INTEGRATED GEOPHYSICS CORPORATION

FOOTNOTES
ON INTERPRETATION

IGC FOOTNOTE SERIES AUGUST 1995 VOLUME 3, NUMBER 1

BOUGUER GRAVITY MAPS IDENTIFY REGIONAL BASIN STRUCTURE AND RESULTANT PREFERRED DIRECTIONS OF LATERAL OIL AND GAS MIGRATION

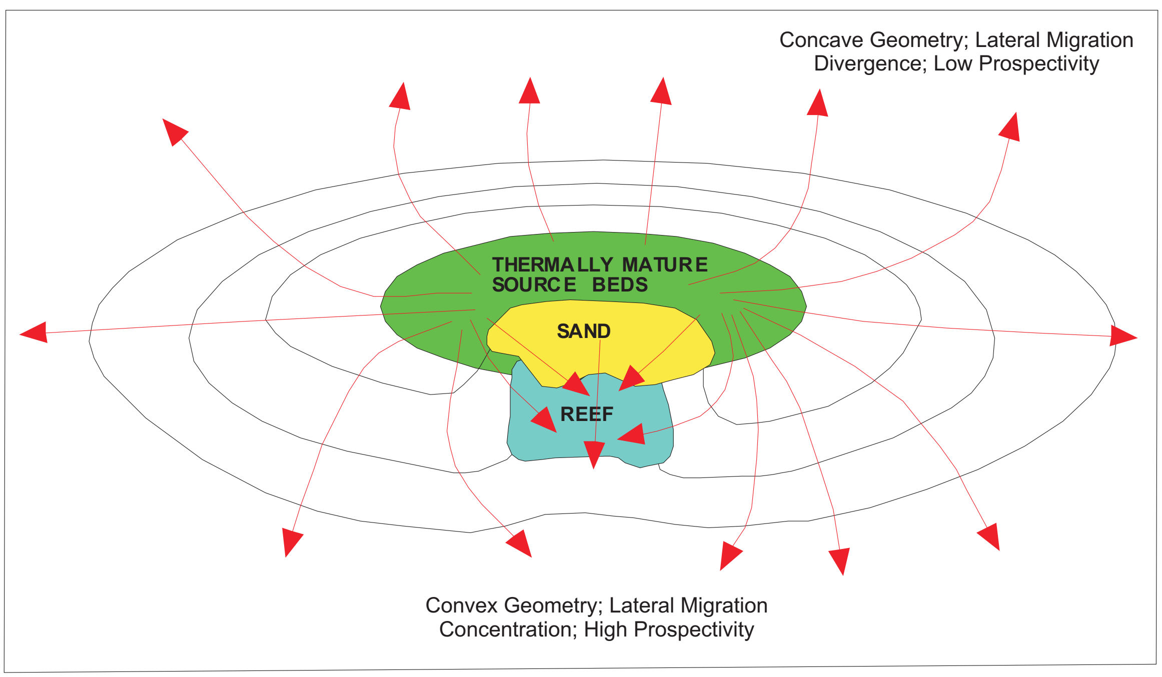

Figure 1 - Basin geometry, preferred migration directions, and prospectivity differences (from Pratsch, 1986)

Introduction

All oil and gas accumulations are the result of oil and gas migration. Hydrocarbons migrate vertically and laterally as far as sufficient permeability is present. Migration extends from the site of (thermal) maturation of oil and gas to the sites of hydrocarbon accumulation or of hydrocarbon loss to the atmosphere. In map view, vertical migration has no or only minor map expression. The lateral migration components in a basin, however, can be defined and predicted. Regional structure, and therefore any regional map indicating regional structure, can be used to determine the preferred lateral hydrocarbon migration directions in a basin. The presence or absence of oil and gas in a specific area's traps can thus be predicted. Even a quantitatively and qualitatively well controlled regional Bouguer gravity map in many cases will indicate deep structural geometry; its contours may be viewed as regional structural form-lines. Integration of well data, deep seismic data, and magnetic data, will of course improve any regional structure map.

Hydrocarbons are generated mainly in deep hot portions of a basin. Given sufficient permeability in suitable carrier beds, oil and gas migrate from the generating portion of a basin into near-by traps or toward the basin flanks (Figure 1). Sedimentary basins contain rocks, fluids and gas; they interact constantly and form a petroleum system in a given time frame. In most basins the deepest part of a basin ("depocenter") is the site of the most effective and most advanced thermal hydrocarbon generation.

Subsurface pressures in a basin are the result of sediment thickness, sediment weight, fluid flow, and thermal effects. Subsurface isobars (lines of equal pressure) control lateral hydrocarbon migration and migration directions, because 1) subsurface isobars in first approximation are parallel to regional structure contours, and 2) oil and gas migrate laterally perpendicular to isobars or parallel to pressure gradients. Thus, oil and gas migrate in a preferred way perpendicular to regional structure contour lines drawn at or reasonably close to the level of the migration (carrier) beds.

Basin Structure

Basin structures can be classified according to their final form ("basin geometry"). Most basins are asymmetrical and curved. There are no perfectly circular basins (the Michigan Basin, northern U.S., and the Paris Basin, France are nearly circular), and there are no or only few symmetrical oval basins. Basins may contain one depocenter ("simple basin"), or they may consist of several individual depocenters ("complex basin"). In the latter case, such individual depocenters may be arranged in-line (like in the Gulf of Suez) or parallel to each other (like in the central Rocky Mountain Region). In a complex basin each individual depocenter has its own migration rules and also interacts with adjacent depocenters. An important side effect is a preferred development of reservoir conditions for both clastics and carbonates on basinward plunging structural highs; where water depth has controlled reservoir development and reservoir quality, better and possibly thicker shallow-water reservoirs will be found on these structural anomalies.

Hydrocarbon Migration

Whatever the basin form is, lateral hydrocarbon migration occurs in a preferred way in directions that lie parallel to pressure gradients or perpendicular to regional subsurface pressure isobars and perpendicular to regional structure contours drawn near regional carrier beds.

Convex regional structural elements concentrate flowlines, while concave structural elements diverge flowlines (Figure 1). By drawing arrows perpendicular to regional structure contours, directions of most preferred hydrocarbon migration pathways can be defined and mapped. The best individual prospects will lie along the most preferred migration pathways. "Best" basin portions are those where migration pathways concentrate. In this way basins or portions of basins can be evaluated early and prior to the investment of larger exploration efforts and cost.

Figure 1 shows the basin geometry of an oval asymmetric basin that possesses a major basinward plunging structural anomaly ("structural nose"). This basin form is quite common. By drawing theoretical migration direction trends perpendicular to regional structure contours one obtains the following results:

1) The narrow basin flank has less surface area of thermally mature source beds than the wide basin flank;
2) the narrow basin flanks are areas of migration path divergence;
3) the wide basin flank containing the basinward plunging structural nose is an area of extreme migration direction convergence.

From the standpoint of lateral oil and gas migration, most hydrocarbons will migrate to this basinward plunging anomaly, given sufficient permeability for migrating fluids. Consequently, in a basin of this general regional structure this anomalous area will contain the most promising traps and prospects, because these traps and prospects will contain most of the oil and gas trapped in the basin. Oil and gas will be geographically concentrated. The importance of lateral oil and gas migration, of favorable basin geometry, and of basinward plunging structural anomalies are also clearly indicated on Figure 2, by the oil and oil field concentrations on the Arauca Arch and the Macarenas Arch.

Applications In Regional Hydrocarbon Exploration

The most reliable regional structure maps across a basin will be based on dense seismic depth data tied to deep wells. In most cases such map quality is not available in early stages of basin exploration. Regional gravity and magnetic maps will substitute for seismic maps in such a case. Wherever ideal density stratification exists in a basin, gravity maps can be utilized as regional depth form-line maps. It is our experience in well over 150 producing basins that regional Bouguer gravity maps clearly define deep structure that in most cases has been found to control lateral oil and gas migration pathway directions.

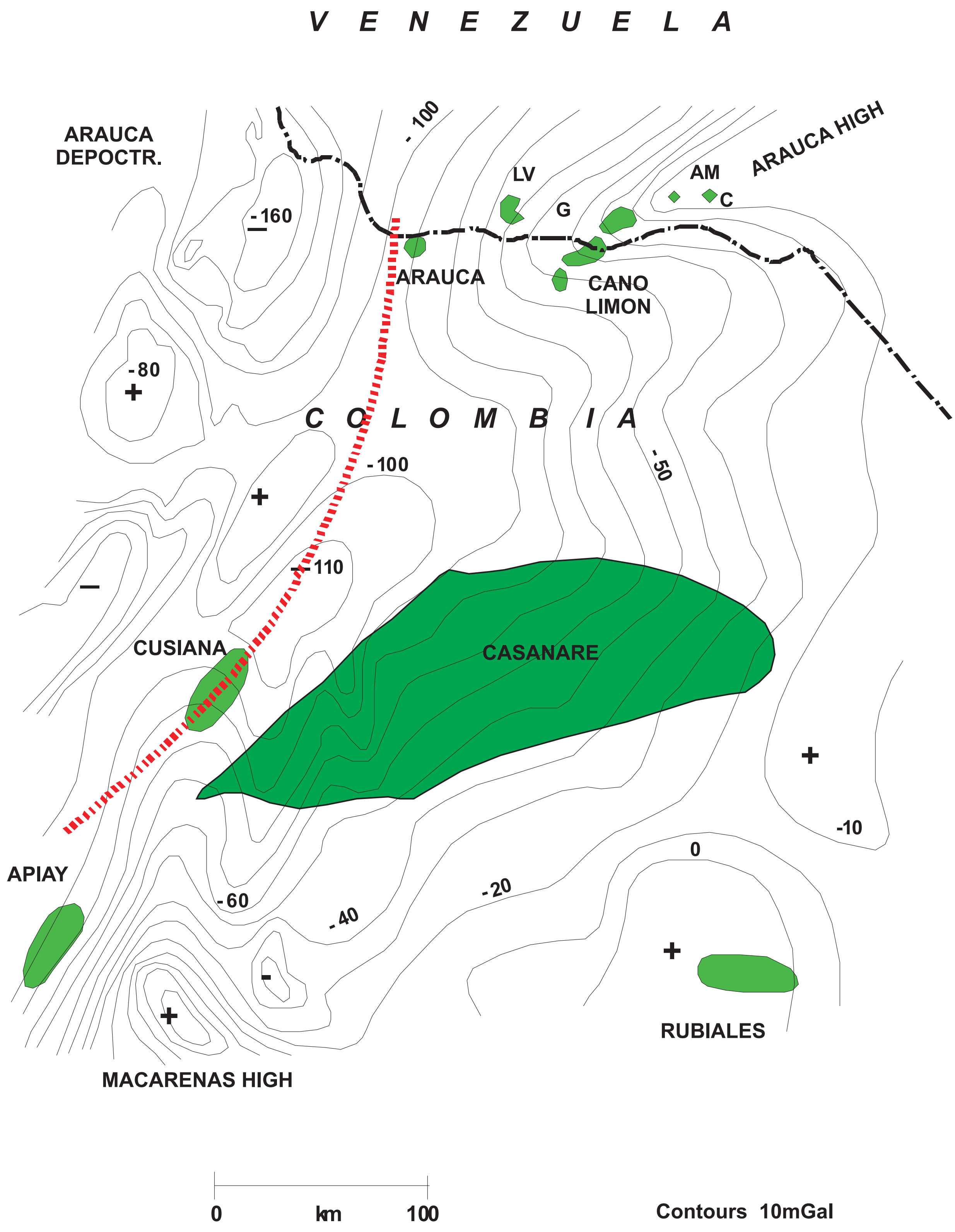

Figure 2. Colombia, Llanos Basin; regional Bouguer gravity and major oil fields (gravityfrom Kellogg et al, 1991); East Cordilleran thrust front (from Pratsch, 1994)

Examples are found in the Rocky Mountains Region, in California, in the U.S. Mid-Continent, in Sub-Andean basins of South America, in Europe, Africa, in the Middle East, and in basins of the Far East.

A new challenging exploration problem occurs today in the offshore portion of the U.S. Gulf Coast Basin: What is the regional distribution of oil and gas in Sub-Salt Play prospects? Do all seismically defined traps contain economically important quantities of oil and gas? One decisive parameter seems to be deep structure at the level of pre-Miocene units (Paleogene, Cretaceous/Jurassic ? or deeper). It would appear that deep structure in the Gulf Coast Region controls oil and gas that have migrated originally from pre-Miocene source beds into pre-Miocene or Early Miocene traps. It is from such early traps that most of the oil and gas produced from Miocene and Plio-Pleistocene reservoirs has "leaked".

Conclusion

The practical conclusion here is that in the U.S. Gulf Coast Region high-quality regional gravity and magnetic data and deep-reaching seismic data need to be integrated to define regional basin-wide structure at deep (pre-Miocene) levels. As one main result, more and less attractive areas will then be definable on the basis of the location and direction of lateral hydrocarbon migration pathways. These pathways will determine where large oil and gas reserves can be expected in Sub-Salt and in Post-Salt traps across the region. It is in these most attractive portions of the region that subsequent detailing exploration will be most successful.

An example from a producing basin may further explain processes and techniques discussed:

> Across the Llanos Basin region, Colombia, South America, the published regional Bouguer gravity map shows a west dipping monocline (Figure 2). Three regional positive gravity anomalies exist. They are identical with basement-rooted highs: The Arauca High, the Macarenas High, and the Rubiales High. The first two anomalies are basinward plunging positive structural anomalies, the third a rare regional high on the eastern basin flank. Of the oil and gas in the region, over 85% of the oil and nearly 100% of the gas reserves discovered so far occur in fields located on these three basement highs; all three high areas are identified as positive Bouguer gravity features! Gravity lows exist in the area of the Eastern Cordillera fold-and thrust belt; here, the Cretaceous and Early Tertiary source beds have matured in local depocenters. Their geometries are still rather unknown due to lack of data in the mountain areas of the Eastern Cordillera. Early recognition of these important petroleum-geological facts could have saved Industry considerable time and effort. In addition, detailed gravity residual maps may well indicate the location of additional local traps in the basin.

In summary, gravity and magnetic data are well suited for regional and local hydrocarbon area evaluations; this applies to both new and on-going exploration operations. Often high-cost detailing exploration programs like 3D-seismic surveys and wildcat wells can be concentrated in relatively small portions of a basin where gravity and magnetic data have been obtained for initial area evaluations and prospect definitions. Gravity and magnetic data are excellent low-cost components in any modern petroleum system approach to hydrocarbon exploration.

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Illustrations

Figure 1- Basin geometry, preferred migration directions, and prospectivity differences (from Pratsch, 1986).

Figure 2 - Colombia, Llanos Basin; regional Bouguer gravity and major oil fields (gravity from Kellogg et al., 1991); dotted: East Cordilleran thrust front (from Pratsch, 1994).

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