Role of Extensional Structures in the development of the Middle Magdalena Valley Basin – Colombia

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TECTONIC EVOLUTION OF THE MIDDLE MAGDALENA VALLEY BASIN (MMVB)

The MMVB (Figure 1) constitutes what Kingston (1983) called a poly-historic basin, developed through different stages closely related with the tectonic events of the northwest corner of South America.

![Figure 1. Location of the MMVB](image)

### TECTONIC EVOLUTION OF THE MIDDLE MAGDALENA VALLEY BASIN (MMVB)

The opening of the proto-Atlantic ocean and the break-up of Pangea were initiated, causing the initial separation of South America, North America and Africa. The extensional stresses within the Precambrian continental block resulted in the formation of a rift structure in central Colombia, which evolved to the stage of aulacogen (Etayo, Barrero and Renzoni, 1969, Etayo et al., 1983, Fabre, 1983). According to Fabre (1983), the rifting process was due to east-west extension that caused crustal and lithospheric thinning. Jurassic – Cretaceous basic intrusions are consistent with the model of passive rifting (Turcotte and Oxburgh, 1978, McKenzie, 1978 and, Segnor and Burke, 1978) which consider this igneous activity due to the elevated position of the asthenosphere / lithosphere boundary under thinned areas, the partial mantle fusion, and the high heat flow.

The syn-rift infill is represented by a tectono-sequence that consists of fluvial and lacustrine sedimentary rocks (Jordan, Giron and Santos formations), overlain by limestones and shales (Rosablanca and Paja formations) (Figure 2). Seismically this sequence comprises irregular, discontinuous reflectors, rotated by normal-fault blocks, which get thicker to the south-east. Changes in thickness suggest that their accumulation took place while normal faults were still active.

By Early Aptian the extension decreased, the heat flow declined (Fabre, 1983), and a post-rift phase controlled by thermal subsidence started. During this phase the Tablazo, Simití, La Luna and Umir formations were deposited. The dominant deformation style was still normal faulting but less pervasive than during the syn-rift phase. This caused the thickness of units to become more uniform along the basin. The seismic character of the post-rift sequence consists of continuous reflectors and slow changes in thickness.

Three main transpressive deformation phases have been observed in the MMVB during late Cretaceous and Paleogene (e.g. Taboada et al., 2000, Rolon et al., 2001), which took place during Late Cretaceous – Paleocene, early to middle Eocene, and Oligocene.

The Late Cretaceous (Campanian – Maastrichtian) – Paleocene phase has been linked to the oblique collision of the Colombian Western Cordillera with the South American plate (Barrero, 1979), which caused thrusting and uplift of the Central Cordillera. This event also triggered deformation in the foothills of the present-day Eastern Cordillera (east edge of the MMVB) with formation of west-verging thrusts. In addition, inside the MMVB the highs of Cachira and La Cira-Infantas were formed, by reactivation of the ancient normal faults. This tectonic phase developed major right-lateral structures in the MMVB, like the Palestina and Cimitarra faults, and also modified
the previous existing extensional style. Even thought there is no direct evidence that relates the occurrence of these faults with the stresses generated by the collision of the Western Cordillera, Feininger (1970) believes that the age of these faults range from Late Cretaceous to pre-Pliocene (which agrees with the age of the collision).

During the late Eocene-early Oligocene tectonic phases, transpressive right-lateral deformation probably occurred along the Romeral and Salinas fault Systems as a result of the oblique convergence between the paleo-Caribbean plate and the Northwestern South American plate (Taboada et al., 2000).

Lately by Early Miocene, a second major compressional event began as a consequence of the collision of the Panama-Choco island arc with the northwestern edge of South America. This event had repercussions in the final configuration of the MMVB and allowed the deposition of the thick sedimentary sequence at the east of the basin (Dengo and Covey, 1993, Rolon et al., 2000).

Finally the MMVB became an intermontane basin. The most dramatic deformation is evidenced in the Eastern Cordillera foothills, by the presence of imbricated fans, and triangle zones.

### Figure 2. Stratigraphic column for the MMVB

<table>
<thead>
<tr>
<th>Epoch</th>
<th>Age</th>
<th>Formation</th>
<th>Lithology</th>
<th>Depositional Environment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maastrichtian</td>
<td></td>
<td>LISAMA</td>
<td>PARALIC</td>
<td></td>
</tr>
<tr>
<td>Turonian</td>
<td></td>
<td>UMIR</td>
<td>MARINE</td>
<td>Delta front deposits</td>
</tr>
<tr>
<td>Conianian</td>
<td></td>
<td>LA LUNA</td>
<td>MARINE</td>
<td>Older to middle shelf</td>
</tr>
<tr>
<td>Albian</td>
<td></td>
<td>SIMITI</td>
<td>MARINE</td>
<td>Inner to middle shelf</td>
</tr>
<tr>
<td>Aptian</td>
<td></td>
<td>TABLAZO</td>
<td>Island</td>
<td>Middle shelf</td>
</tr>
<tr>
<td>Barremian</td>
<td></td>
<td>PAJA</td>
<td>MARINE</td>
<td>Middle shelf</td>
</tr>
<tr>
<td>Hauterivian</td>
<td></td>
<td>ROSABLANCA</td>
<td>MARINE</td>
<td>Middle shelf</td>
</tr>
<tr>
<td>Valanginian</td>
<td></td>
<td>ARCAVILCO</td>
<td>CONTINENTAL</td>
<td>Fluvial systems to marine deposits under tidal influence</td>
</tr>
<tr>
<td>Ryazanian</td>
<td></td>
<td>LOS SANTOS</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tullian</td>
<td></td>
<td>GRON</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### STRUCTURE OF THE RIFT

Reconstruction of the rift structure is not an easy task since many of the structures of the extensional phase have been affected by later compression in most of the MMVB. However, some tectonic features remain well preserved in the northern part of the MMVB, which allows inferences to be made regarding the geometry of the rift.

From the morphologic point of view, the northern portion of the MMVB is a monoclinal dipping southeastward representing a half graben inside the whole structure. There are normal and reverse faults, mainly oriented in northeast-southwest trends with variable vergence. Nevertheless there are some structures whose orientation is northwest-southeast. The dip direction of the monoclinal structure as well as the tendency of the syn-rift sequence to get thicker southeastward (Figure 3), let conclude that the rift was deepening in south-eastern direction. The fact that the syn-rift section is pinching out north-westward, is just an indicator of an emerged area in that sector. The structural features aforementioned are in agreement with the typical geometry of a half graben described by Rosendahl (1987), for the Tanganika Lake in Africa. In this model half grabens switch their polarities and a transfer zone is created in the area where the main faults are overlapping (Figure 4).

Reverse faults are a result of inversion tectonics on ancient normal faults and in some cases they were affected by the Palestina strike-slip fault system, during the Late Cretaceous and Paleocene (Ecopetrol, 2001).

Following the model of kinematics evolution for the Coffee Soil fault, proposed by Cartwright (1992) the normal faults seemed to be rotational during the syn-rift accumulation and non-rotational during post-rift sedimentation. This can be inferred from the divergent pattern of the strata in reflectors that conform the syn-rift section and the parallel pattern at the post-rift section.

### INVERSION OF EXTENSIONAL STRUCTURES

Experimental work of inversion structures shows that thrust and reverse faults commonly form and use existing extensional structures (McClay and Buchanan, 1991), especially where the original structures had a high-angle dip. Many smaller scale compressional structures in the MMVB are cored by high-angle dip. Many smaller scale compressional structures in the MMVB are cored by high-angle dip. Many smaller scale compressional structures in the MMVB are cored by high-angle dip.
Figure 3. Cross section showing thickness changes in the basal lime group.
Figure 4. Structural map of the MMVB showing the hypothetical boundaries of the half graben.
inversion geometries (Holdsworth et al., 1997), represented by thicker rift strata on the hanging wall and by variation of fault throw with depth.

The inversion process of the Jurassic rift in the northern MMVB was mild, since in most of the reversed faults, the syn-rift sequence has been extruded as a major fold, what is in accordance with the models of geometries of inversion proposed by Hayward and Graham (1989). The basement or pre-rift section acted in this case as a buttress against thrusting.

Inversion came about from compression-transpression deformation along the western and eastern edges of the basin. The compressional event started during Campanian time and continues until the Recent. Major pulses of thrust formation occurred during the Paleogene and Middle Miocene. During this time, a great number of former extensional features are inverted (Rolon et al., 2001).

Transpresion caused by the oblique collision of the Western Cordillera, mainly developed during Paleocene, added a strike-slip component to the reactivation process through the clockwise rotation of the blocks. The north-eastern trend, what is the orientation of the Palestina fault is especially evident in the western sector of the area, where Casabe and Cantagallo fields are located. Clockwise rotation is also observed at the scale of individual structures in the eastern side of the basin. Individual thrusts translate displacement between each other either through a transfer zone or a swarm of right-lateral tear faults (Rolon et al., 2001).

CONCLUSIONS

The MMVB was developed through different tectonic stages related with the interaction of the tectonic plates at the Northwestern corner of South America.

During Jurassic and early Cretaceous the MMVB went through rift stage that evolved to an aulacogen. Many of the structures related with the extensional phase of the MMVB were modified after the Tertiary tectonics, however the rift structures in the northern portion of the basin are still well preserved. The northern part of the MMVB is a monocline dipping toward the southeast that represents a half graben inside the rift. The monocline structure is dipping south-eastern, as is the direction, where isopach contours thicken. Most of the structures present at the area are normal and reverse faults of variable vergence, oriented in northeast-southwest direction. Kinematics of the rift seemed to be rotational during the syn-rift accumulation and non-rotational during post-rift sedimentation.

Most of the faults remaining the rift structure were inverted after compressional tectonics that started at Late Cretaceous. According the model proposed by Hayward and Graham (1989), inversion seemed to be mild in the northern MMVB area. Transpresion caused by the oblique collision of the Western Cordillera, added a strike-slip component to the reactivation process, through the clockwise rotation of the blocks.

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REFERENCES

Barrero, D., 1979, Geology of the Central Western Cordillera, west of Buga and Roldanillo, Colombia: Publicaciones Geológicas Especiales INGEOMINAS no.4, pp.1-75.
Dengo, C., and Covey, M., 1993, Structure of the Eastern Cordillera of Colombia; Implications for trap styles and regional tectonics, AAPG, Bull., V.77, pp 1315-1337.
Fabre, A., 1983, La subsidencia de la cuenca del Cocuy (Cordillera Oriental de Colombia) durante el Cretáceo y el Terciario, segunda parte: esquema de evolución tectónica, Geología Norandina, No. 8, pp 21-21.
Figure 5. Line NC-81-2, located in the northern area of the MMVB. The line shows examples of the inverted faults found in the area.


