

## Detecting leaking oilfields with ALF, the Airborne Laser Fluorosensor: case histories and latest developments

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**Abstract:** The majority of the world's onshore oilfields leak small amounts of petroleum as surface seeps (Clarke and Cleverly, 1991). Seeps mark the ends of migration pathways and in unexplored basins, they provide vital clues in the hunt for the oilfields of the future. ALF, the Airborne Laser Fluorosensor, is an airborne geochemical tool capable of detecting very low concentrations of seeped petroleum at the ocean surface, equivalent to micro-seepage levels detected by conventional surface geochemical tools (gravity coring, etc.). The system has detected oil and condensate films as thin as 0.01  $\mu\text{m}$  (microns), an order of magnitude less than observed by the human eye or by passive satellite or airborne sensors as below 0.1  $\mu\text{m}$ , oil films are invisible. ALF also identifies the phase of the seeping petroleum i.e., light oil/condensate, normal or heavy oil.

ALF results from two contrasting deep-water basin settings and from one shallow-water basin are discussed, viz.

- the Gulf of Mexico Slope, a deep-water structured passive margin with high seepage rates.
- the Faeroe Basin, West of Shetlands, a deep-water unstructured passive margin with low seepage rates.
- the East Irish Sea basin, a shallow-water, uplifted rift basin with low seepage rates.

In each basin, ALF data were integrated with sub-surface data (principally seismic and high-resolution magnetics) to generate:

- a map of the limits of the play-fairways
- a prediction of the phase of the trapped hydrocarbons
- a reduction in play-fairway risk

### SEEPS AND OILFIELDS

The value of seeps in exploring for major oil and gas fields is not a new idea and has been well documented over many years (e.g. Cunningham-Craig 1912; Link, 1952). In fact many of the giant oil discoveries made by BP in the Middle East during the 1920's and 30's, such as Kirkuk in Iraq, Majid-i-Sulaiman in Iran and, later, Burgan in Kuwait, were drilled because of the existence of surface seeps.

However, it is only within the last decade that the value of detecting seeps to explore offshore basins has been recognised. Conventionally, this has been achieved by ship-borne shallow coring methods but now a high-resolution, fast coverage airborne detection system is available — ALF.

In offshore basins, macro-seepage can result in the production of visible slicks at the ocean surface, detectable under favourable conditions by the naked eye or by satellite and airborne remote sensing platforms. The appearance of the slick is determined by its thickness and varies from 1 mm (1,000 microns) for a mousse (water-in-oil emulsion) down to 0.1 microns for a silvery oil sheen (International

Tankers Owners Pollution Federation, 1981). Beyond 0.1 microns, oil films are invisible to the naked eye but are 'visible' to ALF which has resolved films down to a thickness of 0.01 microns.

Basins that have sufficiently high leakage rates to generate visible macro-seeps are rare. Most offshore basins leak much more slowly — by micro-seepage — at rates that are insufficient to produce visible seeps and therefore require more sensitive airborne detection systems such as ALF to map them.

### ALF MK 3

ALF was first described by Clarke *et al.* (1988) and in subsequent publications by Martin and Cawley (1991), Thompson *et al.* (1991) and Williams *et al.* (1991). The new ALF, ALF Mark 3, is a miniaturised version with much increased sensitivity and resolution. It comprises a solid state u.v. laser to detect both macro and micro-seepage in offshore basins. The laser is pulsed from an aircraft flying at 80 or 100 metres above sea level (Fig. 1) at a very high frequency (50 Hz) and induces fluorescence in any fresh oil film

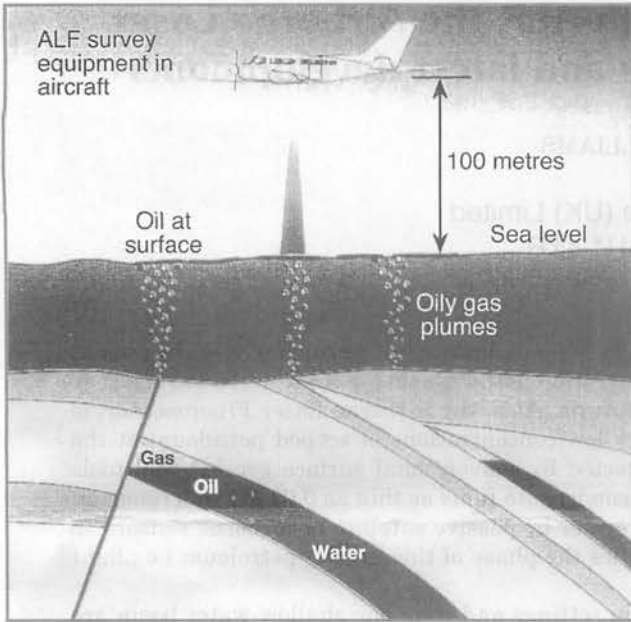


Figure 1. ALF survey equipment in aircraft.

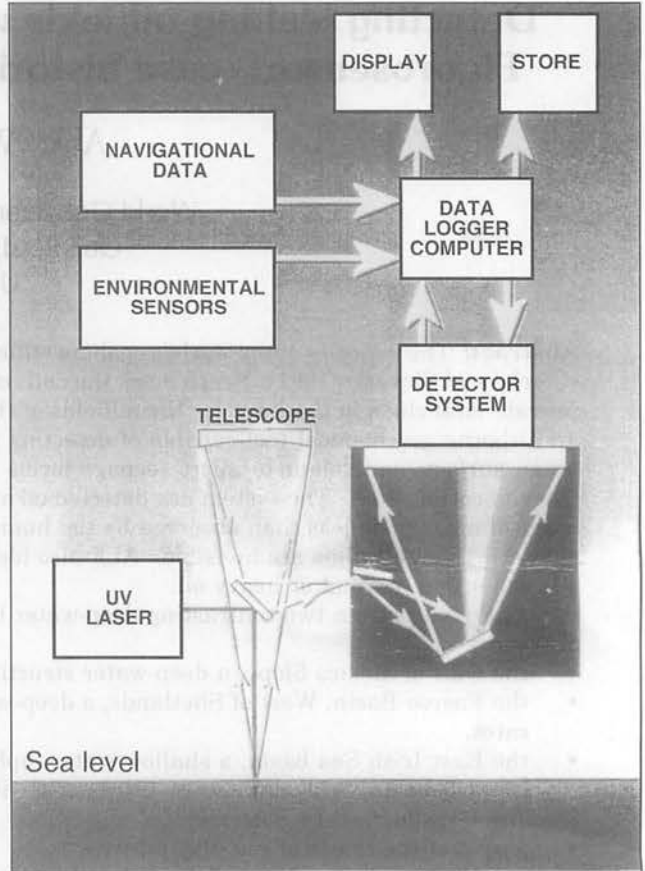


Figure 2. The ALF system.

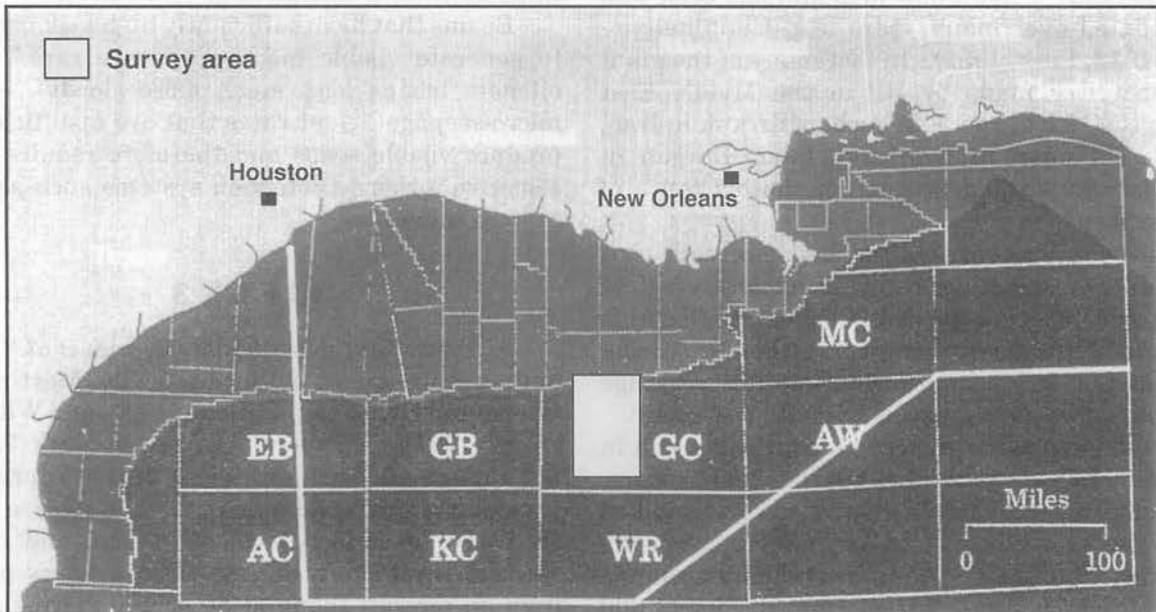


Figure 3. Gulf of Mexico — 1993 ALF survey location map.

encountered on the ocean surface. The returning fluorescence is captured by a powerful telescope and separated into its constituent colours by a spectrograph before being converted into electrical signals by a 500 channel diode array detector (Fig. 2). The data are carefully analysed on a dedicated work station and seep maps generated.

The new ALF system, ALF Mk 3 has a number of advantages over its predecessor, ALF Mk 2, viz:

- Increased discrimination — Use of a lower emission wavelength (reduced from 308 nm to 266 nm), giving a wider spectral window and greater discrimination of slick types, especially to condensates and light oils.
- Increased sensitivity to thin films — ALF Mk 3 is sensitive to very thin films — as thin as 0.01 microns (i.e., 10 times thinner than visible to the naked eye), a factor of 5 times more sensitive than ALF Mk 2.
- Higher resolution — The Mark 3 obtains single shot data as opposed to the 10 point average of the Mark 2 system, enabling smaller slicks to be identified and critically, providing evidence of slick origin — seepage or pollution.

ALF's ability to resolve such small, 'invisible' seeps enables it to detect seeps from traps that have low leakage rates. We interpret this class of fluor to be due to the occasional release of the volatile oil fractions from slow seep sites in the form of oil and gas bubbles.

The spectral characteristics of this class of seep (1 or 2-ring aromatics) indicates that they will be light oils or condensates and will also have short residence times on the ocean (c. 30 minutes, Sivadier and Mikolaj, 1973) and therefore cannot themselves give rise to oil slicks at the sub-metre level.

Such seeps, however, may be providing a far better indication of petroleum migration and trapping than the fracture/fault-related oil slicks which have been observed with other remote sensing systems and earlier ALF systems.

## CASE HISTORY — GULF OF MEXICO SLOPE

The Gulf of Mexico Slope is a classic example of a structured passive margin where recent diapirism, present-day oil generation and high over-pressures combine to generate abundant seepage.

ALF data were collected over part of the Green Canyon protraction area in August 1993 (Fig. 3). The area included the Jolliet, Marquette and Boxer fields on the upper Slope (average water depths, 200–500 metres) and extended into very deep water (> 2,000 m) to the south. Seven visible seepage

slicks were recorded by ALF (Fig. 4) which gave spectral responses typical of a normal gravity oil, with peak wavelengths of c. 500 nm. Observations made on rates of ascent of visible slicks indicate that the amount of displacement from the sea-bed vent to the surface is in the order of twice water depth.

The bulk of the data, however, were condensate/light oil responses with peak wavelengths of c. 340 nm which were not visible to the naked eye or to the ALF video. In the Boxer field area (GC 18/19) (Fig. 5), such responses cluster over the salt wall to the south of the field (directly over a zone of seismic wipe-out) and also appear to show vertical leakage from the underlying gas and condensate traps. Zones of active light oil seepage were also mapped in water-depths up to 2,000 m, such as an undrilled intra-salt basin centred on Green Canyon block 539 (covering blocks 539, 583 and 584).

## CASE HISTORY 2 — FAEROE BASIN, WEST OF SHETLANDS

The Faeroe Basin, West of Shetlands is a Mesozoic failed rift overlain by an Atlantic-type passive margin. Water depths vary from 150 m in the east to 1,000 m in the west. At least three major new oilfields, Solan-Strathmore (block 206/25), Foinaven (block 204/24) and Schiehallion (block 204/20) are now under development in this area, the latter two in water depths of around 500 metres. Oil gravities are heavy (c. 20–25 API) but there are also sub-commercial gas-condensate traps in the basin. The more recent discoveries are thought to be stratigraphic traps at Palaeocene level which are overlain by a largely unstructured clastic Neogene wedge. Seepage rates are therefore anticipated to be low.

ALF data were acquired over the Quad 204 area as part of a non-proprietary survey (Fig. 6). ALF detected subtle condensate seepage in the vicinity of the block 204 discoveries which can be related (with reference to high-resolution aeromagnetic data) to possible reactivated deep-seated fractures (World Geoscience internal report) or, for the Solan-Strathmore field, to leakage up the major basin-bounding structure, the Rona Ridge. ALF also detected a strong condensate signal in deeper-water licensed acreage and also over a large gas chimney at the crest of a major undrilled structured (seen on conventional seismic) in unlicensed acreage to the west, in c. 1,000 m of water (Fig. 7). The spectral information suggests that the composition of these traps will be liquids, probably gas-condensate.

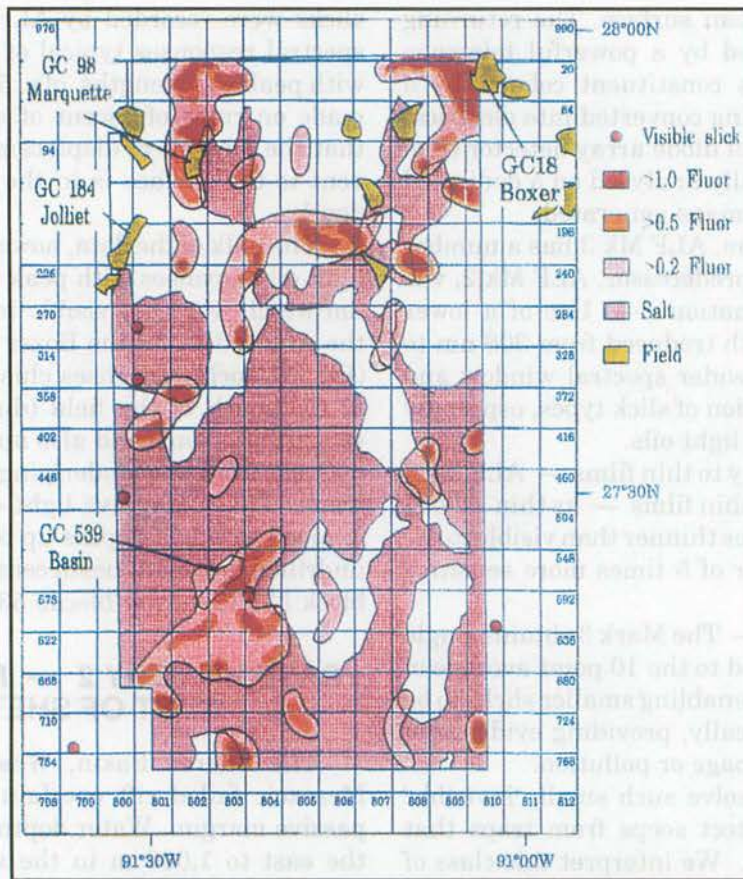


Figure 4. Gulf of Mexico — seep density.

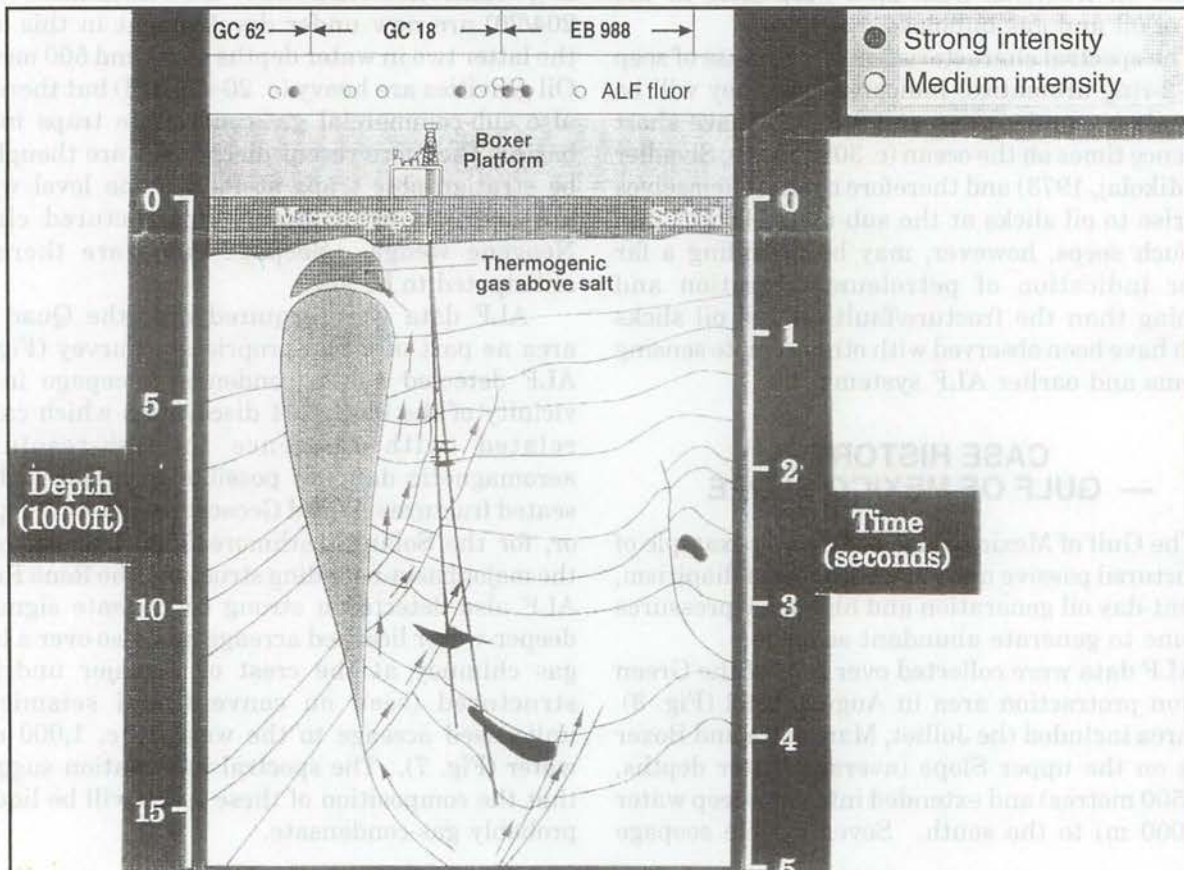


Figure 5. Gulf of Mexico — boxer seepage pathways and ALF blue floors.



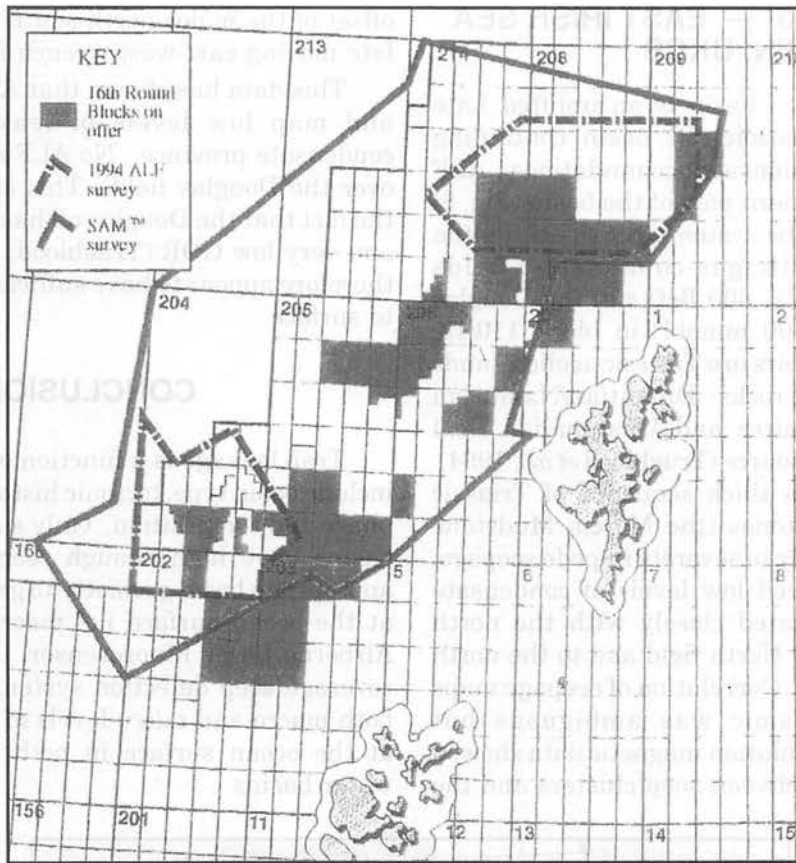


Figure 6. Quad 204 area

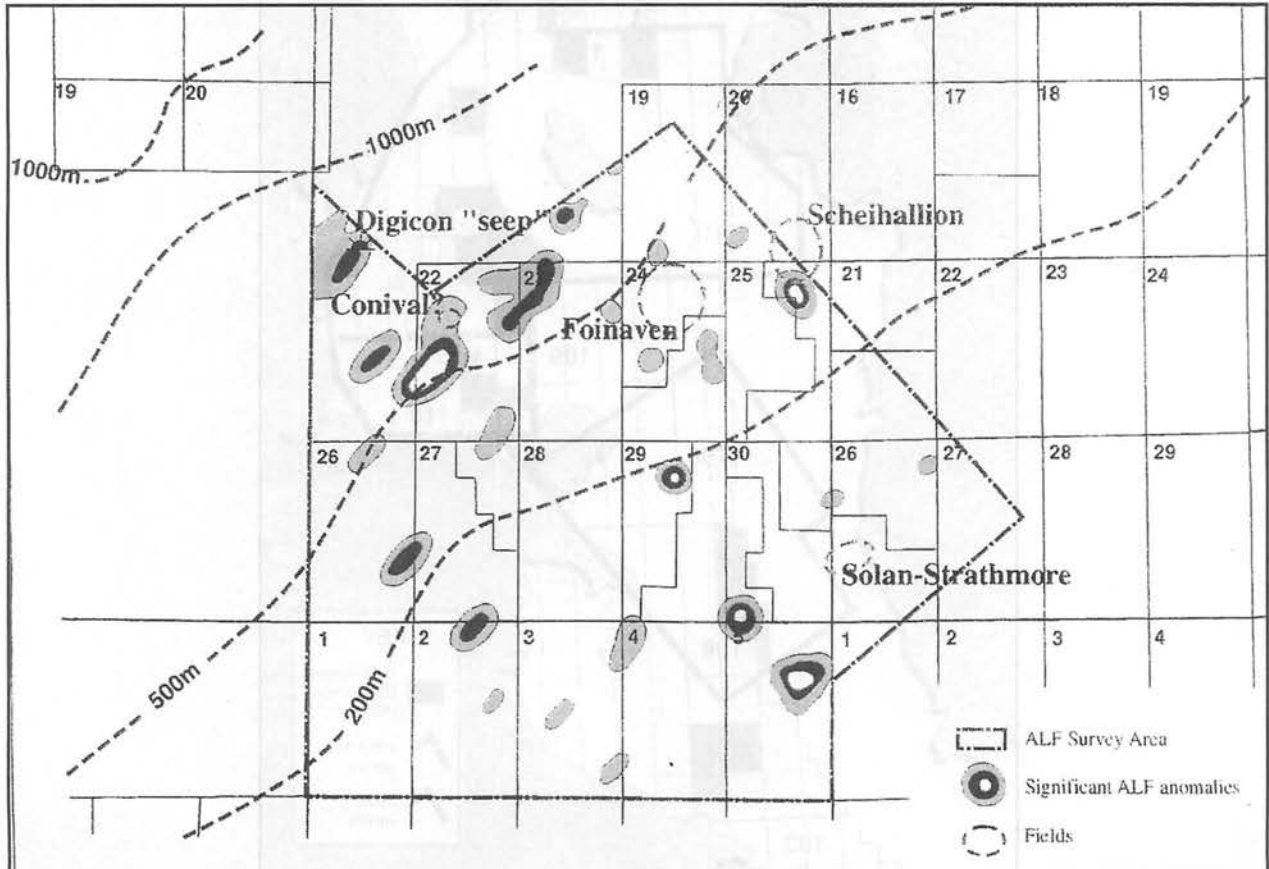


Figure 7. Southern area ALF results.

### CASE HISTORY 3 — EAST IRISH SEA BASIN, UKCS

The East Irish Sea basin is an uplifted Late Palaeozoic/Early Mesozoic rift basin containing major oil and gas-condensate accumulations. ALF was flown in the southern part of the basin (Fig. 8) in order to calibrate the system over the Hamilton and Hamilton North gas-condensate fields (combined reserves of c. 800 Bcf) and the Douglas oilfield (reserves > 100 mmbbl) in block 110/13. The productive reservoirs are Triassic aeolian sands charged by two source rocks: Dinantian/Namurian shales are the oil source and Westphalian Coal measures are the gas source (Trueblood *et al.*, 1994). Seal is provided by a thick sequence of Triassic claystones and mudstones (the Mercia Mudstone Group) which are likely to severely impede seepage.

ALF results showed low levels of condensate seepage which calibrated closely with the north flank of the Hamilton North field and to the north and west of Hamilton. Correlation of seepage maps to the existing seismic was ambiguous but correlation to high-resolution magnetic data showed an excellent match between seep clusters and the

offset of the major north-south bounding faults by late moving east-west wrench faults (Fig. 9).

This data has shown that ALF is able to detect and map low levels of leakage from a lean condensate province. No ALF response was noted over the Douglas field. This can be explained by the fact that the Douglas oil has a high wax content and very low GOR (Trueblood, 1994) and does not therefore appear to have sufficient gas drive to leak to surface.

### CONCLUSIONS

Trap leakage is a function of many factors that include basin type, tectonic history and hydrocarbon phase and composition. Only a minority of offshore basins have high enough seepage rates and the appropriate basin geometry to generate visible seeps at the ocean surface i.e. macro-seeps. ALF, the Airborne Laser Fluorosensor, is a sensitive, high-coverage seep detection system that has detected both macro and micro levels of petroleum seepage at the ocean surface in both shallow and deep-water basins.

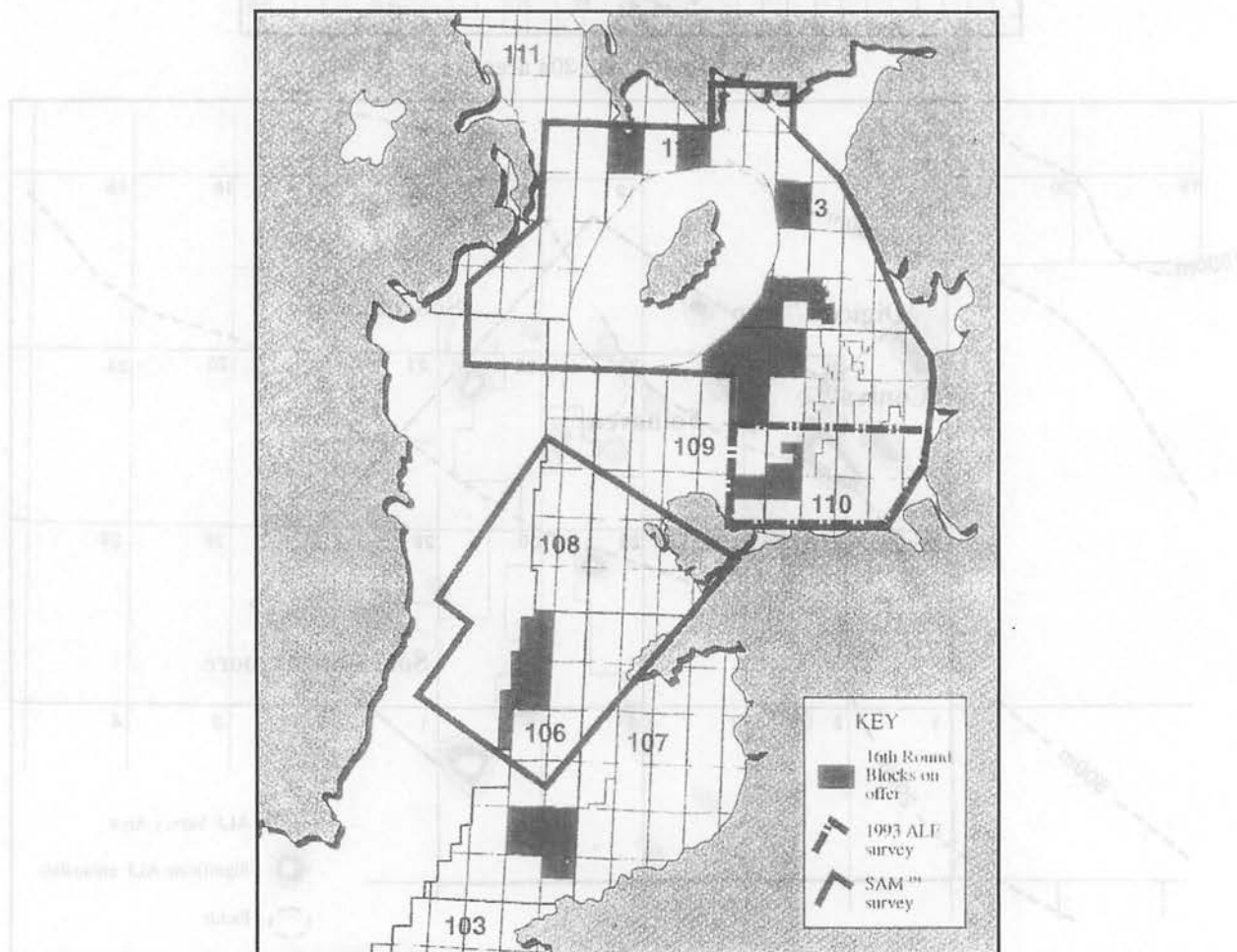


Figure 8. ALF flown over southern part of East Irish Sea basin.



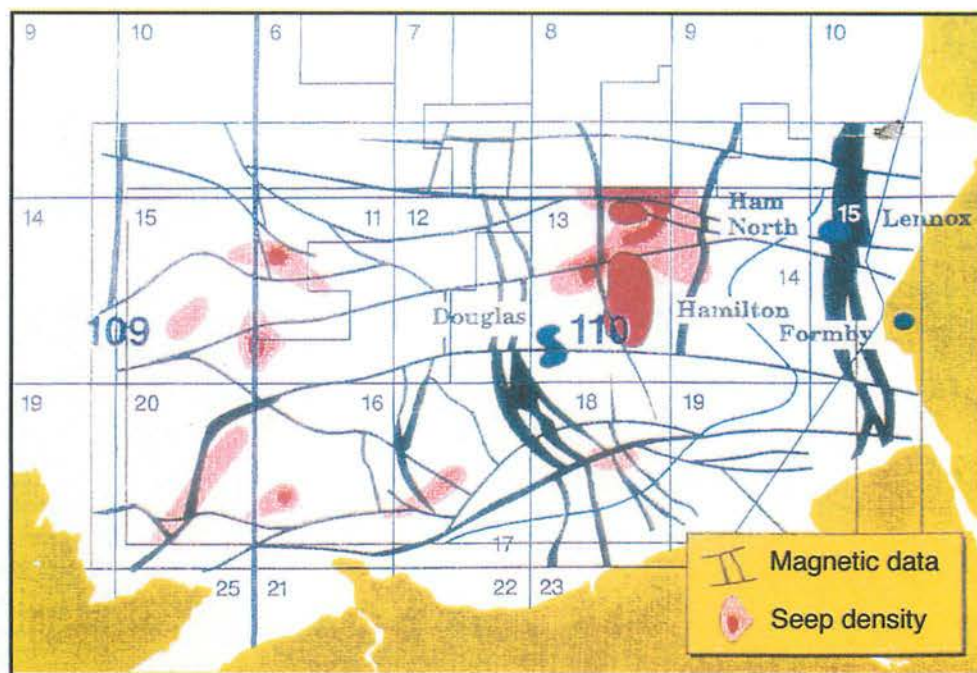


Figure 9. East Irish Sea — ALF survey interpretation.

In the deep water Gulf of Mexico Slope, both visible and condensate/light oil seeps were detected. These were related to known fields on the upper Slope and to undrilled, actively leaking intra-salt basins in the deep-water lower Slope where water depths reach 2,000 m.

In the West of Shetlands, where water depths reach up to 1,000 m, ALF is detecting condensate/light oil seepage which appears to correlate well with the recent major discoveries and identifies the leakage pathways from undrilled deep-water targets.

In the shallow water East Irish Sea Basin, macro-seeps were not observed but ALF located discrete condensate/light oil seepage that correlates closely to recent offsets of the trapping structures by late moving wrench faults.

Sensitive airborne seepage detection systems such as ALF have a role to play in the further exploration of the world's offshore frontier basins by defining the locations of the leaking playfairways and the hydrocarbon phase trapped within them. This value is enhanced by integrating seepage results with sub-surface data, in order to better understand the basin plumbing system and the likely location of undrilled traps, thereby helping to reduce exploration risk and cut costs.

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