PS Magnetic Bright Spots Can Identify the Most Prospective Deep-Water Areas and Prospects*

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Abstract

The presence of magnetic anomalies over oil and gas fields has been noted for decades, but only in recent years has the phenomenon has been critically examined. Studies of geologically and geographically diverse regions document that (1) authigenic magnetic minerals occur in near-surface sediments over many petroleum accumulations, (2) this hydrocarbon-induced mineralization is detectable in high resolution, broad bandwidth magnetic data acquired at low altitude and with closely-spaced flight lines, (3) the magnetic susceptibility analysis of drill cuttings confirms the existence of the aeromagnetic anomalies, (4) sediments with anomalous magnetic susceptibility frequently contain ferromagnetic minerals such as greigite, maghemite, magnetite, and pyrrhotite, and (5) 80% or more of offshore deep-water oil and gas discoveries in Gulf of Mexico are associated with these shallow, sedimentary hydrocarbon-induced magnetic anomalies. The association between hydrocarbon seepage and authigenic magnetic minerals has important applications in deep-water hydrocarbon exploration. Seep-induced sedimentary magnetic anomalies, known as Magnetic Bright Spots (MBS), can reliably identify areas and prospects with the highest petroleum potential in water depths as great as 9000 feet (2800 m). The high-resolution cesium vapor aeromagnetic data used in this study were acquired between 1986 and 1992, and extend from East Breaks to Viosca Knoll in the Gulf of Mexico. A comparison of the processed and interpreted aeromagnetic data with post-survey drilling results documents that 89% of wells drilled on prospects within or adjacent to Magnetic Bright Spots have resulted in commercial discoveries. In contrast, fewer than 30% of wells drilled on prospects located more than 800 m from the MBS have resulted in discoveries. Furthermore, MBS areas account for 65% of production – almost 5 times that from within salt-covered areas where no MBS could be determined, although the areas are roughly similar in size. Although the discovery of MBS anomalies does not guarantee the discovery of commercial oil or gas, it does identify areas requiring more detailed evaluation, thereby focusing attention and resources on a relatively small number of high potential sites.

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MAGNETIC BRIGHT SPOTS CAN IDENTIFY THE MOST PROSPECTIVE DEEP-WATER AREAS AND PROSPECTS

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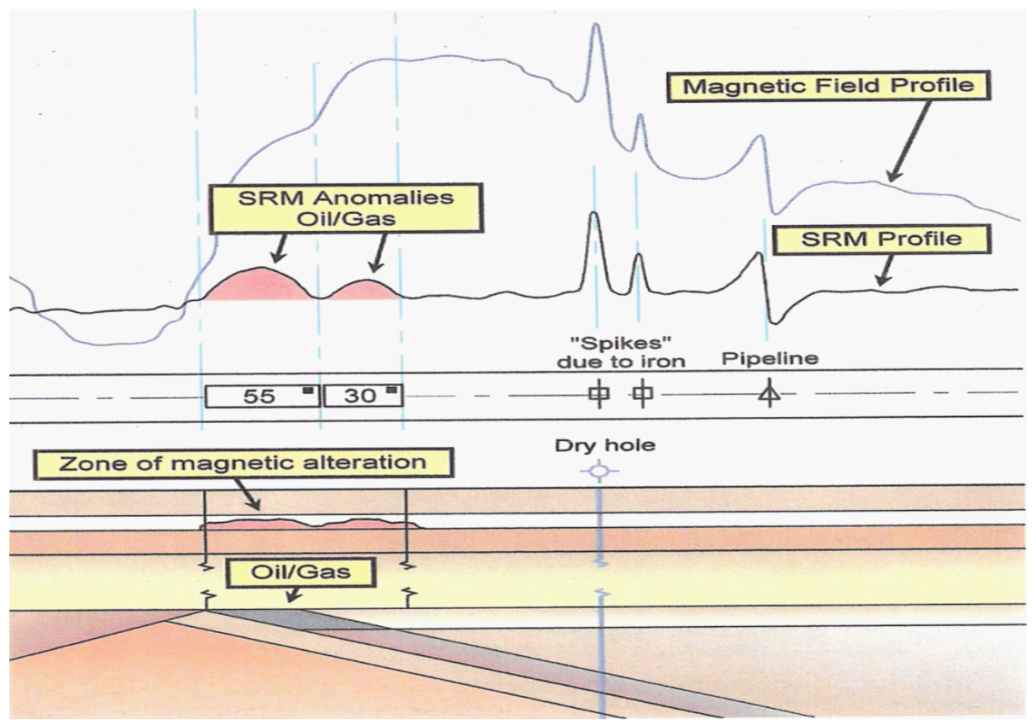
ABSTRACT

The presence of magnetic anomalies over oil and gas fields has been noted for several decades, but only in recent years has the phenomenon has been critically examined. Studies of geologically and geographically diverse regions document that (1) authigenic magnetic minerals occur in near-surface sediments over many petroleum accumulations, (2) this hydrocarbon-induced mineralization is detectable in high resolution, broad bandwidth magnetic data acquired at low altitude and with closely-spaced flight lines, (3) the magnetic susceptibility analysis of drill cuttings confirms the existence of the aeromagnetic anomalies, (4) sediments with anomalous magnetic susceptibility frequently contain ferromagnetic minerals such as greigite, maghemite, magnetite, and pyrrhotite, and (5) 80% or more of offshore deep-water oil and gas discoveries in Gulf of Mexico are associated with these shallow, sedimentary hydrocarbon-induced magnetic anomalies.

The association between hydrocarbon seepage and the formation of authigenic magnetic minerals in near-surface sediments has important applications in deep-water hydrocarbon exploration. Seepage-induced sedimentary magnetic anomalies, known as Magnetic Bright Spots (MBS), can reliably identify areas and prospects with the highest petroleum potential in water depths as great as 9000 feet (2800 m). The high-resolution cesium vapor aeromagnetic data used in this study were acquired between 1986 and 1992, and extend from East Breaks to Viosca Knoll in the Gulf of Mexico. A comparison of the specially processed and interpreted aeromagnetic data with post-survey drilling results documents that 89% of wells drilled on prospects within or adjacent to Magnetic Bright Spots have resulted in commercial discoveries. In contrast, only 40% of wells drilled on prospects located more than 800 m from the MBS have resulted in discoveries. Furthermore, MBS areas account for 65% of production - almost 5 times that from within salt-covered areas where no MBS could be determined, although the areas are roughly similar in size. Production per well in MBS areas is triple that in salt. More significantly, 83% of production comes from the 25% of the survey area represented by Magnetic Bright Spots and the immediately adjacent areas. Although the discovery of MBS anomalies does not guarantee the discovery of hydrocarbon accumulations, it does identify areas requiring more detailed evaluation, thereby focusing attention and resources on a relatively small number of high potential sites. This technology, when properly acquired and interpreted, has the potential to significantly reduce risks and costs in deep-water exploration areas.

Aeromagnetic SRM Data Interpretation



Shallow marine sediments enriched in authigenic magnetic minerals frequently occur between oil/gas accumulations and the seafloor, and cause a subtle but recognizable change in the magnetic field profile. Removal of the magnetic effects of the deeper basement rocks produces the SRM profile. Only then can the low-level magnetic effects created by hydrocarbon microseepage be identified as SRM Anomalies.

INTRODUCTION

The expression of hydrocarbon-induced alteration of soils and sediments can take many forms including mineralogic changes such as formation of calcite, pyrite, uranium, elemental sulfur, and certain magnetic iron oxides and sulfides.

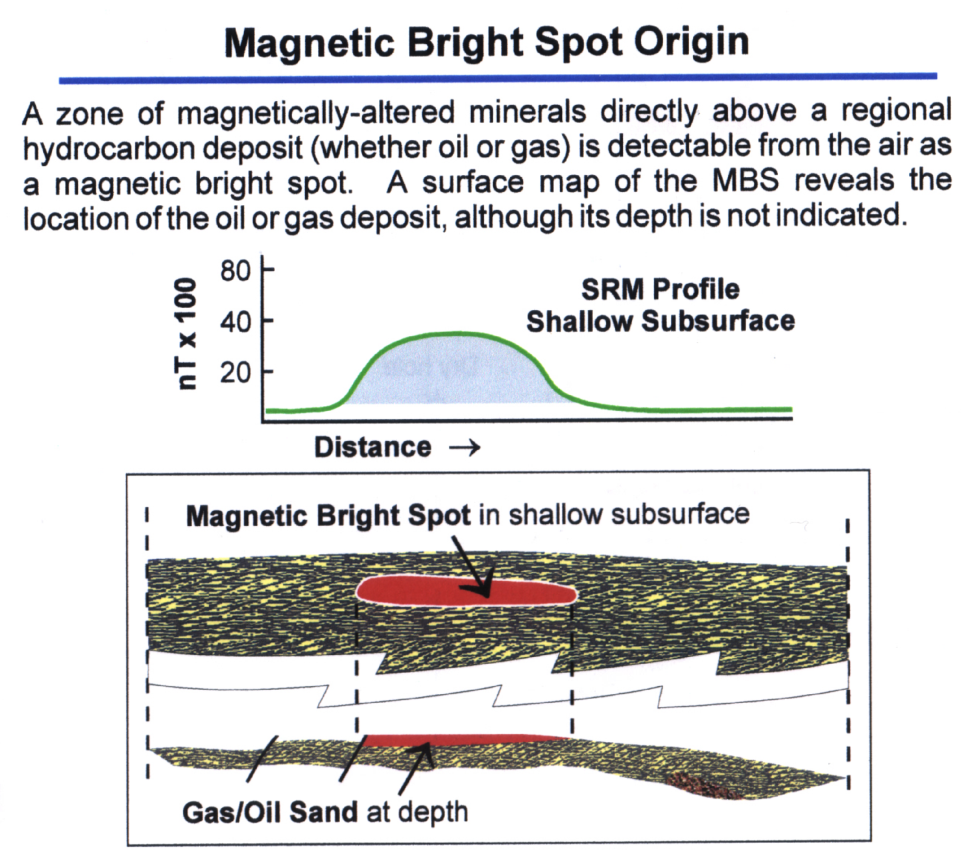
Variation in the measurements of the earth’s magnetic field can result from the following causes:

- Lithologic and magnetic changes associated with basement rocks.
- Igneous intrusive bodies, volcanic deposits, and shallow salt masses.
- Cultural contamination from surface and near-surface iron material.
- Solar modulation of the earth’s magnetic field.
- Authigenic ferromagnetic minerals in near-surface sediments.

The last item in this list forms the basis for the detection of seepage-induced magnetic anomalies associated with oil and gas fields. Anomalous magnetic field increases caused by these magnetic iron-enriched sediments can be detected by careful analysis of the magnetic field record. The dominant authigenic magnetic mineral in offshore sediments in greigite, Fe_3S_4.

Low elevation, high sensitivity cesium vapor aeromagnetic measurements of the earth’s magnetic field are required to detect and map these magnetically enriched zones. The magnetic field data analysis method requires the removal of the regional or basement (longer wavelength) component and where possible also the effects of cultural iron contamination. The residual field then reveals shorter wavelength increases caused by authigenic mineralized bodies, also known as ***Sedimentary Residual Magnetic (SRM) Anomalies***. When these SRM anomalies are positioned line-to-line next to each other, they yield a SRM anomaly cluster that that has been defined by Robert Foote as a ***Magnetic Bright Spot (MBS)***.

Magnetic Bright Spot (MBS)



The Magnetic Bright Spot (MBS) represents an interval of magnetically-enriched sediment or sedimentary rock located above an oil/gas accumulation and commonly within several hundred meters of the seafloor. A surface map of the areal extent of the MBS can approximate the extent of the oil/gas pool in the subsurface, however, it does not provide information about the depth of that accumulation.

OFFSHORE SEEPAGE-INDUCED MAGNETIC ANOMALIES

The presence of shallow Sedimentary Residual Magnetic (SRM) anomalies and Magnetic Bright Spots (MBS) above onshore oil and gas fields has been well documented, and these anomalies are associated with 75% to 85% of onshore oil and gas accumulations. Until relatively recently, the exploration for seep-induced magnetic anomalies has been limited to onshore basins, however, there is no reason why offshore accumulations should not be associated with similar shallow sedimentary magnetic anomalies. The principal drawback to applying this technology to offshore and deep-water exploration has been instrument sensitivity and data quality.

Analytical and interpretive improvements by Geoscience and Technology and by Geoscience International in the deep Gulf of Mexico (500m - 2000m water depth) have achieved a four-fold increase in analytical sensitivity via time synchronization improvement in airborne magnetometer and base station data, and corrections for airborne magnetometer and sea level altitude variations; these improvements have made anomaly detection to 0.05 nano Tesla (nT) possible.

After receiving a quality inspection and fine nonlinear smoothing, aeromagnetic data are analyzed for anomalous waveforms. The total field is corrected by the international Geomagnetic Reference Field (WDC-GMG 2010) which is sensitive to flight altitude. Then the contribution to the residual field is calculated and removed using a nonlinear method, along with any necessary deculturing. High resolution base stations measure the solar (diurnal) magnetic field variations, which correct the data. Salt domes and changing salt lens thickness modulate the magnetic field, creating intensity depressions that prevent evaluation.

The examples presented here are based on interpretations of the 1986-1992 Gulf of Mexico aeromagnetic survey. This survey preceded most of the drilling in deeper waters. Consequently, oil field and pipeline interference is largely absent. The survey contains 148,000 line km (92,500 line miles) and covers more than 3800 MMS blocks to water depths of 2100 m (7000 ft). For depths shallower than 1220 m (4000 ft), most north-south line spacing is 0.8 km (0.5 mi), and east-west tie line spacing is 1.6 km (1.0 mi). For most areas deeper than 1220 m (4000 ft) water depth, the north-south line spacing increases to 1.6 km (1.0 mi). In the Thunder Horse area of Mississippi Canyon, the 0.8 km (0.5 mi) spacing extends to depths greater than 1800 m (6000 ft).

Pompano Field Area, Mississippi Canyon

An example of anomaly resolution in 460 m (1500 ft) of water depth is shown for data from the Pompano field area Mississippi Canyon/Viosca Knoll. The maps below (Figs. 3a, 3b, and 3c) - after removal of basement and salt effects on the magnetic field - show the distribution of the residual increase of the anomalous magnetic field over the westerly extension of the Pompano Field in MC27 and MC28. The residual increase in nT X 100 determines the SRM value and the anomaly position on the four flight lines shown in Figure 3a. The intensity of the SRM field and length are indicated by the blue anomaly (about 0.8 nT).

These SRM anomalies, determined from residual profile lines, comprise the SRM/MBS map (Fig. 3b). All SRM anomaly intensities are normalized to a 1220 m (4000 ft) water depth. An MBS anomaly is defined as the area within the outline surrounding a cluster of SRM anomalies. The SRM contour map (Fig. 3c) with an August 2003 drilling status, shows the regions of highest authigenic magnetic iron concentration within the shallow sediments below the seafloor.

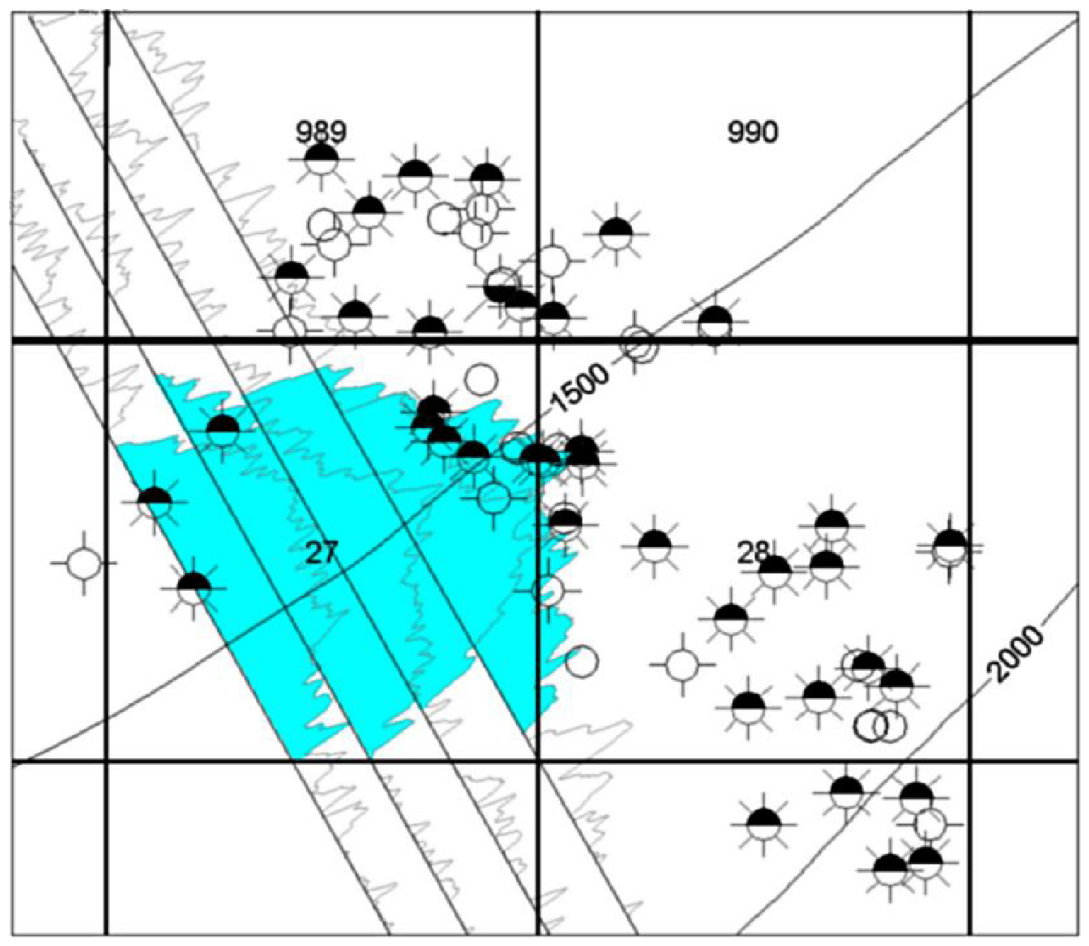


Figure 3a. Profiles showing anomalous residuals on level base lines for four flight lines in the western extension of Pompano field, MC 27.

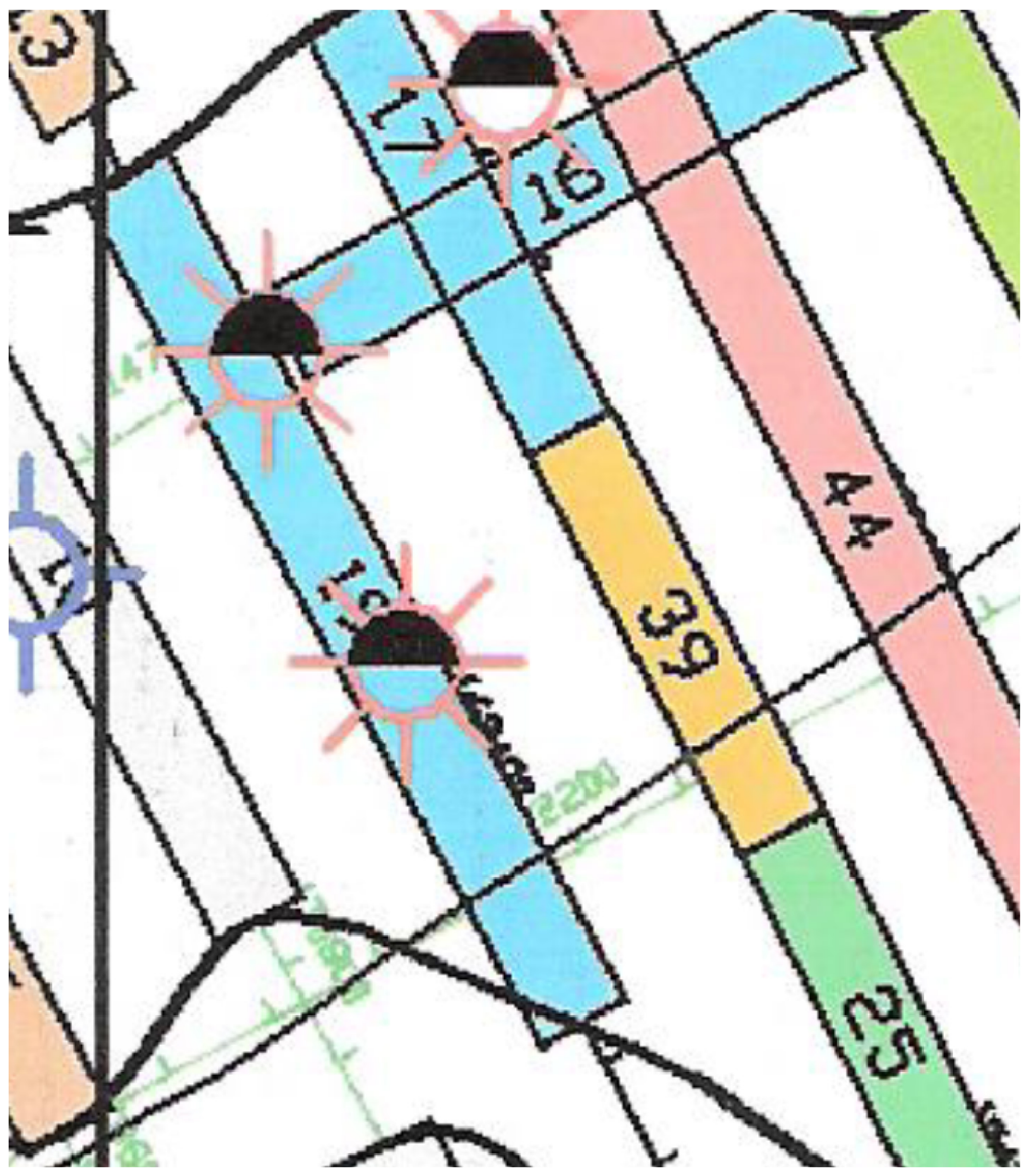


Figure 3b. SRM/MBS map os the western extension of Pompano field.

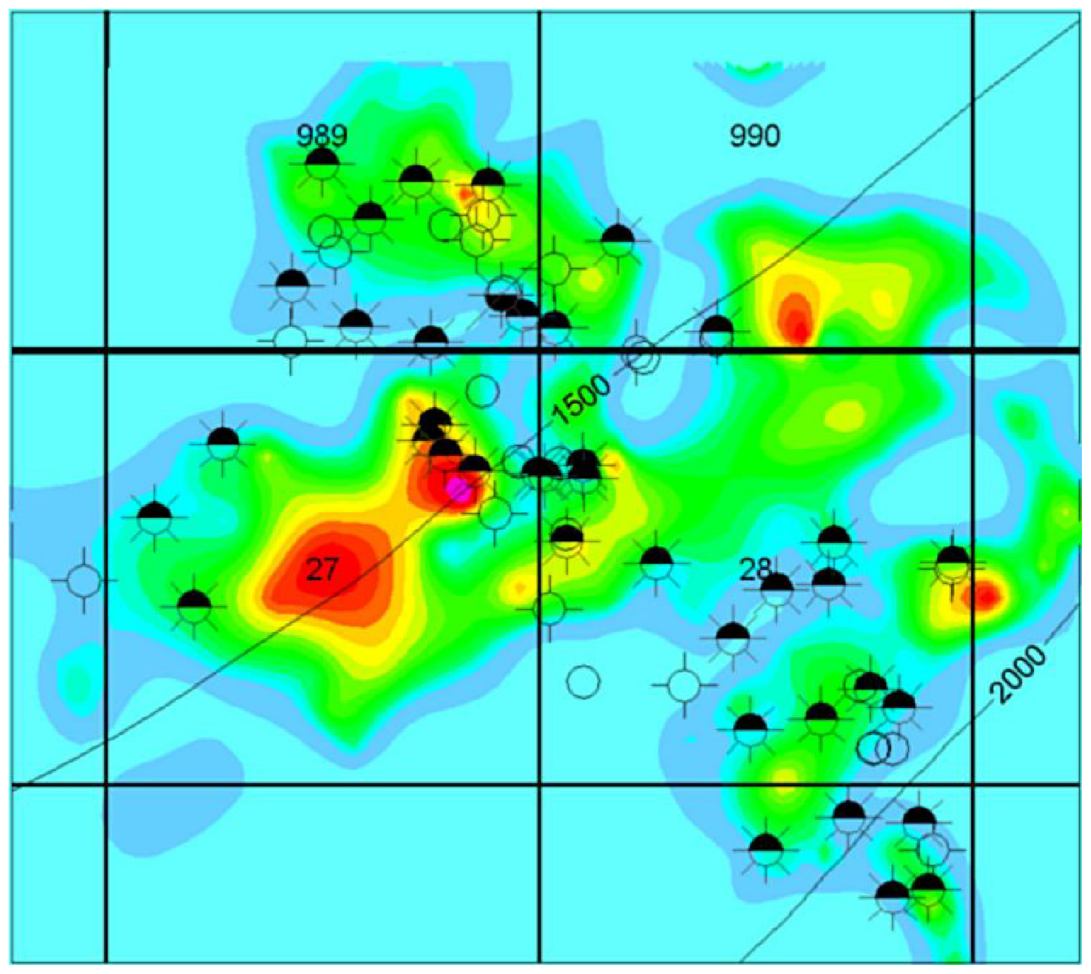


Figure 3c. MBS contour map for Pompano field area.

Thunder Horse Fields, Mississippi Canyon

This is an example of anomaly resolution in deeper waters; water depths are 1675 - 1980 m (5500 - 6500 ft). The large MBS anomaly in MC blocks 732, 776, 777, 778 and 782 includes the BP/ExxonMobil discoveries of Thunder horse and Thunder Horse North fields. Wells shown represent drilling status as of 2009. Estimated reserves are up to 3 billion barrels, making these fields the largest in North America south of Prudhoe Bay, Alaska. Figure 4a is a basement removed profile waveform map for Thunder Horse field in 1800 m water depth. Figure 4b is the corresponding contour map of SRM data for Thunder Horse field.

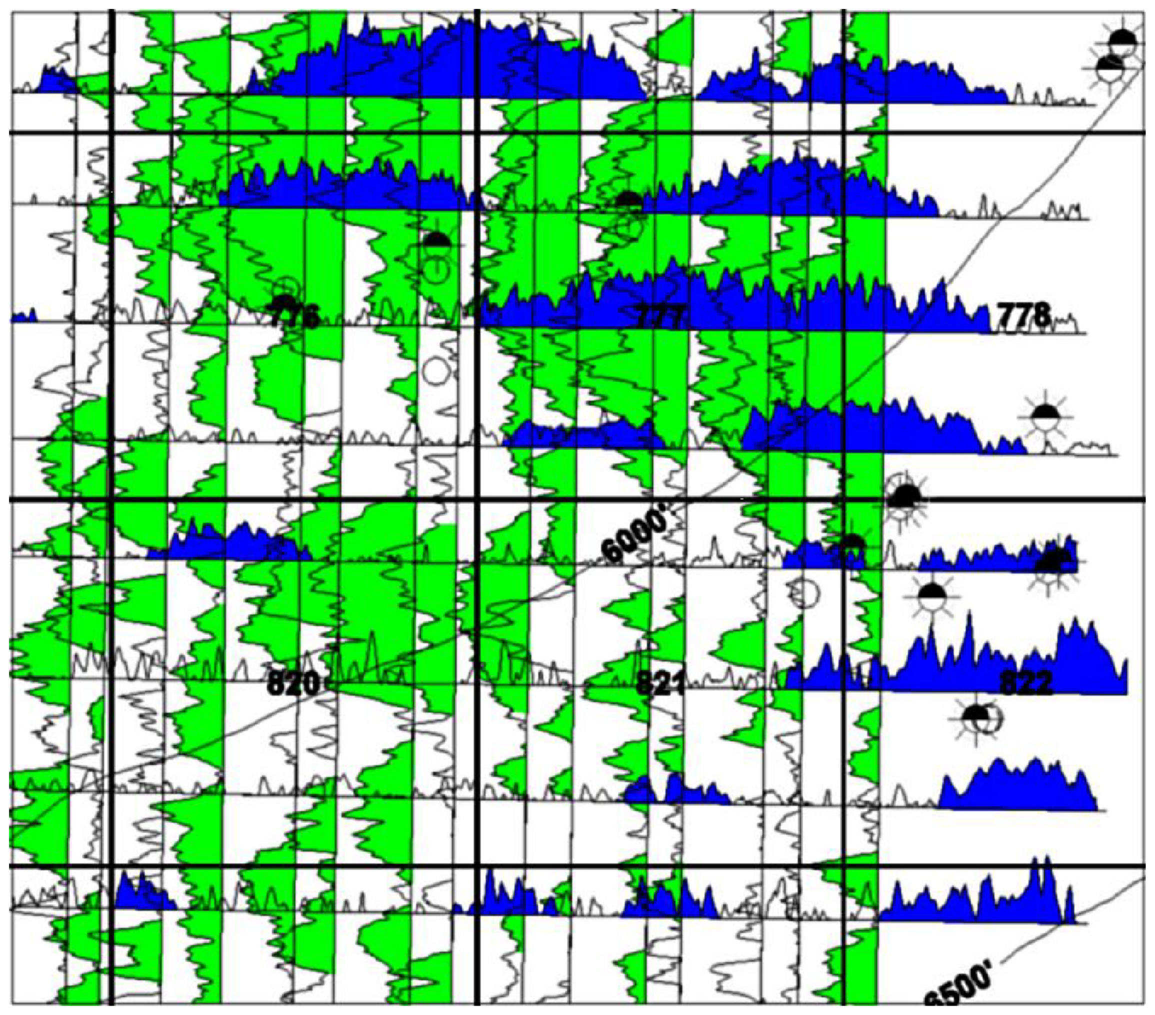


Fig 4a. Basement removed SRM profile waveform map for Thunder Horse field.

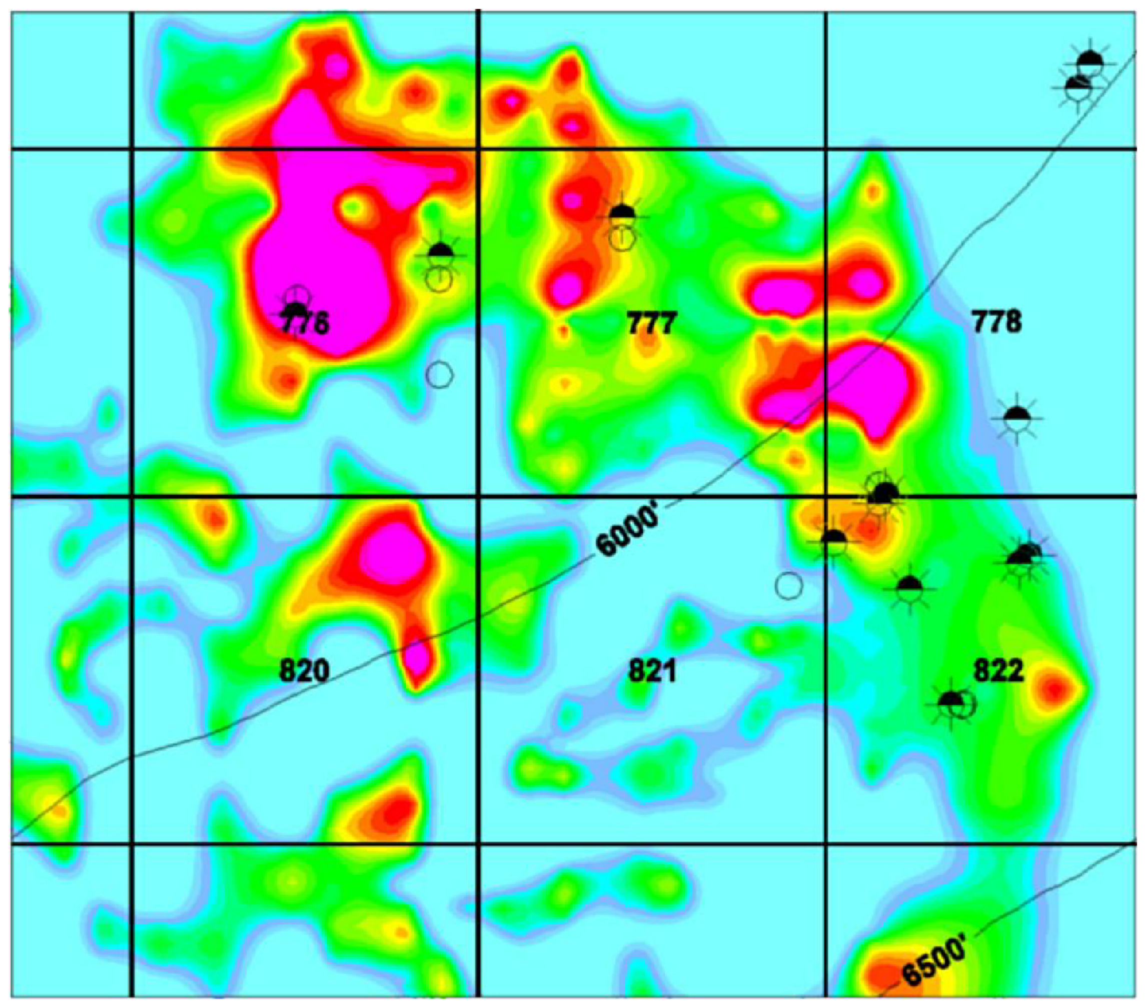


Fig 4b. Contour map of SRM data for Thunder Horse field area.

Relationship of Deep-Water Producing Areas to Magnetic Bright Spots

Tables 1 and 2 summarize the relationship of deep-water wells and production to Magnetic Bright Spots. Bottom hole locations are classified as being IN (within the MBS), EXT (within 800 m of MBS), OUT (more than 800 m from MBS), SALT (within 800 m of Salt). Approximately 15% of the survey area is anomalous (IN) and EXT areas add about 10%. Salt interference with data anlysis is 16% of the survey area.

Production Tables 1 and 2 are depicted in Figure 5. In the 2009 analysis, wells within the Magnetic Bright Spot area account for 83% of the production when the surrounding 800 m extension (IN + EXT. far right column) is included. The 2014 update analysis of these data reinforces this observation.

Proximity to magnetic bright spot

Promixity to MBS.....>	IN	EXT	OUT	Salt	Total	IN + EXT
Production MMBOE	1,756.7	472.3	104.7	349.1	2682.90	2,229.0
Percent of total	65.5	17.6	3.9	13.0		83.1
Wells	367	103	60	162	692	470
Percent of total	53.0	14.9	8.7	23.4		67.9
MMBO / well	4.79	4.59	1.75	2.16	3.88	4.74

Table 1.
Relationship of wells and production to magnetic bright spots and salt areas.
July 2009 Summary

Proximity to magnetic bright spot

Promixity to MBS.....>	IN	EXT	OUT	Salt	Total	IN + EXT
Production MMBOE	2,889.6	869.8	306.3	474.7	4,540.4	3,759.4
Percent of total	63.6	19.2	6.7	10.5		82.8
Wells	448	140	82	179	849	588
Percent of total	52.8	16.5	9.7	21.1		69.3
MMBO / well	6.45	6.21	3.74	2.65	5.35	6.39

Table 2.
Relationship of wells and production to magnetic bright spots and salt areas.
March 2014 Summary

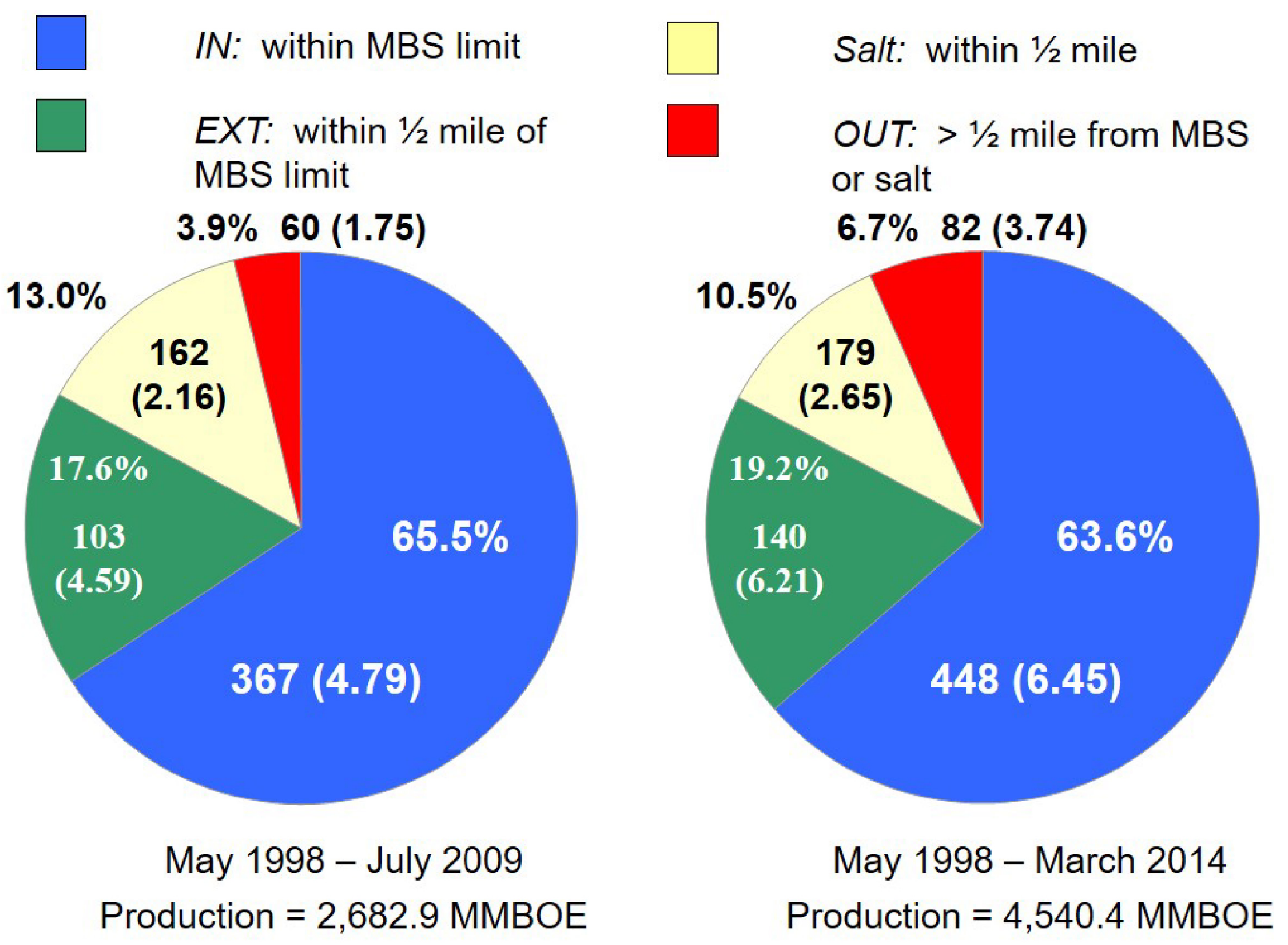


Figure 5. Relationship of wells and production to magnetic bright spots and salt areas. Results for wells spudded between April 1998 and July 2009 shown on left, and through March 2014 shown on right. Production % of total volume, total number of wells, and MMBOE per well are shown.

CONCLUSIONS

1. Hydrocarbon leakage results in direct and indirect geochemical and mineralogic changes to sediments above oil/gas accumulations.

2. Among the most common and reliable of these changes are shallow Sedimentary Residual Magnetic (SRM) anomalies and Magnetic Bright Spots (MBS).

3. The areal extent of the Magnetic Bright Spot can approximate the productive limits of the oil/gas-bearing reservoir.

4. 75% to 85% of exploration wells drilled within the MBS have resulted in oil/gas discoveries. In contrast, fewer than 10% of exploration wells drilled more than 800 m (0.5 mi) beyond the MBS have resulted in discoveries.

5. Proper acquisition and interpretation can significantly reduce exploration risk in deep-water areas by early identification of the specific areas or prospects with highest petroleum potential.

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