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Gravity and magnetic interpretation of the Sunda Shelf and South China Sea

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Gravity, magnetics, interpretation

Summary

Regional interpretations at continental scales provide contexts for exploration that cannot be derived from analysis of even basin-scale areas, and our goal is to provide such a context for the Sunda Shelf - South China Sea region (Figure 1).

Magnetic and satellite-derived free air gravity data are interpreted to provide a regional framework for planning hydrocarbon exploration. Relative detail of rifts, depocenters, carbonate buildups, platforms, major structures, accommodation zones, distribution of volcanics, and depth to magnetic basement as well as definition of oceanic fracture zones and their interaction with prospective continental margin areas are interpreted. The study area is 100° to 120° East by 2° to 23° North, or about the same size as the entire Gulf of Mexico or North Sea. Nine mega-regional modeled cross sections are used to support the interpretation

Interpreted basins include: Beibu Wan, Hoang Sa, Malay, Mekong, Nha Trang, Outer, Pearl River, Sabah, Sokang, Song Hong, Tarakan, Thai, West Natuna, and Yang Ghe. Other important regions interpreted include: Baram Delta, Luconia Platform, McClesfield Bank, Paracel Islands, Reed Bank, and Spratly Islands area.

Introduction

Information from gravity and magnetic data has been integrated with surface and subsurface geology from the literature and, in many areas, the interpretation provides significant new structural information. However, the work is necessarily regional in scope because of the nature of the data involved. This study is intended to be used in the following ways:

- As a guide to creating new plays, or extending existing plays,
- As a means of providing a different way of looking at geological parameters that may have impact on exploration, such as locations of source-rock depocenters,
- To identify hitherto unknown (or little studied) features whose effects on the prospective section should be investigated further, and
- As a guide to planning exploration strategy and to provide an inter-basin as well as intra-basin view of the region.

Details of structure and stratigraphy in the region are complex and diverse. A tremendous amount of work has been done on reconstructing the plate tectonic history of Southeast Asia. Hall & Blundell (1996) have compiled the most recent volume, which includes many useful syntheses.

Data

Satellite-derived free air gravity anomalies

Gravity data are computed from satellite radar altimeter measurements of the sea surface. The precision of these measurements can be as good as 2 cm, which translates to an overall accuracy of derived gravity that is on the order of 4 to 7 mGal.

The best objective spatial resolution is usually given as about 20-25 km, but subjective experience shows occasional fair to good correlation with known geological features at scales of about 15 km or a bit less. As a continuous and uniform data set, the satellite-derived information is actually better than old, wide and irregularly spaced shipborne data in some places. For a review of data resolution issues see Yale et al. (1998).

Total intensity magnetic anomalies

The magnetic data were derived from the Committee for Co-ordination of Joint Prospecting for Mineral Resources in Asian Offshore Areas (CCOP). These data were published by CCOP in map form in 1994 with the cooperation of the Geological Survey of Japan. Digital data from a 2 km x 2 km grid of the original survey data were also made available on CD-ROM. The data came from diverse surveys, ranging from shipborne surveys to airborne data acquired at altitudes ranging from 150 to 2200 meters. Track line spacings vary from wide and irregular (in much of the Natuna Sea) to close and parallel (onshore Thailand, Malaya, and elsewhere).

Sunda Shelf and South China Sea Interpretation

Interpretation approach

This work is an interpretation of the lithologies, structures, and history of the region. The focus is necessarily on the basement, as the greatest density and magnetization contrasts are likely to be found there. We identify features that affect the prospective sedimentary section. Major lithologic boundaries are determined by characterizing the magnetic susceptibility of rocks in the subsurface and inferring rock types and their contacts; such intrabasement zones are likely to be important zones of weakness that may be exploited repeatedly during tectonism.

The map interpretation shows many fault blocks, however no genesis is implied. Faults in many areas (e.g., Pearl River Mouth, Mekong-Saigon Basins, the Spratly and Paracel Islands) probably are extensional normal faults, while others originated as normal faults but have been complicated by wrench activity and inversion due to compression.

The interpretation map also includes some long lineaments which represent aligned disruptions in the gravity or magnetic data or both. In the oceanic terrane of the main South China Sea basin, these breaks in linear magnetic anomalies represent sea-floor spreading fracture zones. Elsewhere, the lineaments can reasonably be inferred to represent accommodation zones for both extensional and compressional stress systems: narrow regions of stress transfer in the former, and possible tear faults associated with thrusting in the latter. In some areas, whether or not they are actual fault zones, they appear to segment basins into sub-basins.

The question of the ultimate origin of large linear features in the earth's crust and basement rocks has received much attention. For this study, that basic question is for the most part left unanswered, and the work is based on the idea that such features do exist, that they are mappable from gravity and magnetic data, and that they have had impacts on overlying sediments and hydrocarbon accumulations in many places. Detailed inferences are made about the geologic nature of the basement tectonic features, and hydrocarbon exploration plays and extensions of plays are developed on that basis.

Depth-to-Magnetic Source Estimation

Straight-slope manual technique is utilized in the study. See Åm (1972) for an excellent review of manual techniques including straight-slope. Caveats associated with all depth-to-magnetic source estimation are:

- Profile-based depth estimation assumes two-dimensional source bodies,
- If a profile crosses an oblong shaped anomaly at an angle less than 90°, then depth estimates will be calculated too deep and should be corrected by multiplying depths by the cosine of this angle, and
- Profiles which cross the flanks of anomalies also yield depths which are too deep.

These obstacles can be overcome by continued referral to profile location with respect to mapped data, and by geologic awareness. That is, we can use our geologic insight for the types of structures expected in an area (=interpretation).

Modeling

Forward modeling of gravity and magnetic data are used, in a quantitative sense, to support the interpretation. Nine modeled cross sections, ranging in length from about 500 km to over 1100 km, are based on information from literature and constrained by the potential fields data. Caveats, and their remedies, related to modeling are similar to those for depth-to-magnetic source estimation.

Interpretation

The principal events affecting post-Mesozoic Southeast Asia are:

- the India-Eurasian collision (middle Eocene, about 45-40 Ma),
- opening of the South China Sea oceanic basin (beginning about Oligocene, 32 Ma),
- counter-clockwise rotation of Borneo and parts of Malaysia and Sumatra,
- clockwise rotation of the Philippine Sea plate, and
- collisions of the northern margin of Australia (mostly Miocene and later).

The region of our study is dominated by the first three events, with impacts of the latter two primarily on the eastern and southern margins of the area.

The principal consequence of the India-Eurasian collision was "extrusion" — eastward and southeastward directed movement of both wide and sliver-like terranes out of the area of collision. Much of Indochina is generally agreed to have reached its present position by displacement along major NW-SE fault zones (Red River, Wang Chao, Three Pagodas or Kachana Buri). The history of strike-slip motion on these and related fault zones is important to understanding the hydrocarbon trapping mechanisms of the region, because inversion structures are important traps in several basins. It seems clear that some major fault zones have undergone strike-slip in two opposite directions at different times in their histories.

Incipient wrench zones, including the modern Gulf of Thailand, Malay-Natuna Basins, and Gulf of Tonkin-Song Hong Basin, were low-lying areas during Eocene and early Oligocene time. They were sites of probable river systems that developed into relatively limited (not necessarily completely closed) basins that harbored lakes during this time. Sediments deposited in these lakes are the primary source rocks in the region. Because these areas have been persistently deformed episodically since Eocene time, they have received the greatest accumulations of sediment. Gravity data can help discern these thick sediment piles, and, knowing something of the depositional history, we can predict locations of most likely source rock kitchens.

In addition to wrench-dominated basins, those that are more conventional extensional basins also contain lacustrine source rocks. These include the Pearl River Mouth, Mekong, and Saigon Basins, all of which are complexes of grabens and half-grabens that represent continental margin extension. Lacustrine sediments are thought to be the source for the hydrocarbons in Lihua Field off the southeast coast of China. It is the largest oil field in the South China Sea

Among the most productive hydrocarbon basins are those with abundant lacustrine source beds in combination with one of two primary reservoir types:

- Deltaic clastic complexes serve as prolific producers in the Baram and Mahakam deltas and similar fluvial and marginal marine clastic facies are reservoirs in the Gulf of Thailand and Malay Basin. Most of these clastics are of Miocene to Pliocene age.
- In the Pearl River Mouth Basins, Luconia Bank, Palawan Island, Tarakan Basin, and Saigon Basin-Con Son Ridge area, carbonate banks of similar age developed on high-standing blocks. Interpretation of gravity anomalies helps to delimit the probable extent of such blocks in a regional sense, and even permits prediction of specific large basement blocks that localized individual reef complexes.

Wrench zones are not simple linear faults, but are wide areas of transtension and transpression, with master faults and large splays with significantly different orientations. The resulting interplay of basins and uplifts is complex, but not overwhelmingly difficult to decipher in most areas.

Conclusions

Our results impact and enhance existing interpretations of the Sunda Shelf-South China Sea region, particularly those related to tectonics, depositional history, and development of play ideas in most of the basins considered. Particular play-oriented applications involve fractured basement reservoirs, extents of prospective carbonate platforms and reefs, and locations of environments of deposition, especially fluvio-lacustrine.

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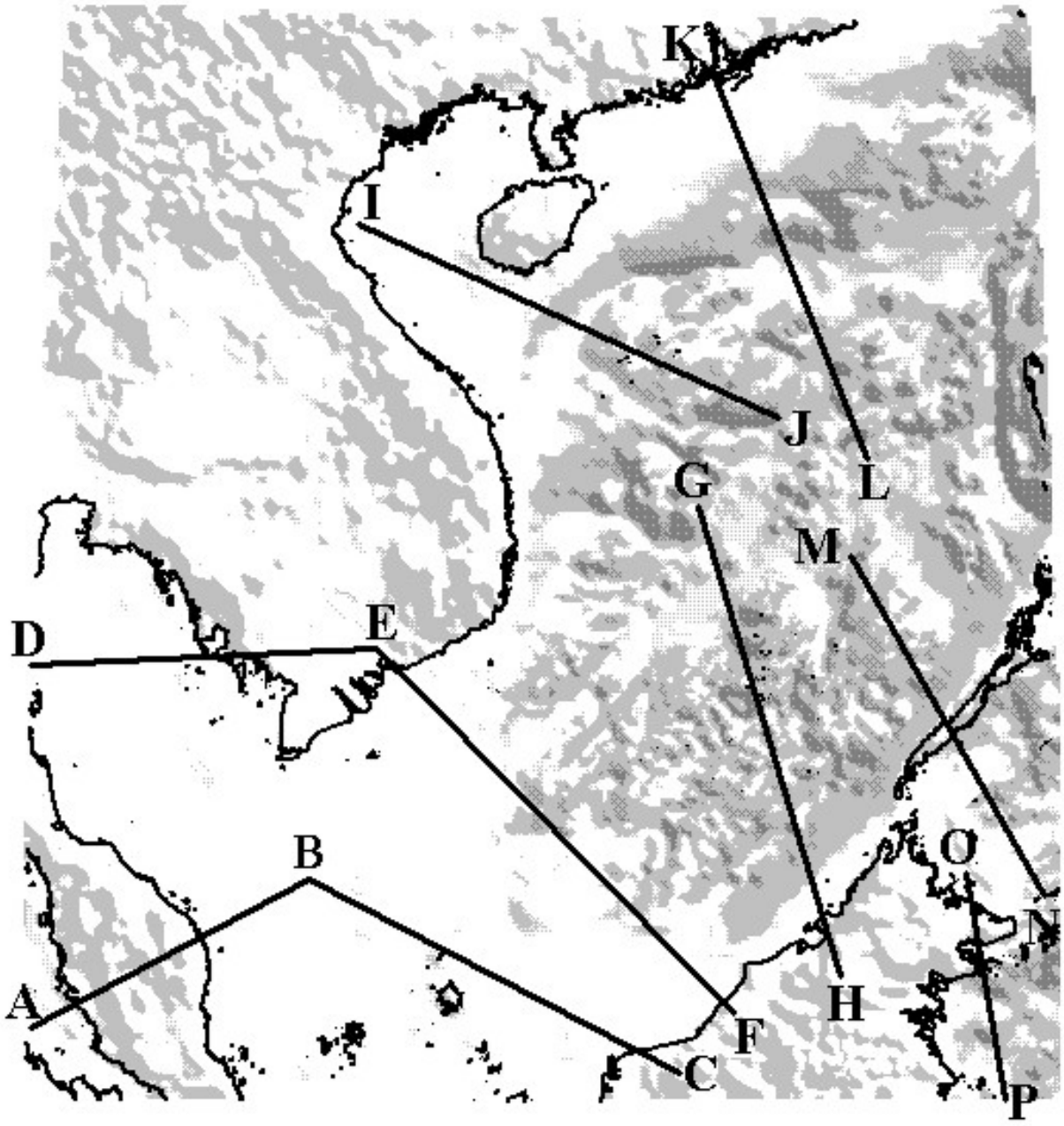

Figure 1

Study area topography and bathymetry showing locations of 2D modeled cross sections.