Characterizing the Lisama Formation: Jewel of the Middle Magdalena Valley, Colombia

Jon Noad
Sedimental Services; University of Adelaide

Summary

The Paleocene Lisama Formation is one of the main producing reservoirs in the Middle Magdalena Basin (MMV) yet has received relatively little attention in the literature. The Lisama Formation may reach 1225 m in thickness with mottled shales interbedded with fine grained, cross-bedded sandstones. The sandstones coarsen towards the top of the Formation, with some associated coal seams. Depositional environments range from fluvial to shallow marine, and it is recognized that the overall sequence is regressive, becoming more terrestrial up section. The Lisama Formation is conformably underlain by the shallow marine, late Cretaceous Umir Formation and is unconformably overlain by the Eocene Chorro Group fluvial deposits (comprising the La Paz and Esmeraldas Formations).

All available cores through portions of the Lisama Formation were logged using modern sedimentological methods. The cores are stored in Corelab, Bogota and Lithoteca, Bucaramanga. The cores were drilled in several oil fields, forming a linear pattern running from the Los Angeles field in the North to the Acordionero Field to the South. Individual cores ranged from 95 feet to 1 foot in thickness and cover only part of the reservoir interval.

The logged core intervals, supplemented by outcrop data, have been integrated with petrophysical wireline logs from a single “type well” to build an interpolated, virtual, cored “master section” throughout the Lisama Formation. The master section is then used to build a relative sea level curve for the Lisama Formation. New depositional maps are constructed based on the curve and the interpreted regional reservoir distribution. Limited data from other fields is used to identify potential upland areas to the west, while published seismic data is used to provide palaeocurrent context to the depositional model. An attempt is made, using Google Earth, to correlate the master section to the type section exposed in Rio Sucio, to the North of Bucaramanga in MMV.

Literature review

Published data on the depositional environments in which the Lisama Formation was deposited include outcrop sections logged at Los Cedros (125 m thick) and Caño Cinco (198 m thick). References include those detailing the Acordionero Field (Prince et al 2008), conglomerates from an unnamed field producing from the Lisama and another Formation (Osorio 2017) and several other references that mention the Lisama Formation. One of these (Guerro et al 2008) focuses on structural aspects of the Tisquirama and San Roque Fields, both producing form the Lisama Formation. Another paper by Morales et al (1958) describes an upward transition from marine to continental deposits.

Osorio (2017) suggests that the Lisama Formation can be subdivided into sands at the bottom of the formation (shallow subtidal environment); the middle of the formation (conglomerates and gravelly sandstone) and the upper part of the formation (sandstone package shallow subtidal environment). Prince et al (2008) describe the Los Cedros outcrop sections with lower meandering channel related conglomerates overlain by biomicritic limestones, capped by estuarine and lagoonal fine to medium grained sandstones with inclined lamination (locally muddy) and uppermost tabular, laminated sands deposited on intertidal flats.

The Caño Cinco section is subdivided into seven intervals, each with sandstones with low angle inclined laminations, overlain by heterolithic facies and capped by mudstone and coal beds. This is interpreted as a regressive system with cycles passing from estuarine up into fluvial and floodplain deposits. A 12 m core from the Acordionero-2 well features eight facies in sandstones, siltstones and mudstones interpreted as muddy and sandy intertidal deposits.

Logged outcrop of the Lisama Formation showing meandering fluvial deposits, Nuevo Mondo Syncline, MMV.

Core logging methodology

Fields producing from the Lisama Formation include (from North to South) the Mono Araña Field; the Los Angeles Field; the Tisquirama Field; the San Roque Field and the Acordionero Field. Cores from 12 wells from these fields were logged in detail in terms of their sedimentology, with a total length of logged core of approximately 850 feet. The longest individual core was 95 feet in length and the shortest was 1 foot long.

A facies scheme was erected that subdivided the facies into three facies associations: Marine, Tidal and Fluvial. All three facies associations included interbedded sandstone and mudstone beds. The facies were identified based primarily on grain size trends, sedimentary structures and on the character, abundance and size of the associated trace fossils. The sandstone beds are of key importance in terms of defining reservoir development, and many are heavily oil stained. However, it is the mudstone beds, and the associated trace fossils, or their absence, that are of most significance when identifying the depositional setting.

Using a carefully selected type log from one of the wells, the logged cores were matched to electrofacies extrapolated from the well log so that they fitted with the character of the logs. In this way it was possible to build up a “pseudo-core” through the entire thickness of the Lisama Formation. Using the interpreted depositional settings, a relative sea level curve was constructed for the Lisama Formation. The sea level curve could then be compared to global sea level curves, and also used to predict the facies distribution across the MMV.

Lithofacies code	Description	Interpretation
TERRESTRIAL		
FS1	Low angle trough cross bedded sandstone	Channel
FS2	Sandstone with lateral accretion surfaces, usually oil stained (FS2L), often capped with a rippled sandstone (FS2R)	Meandering river channel
FS3	Climbing rippled sandstone	Crevasse splay
FM1	Medium grey, mudstone; may be rooted or contain carbonaceous plant debris	Overbank fines
FM2	Orange, red or grey mudstone, usually with slickensides. Bedding not normally visible, though patches of coloured shale are typical	Incipient to mature palaeosol
FM3	Black coal	Swamp or marsh
TIDAL		
TS1	Sandstone beds with lateral accretion surfaces (TS1L) often capped by rippled sandstone beds (TS1R). The sandstone beds with LAS may reach 2 m in thickness.	Tidal channel and creeks
TS2	Sandstone beds with wavy laminae	
TF1	Thin 1-2 cm rippled sandstone beds with thin mudstone interbeds	Tidal sandflats
TF2	Mudstone with interbedded, thin 1-2 cm rippled beds	Tidal mudflats
TM1	Lightly rippled grey or greenish mudstone with occasional stunted burrows. The trace fossil diversity and bioturbation index are low.	Lagoonal
MARINE		
MS1	Trough cross-bed or low angle xlam sst with cemented mud clasts and a marine trace assemblage	Marine sandstone
DT	Heterolithic interbeds of sandstone and mudstone. Sandstone has wavy laminae or is rippled.	Delta top sandstone
MM1	Grey mudstone with a variety of marine trace fossils	Marine mudstone

Table 1. Lithofacies scheme erected to facilitate core logging

Interpreted facies

The interpreted fluvial deposits are composed of fine grained sandstone beds with lateral accretion surfaces (LAS). Typical thicknesses range from 30 cm to 1 m, suggesting that the channels that formed them were relatively small. Stacked trough cross-bedded sandstones make up the basal, higher energy, portions of the channel successions. The channels are encased in grey, overbank mudstone beds, sometimes with visible rooting. Mottled maroon and orange palaeosols with slickensides were also observed.

The tidal deposits can be subdivided into sandstone and mudstone dominated successions. The tidal sandstones are made up of 10 to 200 cm thick beds with steeply dipping LAS. They are often capped by rippled, very fine grained sandstone beds. These are interpreted as tidal creeks crossing tidal flats. There are also intervals with sandstones with common mud intraclasts, possibly sourced locally from bank collapse or rip ups from tidal flats. The mudstone dominated sections feature flasar to lenticular sandy beds encased in mudstone beds. There are also thicker mudstone beds with numerous thin sandy interbeds with wave rippled tops. These deposits are interpreted as tidal flat deposits.

The marine deposits make up only a minor component of the succession as a whole. They comprise more blocky sandstone beds, often heavily bioturbated by marine trace fossils. Sedimentary structures include wavy laminae and wave rippling, as well as trough cross-bedding. These are interpreted as shoreface and embayment deposits. No hummocky cross-stratification was observed. The common comminuted vegetation and occasional coals seen in the core, as well as the equatorial location at the time of deposition (Blakey 1995), suggest a humid, tropical depositional setting.

Potential depositional analogues include the Cretaceous McMurray Formation in Alberta; modern depositional environments of South Carolina; and the modern Ganges Tidal Delta. The McMurray Formation deepens from fluvial deposits at the base, through a thick, stacked tidal channel and estuarine succession in the middle, up into a marine shale (Clearwater Formation) at the top. Like the Lisama Formation, the thick, interpreted channel sandstone beds are commonly heavily oil stained, and are frequently dominated by lateral accretion surfaces. The degree of bioturbation varies widely.

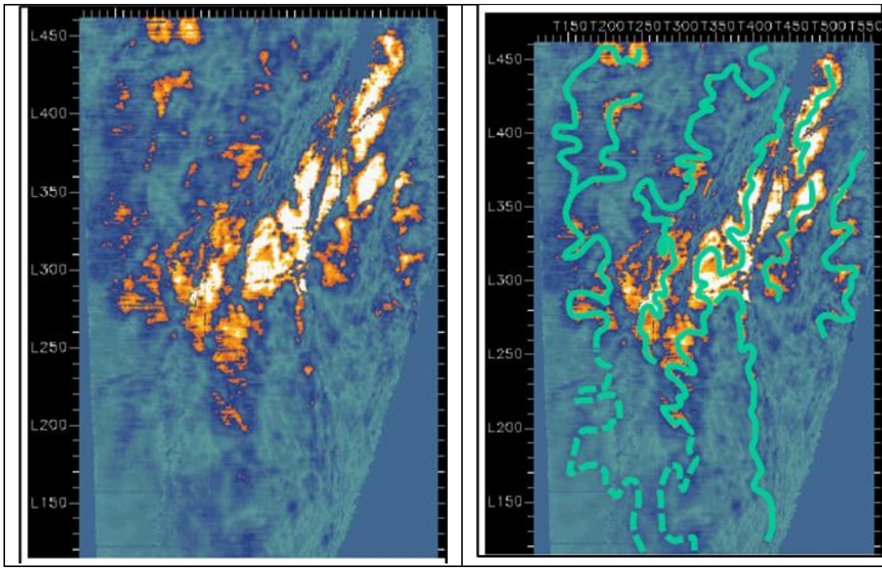
Note that several significant fault breccias and mylonite were identified in the core.

Palaeocurrent data

Several sources of data have been identified:

- FMI data is available for many wells but is held confidential. This data can also be used to subdivide FMI-related depositional facies.
- Oriented core allows cross-bed orientations to be measured and channel flow directions reconstructed.
- Horizontal slices through seismic data can be examined in detail and meandering channels picked out, although the seismic data is frequently noisy and challenging to interpret. Published data from the San Roque Field shows that the channels flow towards the North, which has significant implications for reconstructing regional depositional models.
- Outcrop data can also provide localized palaeocurrent data, but the meandering channel deposits make identifying a dominant flow direction very challenging. Palaeocurrent data may cover a spectrum of more than 240 degrees in such settings.

There is a general acceptance that palaeocurrents tend to flow towards the North in the Lisama B/C and towards the West in the (overlying) Lisama A interval. However, the available evidence suggests a dominantly northward (to NNE) flow direction.



Seismic slice data from the Tisquirama Field showing meandering channel orientation within the Lisama Formation (from Guerro *et al* 2008)

Results and Discussion

A type pseudo core was successfully assembled based on the character of the electrofacies identified through the entirety of the Lisama Formation. This has been used to construct a relative sea level curve based on the changing depositional character of the Lisama reservoir through time. The sea level curve does not match the global (Haq) curve, suggesting an autocyclic, likely tectonic control on relative sea level through time.

The prevailing depositional model for the Lisama Formation is one of fluvial systems flowing perpendicular to the North/South trending basin margins out into the basin. At some point the channels turn northward and flow towards the sea. The absence of strong evidence for an East/West flow direction suggests that this model should be refined with channels flowing northward across the basin.

The oil fields located on the western margin of the basin, including Barranca Lebreja and Dona Maria, are relatively small with poorly developed reservoir sands. This suggests that the western margin of the basin was composed of highlands with more bypass and dominantly small fluvial channels. This evidence has been considered when putting together a map of potential Lisama facies belts.

Conclusions

The work undertake has led to a new understanding of the depositional settings and reservoir distribution of the Lisama Formation in the Middle Magdalena Valley. This is supported by core and outcrop data. Previous published data on the Lisama Formation was based on sparse information and restricted outcrop data. The logging of most of the existing cored Lisama intervals has allowed a far more detailed understanding of the depositional settings and changes in relative sea level through time.

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References

Aguilera, R. 2017. The Middle Magdalena Valley Basin (Colombia) promising for unconventional hydrocarbons. Linked In article online.

Baniak, G.M. and Kingsmith, K.G. 2018. Sedimentological and stratigraphic characterization of Cretaceous upper McMurray deposits in the southern Athabasca oil sands, Alberta, Canada. AAPG Bulletin, v. 102, no. 2 (February 2018), pp. 309–332

Conde-Gomez, J. et al. 2011. Fluid migration history from analysis of filling fractures in a carbonate formation (Lower Cretaceous, Middle Magdalena Valley, Colombia. C.T.F Cienc. Tecnol. Futuro vol.4 no.3 Bucaramanga Jan./June 2011.

Duarte, P.O. Reconstruccin de la historia diagenetica de las areniscas de la formacion Lisama en la Cuenca del valle medio del Magdalena. Thesis: University of Santander.

Enachescu, M. et al. 2015. A holistic approach to petroleum exploration in Colombia: Acordionero Oil Field, Middle Magdalena Valley Basin. Abstract: Geoconvention 2015.

Gomez, E. et al. 2003. Controls on architecture of the Late Cretaceous to Cenozoic southern Middle Magdalena Valley Basin, Colombia. GSA Bulletin; February 2003; v. 115; no. 2; p. 131–147

Goodbred, S.I. and Saito, Y. 2012. R.A. Davis, Jr. and R.W. Dalrymple (eds.), Principles of Tidal Sedimentology, DOI 10.1007/978-94-007-0123-6_7, © Springer Science+Business Media B.V. 2012

Guerrero J.G., Oscar Machado, O. ; and Osorio, C. 2008. Campos Tisquirama y San Roque Áreas que Vuelven a Renacer – Mediante La Caracterización de Yacimientos. ACGGP.

Hathon, L. Detrital Modes of Tertiary units in the Central Middle Magdalena Basin, Colombia. Abstract only.

Martinius, A.W., Fustic, M., Garner, D.L., Jablonski, B.V.J., Strobl, R.S., MacEachern, J.A. and Dashtgard, S.E. 2017. Reservoir characterization and multiscale heterogeneity modeling of inclined heterolithic strata for bitumen-production forecasting, McMurray Formation, Corner, Alberta, Canada. Marine and Petroleum Geology 82 (2017) 336 to 361.
Mora, C. et al. 1996. Petroleum systems of the Middle Magdalena Valley, Colombia. AAPG Bulletin 80(8). Abstract only.

Morales, L.G. 1959. General geology and oil occurrences of the Middle Magdalena Valley, Colombia

Moreno, C. 2010. Paleogene sedimentation patterns and basin evolution during Andean orogenesis, middle Magdalena Valley basin, Colombia. Unpublished PhD. Thesis, University of Texas at Austin (abstract only)

Moreno, C. et al. 2011. Depositional and provenance record of the Paleogene transition from foreland to hinterland basin evolution during Andean orogenesis, northern Middle Magdalena Valley Basin, Colombia. Journal of South American Earth Sciences 32 (2011) 246 to 263.

Moretti, I et al 2010. Integrated exploration workflow in the south Middle Magdalena Valley (Colombia). Journal of South American Earth Sciences 29 (2010) 187–197.

Naranjo-Vesga, J.F. et al. 2013. Methodology proposal for correlation studies of fluvial sediments based on petrophysical and lithogeochemical analysis: examples of its application on Cenozoic rock from the Lisama Formation (Middle Magdalena Valley, Colombia). CT&F Ciencia, Tecnología y Futuro, vol. 5, núm. 3, diciembre, 2013, pp. 19-45
Nie, J. et al. 2012. Integrated provenance analysis of a convergent retroarc foreland system: U–Pb ages, heavy minerals, Nd isotopes, and sandstone compositions of the Middle Magdalena Valley basin, northern Andes, Colombia. Earth-Science Reviews 110 (2012) 111–126.

Osorio, A.P. and Barillas, L.A. 2017. Conglomerates evaluation at Lisama Formation: assessinmg new hydrocarbon plays in Colombia. An example from the Middle Magdalena Basin. SPWLA 58th Annual Logging Symposium, June 17-21, 2017.

Primer Field Trip de Petronorte SA. al Valle Medio del Magdalena. 2015.

Ramon, J.C., Dzou, L. and Giraldo, G. 1997. Geochemical evaluation of the Middle Magdalena Basin, Colombia. CT&F - Ciencia, Tecnología y Futuro - Vol. 1 Núm. 3 Dic. 1997

Ramon, J.C. and Cross, T. 1997. Characterization and prediction of reservoir architecture and petrophysical properties in fluvial channel sandstones, Middle Magdalena Basin, Colombia. CT&F - Ciencia, Tecnología y Futuro - Vol. 1 Núm. 3, Dic.

Rodriguez-Forero, G. et al. 2012. Palynology of the Eocene Esmeraldas Formation, Middle Magdalena Valley Basin, Colombia. Palynology, 2012, 1–20, iFirst article.

Rolon, L. and Toro, J. Role of Extensional Structures in the development of the Middle Magdalena Valley Basin – Colombia. Meeting in Cartagena.

Rubiano, J. L. 1998. Determinacion de las direcciones de paleocorrientes en el Campo Provincia, valle medio del Magdalena. C.T. & F Ciencia, Tecnologia, Futuro, December, 1998, Vol. 1, Issue 4, pp. 33-48

Sanchez, M., Murillo, M., and Enachescu, M. 2008. Acordionero Oil Field Discovery, Middle Magdalena Basin, Colombia: an unusual large stratigraphic trap within Paleocene Lisama Formation. ACGGP.

Sanchez, C.J. 2011. Cenozoic structural evolution of the eastern margin of the Middle Magdalena Valley basin, Colombia: Integration of structural restorations, low-temperature thermochronology, and sandstone petrography. . Unpublished MSc. Thesis, University of Texas at Austin

Sandoval, J R, Sandoval, J, Soto, C P, Perez, H H et al. 2009. New Approach to Integrate Reservoir and Geological Information in Complex Fluvial-Stratigraphic Environments to Determine Potential Areas for Water Injection Processes. SPE-122108-MS.

Santos, G., Serrano, M.A., Villa, L. and Nieto, J. 2010. It Is All About Pressure: Drilling a High-Pressure Well in Record Time Using Real-Time Tools. SPE Latin American and Caribbean Petroleum Engineering Conference, 1-3 December, Lima, Peru. Abstract only.

Spickert, A. 2014. Petroleum System Analysis: Middle Magdalena Valley Basin, Colombia, South America. Masters thesis, unpublished, University of Washington.

Weeks, L.G. 1957. Origin of carbonate nodules in shales, Magdalena Valley, Colombia. GSA Bulletin, January 1957; 68 (1)