Application of Satellite-based Analog Studies to Resolving Reservoir Complexity in the North Malay Basin*

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Abstract

Reservoirs in the northern portion of the North Malay Basin consist of both coarsening-upward and fining-upward sequences and were deposited in a fluvial system. Modern fluvial systems as described in the literature fail to provide a reasonable model for understanding the observed complexity and distribution of reservoirs in the North Malay Basin. The modern fluvial analogs described in the literature are found in temperate climates, whereas North Malay Basin reservoirs were deposited in a tropical climate. In order to better understand tropical fluvial systems, a study of modern rivers in northern Thailand was conducted using Landsat satellite imagery.

It was observed that as tropical rivers flowed into wide valleys, the channel began to branch into multiple anastomosing channels. Extensive areas of wetlands formed between the channels, and crevasse-splay deposits were prevalent. Tributary rivers flowing into these wide valleys formed fluvial-fan deltas along the valley margins. Four depositional facies were recognized: channels, crevasse splays, fluvial-fan deltas, and wetlands. Channels comprise less than 10% of the total system, Crevasse splays and fluvial-fan deltas comprised 20 – 45% of the total system. Shale-prone wetlands ranged from 25 to 60% of the total.

Clean channel sandstones, laminated crevasse-splay and fluvial-fan delta sandstones, and organic-rich shales are observed in cores from several wells drilled in the North Malay Basin. The well logs were calibrated to the core facies, and the vertical distribution of these facies was measured and found to be consistent with the lateral distribution of the facies observed in the modern analog study.

The analysis of modern tropical rivers has provided an excellent analog to the North Malay Basin reservoirs, both at an exploration-scale and at a development-scale. At the exploration-scale, we can better predict reservoir occurrence. At the development scale, we can apply the analog study to better understand reservoir distribution in order to calculate gas-in-place and to define the optimal drainage points for infill drilling.

North Malay Basin Stratigraphy

A series of regionally correlative shales and resistivity makers were identified and correlated through the northern portion of the North Malay Basin (Figure 1). With these markers and correlative shales, we were able to subdivide most of the formations into upper and lower members (Figure 2).

Formation 0 is Late Eocene to Late Oligocene in age and consists of alluvial and lacustrine sediments deposited during the syn-rift period (Figure 2). Formation 1 is Late Oligocene to Early Miocene in age and consists principally as an alluvial outwash plain deposited unconformably over Formation 0 (Figure 2). Formation 2, ranging from Early to Middle Miocene in age unconformably overlies Formation 1. Formation 2 consists of an overall retrogradational package of fluvial reservoirs that grade southward to estuarine deposits.

The Early to Middle Miocene Formation 2 reservoirs observed in the North Malay Basin are extremely complex, exhibiting both the coarsening-upward sequences characteristic of deltaic deposits, interbedded with fining-upward to blocky sequences of channels. These two facies do co-exist in the delta-plain setting; however, the northern portion of the North Malay Basin lies considerably to the northwest of the locus of Early to Mid-Miocene deltaic deposition. As such, a depositional setting of delta plain is not considered likely for the region.

Likewise, anastomosing river systems will exhibit mixed coarsening-upward crevasse-splay deposits and fining-upward to blocky channel sands. However, in anastomosing river systems, the channels exhibit much less sinuosity than do the channels in meandering river systems, and seismic amplitude maps suggest that the channels in the North Malay Basin are more meandering in nature. Based on existing modern analog studies, however, meandering river systems do not have extensive crevasse-splay deposits associated with them.

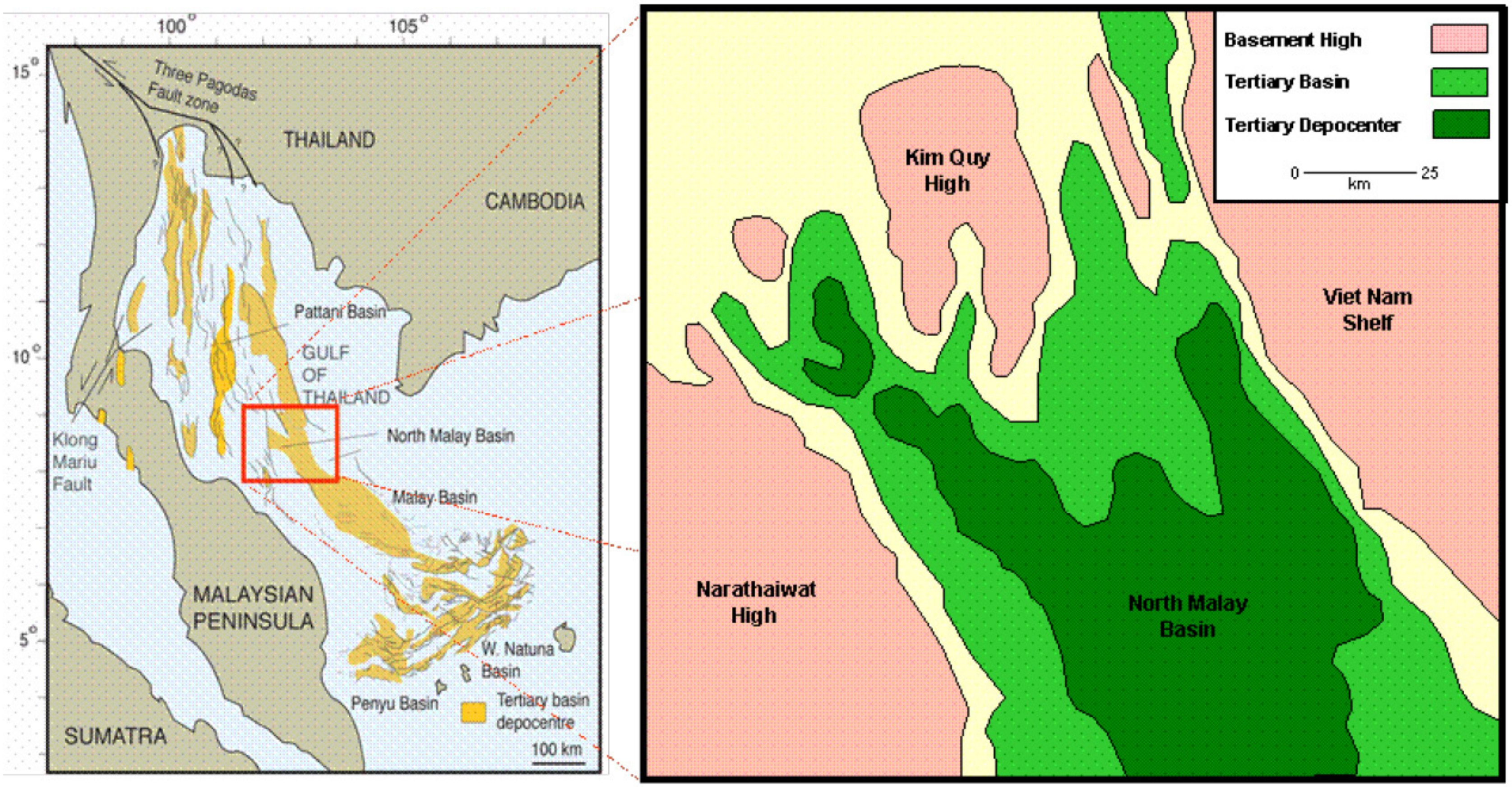


Figure 1: Location map, North Malay Basin.

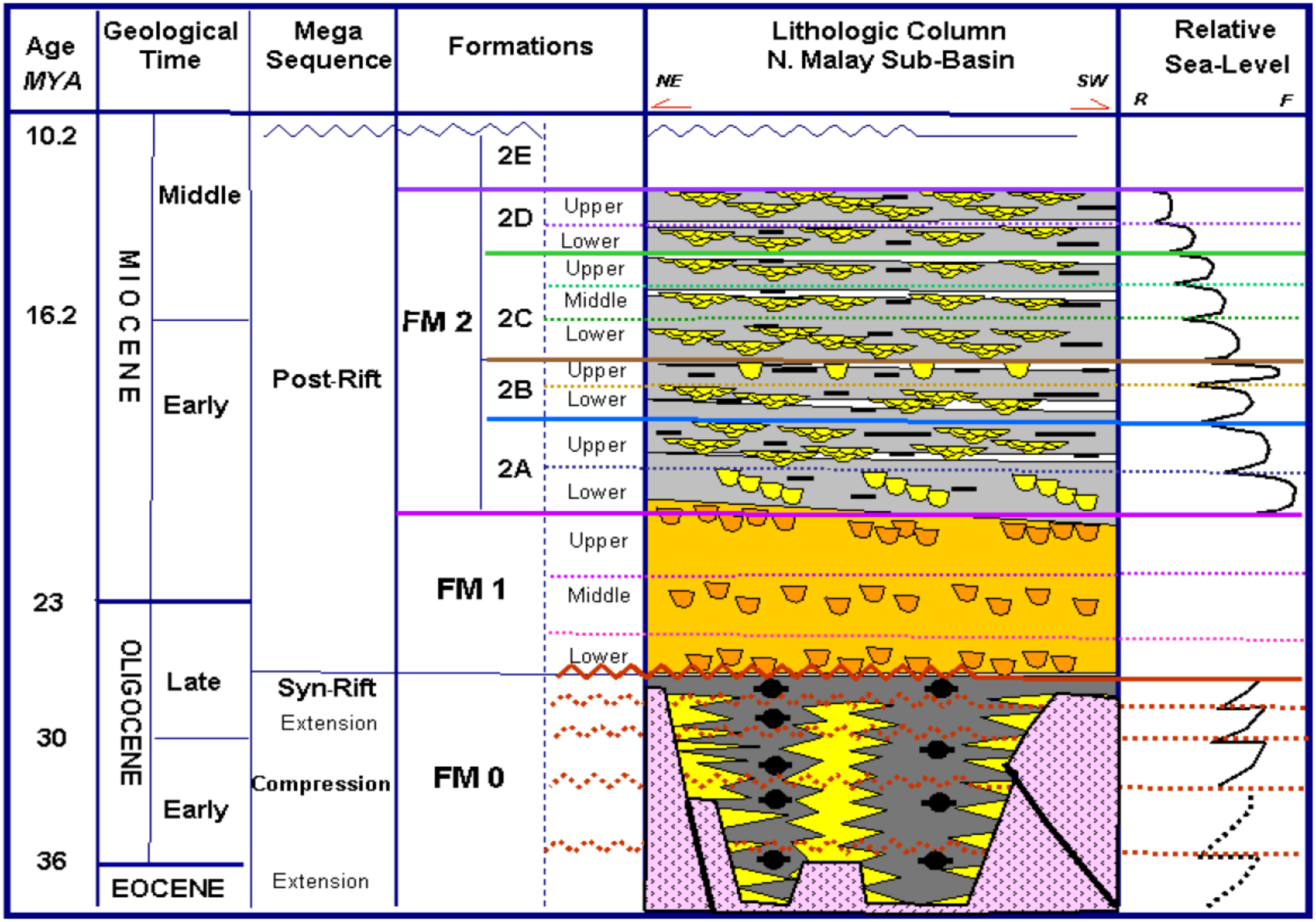


Figure 2: Stratigraphic column, North Malay Basin.

Modern Analog Study

The majority of modern analog studies for meandering river systems were conducted in temperate climates. River systems in tropical climates, such as Thailand, have significantly different facies distributions than do temperate climate meandering river systems. Unfortunately, tropical river systems are poorly documented in the literature. To better understand the depositional pattern and facies distribution of tropical river systems, a study was conducted of modern tropical rivers in north-central Thailand utilizing Landsat satellite data (Figure 3).

The drainage patterns and river morphology in north-central Thailand are strongly influenced by the regional topography. Where rivers flow through structurally constrained narrow valleys, the river consists of one channel that exhibits very low sinuosity (Figure 4; right). As the river flows into wider valleys, the river changes character to a meandering river (Figure 4; middle). There is a well defined floodplain within which oxbow lakes are prevalent. As valley width increases, the river will begin to branch into a number of channels forming a complex anastomosing river system (Figure 4; left).

During the rainy season, extensive areas of wetlands develop within the wider valleys. As the rivers flow through these flooded wetlands, they deposit extensive levee and crevasse-splay sediments along the length of the valley (Figure 5). Tributaries flowing into the valley develop fluvial-fan deltas along the margins of the valley. As a result, the alluvial fill of these wide valleys consists of mixed coarsening-upward deltaic and crevasse-splay deposits interbedded with fining-upward channel deposits as well as organic-rich shales and coals. Channel deposits will be oriented both parallel and perpendicular to the overall trend of the river valley.

For most of the broad river valleys that were examined, the most significant facies observed was the tributary river fluvial-fan deltas. These were found to contribute from 30% to over 75% of the total sediment fill of the valley. Crevasse-splay deposits contribute between 15% and 50% of the total sediment fill. The wetlands were observed to cover 5% to 20% of the valley area, although that number will vary considerably from dry season to wet season.

At the prospect and development scale, the distribution of reservoir sandstone will be extremely complex (Figure 6). Clean channel sands will occur as a series of narrow belts. The average channel width is between 50 and 60 meters, although the main channel body can be as wide as 250 meters. Along the course of the anastomosing river, channel orientation will be highly variable, only generally following regional strike. Distributary channels associated with the fluvial fans and tributary deltas will have a general orientation perpendicular to regional strike.

Inter-channel deposits will consist of thin coarsening-upward sequences. Close to the channel, these sequences will consist of generally good quality sand with laminated siltstones (Figure 4). The farther one moves from the channel, the more laminated the section will become, eventually becoming a non-reservoir siltstone with shale and organic laminae. Interbedded organic-rich shales and coals will be common.

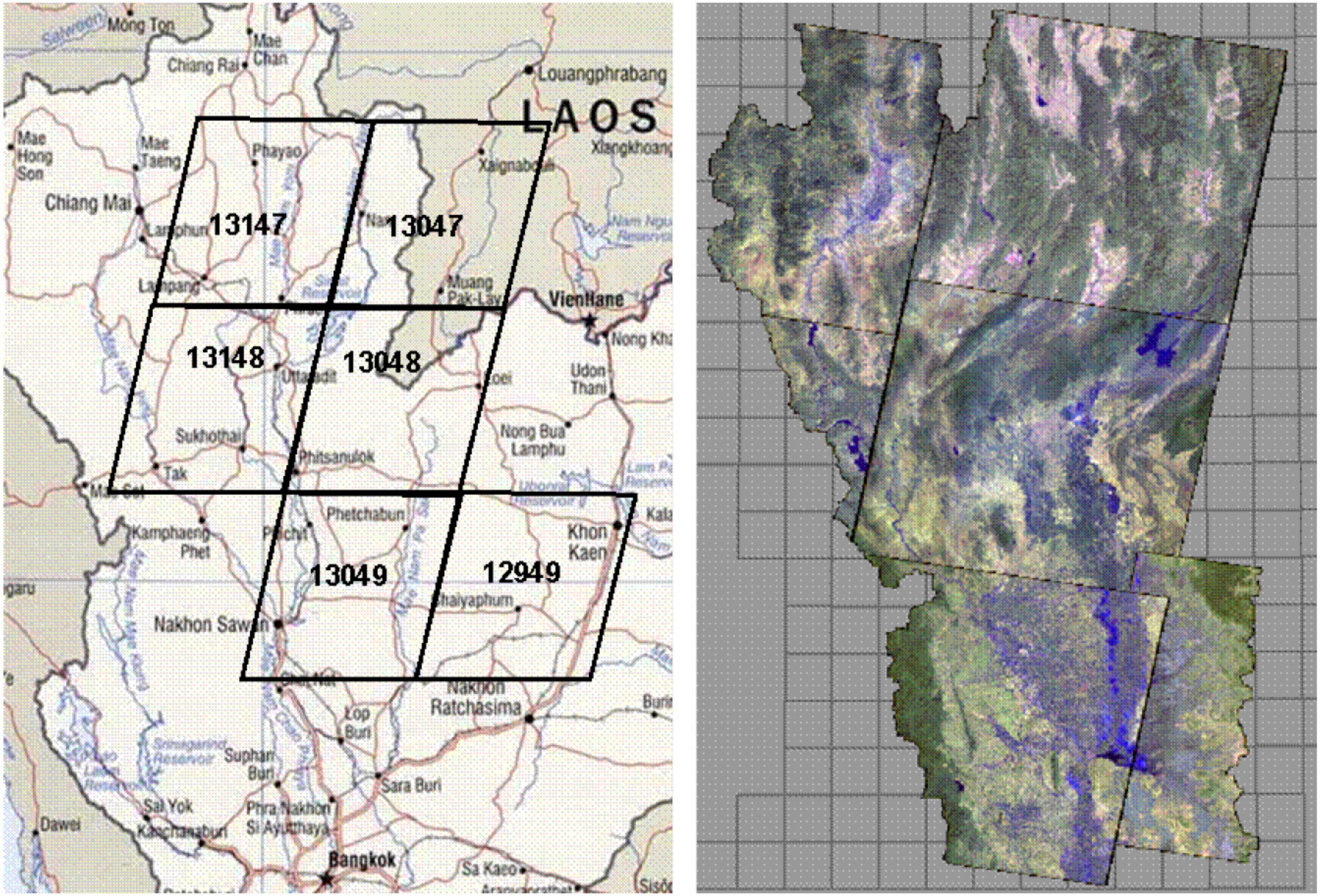


Figure 3: Location of Landsat Images used for Modern Analog Study

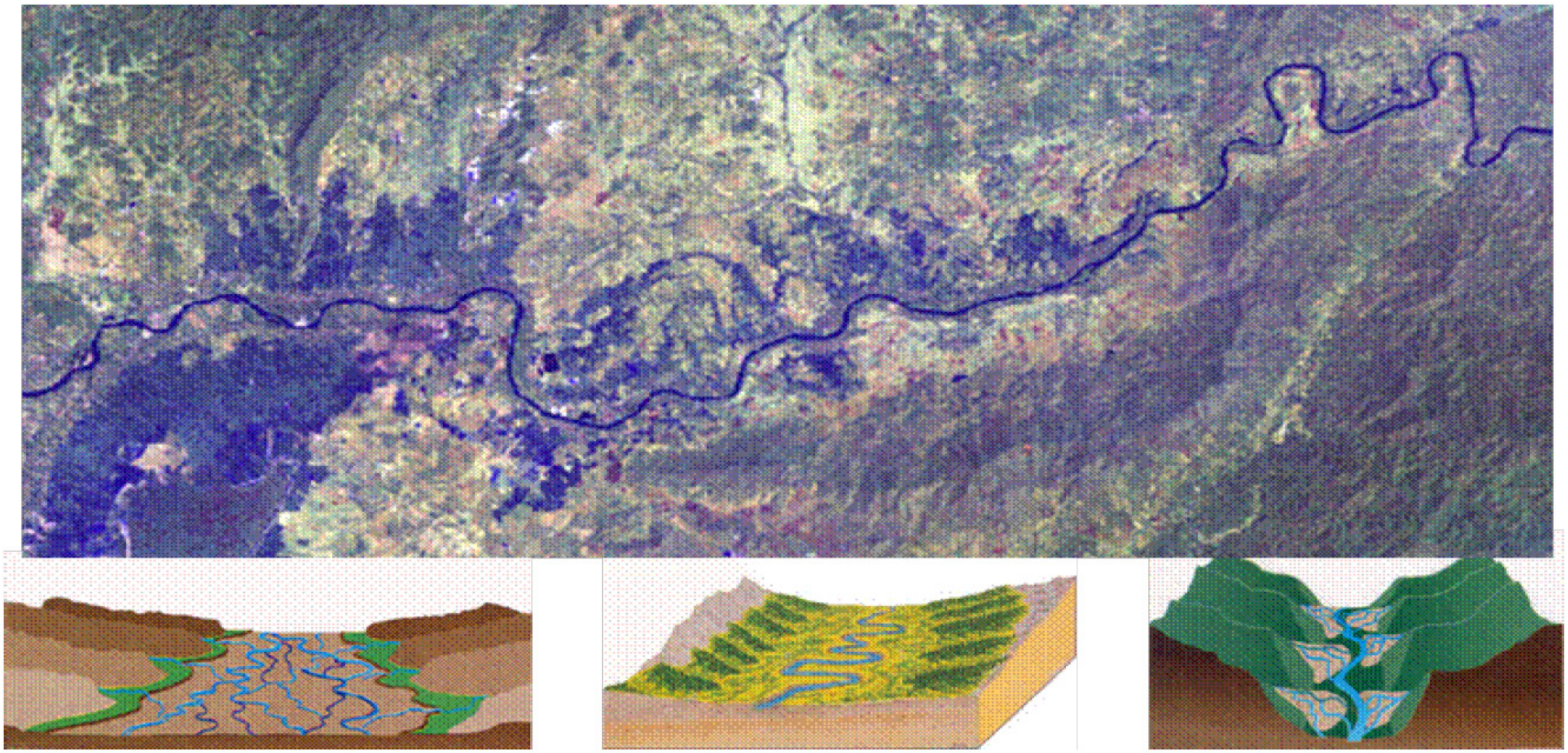


Figure 4: Change in river morphology from constrained to open valleys, north Thailand.

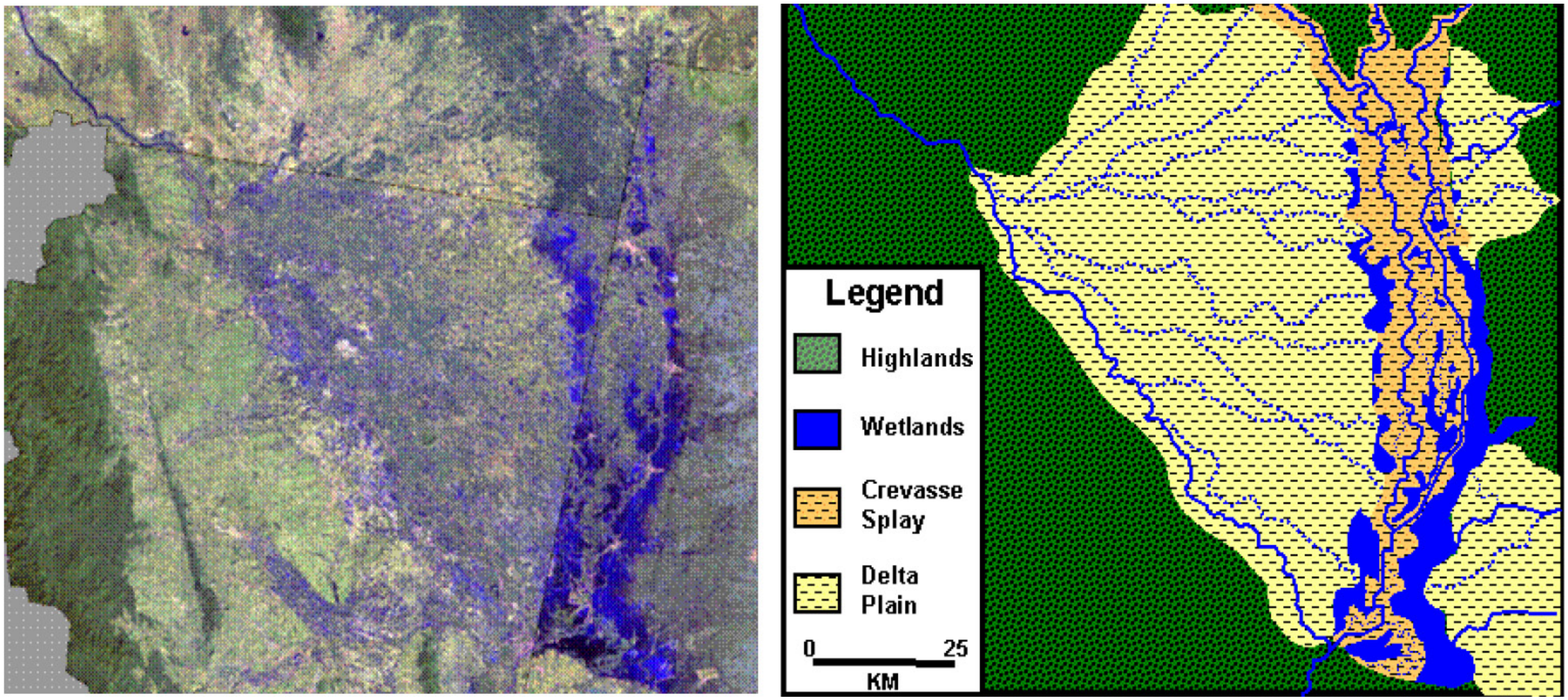
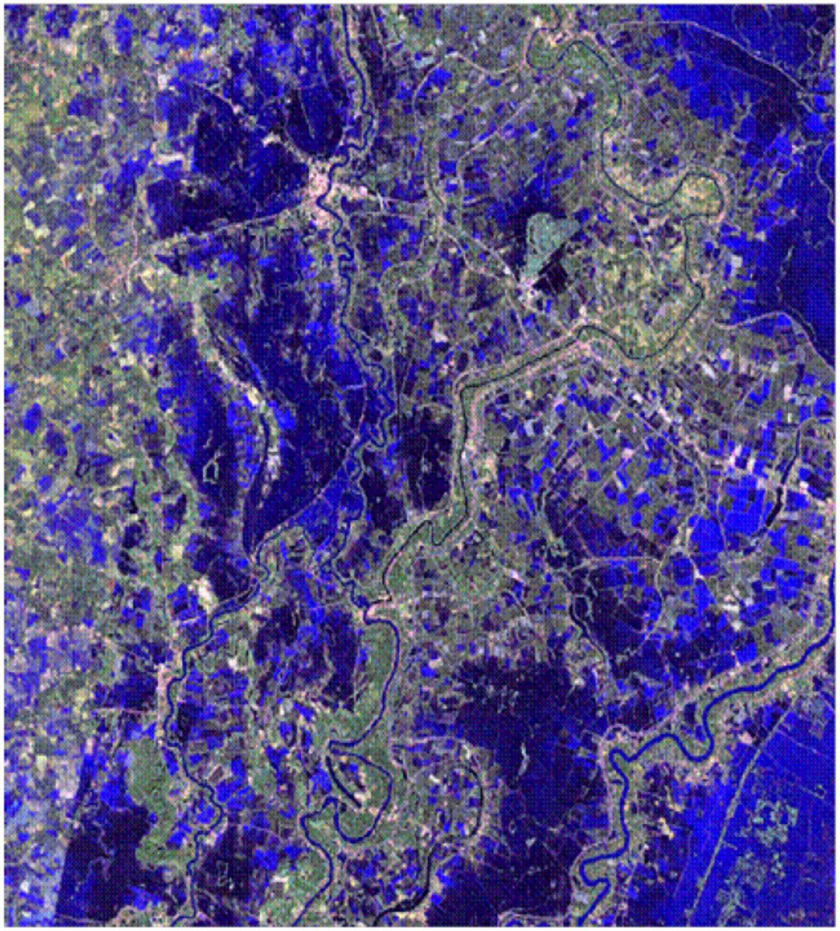


Figure 5: Regional-scale distribution of facies associated with tropical anastomosing rivers.



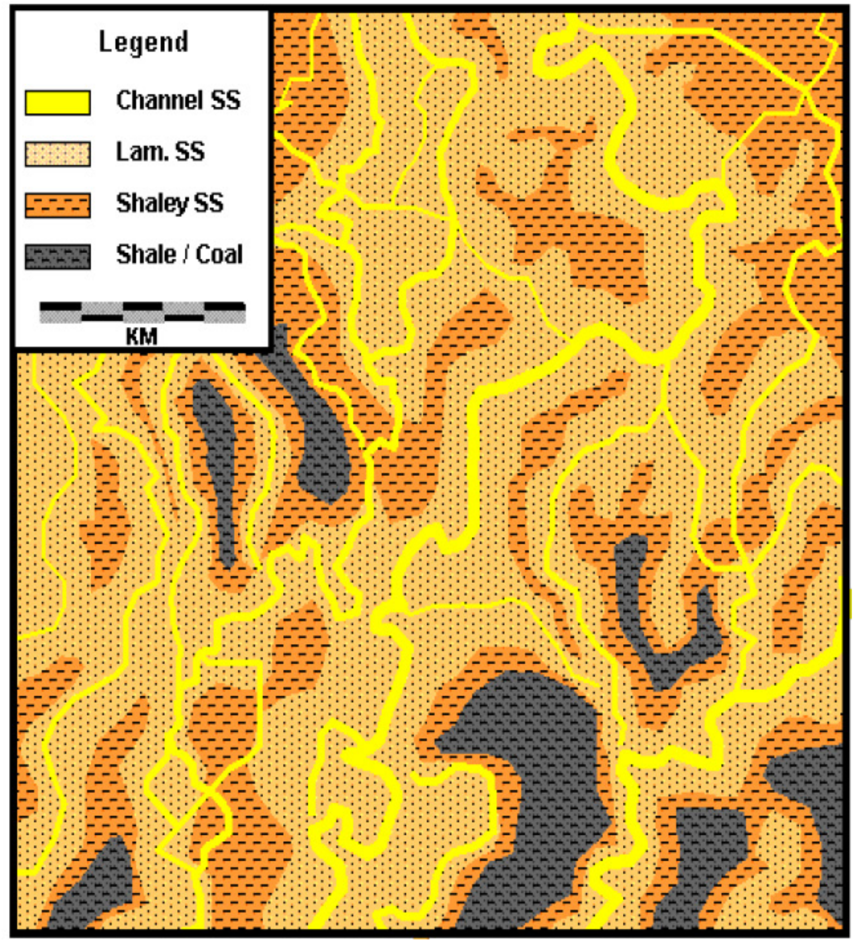


Figure 6: Prospect-scale distribution of facies associated with tropical anastomosing rivers.

Validation to the Subsurface

In order to test the validity of the satellite-derived modern analog, a producing field in the North Malay Basin was selected to determine if the distribution of the reservoir facies observed in the field was similar to that observed in the satellite study.

The first step was to calibrate the well log curves to the depositional facies observed in core (Figure 7). Clean sandstones were classified as facies 1 and assumed to represent the channel sands (Figure 8). Laminated sandstones were classified as facies 2 and assumed to represent tributary deltas or overbank crevasse-splay deposits. The shales and coals were classified as facies 3 and were assumed to be deposited in the wetlands.

Once the core facies were calibrated to the well logs (Figure 8), they were extended throughout the log and correlated to the additional wells (Figure 9). The percentage of each facies observed in the well logs (Table 1) was similar to the percentages of the facies observed in the modern analogs.

Application in the Subsurface

Based on the facies distribution observed in the well logs, it appears that the complex reservoir distribution observed on the satellite data represents an ideal analog for reservoirs in the North Malay Basin, at least for the Middle to Upper Miocene Formation 2. We can also see that it poses several challenges to the exploitation of these reservoirs.

The first challenge has to do with recognition of reservoir and of pay. Although the laminated sandstones contain good quality reservoir, the interbedded siltstones and mudstones suppress the log readings such that these laminated reservoirs often do not meet the petrophysical cut-offs to be recognized as reservoir or as pay (Figures 7 and 8). By not including these sands as reservoir, the assessment of OGIP and reserves will be incorrect.

A second challenge lies in the fact that many of the inter-formational sands are not in communication, resulting in multiple water levels and perched wet sands. Water floods in several fields with similar reservoirs have experienced water break-through in a number of sands between pay sands, illustrating the complexity of the reservoir connectivity.

This leads to the biggest challenge, economically exploiting these reservoirs, particularly in planning development well locations and perrforation strategies. The ideal targets for development wells are the clean channel sandstones. However, the majority of the channels are less than 100 meters wide and there is no strongly preferred orientation to them; so targeting them is difficult.

Posting the percent clean facies onto a RMS amplitude map of the field, we can see a reasonable correlation with high percent of clean sands and high RMS amplitudes (Figure 10). The facies interpretation (right, Figure 10) fits well with the RMS data and honors both the well data and the geologic model. However, many of the smaller channels and the laminated reservoirs do not typically exhibit strong amplitude anomalies so they are hard to identify; consequently, many other interpretations are reasonable, such as the one presented in Figure 11.

The wells are located near the structural crest. However, the sands located down dip from the crest near the water-level (dashed red line, Figure 10) cannot be produced from those crestal wells, as there is a region of facies 3 separating it from the crest. If the interpretation in Figure 11 is more nearly correct, then several of the crestal wells are also isolated.

Developing and exploiting these reservoirs requires an integrated team effort with the geologist and geophysicist working closely with the petrophysicist and with the reservoir engineers. Working together to integrate all of the data, including pressure data, they can optimize the development of these complex reservoirs.

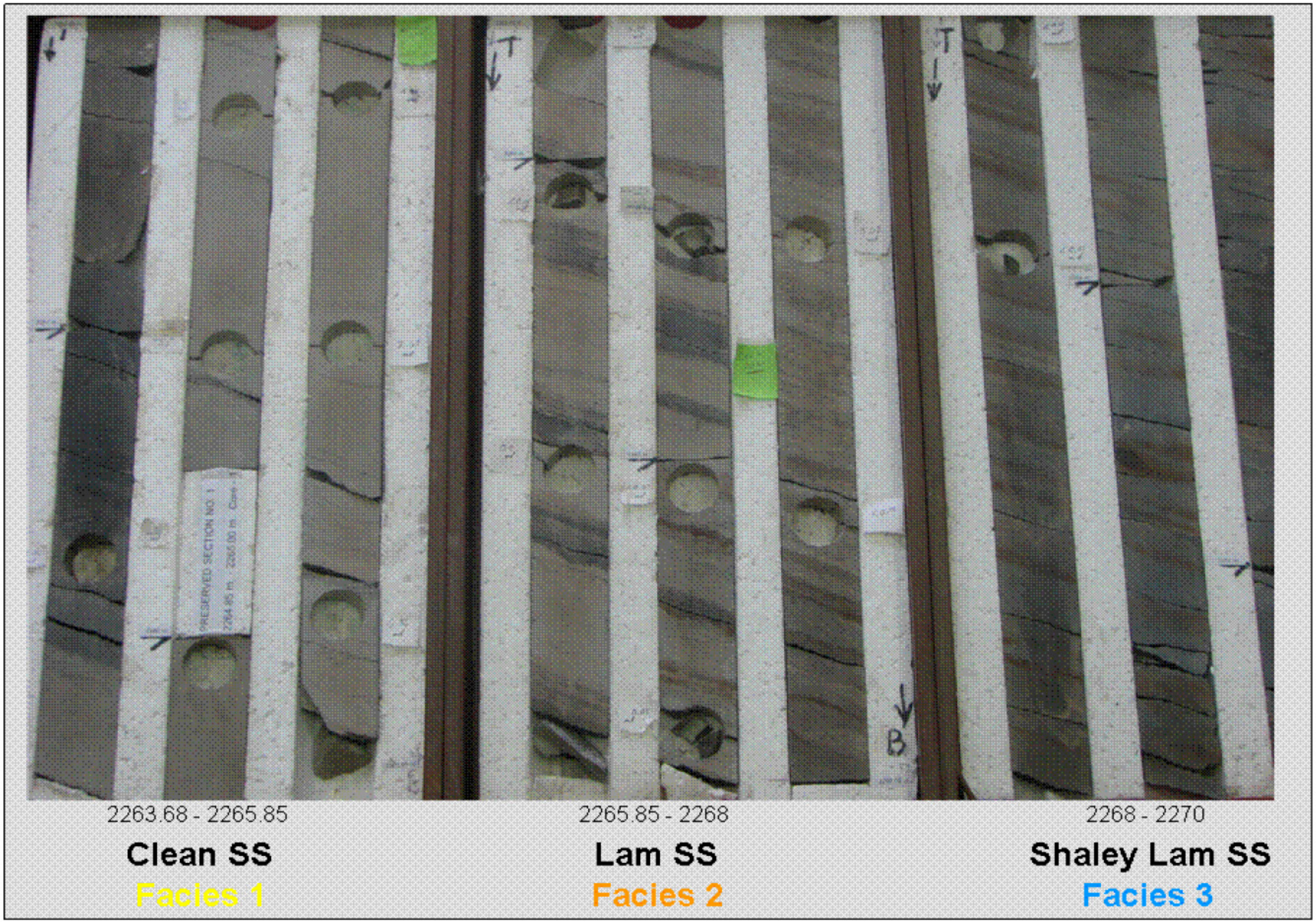


Figure 7: Core from North Malay Basin well showing laminated sandstone in Formation 2C.

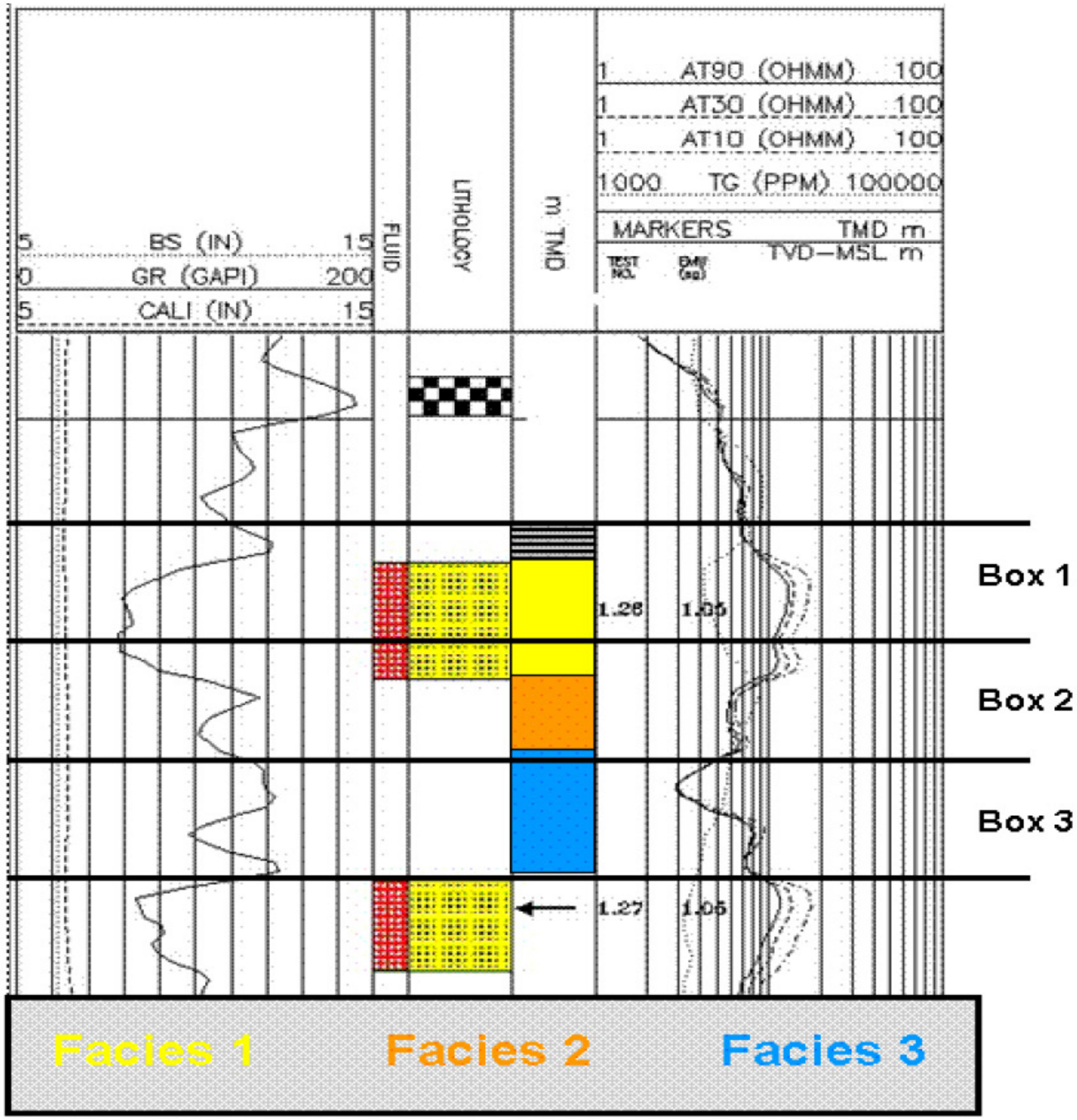


Figure 8: Calibration of the Gamma Ray curves across the cored interval seen in Figure 7. Note: Core depths are shifted ~ 4 m up from log depths.

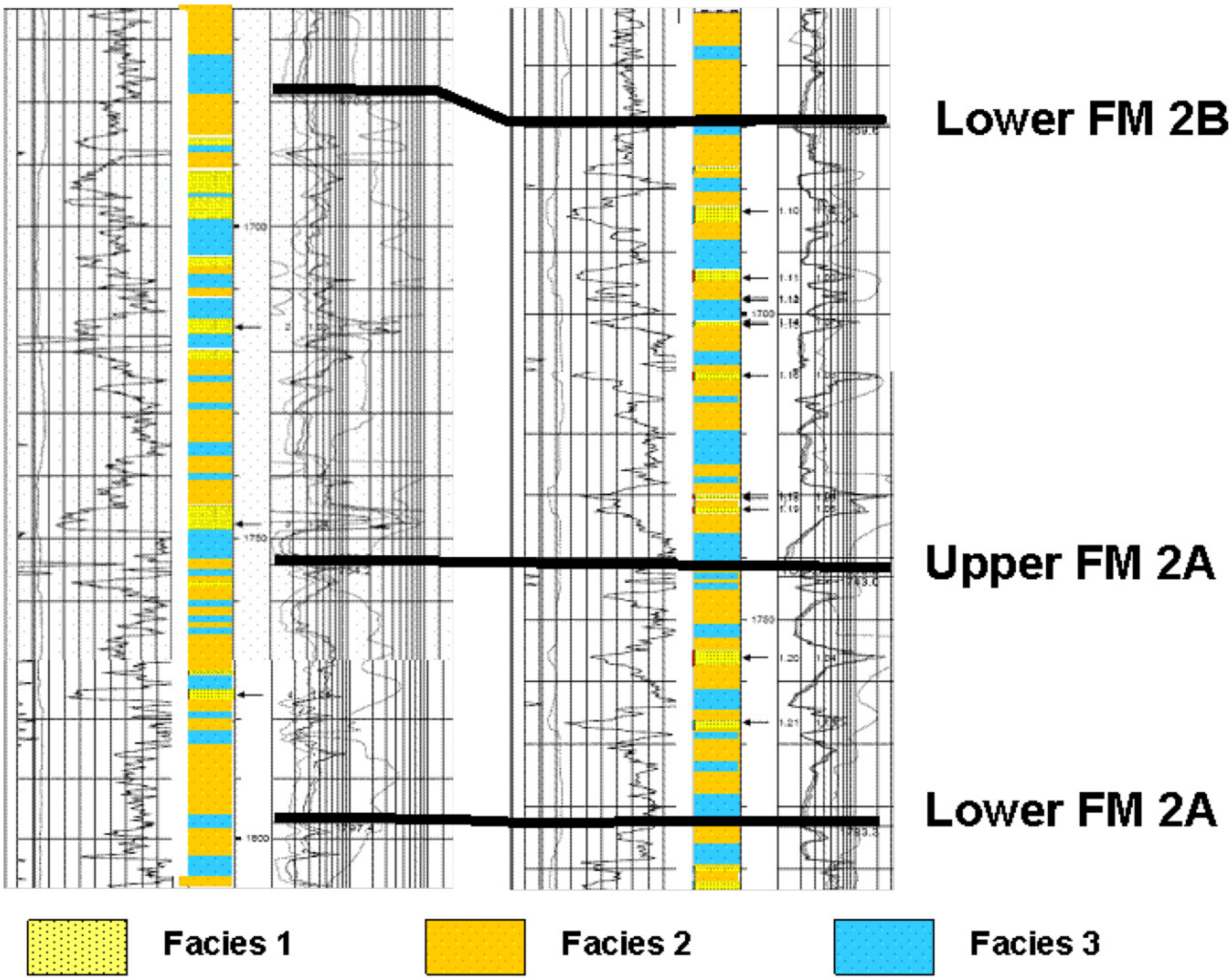


Figure 9: Vertical Facies distribution for 2 wells in a producing field in the North Malay Basin. Wells are approximately 1.5 kilometers apart.

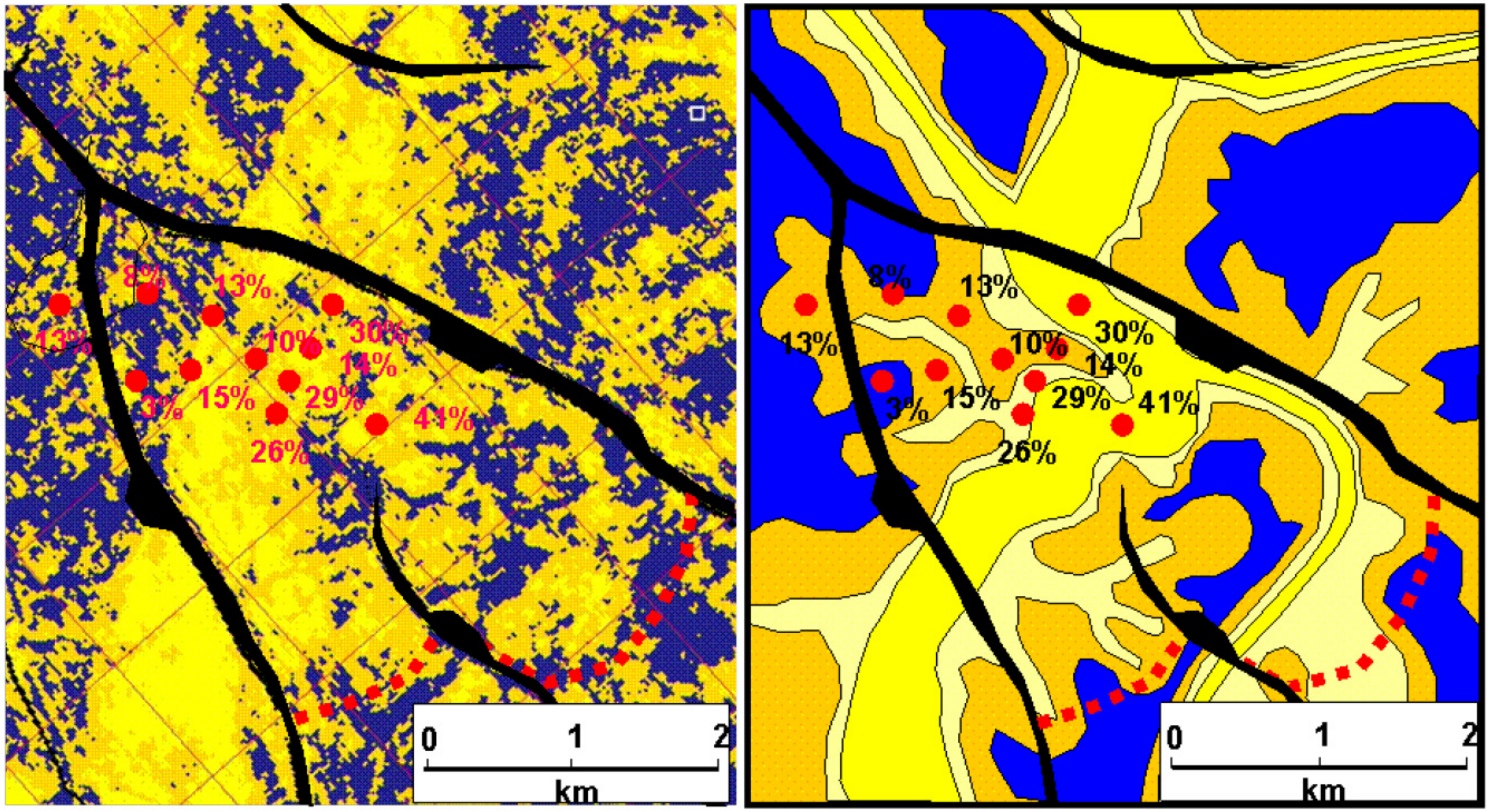


Figure 10: RMS amplitude and facies distribution map across a field in the North Malay Basin.

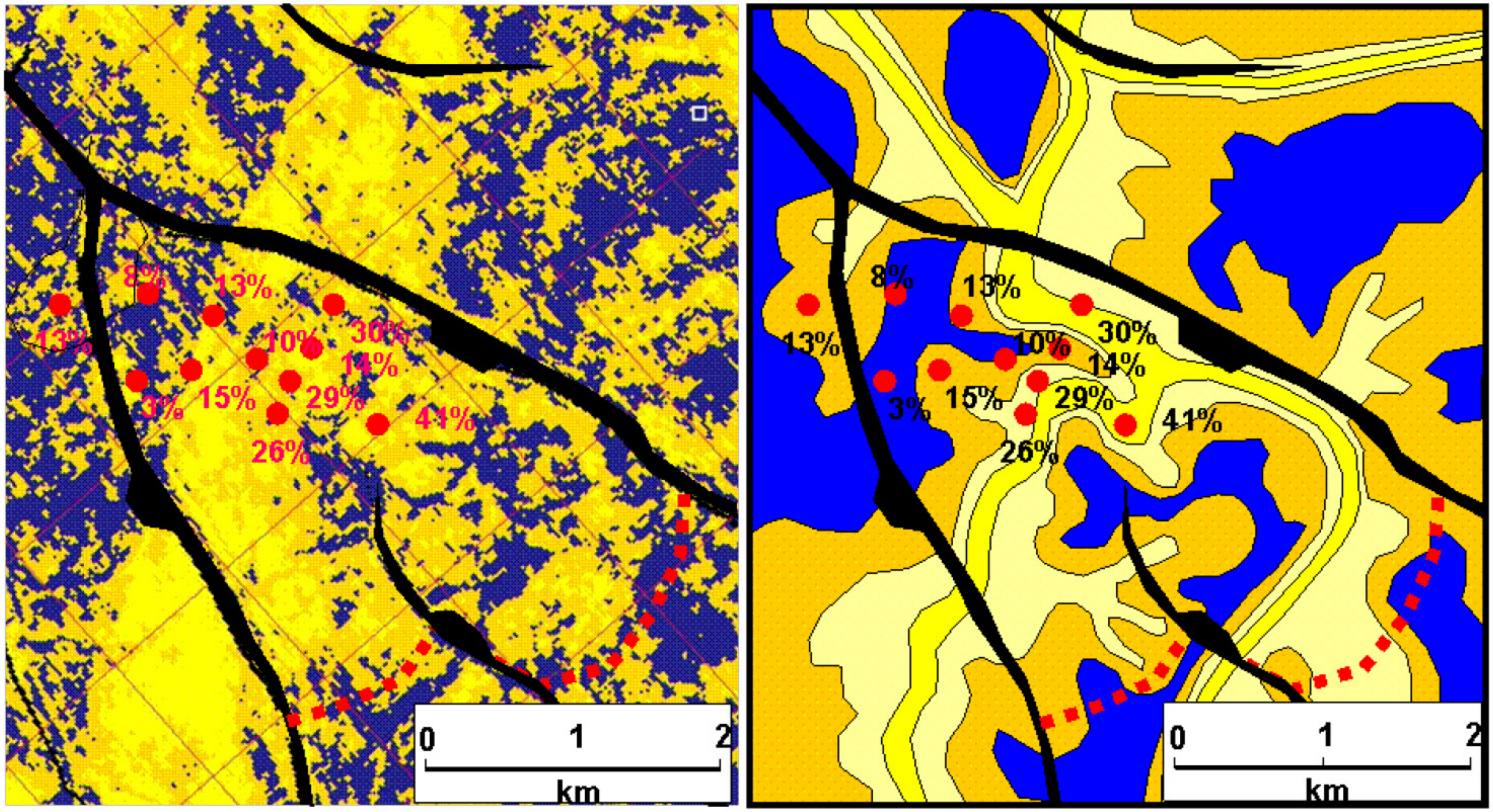


Figure 11: RMS amplitude and facies distribution map: Interpretation 2.

Formation Top	Total (m)	Clean ss		Laminated ss		Shale	
		m	%	m	%	m	%
Top 2D	95.0	**41.0**	43.2	**23.5**	24.7	**30.5**	32.1
Top 2D_Lower	95.0	**36.5**	38.4	**17.5**	18.4	**41.0**	43.2
Top 2C	63.0	**2.0**	3.2	**16.0**	25.4	**45.0**	71.4
Top 2C_Middle	91.0	**10.5**	11.5	**22.0**	24.2	**58.5**	64.3
Top 2C_Lower	56.0	**10.5**	18.8	**13.5**	24.1	**32.0**	57.1
Top 2B	41.0	**12.5**	30.5	**11.0**	26.8	**17.5**	42.7
Top 2B_Lower	72.0	**4.2**	5.8	**19.0**	26.4	**48.8**	67.8
Top 2A	124.0	**15.5**	12.5	**41.0**	33.1	**67.5**	54.4
Top 2A_Lower	91.0	**25.0**	27.5	**15.5**	17.0	**50.5**	55.5
Top 2D	92.5	**13.0**	14.1	**23.5**	25.4	**56.0**	60.5
Top 2D_Lower	98.0	**26.0**	26.5	**16.0**	16.3	**56.0**	57.1
Top 2C	57.5	**3.0**	5.2	**13.5**	23.5	**41.0**	71.3
Top 2C_Middle	89.0	**14.5**	16.3	**18.0**	20.2	**56.5**	63.5
Top 2C_Lower	49.0	**9.0**	18.4	**9.0**	18.4	**31.0**	63.3
Top 2B	37.5	**4.0**	10.7	**10.0**	26.7	**23.5**	62.7
Top 2B_Lower	74.5	**13.5**	18.1	**10.5**	14.1	**50.5**	67.8
Top 2A	128.5	**11.5**	8.9	**23.0**	17.9	**94.0**	73.2
Top 2A_Lower	93.0	**12.0**	12.9	**11.0**	11.8	**70.0**	75.3

Table 1: Percentage of each facies, by formation, for two wells in the North Malay Basin.