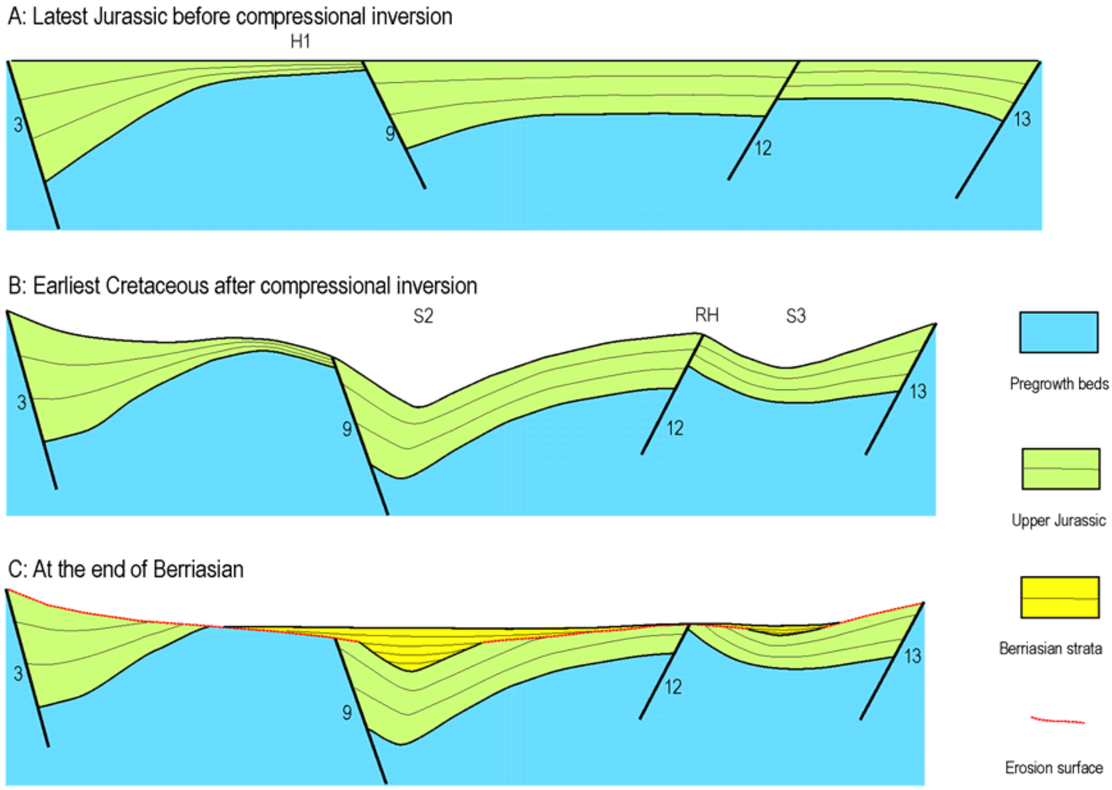

Figure 9. A schematic W-E trending cross section, showing the evolution of the southern part of the study area during the latest Jurassic-earliest Cretaceous.

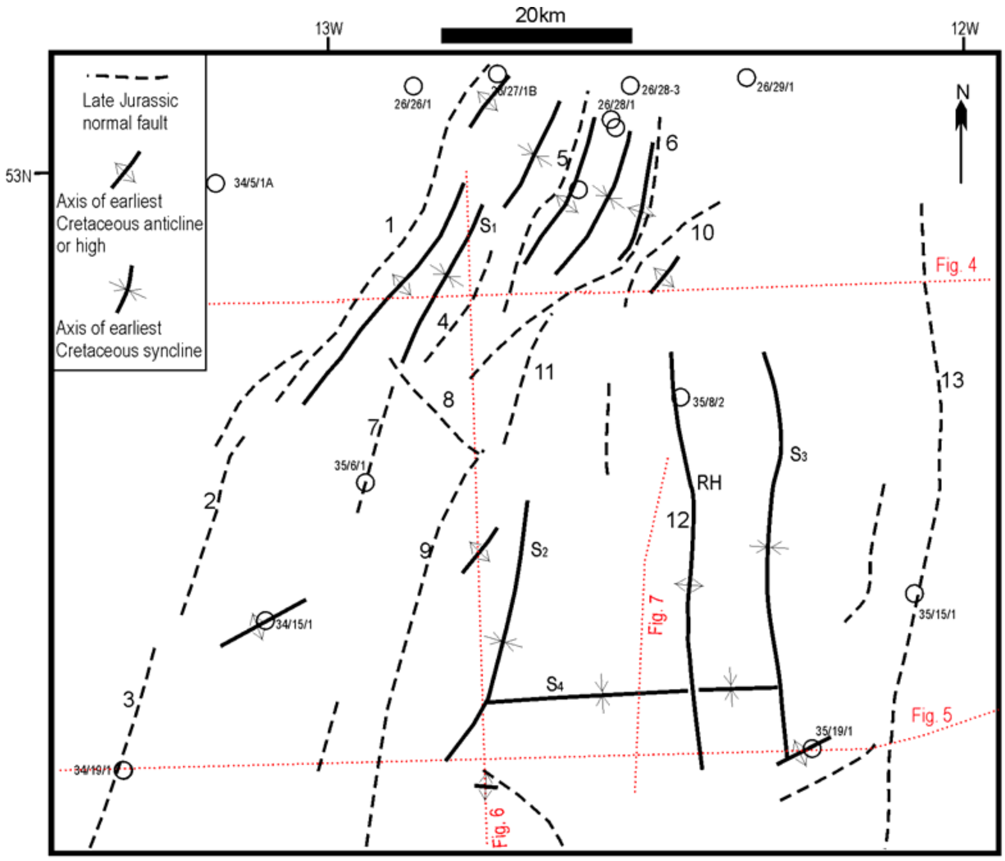

Figure 10. Distribution map of anticlines, highs and synclines in the northern Porcupine Basin, formed during the latest Jurassic-earliest Cretaceous, showing seismic lines used in figs. 4, 5, 6 and 7.

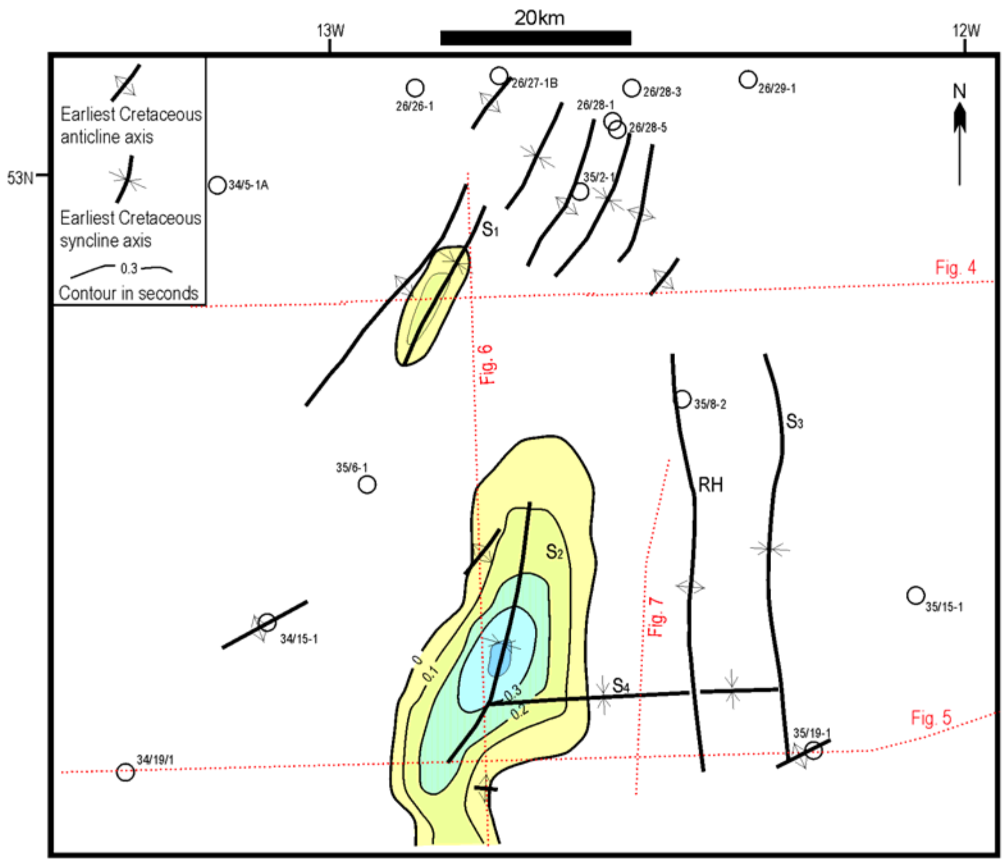

Figure 11. The isopach map of the Lower Berriasian, showing seismic lines used in figs. 4, 5, 6 and 7.

it shares its southern limb with a fault-related anticline which has a high fold amplitude. This structure cannot be traced to other seismic lines, suggesting that the trend of the related fault is oblique to the compressional stresses, producing strike-slip or local transpressive folds. Alternatively, the basement high (H_1) could have buffered compressive stresses resulting in a re-orientation of the stress field and the resulting deformation.

RH is an elongate N-S structural fault-controlled complex feature (Figs 5, 10), almost 100 km long, named as the Ruadan Ridge by Tate (1993) and the Ruadan High by Naylor et al. (2002). Tate (1993) suggested that the feature might be the product of transpressional inversion across the Jurassic-Cretaceous boundary. Naylor et al. (2002) proposed that it may have been produced during a shearing or inversion episode. Here the RH is interpreted as an asymmetric structural high that was inverted during the earliest Cretaceous, driven by compressional or transpressional stresses (Fig. 9). Fault 12 is the focus of the inverted structure, with opposing strata dips on both sides (Fig. 5). Due to the uplift of the RH structure, Upper Jurassic strata near its axis were eroded, forming an angular unconformity between the Jurassic and Cretaceous strata at the limbs of the high, with Cretaceous and earliest Tertiary strata draped across the crest of the structure.

The N-S trending synclinal depocentre S_3, located at the eastern part of the study area, is sub-parallel to the high RH (Figs 5, 10). Its formation is closely related to the inversion of the RH. Due to uplifting of the RH and the buttress effect of the footwall block of the fault 13 during inversion, a synclinal depocentre was formed. The sediments within this structure show the progressive onlap of post-BCU strata onto the structural highs to the east and west (Fig. 9).

Syncline S_4 has a W-E trend (Figs 7, 10). At its western end, it intersects with the syncline S_1, although the exact nature and details of the contact are poorly constrained. Towards the east, it is offset by the RH structure, but to the east of the RH, it still can be traced to the boundary with syncline S_3. Syncline S_4 lies to the north of a Jurassic palaeohigh (Fig. 8). It is suggested that compressional stresses were focussed by the paleohigh, resulting in the formation of the S_4 synclinal structure immediately to the north of the palaeohigh.

5. Early Cretaceous deposition

Lower Berriasian strata have not been drilled in the study area (Fig. 3). Seismic data (Figs 4, 5, 6) suggest that earliest Cretaceous strata were deposited in synclinal depocentres S_1 and S_2, with a long oval pattern focusing the axes of synclines (Fig. 11). The axis of the syncline S_2 received the thickest Lower Berriasian sediments. Well 35/19-1 is located on a local structural high in the S_3 syncline, and the absence of Lower Berriasian strata in this well doesn’t negate the possibility of the presence of a thin and localized Lower Berriasian succession in the deepest part of the S_3 depocentre as seismic data show older post-BCU strata than that drilled in the well (Figs 3, 5). Therefore, it is suggested that during the Early Berriasian, with the exception of the synclinal depocentres, extensive areas in the northern Porcupine Basin experienced uplift and became erosional areas.

During the Late Berriasian, sediments were still deposited surrounding the synclinal depocentres S_1, S_2, and S_3, but with a more extensive distribution than the Lower Berriasian strata (Figs 4, 5, 6, 7, 12). The syncline S_2 in the central part continued to be the major depocentre. The Ruadan High also received thin and localized Upper Berriasian strata (Figs 5, 12). However, the southwestern part and the northernmost part of the study area were uplifted and erosional areas throughout the Berriasian time. Due to the uplifting of the southwestern area to the west of fault 9, the Upper Jurassic strata on the H_1 structural high was eroded and an angular unconformity was formed between the Jurassic strata in the half-graben and the onlapping Cretaceous strata (Figs 5, 9). The

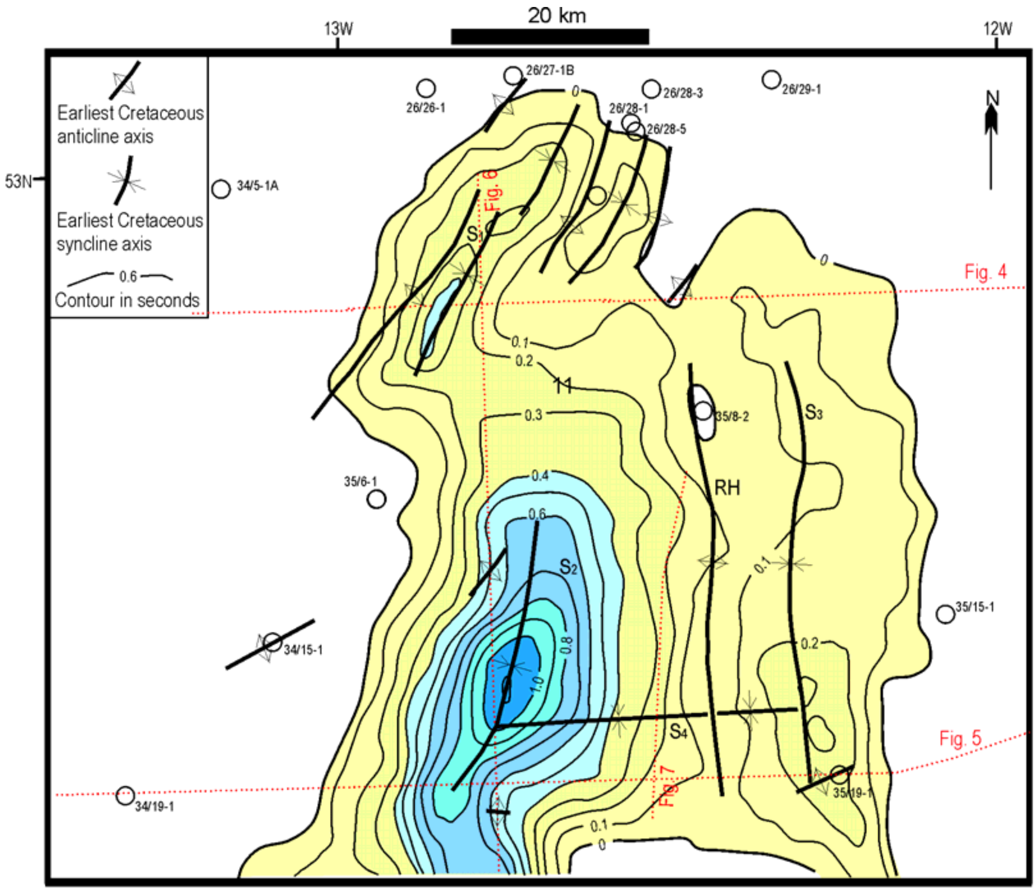

Figure 12. The isopach map of the Berriasian, showing seismic lines used in figs. 4, 5, 6 and 7.

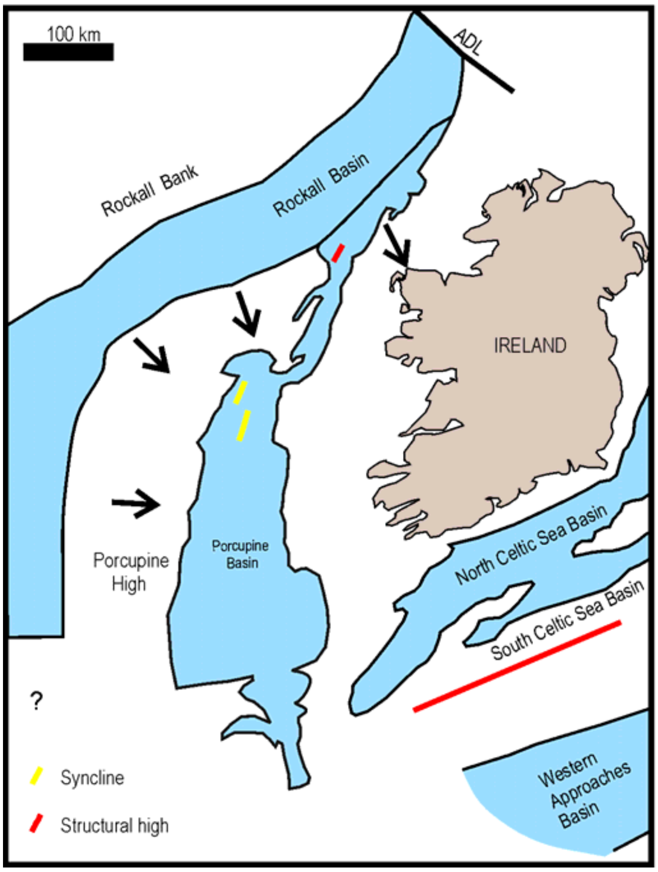

Figure 13. The restored Rockall Trough before its major extension, based on Corfield et al. (1999). The major extension in the Rockall Basin during the latest Jurassic-earliest Cretaceous produced intense compressional stresess to its neighbouring areas, resulting in intense deformation. A series of NNE-trending folds were formed in the northern Porcupine Basin.

northernmost part of the basin underwent long-term erosion of more than 20 Ma in some areas (Fig. 3).

Significant erosion and a depositional hiatus of the uplifted areas in the northern Porcupine Basin during early Cretaceous times are suggested. The eroded material is likely to have been deposited in the adjacent structural lows through a range of deposional systems (e.g. basin floor fans, debris flows or fluvio-deltaic systems depending upon the water depth), offering the potential for early Cretaceous stratigraphic traps. The quality of the reservoirs will be governed by the nature of the basement (e.g. Devonian, Carboniferous or Lower Palaeozoic rocks) and the Jurassic strata. The sediment transport pathways, and the distribution of the resultant reservoir fairways, will be controlled by the shape and extent of the structural highs and lows. Research to test these hypotheses is planned within the PIP-funded Jurassic-Cretaceous research programme.

6. Deformation mechanisms

As described in section 4 above, a set of NNE-trending structural highs and lows were formed in the northern part of the Porcupine Basin during the latest Jurassic-earliest Cretaceous. These elongate structures typically trend NNE-SSW. The highs are associated with major syn-rift faults and generally show indications of folding, while the lows show many of the characteristics of compressional synclines but may also have a compactional component. This is consistent with the results of numerical and analogue models showing that pre-existing weak zones exert an important control on the location and orientation of structural inversion (Eisenstadt and Withjack, 1995; Buiter and Pfiffner, 2003; Panien et al., 2005). The formation of syncline S2 in the central study area is the most prominent feature of the compressional deformation during the late Jurassic-earliest Cretaceous, consistent with the analogue model showing that hangingwall syncline of major normal fault becomes more pronounced with increased shorting (Elsenstadt and Withjack, 1995). The NNE-trending structures are most pronounced in the western and northern parts of the study area which underwent relatively longer uplift and erosion, suggesting that the northern Porcupine Basin may have received SE-directed compressional stresses coming from an area to the northwest of the Porcupine Basin (Fig. 13).

The Rockall Basin experienced rifting during the Late Jurassic and Early Cretaceous (Shannon et al., 1999), with associated volcanic systems during the earliest Cretaceous (Scrutton and Bentley, 1988; Corfield et al., 1999) (Figs 1, 13). Crustal extension beneath the Rockall Basin is likely to have had an impact on the basin flanks and on adjacent regions, producing major flexural cantilever-driven basin margin footwall uplift, while transmitted stresses may have resulted in either compressional stresses or themally-driven uplift in neighbouring areas (Fig. 13). These stresses are likely to have modified the original geometry of the Late Jurassic rift basin and may have given rise to flexure, folding and transpressional movement along faults to explain the features described in the study.

7. A regional tectonic event

In a regional context, a series of features in the earliest Cretaceous succession can be attributed to the extension of the Rockall Basin (Fig. 13). During the earliest Cretaceous, the western margin of the Erris Basin experienced extensive uplift and consequent erosion (Chapman et al., 1999). During the Berriasian-Valanginian, the Slyne Basin underwent a significant exhumation and erosion, forming a major unconformity at the base of the Cretaceous succession (Corcoran and Mecklenburgh, 2005). These authors interpreted the Corrib anticlinal structure to be a product of continued Permo-Triassic halite doming and Middle-Late Jurassic extension. However, it is possible that a component of the NE-trending Corrib structure may be attributed to compressional stresses produced by the extension of Rockall Basin during the latest Jurassic-earliest Cretaceous.

To the south of Ireland, a major unconformity also marks the Jurassic-Cretaceous boundary throughout the Celtic Sea, suggesting a basin inversion episode (Shannon, 1991) (Fig. 13). An intense compressional deformation and subsequent erosion in the South Celtic Sea Basin during the early Cretaceous has been proposed (Van Hoorn, 1987; Bulnes and McClay, 1998). Lake and Karner (1987) suggested that regional subcrustal lithospheric readjustment to local crust extension caused uplift in the Wessex basin, south UK, during the earliest Cretaceous. A Late Jurassic-Early Cretaceous uplift and subsequent erosion in the Western Approaches Basin, offshore France has also been demonstrated (Ruffell, 1995). McMahon and Turner (1998) mapped a latest Jurassic-earliest Cretaceous NEE-trending uplift at the Cornubian Platform between the South Celtic Basin and the Western Approaches Basin. Structural deformation and uplift in the offshore area to the south of Ireland and the UK, and to the northwest of France during the latest Jurassic-earliest Cretaceous may been caused largely by N to NE-directed compression resulting from co-eval rifting in the Bay of Biscay region. However, there may also have been a component of NW-directed compression from the extension in the Rockall and southern Porcupine basins. Further detailed work will be necessary to quantify the timing and magnitude of regional uplift, together with assessment of kinematic indicators of stress directions to unravel the causes of what appears to be a regionally extensive and important inversion phase.

8. Future plans

The major tasks and objectives of the coming months are as follows:

1. Evaluate the likely extent and effect of compressional deformation throughout the Porcupine Basin in the earliest Cretaceous, and constrain the magnitude of exhumation and erosion of the crestal highs.
2. Investigate the seismic character of the earliest Cretaceous strata with a view to elucidating the depositional setting and to developing potential stratigraphic trap potential in the Early Cretaceous structural lows. This work also has the possibility of providing input for the ongoing provenance PhD project.
3. Extend the regional aspect of the research through reviewing data and interpretations from other parts of the Atlantic Margin, and particularly the Canadian offshore, if such data can be located and accessed.
4. Prepare and submit a paper to an international peer-reviewed journal on the nature and extent of Early Cretaceous compressional structures.

9. References

Buiter, S. J. H. & Pfiffner, O. A. 2003. Numerical models of the inversion of half-graben basins. *Tectonics*, **22**, 10.1029/2002TC001417.

Bulnes, M. & McClay, K. 1998. Structural analysis of the inverted central South Celtic Sea Basin. *Marine and Petroleum Geology*, **15**, 667-687.

Chapman, T. J., Boks, T. M., Corcoran, D. V., Ducan, L. A. & Dancer, P. N. 1999. The structural evolution of the Erris Trough, offshore northwest Ireland, and implications for hydrocarbon generation. *In:* Fleet, A. J. and Boldy, S. A. R. (eds) *Petroleum geology of northwest Europe: proceedings of the fifth conference*, Geological Society, London, 455-469.

Corcoran, D. V. & Mecklenburgh, R. 2005. Exhumation of the Corrib Gas Field, Slyne Basin, offshore Ireland. *Petroleum Geoscience*, **11**, 239-256.

Corfield, S., Murphy, N. & Parker, S. 1999. The structural and stratigraphic framework of the Irish Rockall Trough. *In*: Fleet, A. J. & Boldy, S. A. R. (eds) *Petroleum Geology of Northwest Europe: Proceedings of the 5th Conference*. Geological Society, London, 407-420.

Croker, P. F. & Shannon, P. M. 1987. The evolution and hydrocarbon prospectivity of the Porcupine Basin, offshore Ireland. *In*: Brooks, J. and Glennie, K.W. (eds) *Petroleum geology of North West Europe*. Graham and Trotman, London, 633-642.

Eisenstadt, G. & Withjack, M. O. 1995. Estimating inversion: results from clay models. *In*: Buchanan, J. G. & Buchanan, P. G. (eds) *Basin Inversion*, Geological Society, London, Special Publications, 88, 119-136.

Lake, S. D. & Karner, G. D. 1987. The structure and evolution of the Wessex Basin, southern England: an example of inversion tectonics. *Tectonophysics*, 137, 347-78

McMahon, N. A. & Turner, J. 1998. The documentation of a latest Jurassic-earliest Cretaceous uplift throughout southern England and adjacent offshore areas. *In*: Underhill, J. R. (eds) *Development, Evolution and Petroleum Geology of the Wessex Basin*. Geological Society, London, Special Publications, **133**, 215-240.

Moore, J. G. 1992. A syn-rift to post-rift transition sequence in the Main Porcupine Basin, offshore western Ireland. *In*: Parnell, J. (eds) *Basins on the Atlantic Seaboard: Petroleum Geology, Sedimentology and Basin Evolution*. Geological Society, London, Special Publications, **62**, 333-349.

Naylor, D. & Anstey, N. A. 1987. A reflection seismic study of the Porcupine Basin, offshore west Ireland. *Irish Journal of Earth Sciences*, **8**, 187-210.

Naylor, D., Shannon, P.M. & Murphy, N.J. 2002. Porcupine-Goban region - a standard structural nomenclature system. Petroleum Affairs Division, Special Publication, 1/02.

Panien, M., Schreurs, G. & Pfiffner, A. 2005. Sandbox experiments on basin inversion: Testing the influence of basin orientation and basin fill. *Journal of Structural Geology*, **27**, 433-445.

Praeg, D., Stoker, M. S., Shannon, P.M., Ceramicola, S., Hjelstuen, B.O. & Mathiesen, A. 2005. Episodic Cenozoic tectonism and the development of the NW European 'passive' continental margin. *Marine and Petroleum Geology, 22*, 1007-1030.

Ruffell, A. 1995. Evolution and hydrocarbon prospectivity of the Brittany Basin (Western Approaches Trough), offshore north-west France. *Marine and Petroleum Geology*, **12**, 387-407.

Scrutton, R. A. & Bentley, P. A. D. 1988. Major Cretaceous volcanic province on the southern Rockall Trough. *Earth and Planetary Science Letters*, **91**, 198-204.

Shannon, P. M. 1991. Tectonic framework and petroleum potential of the Celtic Sea, Ireland. *First Break*, **9**, 107-122.

Shannon, P. M., Jacob, A. W. B., O'Reilly, B. M., Hauser, F., Readman, P.W. & Makris, J. 1999. Structural setting, geological development and basin modelling in the Rockall Trough. *In*: Fleet, A. J. & Boldy, S. A. R. (eds) *Petroleum Geology of Northwest Europe: Proceedings of the 5th Conference*. Geological Society, London, 421-431.

Sinclair, I. K., Shannon, P. M., Williams, B. P. J., Harker, S. D. & Moore, J.G. 1994. Tectonic control on sedimentary evolution of three North Atlantic borderland Mesozoic basins. *Basin Research*, **6**, 193-218.

Stoker, M. S., Hoult, R. J., Nielsen, T., Hjelstuen, B. O., Laberg, J. S., Shannon, P. M., Praeg, D., Mathiesen, A., van Weering, T. C. E. & McDonnell, A. 2005. Sedimentary and oceanographic responses to early Neogene compression on the NW European margin. *Marine and Petroleum Geology*, **22**, 1031-1044.

Tate, M. P. 1993. Structural framework and tectono-stratigraphic evolution of the Porcupine Seabight Basin, offshore western Ireland. *Marine and Petroleum Geology*, **10**, 95-123.

Van Hoorn, B. 1987. The South Celtic Sea/Bristol Channel Basin: origin, deformation and inversion history. *Tectonophysics*, **137**, 309-334.

Williams, B. P. J., Shannon, P. M. & Sinclair, I. K. 1999. Comparative Jurassic and Cretaceous tectono-stratigraphy and reservoir development in the Jeanne d'Arc and Porcupine basins. *In*: Fleet, A. J. & Boldy, S. A. R (eds) *Petroleum Geology of Northwest Europe: Proceedings of the 5th Conference*. Geological Society, London, 487-499.