Impact on Ireland’s hydrocarbon potential of Cenozoic deformation and faulting

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1. Introduction

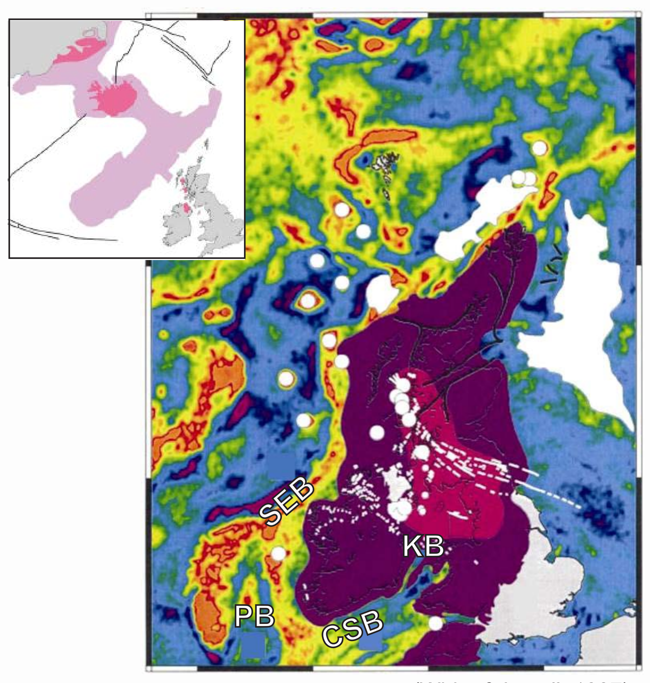
In much of the NW European continental shelf hydrocarbons are most often contained within Upper Jurassic traps, though increasing numbers of both structural and stratigraphic traps are hosted within younger Mesozoic and Cenozoic sequences. Previous work suggests that the 3 principal controls on Cenozoic deformation in offshore and onshore Ireland are:
(i) the Icelandic plume, causing widespread uplift and denudation, (ii) Alpine compression and (iii) Atlantic spreading, generating both extensional and compressional structures (Box 2 & 3). The predominance of any one factor on the nature and spatial distribution of Cenozoic structures is uncertain and likely to vary both spatially and temporally.

Whether or not Cenozoic faults arise from later compresion or extension they could play an important role in hydrocarbon leakage, either to higher structural levels or to the sea floor; as faults are widely recognised as fluid flow pathways, and seal breach by reactivation of trap-bounding faults is a major risk to hydrocarbon preservation. However, seal breach and trap integrity are dependent on the geometrical and kinematic attributes of trap-bounding faults. Thus, central to determining trap integrity is understanding the fault reactivation mechanisms and the factors controlling the geometry and growth of reactivated faults. Factors idenitifed as strongly influencing fault reactivation and subsequent fault geometry include fault size, orientation,dip direction and displacement distribution (Box 4)

In this project, we aim to establish much improved constraints on the nature, evolution and spatial distribution of Cenozoic structures which have the potential not only to provide for up-fault leakage of pre-existing traps, potentially to traps at higher structural levels, but could also form anticlinal or fault-related traps. The Fault Analysis Group has previously developed structural models for Cenozoic deformation in the Irish Sea and Porcupine basin, elements of which are presented here. This structural analysis will be extended to include the other major Irish offshore basins.

2. Cenozoic deformation

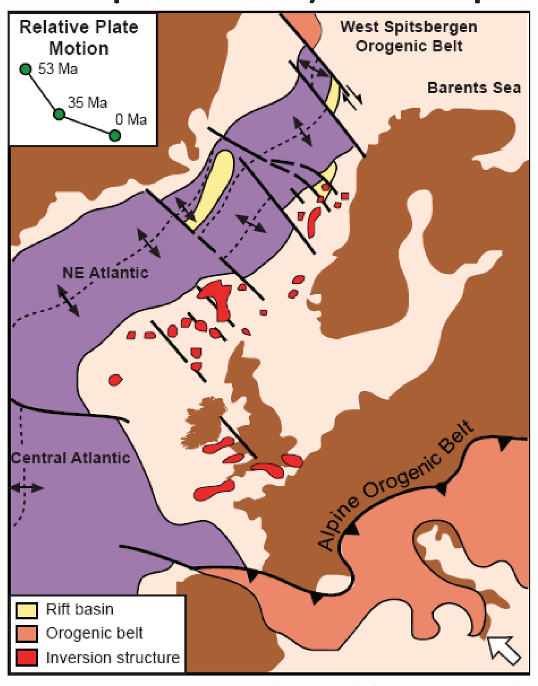
1) Icelandic plume activity



(White & Lovell, 1997)

A prolonged period of plume-related igneous activity during the Paleocene caused widespread uplift and denudation. The satellite free-air gravity map shows denudation of 0.5 - 1km (purple) to 2-3km (pink) during the Palaeogene. Large and small white circles indicate major and minor intrusive centres respectively. Labels mark Slyne-Erris Basin (SEB), Porcupin Basin (PB), Celtic Sea Basin (CSB) and Kish Bank Basin (KB).Inset shows onshore (pink) and offshore (purple) basalts associated with the plume (Cooper et al., 2012)

2) Alpine compression & 3) Atlantic spreading



(Naylor & Shannon, 2011)

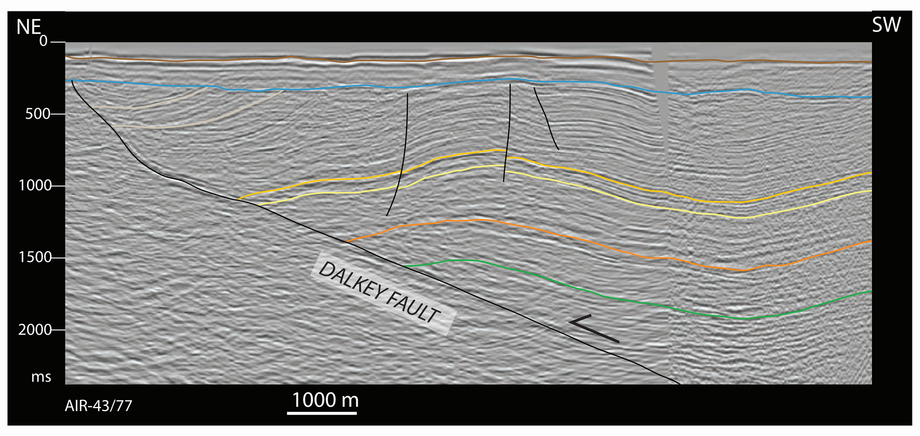
Alpine deformation is manifest as regional scale basin inversion and compressional deformation against earlier normal faults, as either fault reactivation, hangingwall buttressing or strike-slip faulting.

Deformation linked to Atlantic spreading can be either extensional, caused by rifting, or compressional arising from ridge-push related stresses or local plate reorganisation.

3. Cenozoic structures

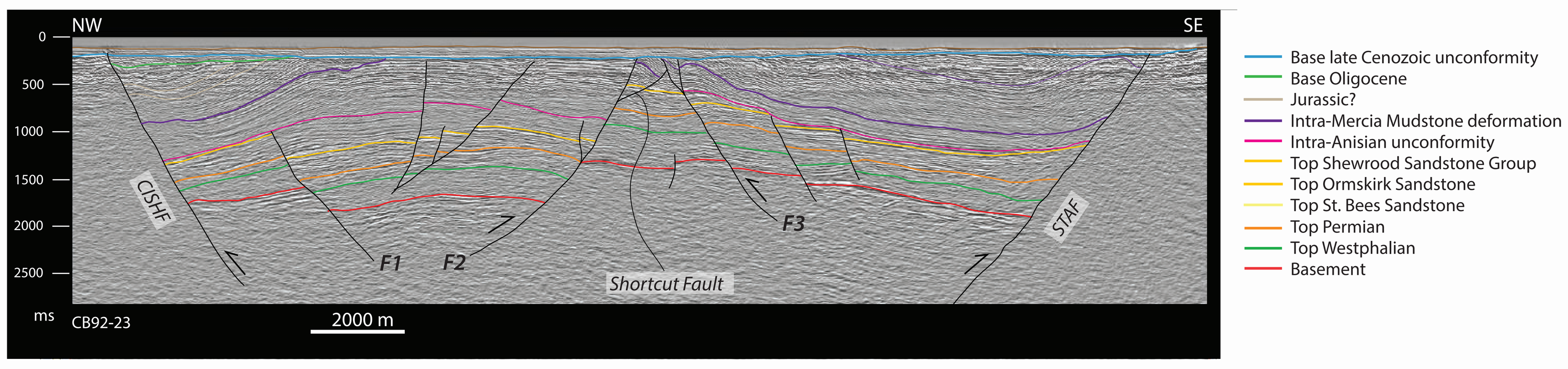
The seismic sections below illustrate the various forms of Cenozoic reactivation structure that have been observed within the Irish offshore basins to date, including buttressing, compressional anticlines and segmentation of upward propagating reactivated faults

Kish Bank & Central Irish Sea Basins

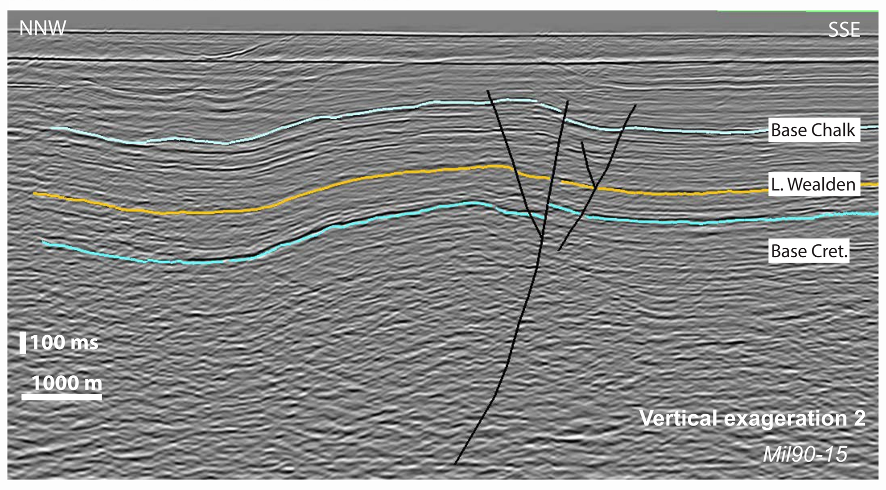
a)


a) Inversion in the Kish Bank Basin is exhibited as a ~4km wide anticline adjacent to the Dalkey Fault. The hinge of the fold is ~5km from the fault with a smaller syncline in the immediate hangingwall. This typeof buttress folding is restricted to the central section of the Dalkey Fault (Anderson, 2013).

b) The Central Irish Sea Basin has a much larger wavelength inversion-related anticlinal fold, ~13km wide and up to 2km in amplitude. The anticline is flanked by 2-3km wide hangingwall synclines and anticlines on the Central Irish Sea High (CISHF) and Tudwal’s Arch Faults (STAF) (Anderson, 2013).

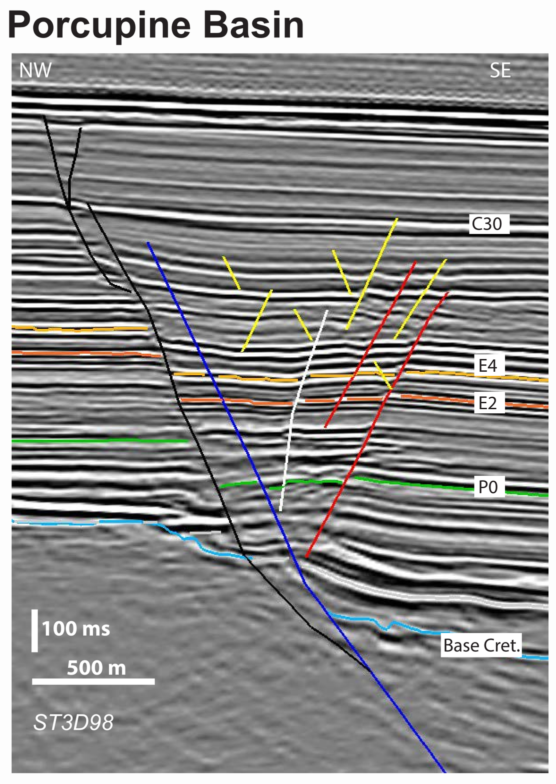
b)


North Celtic Sea Basin



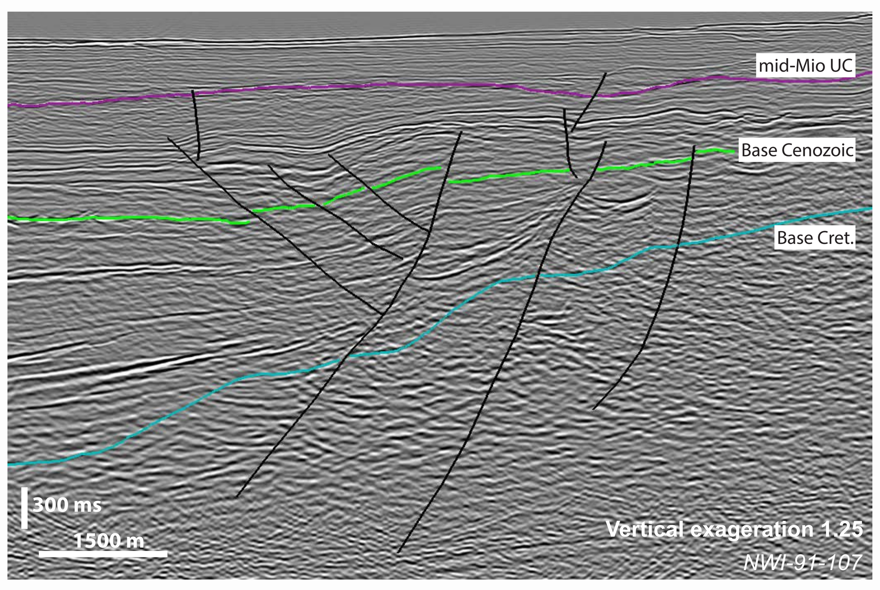
Alpine-related uplift and inversion is widespread in the North Celtic Sea. Characterised by basin doming and reverse faulting, which has formed km-scale compressive anticlines.

Porcupine Basin



Reactivation of a Jurassic basin bounding normal fault in the NW of the Porcupine basin during the Eocene (E2) (Worthington, 2007). Upward propagation of faults into the overlying cover sequences is often characterised by the formation of fault segment arrays. Segments may be soft linked through the Tertiary sequence or hard linked to the underlying Jurassic fault (Box 4 & 5).

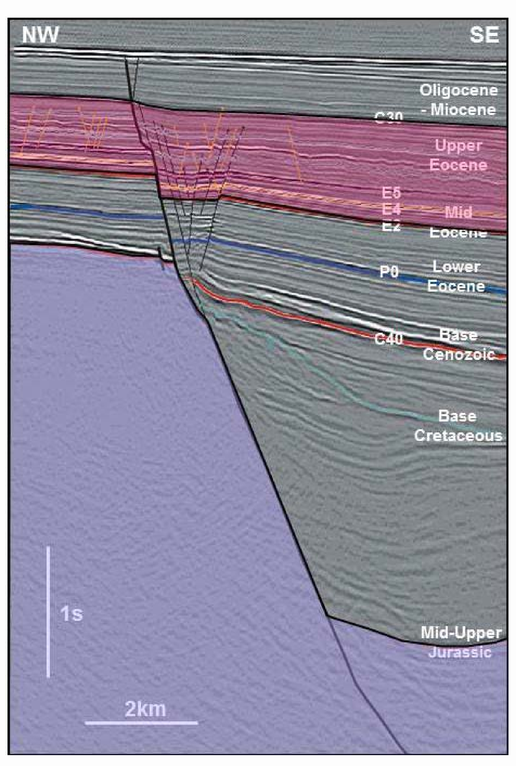
Erris Basin



Preliminary analysis of structures in the Erris basin has revealed the existence of reverse reactivation of normal faults and hangingwall buttressing, as represented in this seismic section from the Southern Erris Basin.

4. Geometric and kinematic analysis of reactivated faults

Kinematic analysis of faults within the Porcupine Basin by Worthington (2007) revealed a period of fault reactivation during the Eocene. These structures were previously attributed to compaction-driven faulting, but the fault geometry and growth indicate they were driven by a phase of extension, with regional fault-related strains of <0.5%.

a)


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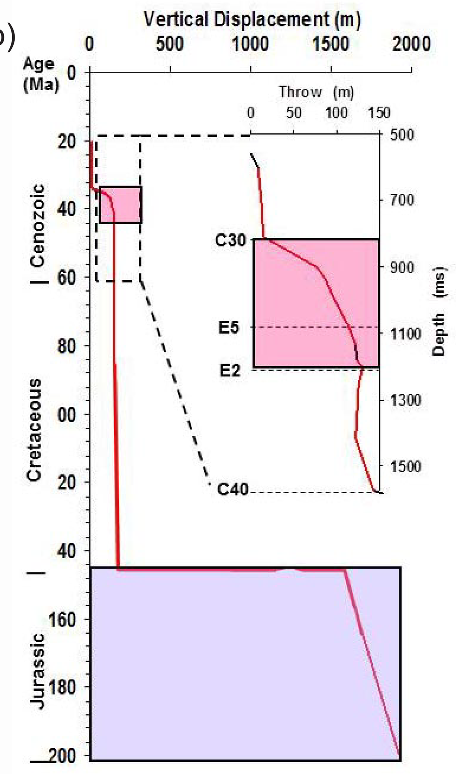
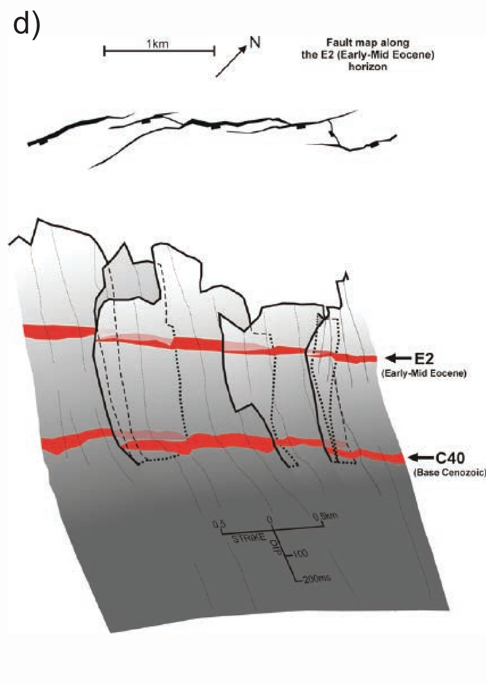


a) The seismic section shows a period of fault reactivation during the mid-upper Eocene indicated by sequence growth between E2 and C30 horizons.

b) The plot illustrates the upward change in displacement along the fault. With 2km of displacement during the Jurassic and 150m of reactivated displacement within a ~5Myr period during mid-upper Eocene time.

c)


d)


(Figures a-d from Worthington, 2007)

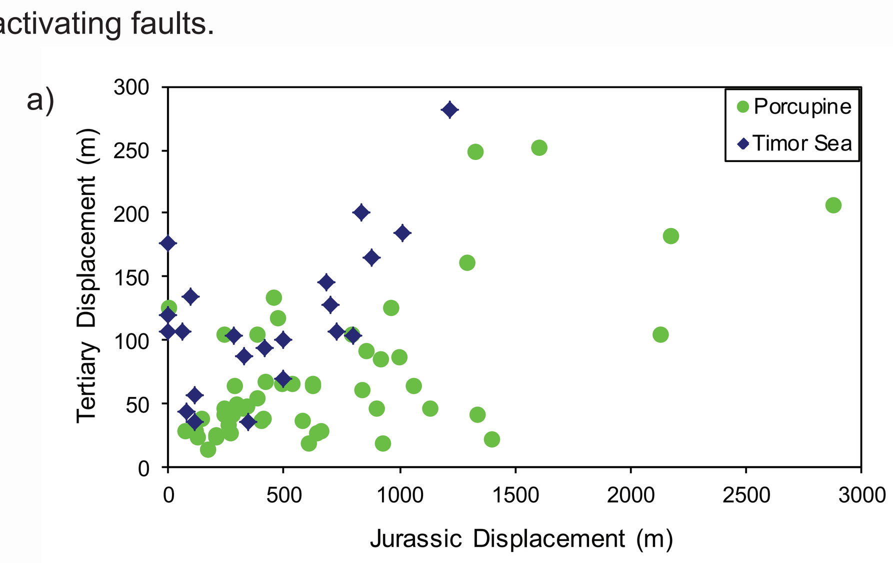
c) A horizon map through the mid-Eocene shows the segmented nature of the fault as it propagates upward into theTertiary cover sequence.

d) Some segments may not be linked to the underlying fault, as shown by the 3D model for this fault.

Segments become linked with increasing displacement by breaching of the intervening relays. The nature of fault segment linkage (soft-linked or hard-linked)has important implications for up-fault migration/leakage.

5. Geometric controls on reactivation and Trap integrity

Previous work by the Fault Analysis Group (Walsh et al., 2002) suggests that fault reactivation is controlled by certain geometrical parameters (fault size, orientation, dip direction) - a) Large faults are more likely to reactivate than smaller faults but b) whether reactivated fault segments are hard-linked through the cover sequence depends on the thickness of the cover sequence. Hence quantitative analysis of fault geometries may provide a basis for predicting the upward continuity of reactivating faults.

a)


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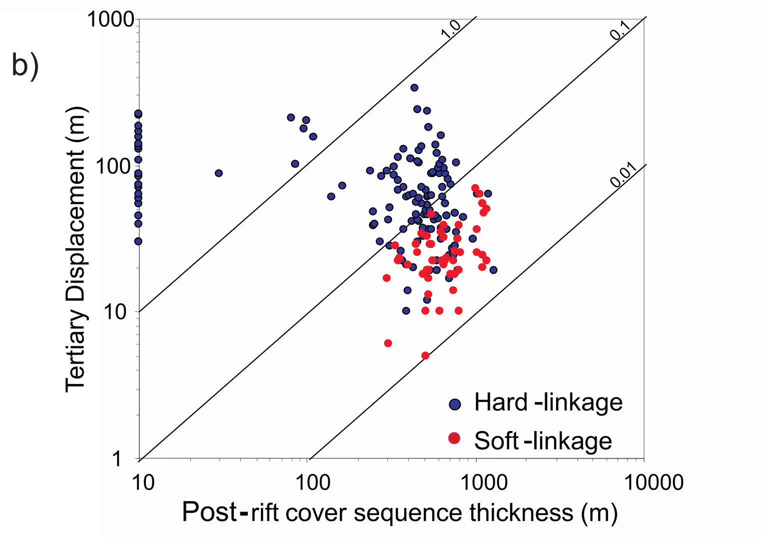
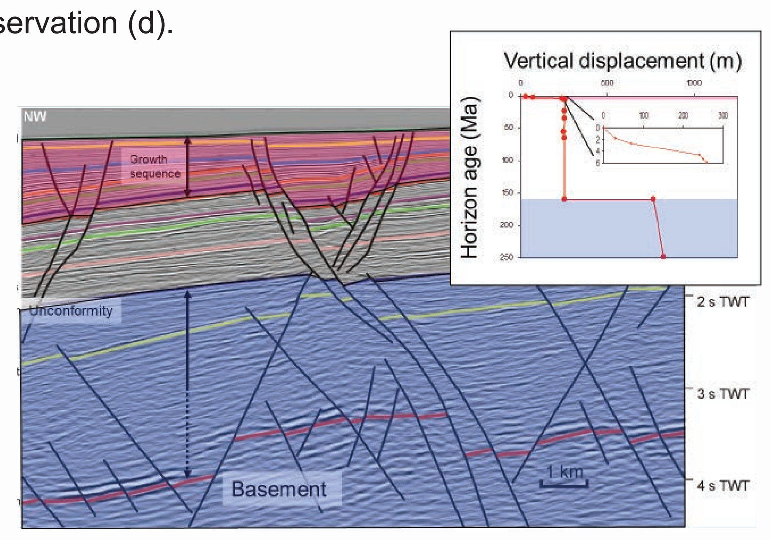
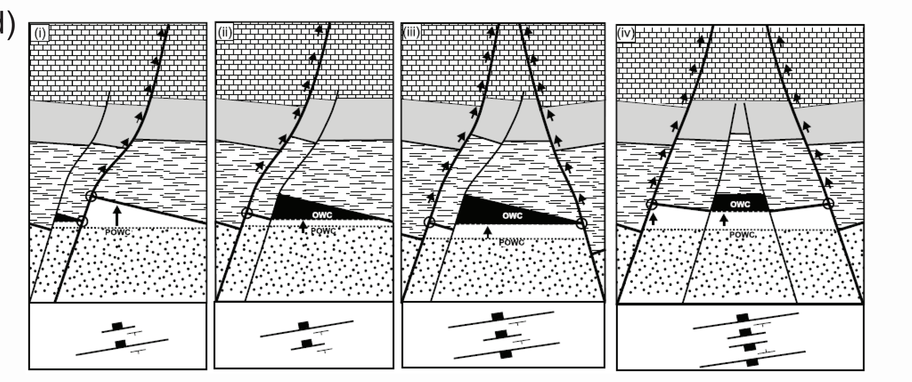


Such an approach was applied by Gartrell et al., (2006) in assessing the integrity of reactivated fault-bound traps and hydrocarbon preservation in the Timor Sea (c). Their work demonstrated the importance of the relationship between trap geometry and post-rift displacement distribution on the bounding faults. Interactions between overlapping faults resulted in heterogeneous displacement distributions associated with low-risk trap geometries and greater likelihood of hydrocarbon preservation. From these observations simple models were developed with which to risk trap integrity and hydrocarbon preservation (d).

c)


d)

(Figures c & d from Gartrell et al., 2006)

Reactivated faults within the Porcupine basin have features similar to those in the Timor Sea and it appears that similar factors control fault reactivation. Thus the trap integrity models developed for the Timor Sea may serve as a guide for assessing trap integrity within that basin - this project will explore this issue further.

6. Conclusions

Geometric analysis of reactivated faults offshore Ireland suggests that there are spatial and temporal changes in the nature of Cenozoic deformation. Alpine compression is the predominant influence on deformation in the Irish Sea and Celtic Sea Basins. The origin of Cenozoic deformation in the Porcupine and Slyne-Erris basin is unclear, and may be linked to Atlantic spreading or plume activity or both; thus far both extensional and compressional structures have been observed.

Determining the factors controlling fault reactivation and the geometry of the structures resulting from these driving forces is central to assesing the potential for reactivation of trap-bounding faults and thus trap integrity, as well as identifying possible anticlinal or fault-related traps.

Using a combined approach of structural analysis and hydrocarbon migration modelling this project will identify the factors controlling Cenozoic deformation and fault reactivation, the link between Cenozoic structures and underlying structures or potential traps and the impact of later deformation on trap formation and integrity.

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