APPLICATION OF UNSUPERVISED SEMIVARIOGRAM TEXTURAL CLASSIFICATION (USTC) FOR THE DETECTION OF NATURAL OIL SLICKS USING RADARSAT-1 DATA

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INTRODUCTION

Natural oil seeps indicate the presence of generative hydrocarbon source rocks, without which there can be no accumulations. The high cost of offshore exploration has made the identification of seeps a well-accepted risk assessment methodology. This paper describes a pilot project in a frontier area offshore the Amazon River mouth (Foz do Amazonas basin; Figure 1). The region is cloud-covered all year round. Spaceborne radars such as RADARSAT-1 are therefore the ideal choice, since they are only weakly affected by cloud conditions and are able to detect natural oil slicks.

PETROLEUM HABITAT

The Foz do Amazonas sedimentary basin embraces 268,000 km^2 in the north-westernmost portion of the Brazilian Equatorial Margin (Figure 1; Brandão and Feijó, 1994). Petroleum reservoirs are Early to Mid Albian syntectonic clastic rocks of Caciporé Formation and Paleocene to Miocene biocalcarenites of the carbonate platform of the Amapá Formation (Mello et al., 1993). Geochemical data indicate that oils recovered from Amapá and Caciporé formations are correlated with organic extracts from shales of Caciporé and Limoeiro (Albian to Paleocene) formations. Hydrocarbons migrated updip through regional unconformities or normal faults to reservoirs mostly in the Amapá Formation. Structural and stratigraphic traps were created as a result of Cenozoic gravitational tectonics, which gave rise to listric normal, thrust and strike-slip faults.

OCEANOGRAPHIC SETTING OF THE STUDY AREA

The study area includes oceanic regions located between 15 and 2800 meters of water depth offshore the Amazon River mouth. The Amazon plume of inorganic suspended sediments can extend up to 200 km seaward from the river mouth (it affects the south-westernmost portion of the study area down to the 60-meter isobath). Offshore oceanic flow occurs mostly north-westward in the alongshore direction, being dominated by the North Brazil Coastal Current (NBCC). The main tidal current component in the Amazon continental shelf is semidiurnal (M_2), with amplitudes ranging from 0.7 to 0.85 m at the northern outer shelf. At the inner northern shelf, M_2 amplitudes can reach values between 1.5 to 3.0 m, as a result of a resonance mechanism. The tidal currents are almost rectilinear and oriented in the cross-isobath direction (Beardsley et al., 1995).

RADARSAT-1 DATA

RADARSAT-1 images in the ScanSAR Narrow (SCN1) and Wide (W1) beam modes were used in this investigation. The shallow incidence angles pertaining to these beam modes improve the detection of oil slicks. Data acquisition took place on 14 August 1996 (W1) and on 12 May 1997 (SCN1), about 06:00 AM local time. These images were selected for natural oil slick detection after a thorough inspection of the archived RADARSAT-1 data set in the region.

METHODS

The physical mechanism that allows detection of oil seeps is the dampening of capillary waves present on the ocean surface. These capillary waves, which are only a few centimeters in wavelength, produce backscattering of the incident radar pulse due to a Bragg scattering mechanism (Johannessen et al., 1994). As a result, ocean regions containing oil are dark in contrast with the background radar signal. However, with regard to radar-imaging, the suppression of the wave backscatter is unfortunately not unique to the presence of oil. False targets include wind shadow, biological surfactants, local upwelling, shallow marine vegetation, and areas of heavy rainfall. Our proposed approach circumvents these pitfalls by using the textural classification algorithm USTC (Unsupervised Semivariogram Textural Classifier; Miranda et al., 1997) that enhances areas of smooth texture on RADARSAT-1 images. Oceanic databases and modelling results for winds, waves and tidal elevation where used to provide information about the environmental conditions at the time of RADARSAT-1 data acquisition. This information is crucial to select smooth texture areas interpreted as natural oil slicks. These regions are then combined with seismic and bathymetry data in order to identify geologic controls on natural hydrocarbon seepage.

Data from the AVHRR (Advanced Very High Resolution Radiometer) sensor are generally used as an aid to the interpretation of RADARSAT-1 images for oil slick detection. However, AVHRR images were not available for the study area simultaneously with the analysed RADARSAT-1 data.

RESULTS

Wind and Wave Characterization

The wind field at 10 meters height was forecasted for the time of RADARSAT-1 data acquisitions. Wind values obtained using a limited area atmospheric numerical model (Innocentini and Caetano Neto, 1996) were 6 m s^{-1} for 14 August 1996 (W1) and 4.0 to 4.7 m s^{-1} for 12 May 1997 (SCN1). These results are above the lower limit of wind magnitude (3 m s^{-1}) necessary for obtaining a good SAR return echo (Staples and Hodgins, 1998). There was a predominance of trade winds from NE and SE. The wave field forecasted for both dates was characterized by wave heights of less than 1.0 meter propagating from NE and SE.

The tidal regime

Time series of elevations at Ponta do Céu were calculated for three days centered at the dates of RADARSAT-1 image acquisition using an harmonic model (Franco, 1988). The high tide at Ponta do Céu was reached at 05:00 AM local time on 12 May 1997 and at 01:30 AM local time on 14 August 1996. Taking the phase lag of 8 hours between Ponta do Céu and the center of the study area (as suggested by the M_2 elevation phase map of Beardsley et al., 1995), the most probable relative tidal elevations for the RADARSAT-1 images are indicated in Figures 2 and 3. The SW, C, and NE annotations refer to the south-western corner, the center, and the north-eastern corner of the study area, respectively. Results suggest the presence of flooding tides for the 12 May 1997 image. For the 14 August 1996 RADARSAT-1 acquisition, ebbing tides were forecasted for the center and north-eastern corner of the study area, while flooding tides occurred in the south-western corner.

Interpretation of Remotely Detected Oil Slicks

Raster polygons defining smooth texture regions on USTC-classified RADARSAT-1 images were merged with geophysical and bathymetric data. Distinctive and elongated features were interpreted as natural oil slicks (Tables 1 and 2).

A total of seven surface slicks were identified on the SCN1 RADARSAT-1 image acquired on 12 May 1997 (Table 1). The slicks range in length from 4.6 to 11.3 km; they have a mean value of 7.1 km and standard deviation of 2.04 km.

A total of five surface slicks were distinguished on the W1 RADARSAT-1 image acquired on 14 August 1996 (Table 1). The slicks range in length from 1.0 to 2.6 km; they have a mean value of 1.8 km and standard deviation of 0.52 km.

CONCLUSIONS

The Unsupervised Semivariogram Textural Classifier (USTC) was effective in defining distinct and elongated smooth textural features interpreted as natural oil slicks on SCN1 and W1 RADARSAT-1 images. Environmental conditions (ocean winds and waves) at the time of SAR data acquisition were suitable for oil slick detection, as anticipated by modelling results.

Surface slicks on the SCN1 image do not have corresponding features on the W1 image. This fact suggests that seepage has occurred intermittently in the study area within the investigated time frame.

Spatial coincidence of surface slicks and geologic structure at the top of Amapá Formation allowed inferences about the control of Cenozoic gravitational tectonics on natural seepage. Most of surface slicks originated in the extensional domain from sources near listric normal faults (Table 2; Figures 2 and 3). Only one surface oil slick was found in the compressional domain at greater water depths.

These results may be used for identifying the most promising acreage for oil exploration. They also indicate potential locations for collection of sea bottom cores for geochemical analysis.

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Table 1 – Characteristics of interpreted natural oil slicks

INTERPRETED OIL SLICK	RST-1 BEAM MODE	ACQUISITION DATE	LEN GTH (km)	PREFERENTIAL ORIENTATION	MAIN OCEANOGRAPHIC CONTROL	WATER DEPTH (m)
A	SCN1	12 MAY 1997	7,6	E to W	Flooding tidal current	1400 to 1600
B1	SCN1	12 MAY 1997	5,6	E to W	Flooding tidal current	80
B2	SCN1	12 MAY 1997	11,3	E to W	Flooding tidal current	75
B3	SCN1	12 MAY 1997	8,2	E to W	Flooding tidal current	80
B4	SCN1	12 MAY 1997	5,9	E to W	Flooding tidal current	80
B5	SCN1	12 MAY 1997	4,6	E to W	Flooding tidal current	80
B6	SCN1	12 MAY 1997	6,8	E to W	Flooding tidal current	80
C1	W1	14 AUG 1996	1,8	W to E	Ebbing tidal current	95
C2	W1	14 AUG 1996	1,0	W to E	Ebbing tidal current	95
C3	W1	14 AUG 1996	1,7	W to E	Ebbing tidal current	95
D	W1	14 AUG 1996	2,6	W to E	Ebbing tidal current	95
E	W1	14 AUG 1996	2,0	SE to NW	NBCC	620

Table 2 – Tectonic control on natural seepage

INTERPRETED OIL SLICK	RADARSAT-1 BEAM MODE	ACQUISITION DATE	ADJACENT GEOLOGIC STRUCTURE	TECTONIC DOMAIN
A	SCN 1	12 MAY 1997	Strike-slip fault and structural high associated with a thrust fault	Compressional
B1 to B6	SCN1	12 MAY 1997	Listric normal fault	Extensional
C1 to C3 and D	W1	14 AUG 1996	Listric normal fault	Extensional
E	W1	14 AUG 1996	Listric normal fault and structural high (rollover anticline)	Extensional

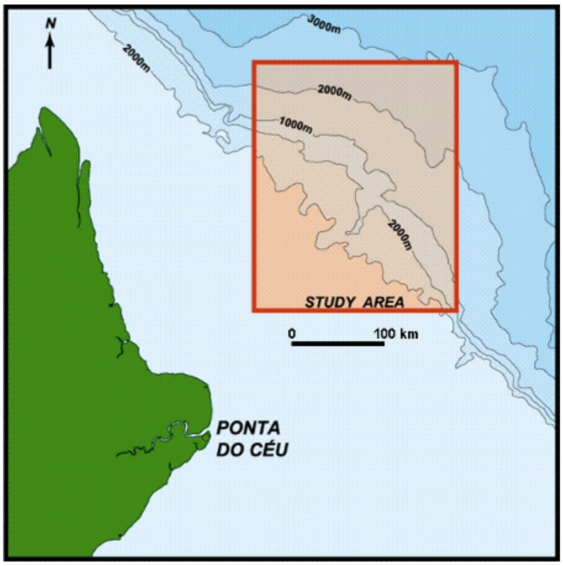

Fig. 1 – Location map

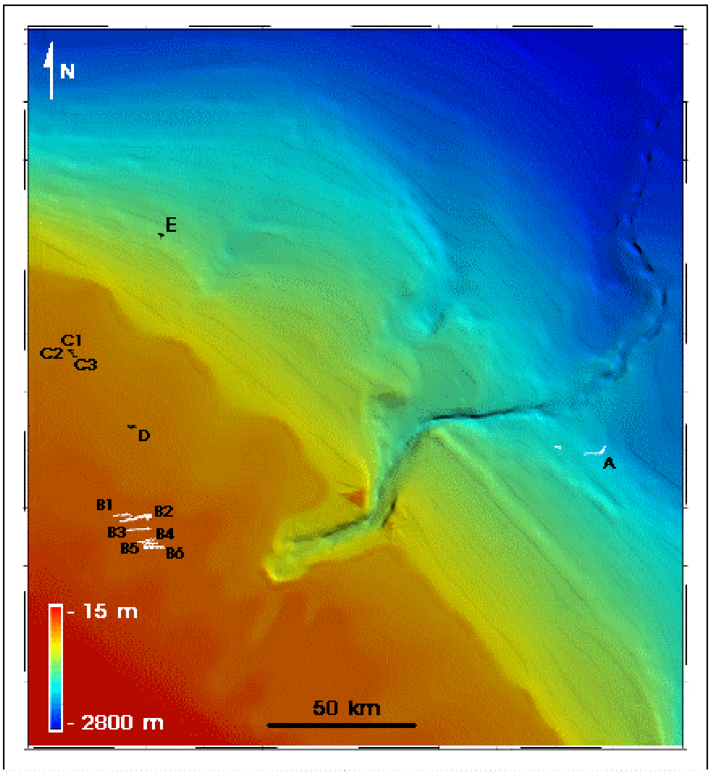

Fig. 2 –Interpreted natural oil slicks in the bathymetric context of the study area

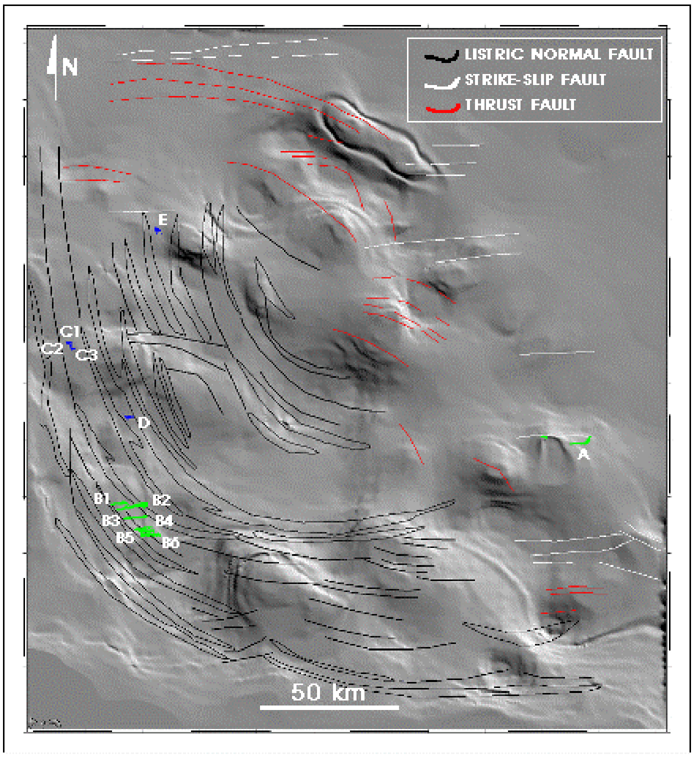

Fig. 3 - Interpreted natural oil slicks in the tectonic context of the study area. Top of the Amapá formation is illuminated from NE.