Comparison of airborne and marine magnetic data in Donegal Basin, Ireland

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Exploration of Ireland's Donegal Basin in the last 10 years concentrated on structural plays within the Triassic Sherwood Sandstone and culminated in the Corrib gas discovery in 1998. Despite this economic success, the structural history (and hence petroleum geology) of the basin remained poorly understood, due in large measure to igneous intrusives and salt which degrade seismic data quality. These problems caused operators to consider alternative methods and, given the success of potential fields in adjacent areas (Faroes, Irish Sea), new gravity and magnetic surveys were undertaken in 1999.

Before 1999, the only speculative magnetic data set over Donegal Basin was a 5-km grid of various vintages compiled by the Geological Survey of Canada. This was useful for identifying regional structural trends but little else. As exploration intensified in 1999, a 2D seismic survey was acquired along with marine gravity and magnetics data.

The new data enabled better structural definition within the basin but still left many unanswered questions about the detailed character and extent of igneous intrusions. To address this, a high-resolution aeromagnetic (HRAM) survey was flown in late 1999. The dense data coverage and high sampling rate provided much greater detail than previous surveys (Table 1).

This paper discusses the advantages and disadvantages of the various data types acquired in Donegal Basin. Each has an optimum application determined by technical objectives and budget, but to choose the most appropriate, it is important to understand the limitations that each has.

The underlying aim of this paper is to help explorationists make better-informed decisions when planning acquisition of potential fields data.

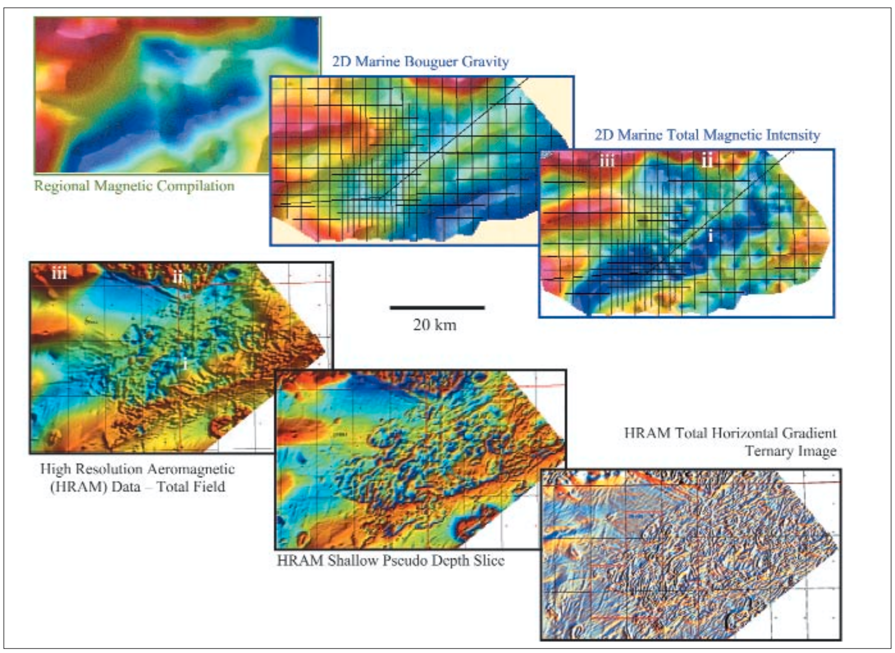

Figure 1. *Regional magnetic compilation (top left), 2D marine Bouguer gravity (top middle), 2D marine total magnetic intensity (top right), HRAM total field (lower left), HRAM shallow pseudo depth slice (lower middle), and HRAM total horizontal gradient ternary image (lower right).*

Data comparison. The 2D marine gravity and magnetics data acquired in conjunction with the 1999 seismic survey had line orientations that were north-south and east-west, respectively, and line spacing of 2-6 km. All data (magnetics, gravity, bathymetry) were recorded onboard the seismic vessel, meaning data were contaminated by noise from the vessel and other acquisition equipment (Table 1). Typically, a 300-s filter is applied to lessen these high-frequency effects.

Comparison of the existing regional and 2D marine data sets (Figure 1) shows the latter has better resolution of midwavelength features, especially in the west. It also enhances the higher frequencies caused by intrasedimentary volcanics through the central and eastern parts.

The improvements are due predominantly to tighter line spacing and closer sample rate, and because the boat is nearer to the source. Tighter acquisition parameters enable the data to be gridded with a smaller cell size (2 km compared to 5 km for the regional data) to reveal much more detailed intrabasinal features.

Although the 2D magnetic data provided important additional information along seismic lines, they did not contain

Table 1. *Comparison of acquisition parameters for various surveys acquired in the Donegal Basin*

Data type	Acquisition height (amsl)	Total line kms	Line spacing (km)	Sample rate	Sample spacing	Noise envelope	Grid cell size
Regional	variable	< 1000 km	variable	variable	variable	10+ nT	5000 m
2D marine	0 m	2750 km	2 – 6 km	0.1 Hz	25 m	1 – 5 nT	2000 m
High-resolution aeromagnetic	80 m	15 040 km	500 x 1500m	1000 Hz	70 cm	0.01 nT	167 m

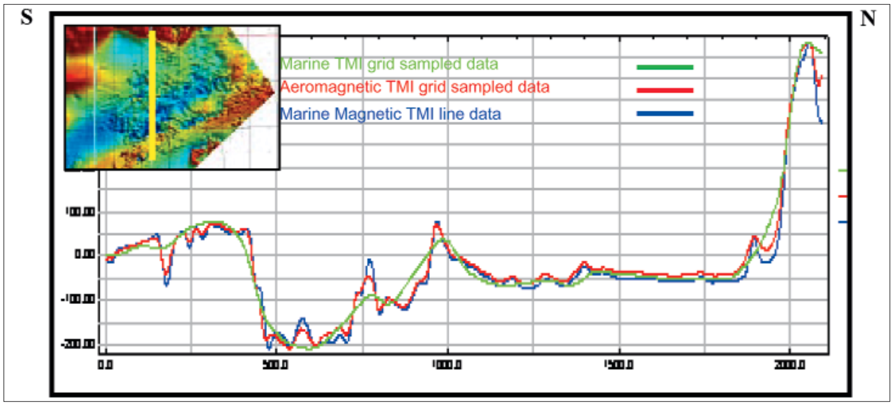

Figure 2. *Comparison of gridded and line data for marine and aeromagnetic acquisition.*

enough high-frequency information to enable detailed mapping of the igneous rocks. Using the existing data to design optimum survey specifications, a high-resolution aeromagnetic survey was flown in 1999 by World Geoscience (now Fugro Airborne Surveys). The survey was flown with a flight-line spacing of 500 m oriented northeast-southwest. Data were recorded by a magnetometer in a stinger at the back of the aircraft, thus minimizing interference and ambient noise.

To understand the differences between marine and airborne magnetics data, we need to appreciate how the two acquisition techniques vary:

- The methods employ different magnetometers.
- The data sample interval is a function of the frequency of the acquisition system and the speed at which it is passing over the ground. Marine data are acquired with a slower vessel and a 0.1 Hz system is sufficient to give a data sampling of ~25 m. Airborne data are acquired at much faster speeds and hence high-frequency sampling is required (10 or 1000 Hz) to give data samples every ~ 70 cm.
- The amount of "usable data" is constrained by the noise envelope. The marine system is affected by the seismic equipment and ship noise but an airborne survey is recorded in a much quieter environment with the magnetometer compensated and positioned to minimize system noise.
- Aeromagnetic data are acquired over a regular grid but 2D marine magnetic data usually have a wider, more variably spaced grid. The tighter line spacing of high-resolution surveys allows the interpreter to spatially link observed anomalies, especially higher-frequency ones that would be undetected by typically spaced 2D surveys.

By directly comparing marine and airborne gridded data sets, the advantages of mapping fault patterns and distribution of igneous material using the latter are immediately apparent.

In Figure 1, the 2D marine magnetic image clearly defines the basinal areas (blue) and structural highs (red). It hints at a higher-frequency component within the data to the east (i) and a difference in basement form/composition to the north (ii/iii).

However, in the airborne data grid, the high-frequency information (i) is much better defined, and even in quieter areas to the northwest, more structural information from sedimentary features is visible. The new aeromagnetic data made it possible to see hints of these features on earlier data sets but these could not be mapped confidently over any distance due to the larger grid sampling.

Such comparisons demonstrate that gridded data derived from aeromagnetic surveys provide the most information for mapping detailed (prospect-scale) fault distribution in a region such as Donegal Basin.

When actual line data are examined, the differences between marine and airborne data become less noticeable. But by comparing line data derived from sampling the grids to the actual acquired line data, we will show how data can be degraded by the gridding process when the grid comprises wide, variable line-spaced data.

The 2D marine magnetic data were gridded at 2000 m to account for the variable line spacing of the acquisition. Comparing this to the original line data with a 25-m sample interval, it is clear that data (particularly high-frequency data) will be lost through gridding.

In areas where the magnetic map is dominated by long-wavelength anomalies, loss of information is less noticeable. Where more high-frequency data are visible, the gridding appears to have clipped some anomalies and, more importantly, aliased the high-frequency data. This is obvious in Figure 2, where very sharp magnetic highs now appear as broader anomalies. Interpretation of the mapped data will lead to an erroneously deep and incorrect lateral positioning of the source.

This example emphasizes the importance of knowing the original data on which a map is based. In this case, the mapped data can be used for qualitative work but only line data will permit accurate quantitative interpretation of higher-frequency anomalies.

With high-resolution airborne data, degradation through gridding is not as pronounced because tighter, regular line spacing means gridded data very closely follow line data. Typically, data are gridded at 1/3 to 1/4 the flight line spacing; this honors the data without introducing artifacts into the grid.

Data from a marine and from an airborne-derived magnetic grid are clearly different, especially in magnetically "active" areas with a strong high-frequency component. In Figure 2, the marine data do not honor many sharp, high-frequency features in the airborne data. In quieter areas dominated by long wavelengths, the differences are less obvious.

These differences are directly related to the gridding process. High-frequency information has been recorded "along-line" by the marine acquisition system but is degraded or lost in the grids because of the coarse grid sampling required to account for the variable line spacing.

This means that a high-resolution airborne data grid can be sampled anywhere and in any direction without jeopardizing data quality. For marine data, the best data are restricted to the acquisition lines, thus limiting the interpreter's choices when it comes to 2D modeling. For marine surveys it is best to model the original line data. However, with airborne data, any line sampled from the grid will be suitable.

Getting the most from potential fields data. What can be done to optimize the amount of geologic information available for interpretation?

Grid enhancements: There are various enhancements that can be applied to the final processed data. These range from simple sun illuminations, colors, and shading through to derivative techniques, ternary images, and sophisticated filtering. Simple changes in color table and sun illumination direction can reveal different structural features and trends.

Filters/pseudo depth slicing: Application of filters to the data to separate it based on frequency and wavelength is common.

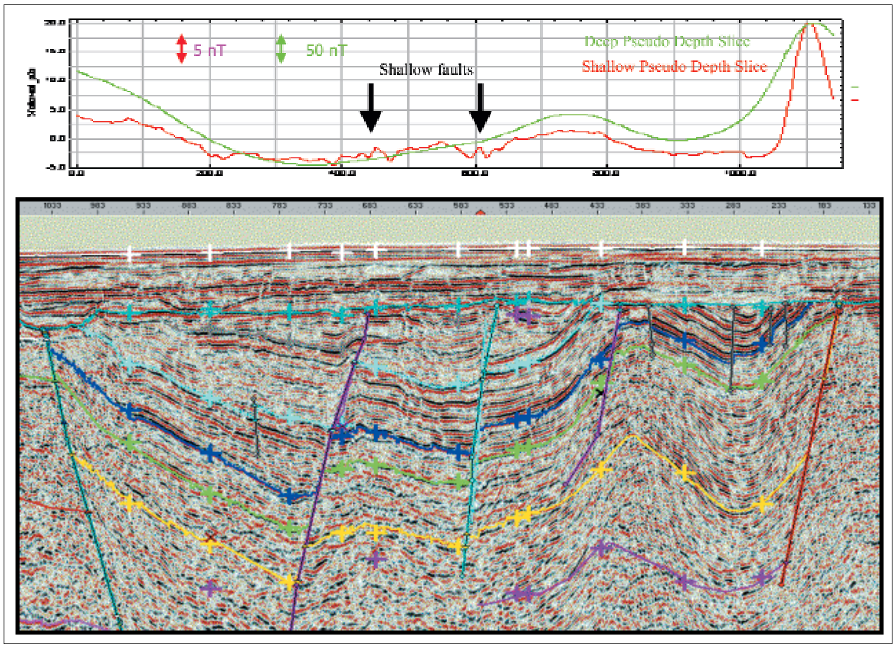

Figure 3. *Interpreted seismic section with deep and shallow pseudo depth slice profiles.*

It is generally accepted that magnetic anomalies sourced from shallow depths are typically high frequency and low amplitude (the latter is also a function of susceptibility contrast). Anomalies from deeper in the section are long wavelength, lower frequency, and high amplitude. Pseudo depth slicing attempts to separate the data into families based on this frequency relationship. For the Donegal Basin survey, a series of "pseudo depth slices" was generated to highlight deep- versus shallow-sourced anomalies.

Figure 1 (center of bottom row) shows the shallowest pseudo depth. It has a dynamic range of 30 nT and is particularly sensitive to the intrusives which dominate the section to the east. In contrast, the deeper depth slice is a lot smoother and looks at the deeper geologic picture. It has a much greater dynamic range of 110 nT.

Comparison of the marine gridded data with the airborne data pseudo depth slices shows that the marine data grid closely approximates the deeper depth slice which contains less high-frequency information.

The correlation is comforting in that the two separately acquired data sets are showing the same basinal trends and anomalies. But the airborne gridded data take that one step further by revealing more information about the sedimentary section. These data also highlight the amount of data lost in the case of the marine data set between acquisition and gridding.

Gravity and magnetic data are most valuable when integrated with other data sets such as seismic data and well data. The two potential field data sets measure different physical properties (susceptibility and density) of the subsurface rocks and so, by considering both data types, it is often possible to reduce ambiguities in the interpretation of one data set alone.

In the Donegal region, the 2D marine magnetics show a (basement) high at the northern edge of the survey. The HRAM data suggests a change in the basement configuration; along trend to the east, basement appears to have an overlying high-frequency fabric (ii) and to the west it is smoother (iii). This variation is reinforced by pseudo depth slicing and examination of the complimentary Bouguer gravity data.

It is also noticable that the positive ridge trending north across the center of the survey is observed both in the gravity and magnetic data. Interestingly, though, the gravity high is offset to the southeast. Again, this implies a more complex origin to these anomalies than first appears from the mapped data.

Having compared different data grids for image analysis, the next step requires detailed profile analysis of the data.

Figure 3 shows that simple observations are sufficient for inferences between magnetic data and an interpreted seismic section to be made. Pseudo depth slicing is used to give more information concerning different parts of the geologic section, confirming earlier ideas based on the data grids. The deeper depth slice (green) is closely related to the basement form. In contrast, the higher frequencies in the shallower depth slice are coincident with interpreted shallow faults and intrusives.

To develop a quantitative interpretation and more precise understanding of these observations, 2D and possibly 3D modeling are required along with depth inversion techniques such as Euler and Werner analysis.

Conclusions. Profile and grid comparisons of the various magnetic data sets acquired in Donegal Basin demonstrate that:

- The line data for both aeromagnetic and marine surveys contain comparable levels of high-frequency information.
- The tight acquisition parameters of HRAM result in very little loss of high-frequency data from the actual flight lines when the data are gridded.
- Gridding of broadly spaced 2D line data (marine and gravity) results in a significant loss of high-frequency information.
- High-resolution aeromagnetic grids provide the best control for mapping of high-frequency geologic features.
- The different magnetic (and gravity) data sets have provided geologic control from regional down to prospect scale.
- When planning acquisition of potential fields data, the technical objectives of a particular project will dictate the most appropriate acquisition parameters. HRAM surveys provide the greatest level of detail, but if seismic data are being acquired anyway, a 2D marine survey can provide important information along the seismic lines.

In Donegal Basin, multiple data sets provide a unique chance to directly compare observed features from each and to assess their contribution to oil exploration.

Each successive survey brought a new level of detail that ultimately helped to better constrain the seismic interpretation at prospect scale.

These data sets have been crucial in helping to understand the nature and distribution of shallow intrusives, intrasedimentary faulting, and basement geometry, all of which are integral to unraveling the structural development of the basin and reducing exploration risk. TLE

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