

Real and Relict Direct Hydrocarbon Indicators in the East Irish Sea Basin

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Abstract

Seismic amplitude anomalies associated with the presence of hydrocarbon gas now play an important role in the exploration of the East Irish Sea basin. Tilted flat spots were first observed on data acquired by JEBSCO Seismic Ltd. in 1986 within the productive Triassic reservoir of the Sherwood Sandstone Group located in Quadrant 110 (offshore North Wales). With hindsight Direct Hydrocarbon Indicators (DHIs) can now be identified on seismic data acquired in earlier phases of the exploration of the East Irish Sea basin, although many anomalies were not always identified as such at that time.

This study determines the geophysical parameters by which amplitude anomalies associated with diagenetic variations could be separated from anomalies associated with the presence of gas in the reservoir. The predicted model results are compared with the seismic response of proven fields, discoveries and relict or palaeo-DHIs around the basin. Practical implications for effective exploration, development and production methods in the Sherwood Sandstone are suggested.

Anomalous seismic reflections and amplitude variations associated with the presence of hydrocarbon fluids have been observed over the last twenty years in many localities worldwide and described by various authors, Backus and Chen (1975), White (1977) and Brown (1986). The presence of DHIs on seismic data acquired in the East Irish Sea was first reported by geoscientists working the basin in the mid and late 1970's (V. Colter pers. comm. 1991).

The existence of relict or palaeo gas-water contacts associated with the distribution of diagenetic platy illite in the sub-surface, had been determined previously by mapping borehole data for the Morecambe Gas field (Bushell 1986). The hypothesis that some of the observed seismic amplitude anomalies in this basin are associated with diagenetic boundaries in the Triassic sandstones (palaeo-DHIs or direct porosity indicators) rather than the presence of present day gas was postulated.

The seismic reflection character of the main lithostratigraphic units is well established in the East Irish Sea basin (Ross & Flack 1992). Seismic markers for the major formation and member boundaries of the top Ormskirk, Calder, Rottington and Manchester Marls and also the Hercynian unconformity have been recognised and used across the basin by various authors (Arter & Fagin 1993; Knipe *et al.* 1993).

The Permo-Triassic structure and stratigraphy of the East Irish Sea basin is well known and has been described by various authors (Jackson & Mulholland 1993; Jackson *et al.* 1987; Colter 1978). The basin is linked to the contiguous onshore West Lancashire basin where similar stratigraphic sequences have been described (Warrington *et al.* 1980; Smith *et al.* 1974) and similar structural styles exist.

The Formby Point platform is a major structural element of the study area (Fig. 1). The feature is associated with a positive Bouguer gravity anomaly which defines the platform's



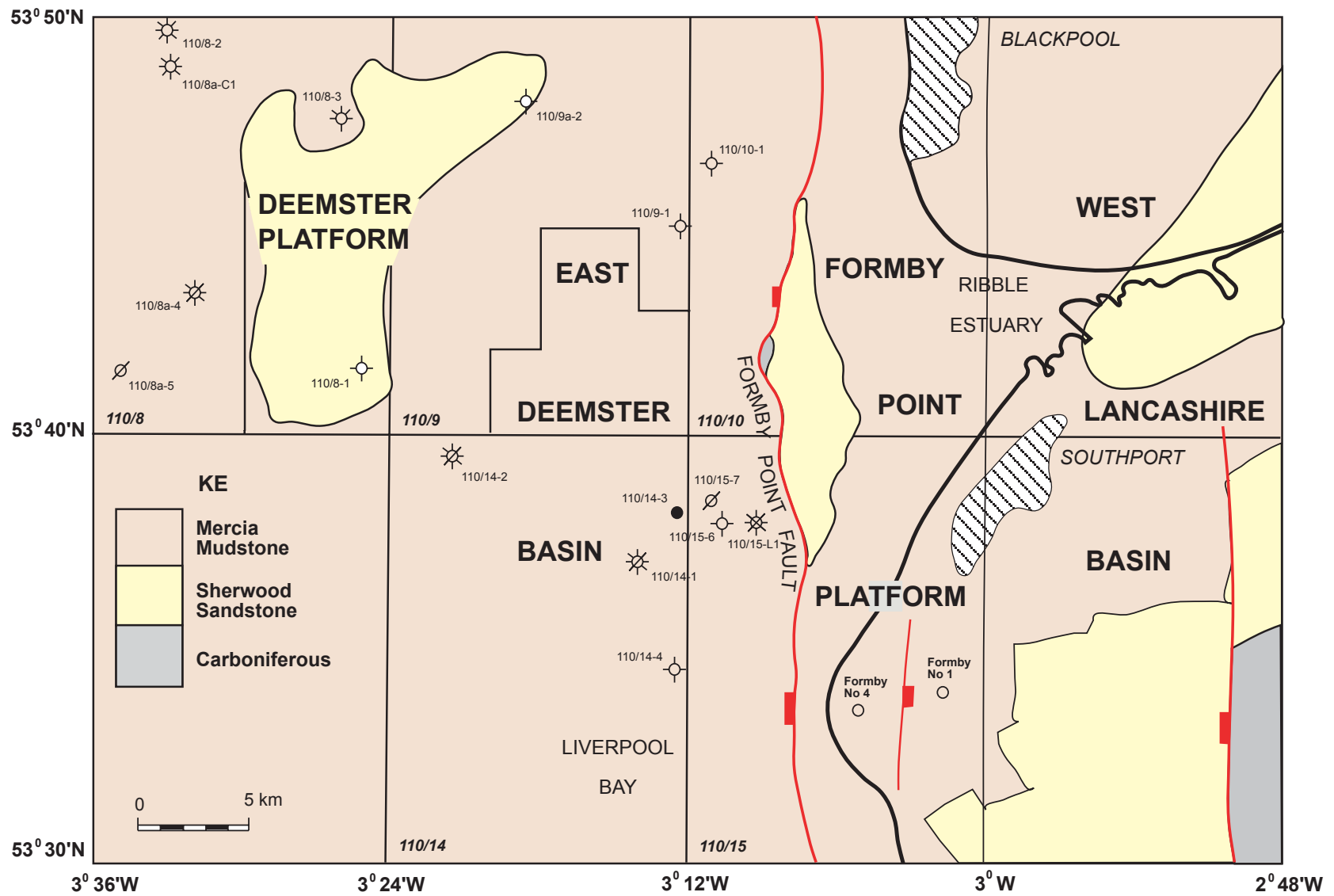
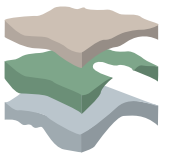


Figure 1 Location Map of the Study Area

From Meadows, N.S., Trueblood, S.P., Hardman, M. & Cowan, G. (eds), 1997, *Petroleum Geology of the Irish Sea and Adjacent Areas*, Geological Society Special Publication No. 124, pp. 185-194



extent along the Lancashire coast (Deegan 1977). It is bounded on the east and west sides by gravity lows which are associated with Permo-Triassic basins that contain Mercia Mudstone Group sediments at outcrop (Chesher & Jackson 1994), as proved by wells Formby No. 1 onshore (Kent 1948) and 110/9-1 offshore (Jackson *et al.* 1987).

Prior to the removal of the Mercia Mudstone Group seal during the Tertiary, it is probable that the Formby Point platform, like the nearby Deemster platform in Block 110/8, was a major hydrocarbon trap (Fig. 1). Well composite logs for borehole 110/8-1 on the Deemster platform record the existence of live and dead oil staining in the Sherwood Sandstone Group from 450 feet down to 1900 feet sub-sea level (137m to 580m), implying either a hydrocarbon fluid migration route or the remnants of a previously filled trap.

Observed amplitude anomalies

Fig. 2 shows an east-west orientated 2D seismic line located offshore in Quadrant 110. (For reasons of commercial confidence the exact location of this line cannot be shown). The line illustrates four of the significant structural elements of this area; the West Lancashire basin, the tilted fault block of the Formby Point platform; the Formby Point fault and the East Deemster basin (part of the main East Irish Sea basin).

Two significant seismic amplitude anomalies are apparent on Fig. 2. To the east, on the Formby Point platform, a strong anomaly at 280 msec (estimated depth 1640 feet or 500 metres) cross-cuts the dipping reflectors of the Triassic Sherwood Sandstone Group. To the west at 580 msec a bright spot is apparent in the Ormskirk Sandstone Formation on the crest of the roll-over anticline, that contains the Lennox field, next to the Formby Point fault.

The possibility that the amplitude anomaly located on the Formby Point platform is due to a present day gas-water contact within the Triassic Sherwood Sandstone Group can be discounted for the following reasons:-

- (i) The platform was tested onshore by the Formby No. 4 well located near Formby Point (Fig. 1). This well was spudded in the Mercia Mudstone Group and penetrated the water-wet Triassic Sandstone, above the level of the offshore seismic anomaly, at a depth of 720 feet (220 metres) below Ordnance Datum (Falcon & Kent 1960).
- (ii) Offshore mapping to the north of Formby Point demonstrates that the Sherwood Sandstone Group sub-crops the recent marine sediments in the mouth of the Ribble Estuary (Chesher & Jackson 1994) thereby breaching any potential platform-wide trap (Fig. 1).
- (iii) Seismic interpretation of Fig. 2 confirms that the Sherwood Sandstone Group strata sub-crop the Quaternary offshore and so lack a competent enough seal above the anomaly (c.f well 110/8-1 on the Deemster platform).

It is proposed here that the most likely explanation for the anomalous seismic event on the Formby Point platform seen on Fig. 2 is that it arises from an acoustic impedance contrast caused by a diagenetic boundary within the Triassic sandstones. Above this boundary, the formations have had a different diagenetic history to those parts of the same formation lying below the event. A different diagenetic history can best be explained by the existence of a former hydrocarbon fill in the sandstones of at least 500 metres (1640 feet) present thickness, and estimated to be originally 1100 metres (3600 feet) pre-Tertiary erosion.



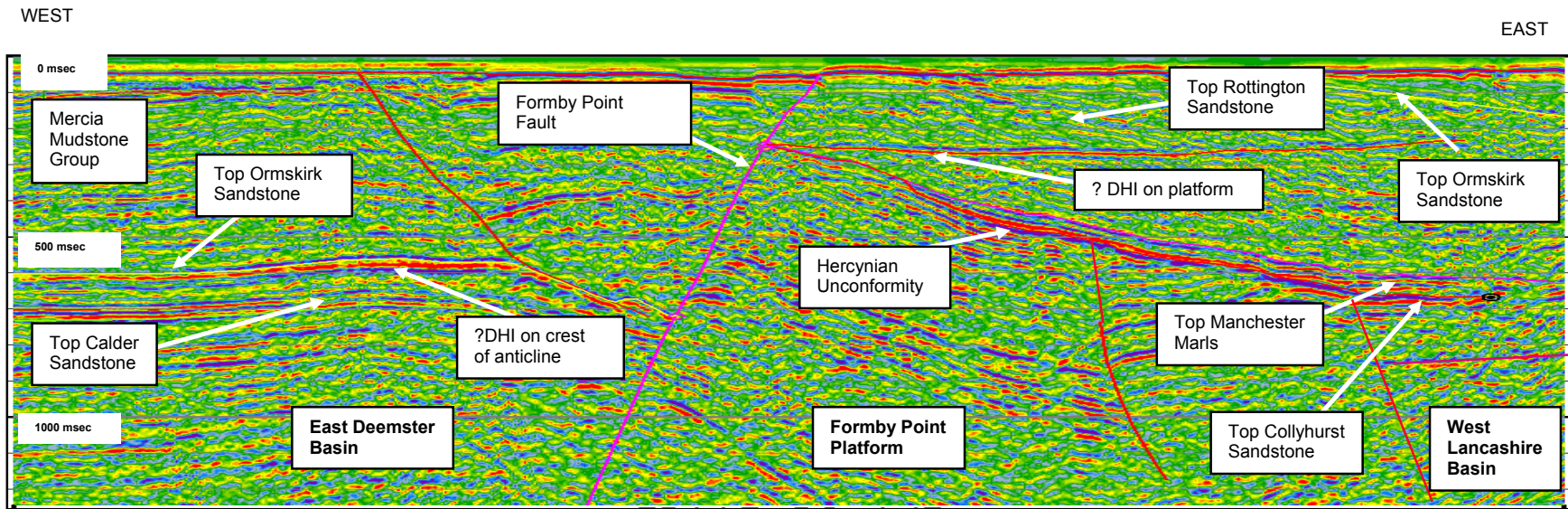


Figure 2 East-west seismic section across the Formby Point platform in Quadrant 110

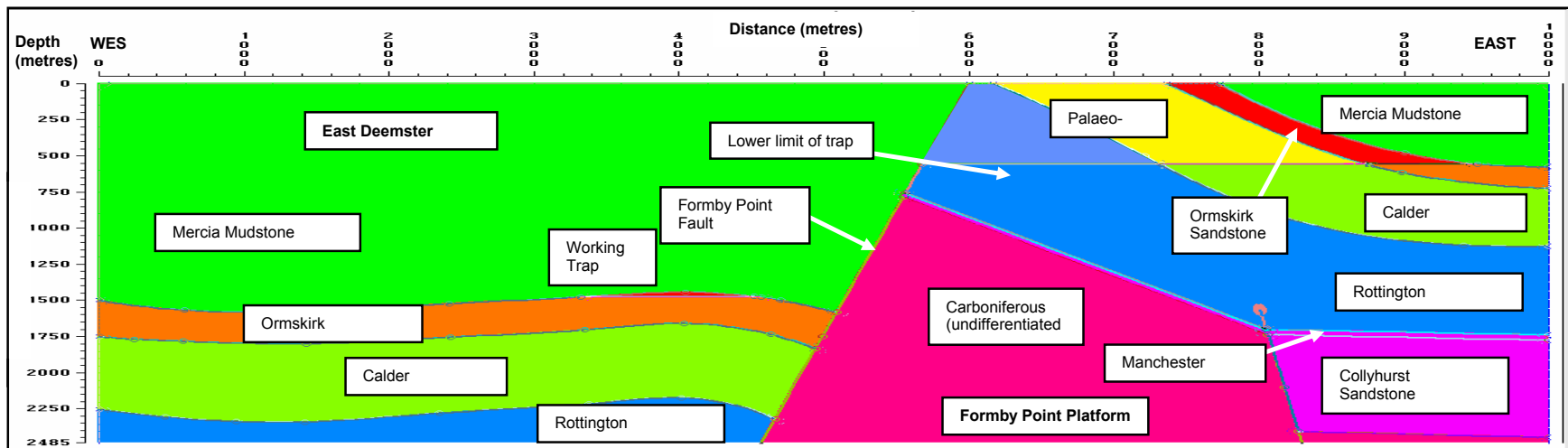
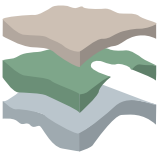


Figure 3 Model depth cross-section (metres)



Model Construction

To determine the likely rock property contrast necessary to produce the observed seismic anomaly a simple synthetic structural model was built. This was populated with petrophysical parameters derived from data for the Permo-Triassic formations within the basin.

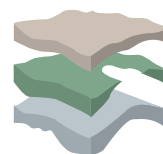
Fig. 3 shows the geometric template used in the seismic modelling analysis and is based on the seismic interpretation of Fig. 2. The depth parameters for the Permo-Triassic intervals in the model were derived from well 110/9-1 for the East Deemster basin, Formby No. 4 for the Formby Point platform and Formby No. 1 for the West Lancashire basin. The Formby Point fault was modelled as a planar surface dipping 60 degrees from horizontal (Jackson & Mulholland 1993).

Table 1 lists the petrophysical parameters of interval velocity and formation density used for this study. These data were derived from onshore and offshore wells which prove the Carboniferous, Permian and Triassic stratigraphy of the basin (Jackson *et al.* 1987) combined with the detailed rock property values of Poisson's Ratio (Ross & Flack 1992). The calculated acoustic impedance values were used to populate the model's geometric template (Fig. 3) and produce an acoustic impedance section. Formation porosities for the Sherwood Sandstone Group have been estimated using a pure quartz matrix with a density of 2.65 g/cm³ (Table 1).

Using GX Technology's forward modelling package GXII the synthetic seismic section (Fig. 4) was generated by convolving a zero-phase Ricker wavelet (peak frequency = 30 Hz) with

Table 1

Layer	Delta T (μ S/ft)	Vp (m/s)	Vp (ft/s)	Density (g/cc)	Poisson's Ratio	Acoustic Impedance (m/s*g/cc)	Porosity (estimated)
Mercia Mudstone Group	70.0	4360	14300	2.40	0.28	10464	
Ormskirk Sandstone Formation (gas-charged)	96.0	3180	10400	2.33	0.12	7409	20%
Ormskirk Sandstone Formation (palaeo-trap)	90.0	3400	11150	2.34	0.30	7956	19%
Ormskirk Sandstone Formation (water-wet)	85.0	3600	11800	2.36	0.30	8496	17%
Calder Sandstone Member (palaeo-trap)	80.2	3800	12500	2.38	0.30	9044	16%
Calder Sandstone Member (water-wet)	65.0	4200	13800	2.40	0.30	10080	15%
Rottington Sandstone Member (palaeo-trap)	74.0	4100	13450	2.50	0.30	10250	9%
Rottington Sandstone Member (water-wet)	65.0	4690	15400	2.60	0.30	12194	3%
Manchester Marls Formation	55.4	5500	18000	2.64	0.28	14520	
Collyhurst Sandstone Formation	55.4	5500	18000	2.60	0.30	14300	3%
Carboniferous (undifferentiated)	50.8	6000	19700	2.60	0.30	15600	



the modelled reflectivity series. In Fig. 4 the synthetic traces are shown using a wiggle trace variable area normal polarity display to illustrate the stratigraphic boundaries. An acoustic impedance increase down section is represented by a black peak (after Ross & Flack 1992).

The synthetic section is displayed with the fault plane reflections turned off to optimise the amplitude scaling for the horizon reflectors. This procedure is necessary because the largest reflection coefficient (and hence the greatest seismic amplitude) occurs between the water wet Ormskirk Sandstone Formation and the undifferentiated Carboniferous strata across the dipping Formby Point fault (Table 2).

The acoustic impedance parameters for the model were varied to determine their sensitivity to both the timing, shape and amplitude strength of the reflections produced on the synthetic section. The parameters listed in Table 1 produce a model section that has a good visual match to the original seismic data (Fig. 2) both in terms of two-way time (TWT), which relates to the interval velocity component and the reflection amplitude character, which also relates to the acoustic impedance contrasts in the model.

In order to study the effects of gas charge on the seismic properties of the Ormskirk Sandstone Formation reservoir a set of synthetic gathers were generated using GXII for the anticline trap at the foot of the Formby Point fault (Fig. 2). Using the Hampson Russell seismic amplitude versus offset modelling package AVO, the trap was modelled to contain either a gas accumulation or a water filled high porosity zone, set against a background water-wet porosity of 17% for the rest of the reservoir. The modelled synthetic gathers (Fig. 5) were analysed to identify changes with offset of amplitude strength and phase to establish if AVO is a valid technique for differentiating gas filled structures from empty palaeo-traps in this case.

Results

Palaeo-DHI

Fig. 4 successfully models the suspected palaeo-DHI located over the Formby Point platform. On the original seismic section (Fig. 2) the anomaly has a "concave up" time profile. The simple model has replicated this TWT geometry as well as the varying amplitude strength seen along the profile as the boundary passes from Rottington Sandstone Member stratigraphically upwards, into the Calder Sandstone Member and then into the Ormskirk Sandstone Formation, to the east.

The concave shape of this seismic profile reflects the varying travel time within the model as the steeply dipping Ormskirk Sandstone, with its lower velocity (3,400 m/s), is progressively buried to the east by higher velocity Mercia Mudstone Group (4,360 m/s) located in the near surface. The eastward decrease in strength of the palaeo-DHI on the Formby Point platform (Fig. 2) can be explained by changes in reflection coefficient of the anomalous boundary (from 0.0866 to 0.0542 to 0.0328) as it passes up sequence through the separate sandstone units of the Sherwood Sandstone Group (Table 2).

Genuine DHI

Fig. 4 shows a simple model that effectively explains the amplitude brightening caused by seismic tuning seen in the Lennox field anticline at the foot of the Formby Point fault. This feature was modelled assuming a gas-filled trap with a horizontal gas-water contact within the Ormskirk Sandstone. The model parameters for a water-filled palaeo-trap also produce a similar, though less pronounced, seismic anomaly which suggests that this anomaly relates to a working trap with a gas fill.

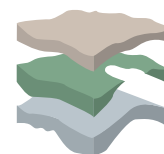


Table 2

Layer Above Layer Below	Mercia Mudstone Group	Ormskirk Sandstone Formation (gas-charged)	Ormskirk Sandstone Formation (palaeo-trap)	Ormskirk Sandstone Formation (water-wet)	Calder Sandstone Member (palaeo-trap)	Calder Sandstone Member (water-wet)	Rottington Sandstone Member (palaeo-trap)	Rottington Sandstone Member (water-wet)	Manchester Marls Formation	Collyhurst Sandstone Formation
Ormskirk Sandstone Formation (gas-charged)	-0.1709									
Ormskirk Sandstone Formation (palaeo-trap)	-0.1362									
Ormskirk Sandstone Formation (water-wet)	-0.1038	0.0683	0.0328							
Calder Sandstone Member (palaeo-trap)			0.0640							
Calder Sandstone Member (water-wet)				0.0853	0.0542					
Rottington Sandstone Member (palaeo-trap)	-0.0103				0.0625					
Rottington Sandstone Member (water-wet)	0.0764					0.0949	0.0866			
Manchester Marls Formation	0.1623							0.0871		
Collyhurst Sandstone Formation									-0.0076	
Carboniferous (undifferentiated)	0.1971			0.2948		0.1833		0.1139	0.0359	0.0435



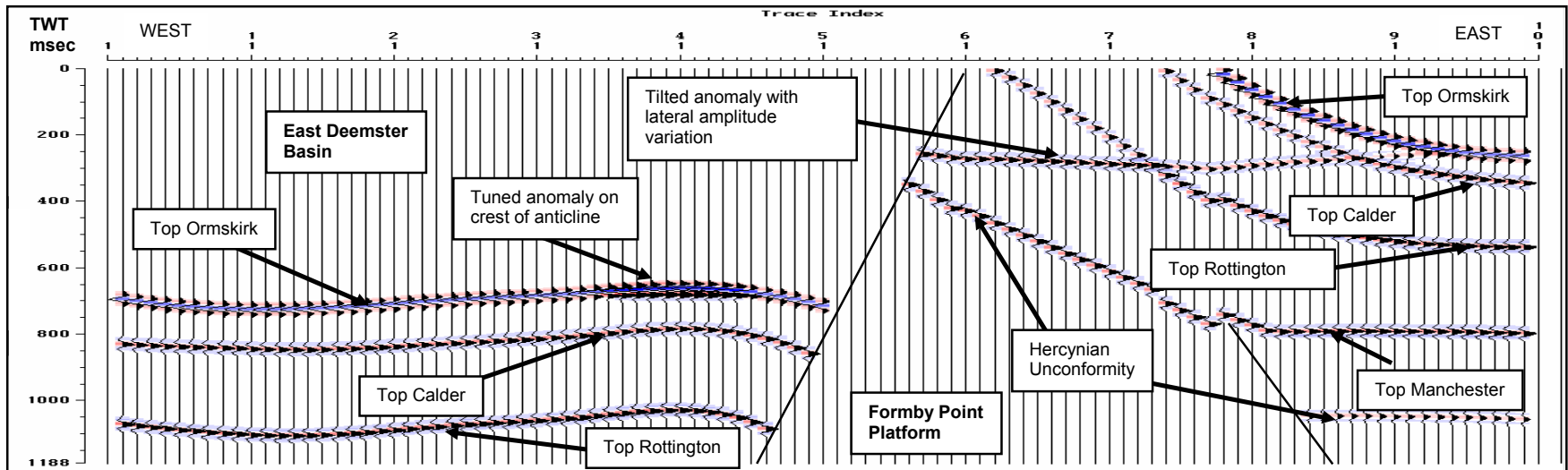
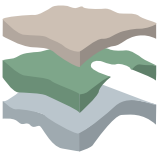


Figure 4 Model P-wave seismic reflections



AVO Modelling

AVO modelling of the bright spot in the rollover anticline (Fig. 2) produced the following results:-

- (i) Synthetic gathers for the brine-filled palaeo-trap in the Ormskirk Sandstone show no significant lateral change in top reservoir trough amplitude and no phase rotation of the wavelet with increasing offset angle for the Top Ormskirk reflector (Fig. 5a).
- (ii) In contrast the synthetic gathers for the gas-charged Ormskirk Sandstone demonstrate a lateral change in trough amplitude strength for the Top Ormskirk and a significant associated phase rotation of the wavelet with increasing offset angle (Fig. 5b).

These observations suggest that gas-charged traps can, in principle, be distinguished from palaeo (water-wet) traps for the Ormskirk Sandstone formation of the East Irish Sea basin. The significant Poisson's Ratio variation observed between a gas-charged reservoir in a present day working trap and enhanced porosity preserved in a breached palaeo-trap allows AVO analysis to be a successful discriminator for the Ormskirk Sandstone reservoir.

Fault Modelling

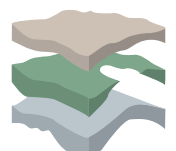
In the seismic model, the Formby Point fault was drawn as a planar boundary dipping at 60 degrees to the horizontal (Fig. 3). Major faults seen in the East Irish Sea basin produce a boundary that may be imaged on a reflection seismic survey. The reflection coefficient data (Table 2) show that the fault plane can produce significant seismic reflections depending on the lithological contrast across the fault. Within the model, the strongest observed fault plane boundary lies between the water-wet Ormskirk Sandstone formation and the Carboniferous (reflection coefficient 0.2948). The weakest boundary modelled (reflection coefficient -0.0103) lies between the Mercia Mudstone Group and the palaeo-gas charged portion of the Rottington Sandstone member (Table 2). The model explains the major variations in fault plane reflection character seen on real seismic data within the East Irish Sea basin.

Conclusions

The seismic anomaly of the Formby Point platform which cuts across the tilted Sherwood Sandstone stratigraphy is a palaeo-DHI. One possible mechanism for this feature is that preserved reservoir porosity exists within the former trap. However, the preserved porosity in the Rottington Sandstone would need to be over 6% higher than in the uncharged part of the former trap (Table 2). This explanation requires a significant and physically unrealistic contrast in matrix density at the boundary of the trap as the seismic amplitude of the palaeo-DHI is very pronounced (Fig. 2). In addition there is little supporting evidence for such a hypothesis, in that diagenesis is often related in the East Irish Sea basin to permeability loss due to the presence of platy illite (e.g. South Morecambe field) but not to a porosity change in the range suggested.

Other diagenetic explanations for the observed seismic response are possible; e.g. a thin trap-wide tar mat or an extensive layer of preferentially cemented sandstone at the base of the trap. Our preferred model postulates the presence of an iron sulphide precipitate which could provide the necessary density contrast to produce the observed seismic amplitude strength and also peak over trough signature typical of a thin bed (Fig. 2).

The mobility of deep formation waters resulting in the emplacement of diagenetic haematite ore in the Carboniferous limestones of the Furness peninsular is well documented as a feature of the fluid history of the East Irish Sea basin (Rose & Dunham 1977). This movement of iron-rich formation waters could also account for the creation of a layer of iron



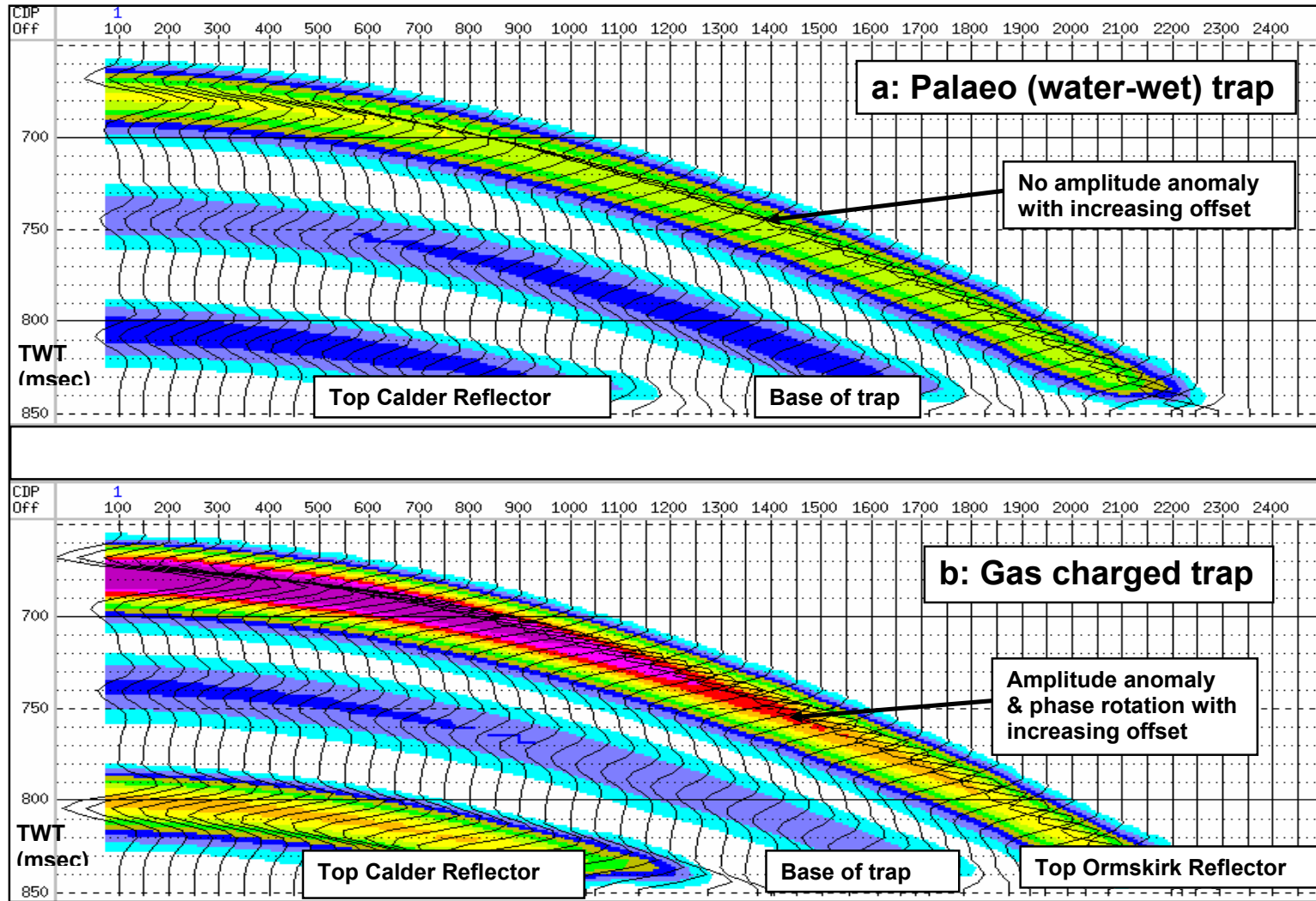
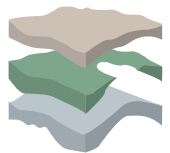


Figure 5 Synthetic AVO gathers for the Ormskirk Sandstone Formation



cemented sandstone at the base of the Formby Point platform trap, prior to the loss of the hydrocarbon fill. Reaction between iron-rich formation waters and trapped hydrocarbons containing a postulated high sulphur content (e.g. up to 400 ppm H₂S for Lennox gas cap) could result in precipitation at a palaeo-OWC of high density minerals, such as pyrite.

The horizontal nature of the depth surface used to model the Formby Point platform palaeo-DHI demonstrates that no significant tilting of the platform has occurred after the trap was breached. Local uplift of the platform along the Formby Point fault in the Tertiary might have resulted in block rotation, so tilting the relic boundary. Absence of tilt suggests that during the regional uplift the relationship between the platform and its associated basins was maintained.

Distinguishing between palaeo and genuine DHI events carries a significant exploration risk in the East Irish Sea basin. The AVO modelling results suggest that this technique can be used to identify gas-charged traps in Triassic sandstone reservoirs. The technique will be limited to locations where the Ormskirk Sandstone can be clearly imaged and the geometry of the overlying Mercia Mudstone group seal allows recovery of sufficient offset information to permit successful modelling of the ray paths.

The authors would like to thank JEBSCO Seismic Ltd for permission to use the seismic line displayed in this paper.

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