Hydrocarbon Prospectivity Definition, The Kra Basin, Northern Gulf of Thailand*

Tianpan Ampaiwan[1], Minarwan Minarwan[1], Paul Swire[1], and Paolo Tognini[1]

Search and Discovery Article #20357 (2016)**
Posted July 5, 2016

*Adapted from extended abstract prepared in conjunction with oral presentation given at AAPG Geoscience Technology Workshop Characterization of Asian Hydrocarbon Reservoirs, March 31 – April 1, 2016, Bangkok, Thailand

[1]Mubadala Petroleum, Bangkok, Thailand (paul.swire@mubadalapetroleum.com)

Abstract

The Kra is a Tertiary aged, rifted, mainly lacustrine basin. Commercial hydrocarbons discovered in 2009 led to the Manora Field development in 2014 (Figure 1). A successful exploration well in 2013 (Malida-1) located towards the axis critically re-defined prospectivity in this high potential basin. World class source rocks, multiple good quality sandstone reservoirs and trap types with proven seals will be discussed with their associated petroleum system.

The VIM Stratigraphic nomenclature is one that was developed by using an integrated multidisciplinary sequence biostratigraphic approach and tied to lithologies and seismic which has been used by Mubadala Petroleum across Southeast Asia for all regional correlations (see Morley et al., 2011 and 2015). The recent addition of T is for Gulf of Thailand sequences.

Biostratigraphy (palynology/foraminifera), sedimentology and geochemical analyses undertaken by external laboratories on cuttings, cores and fluid data collected from the Malida wells (Malida-1 plus two sidetrack wells) were used in the post drill analysis and were integrated with prior knowledge of the basin. Biostratigraphy was used for regional and local correlations and for paleoenvironmental interpretations.

Malida-1 Well Stratigraphy

The Malida-1 well has been subdivided into five main units. A basal package is attributed to a Late Oligocene supercycle (VIMT 20), above this is an Early Miocene succession with pulses of agglutinated foraminifera, abundant pollen from mangrove-like plants and freshwater algae (VIMT 30). The section above initially is characterized by mangrove pollen without freshwater algae and then increasing to abundant freshwater algae and pulses of planktonic foraminifera indicating occasional fully marine conditions (VIMT 40 and VIMT 50). The top of the VIMT 50 marks the top of the syn-rift mainly lacustrine section in the Kra Basin, it is also coincident with the regional Middle Miocene Unconformity which does not have an angular nature in the Kra Basin. Above the syn-rift section in the Kra Basin is mainly a fluvial section with palynological assemblages indicating a Middle to Late Miocene age.

Foraminiferal analyses were mostly barren down to the top of the syn-rift section (VIMT 50), below the well yielded pulses of benthonic foraminifera and some brackish or marine floods are expected through this succession. In the VIMT 53 main reservoir section occasional fully marine conditions are indicated with the presence of the planktonic foraminifera *Globigeoinoides subquadtatus* and *Cassigerinella chipolensis*, plus the age diagnostic fauna *Globorotalia birnageae* (N8 Zone). The sequence stratigraphy and biostratigraphical zones are summarized in Figure 2.

The lithofacies in the Malida conventional core include fan/delta, gravity flow laminated and structureless deposits, mudstones and storm deposits (Figure 3). Some trace fossils were also observed, with *Scolicia* (the heart urchin) the most important in depositional interpretation being diagnostic of a marine setting. Based on sedimentology interpretation, the core was deposited in an upper offshore setting, above storm wave base but below fair-weather wave base. Salinity fluctuations occurred, as identified by the presence of synaeresis cracks within the claystone layers.

Interpretation

It is probable that during periods of exceptionally high fluvial discharge sediment was transported offshore by hyperpycnal flows or density currents. Thin turbidites and debrites have been identified within the cored sediments. The majority of fine-grained sediments were deposited and/or were reworked during storms, hence the predominance of wave generated structures. The coarser-grained sediments are interpreted as fan delta deposits and were probably supplied from a different source. There was limited access to this source which appears to be linked to syn-rift tectonism. The arkosic nature of the reservoir suggests a granitic sediment source. A mapped perched alluvial system brought sediment into the Kra Basin from the northwest. The recovery of the extant intermontane pollen *Abies* and *Liquidambar* (Morley, 2015) within the reservoir section suggests that concurrent fault footwall uplift could have been in excess of 1000 metres. The presence of volcanic ash bands (tuffs) would also have been related to this tectonic phase. The preservation of tuff bands thoughout also demonstrates that there were periods when the bottom waters would have been anoxic and this would also account for the absence of trace fossils within certain intervals of the core. Organisms might also have struggled to survive if there were frequent changes in salinity due to variations in freshwater input or periodic isolation from the open sea. Deposition was probably within a pro-delta rather than a shoreface setting given the importance of the fluvial input.

A core from a correlatable section in the more proximal Manora-4 well has better developed fan delta sandstones that are thicker than in Malida-1 ST#1. *Scolicia* traces occur throughout the cored intervals in both wells indicating periods when basin waters were fully marine, the presence of synaeresis cracks again suggest fluctuations in salinity.

Reservoir Characterization

Reservoir quality in the more proximal Manora Field and even in the more distal Malida wells can be excellent but partly this is due to secondary diagenetic processes enhancing reservoir properties. Measured porosities are in the range of 18-25% and permeabilities up to multi-Darcies even at deeper burial depths (-7700 ft TVDss) as seen at Malida. The enhancement of rock properties is due primarily to feldspar dissolution. In Malida for instance alkali and plagioclase feldspar grains average 25.6% and 11.8% respectively by modal analysis. All feldspar grains seen in thin-section are partially, though variably, altered to clays and some also contain cryptic microporosity. Partial dissolution of some feldspar leaves skeletal remnants (Figure 4) and some plagioclase grains have been partially altered to cloudy sericite (essentially illite) (Figure 5). The plagioclase content of the samples examined by XRD varies considerably, from 4.8-20.9%. The highest values occur within the finest sediments (silt and very fine sands). This can be explained in part by the fact that the coarser sediments have more of their plagioclase within “granitic” fragments rather than as individual grains. However, this does not explain the full variation, and alkali feldspar proportions vary rather less. The most probable explanation is that plagioclase is particularly susceptible to dissolution during burial, but that such dissolution occurs mainly within coarser, more permeable deposits in which there is a greater flux of the dissolving pore fluids. Significantly higher proportions of plagioclase are therefore preserved within the finer-grained, less permeable, deposits.

The abundance of kaolinite clay is notably low, averaging just 0.3% by whole-rock XRD. This is noteworthy in view of the evidence for significant amounts of feldspar dissolution. Such dissolution commonly results in the precipitation of substantial volumes of kaolinite, since aluminium released from feldspars has low mobility in most diagenetic settings and is reprecipitated as clays. Feldspar dissolution and aluminium mobility is known to increase where there is a significant flux of organic acids within an open diagenetic system, and such conditions often arise as aqueous fluids flow through a reservoir system in advance of hydrocarbon migration and/or charge (Surdam and Crossey, 1987). This is thought to be the most probable explanation both for the extent of feldspar dissolution (and accompanying development of secondary porosity) and the low observed volumes of kaolinite.

Source Rocks

Malida wells provided evidence for high potential source rocks younger than the Oligocene shales with measured TOC up to 5-7 wt%. The Hydrogen Index can be up to 750 mg HC/gr TOC, indicating rich oil-prone kerogen. The TOC vs Depth plot shows that organic-rich shales occur consistently from ~7000 ft to ~10,000 ft MD in the central part of the basin (Figure 6). These shales were deposited during the synrift phase and were initially believed to be purely lacustrine. GCMS of some Malida samples and oils from Manora and Malida actually show that the claystones were most likely deposited in an estuarine or shallow lacustrine setting with some terrestrial input. Oil and source rock GC fingerprints, stable carbon analysis and biomarker-based oil to source rock correlation indicate that Malida and possibly Manora oils are sourced from the Early Miocene and are early mature. Organofacies types of source rocks in the Kra Basin are most likely a mixture between Organofacies C (lacustrine algae) and Organofacies D/E (terrigenous, higher plant input). This organofacies mixture is consistent with interpreted depositional settings from new biostratigraphy and sedimentology data.

References Cited

Leppard, R. 2014, Core description and sedimentology of the Early Miocene core from the Malida-1 ST1 well, offshore Thailand, Leppard: Sedimentology Report No. 100/14, prepared for Mubadala Petroleum (unpublished).

Morley, R.J., T. Swiecicki, and D.T.T. Pham, 2011, A sequence stratigraphic framework for the Sunda Region, based on integration of biostratigraphic, lithological and seismic data from Nam Con Son Basin: Vietnam Proceedings, Indonesian Petroleum Association 35th Annual Convention & Exhibition, May 2011, IPA11-G-002, 22 p.

Morley, R.J., T. Swiecicki, and P. Restrepo-Pace, 2015, Correlation across the South China Sea using VIM transgressive-regressive cycles: AAPG Workshop, Kota, Kinabalu.

Surdam, R.C, and L.J. Crossey, 1987, Integrated diagenetic modelling: a process-oriented approach for clastic systems: Annual Review of Earth and Planetry Sciences, v. 15, p. 141-170.

Weatherford KSP Company Ltd., Petrographic analysis of sidewall core samples from Malida-1 Well, Gulf of Thailand.

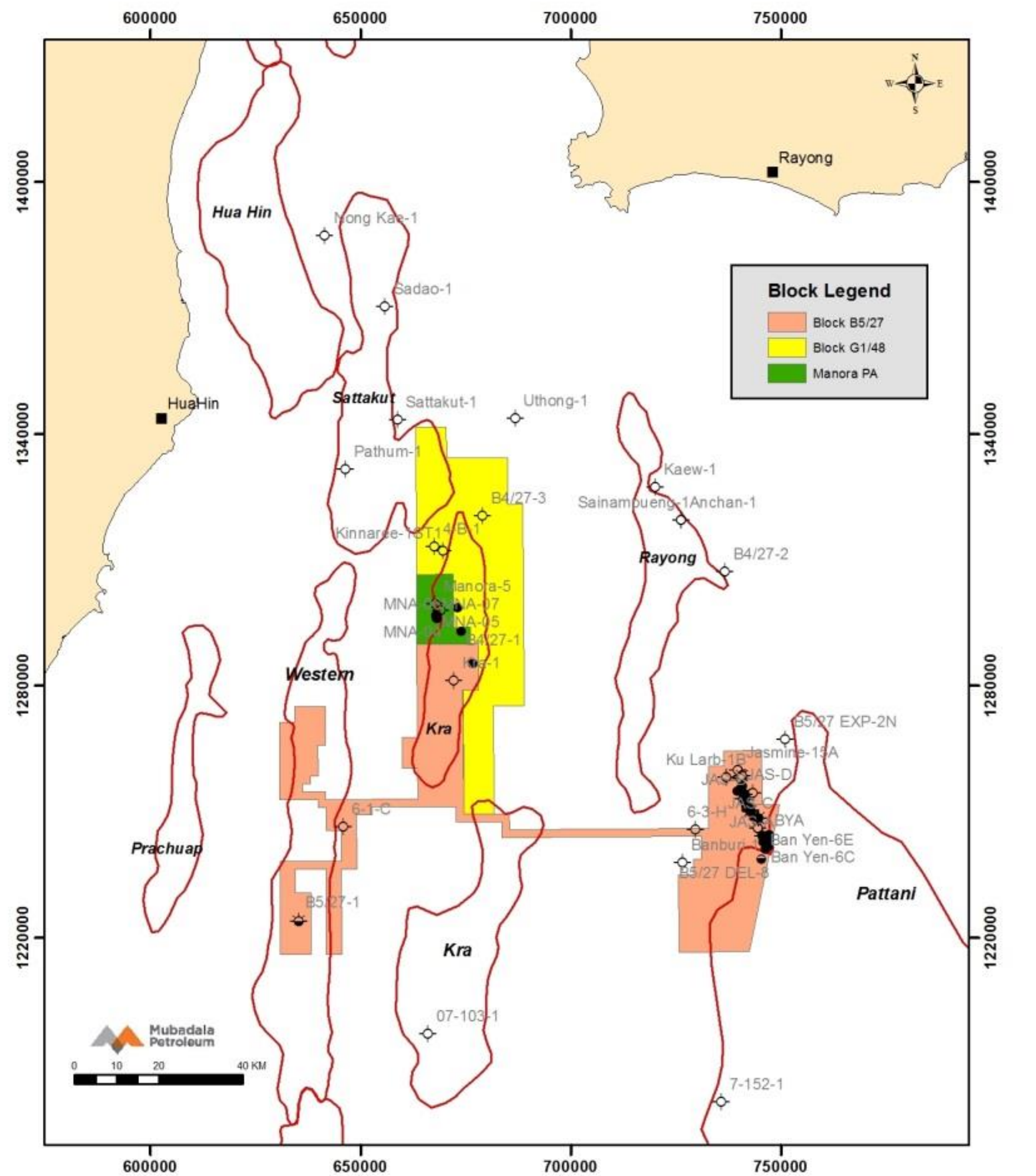

Figure 1. Location map for the Kra Basin, the Manora Oil Field and the G1/48 Concession, Northern Gulf of Thailand.

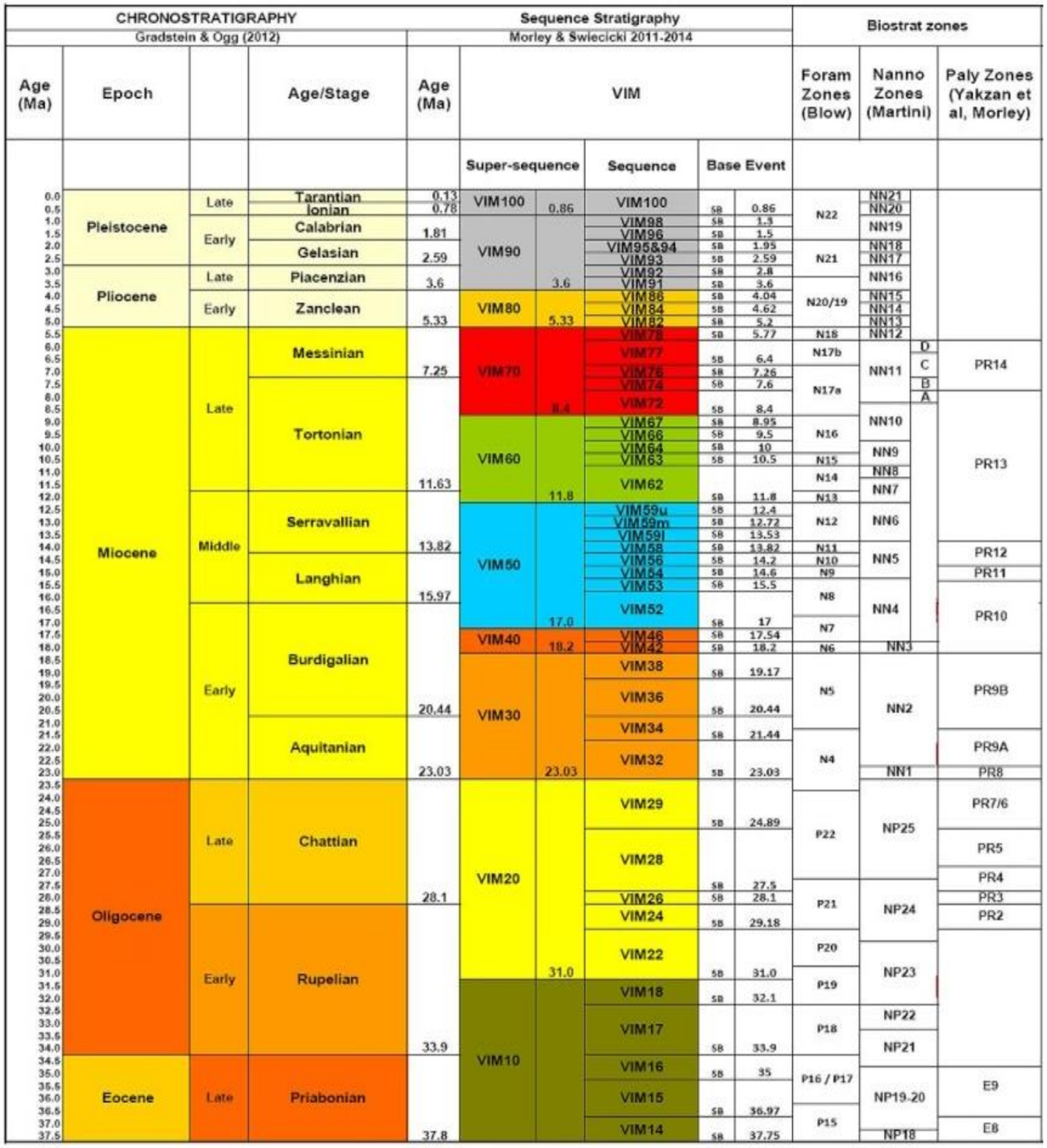

Figure 2. The VIM (Vietnam, Indonesia, Malaysia) Stratigraphic Nomenclature (after Morley, 2015).

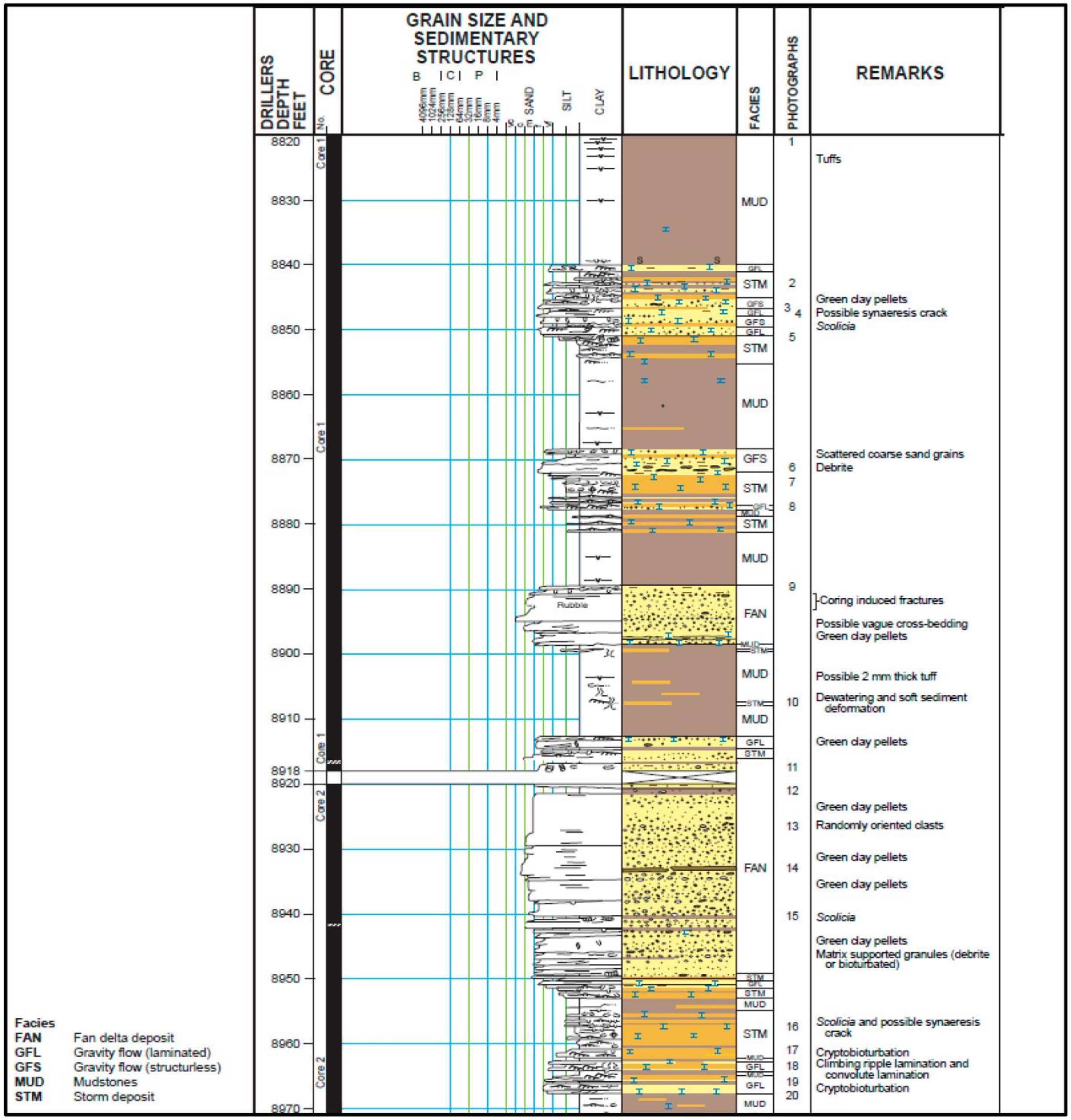

Figure 3. Malida-1 ST#1 conventional core description (after Leppard, 2014).

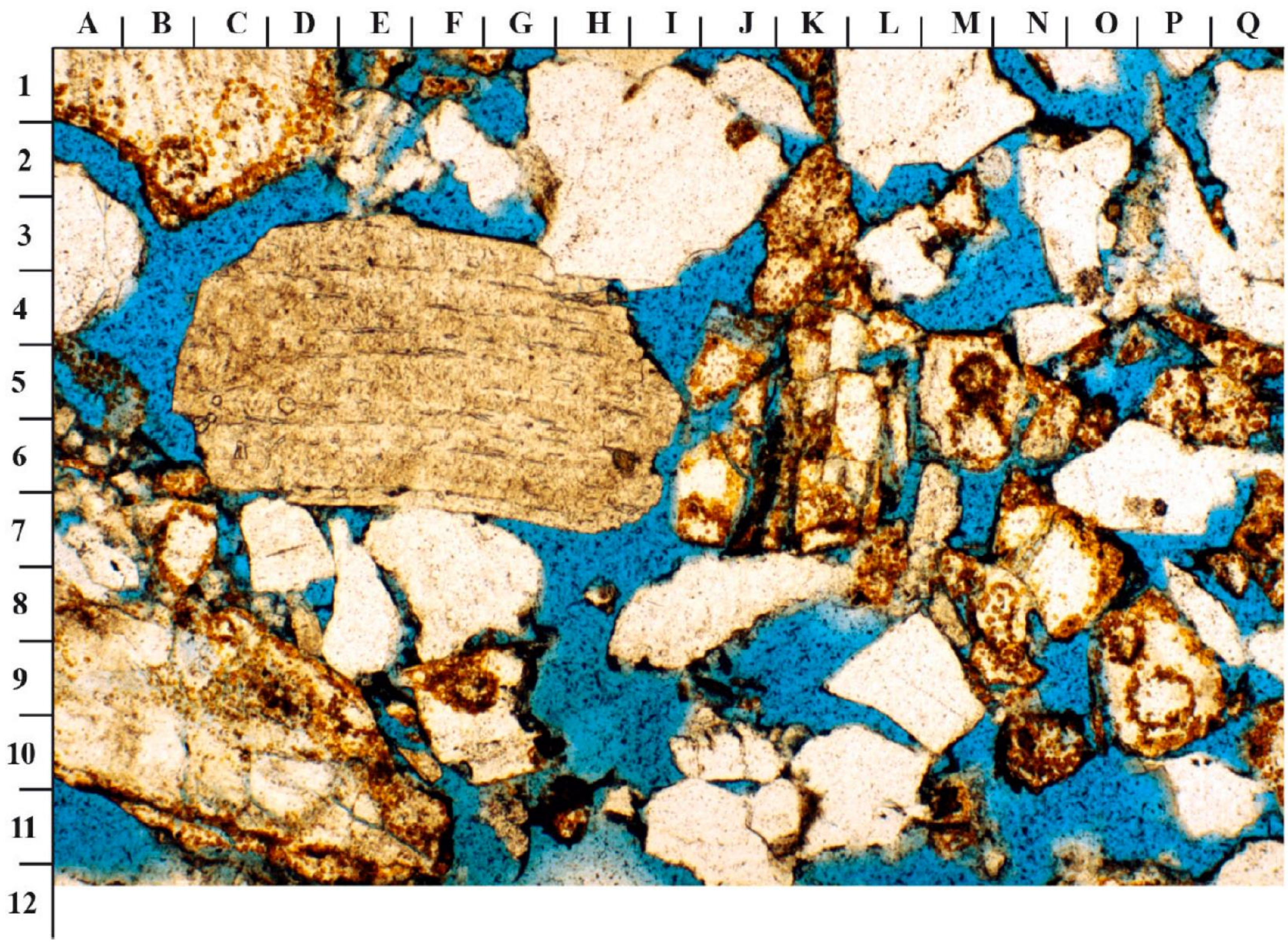

Figure 4. Partial dissolution of some feldspar.

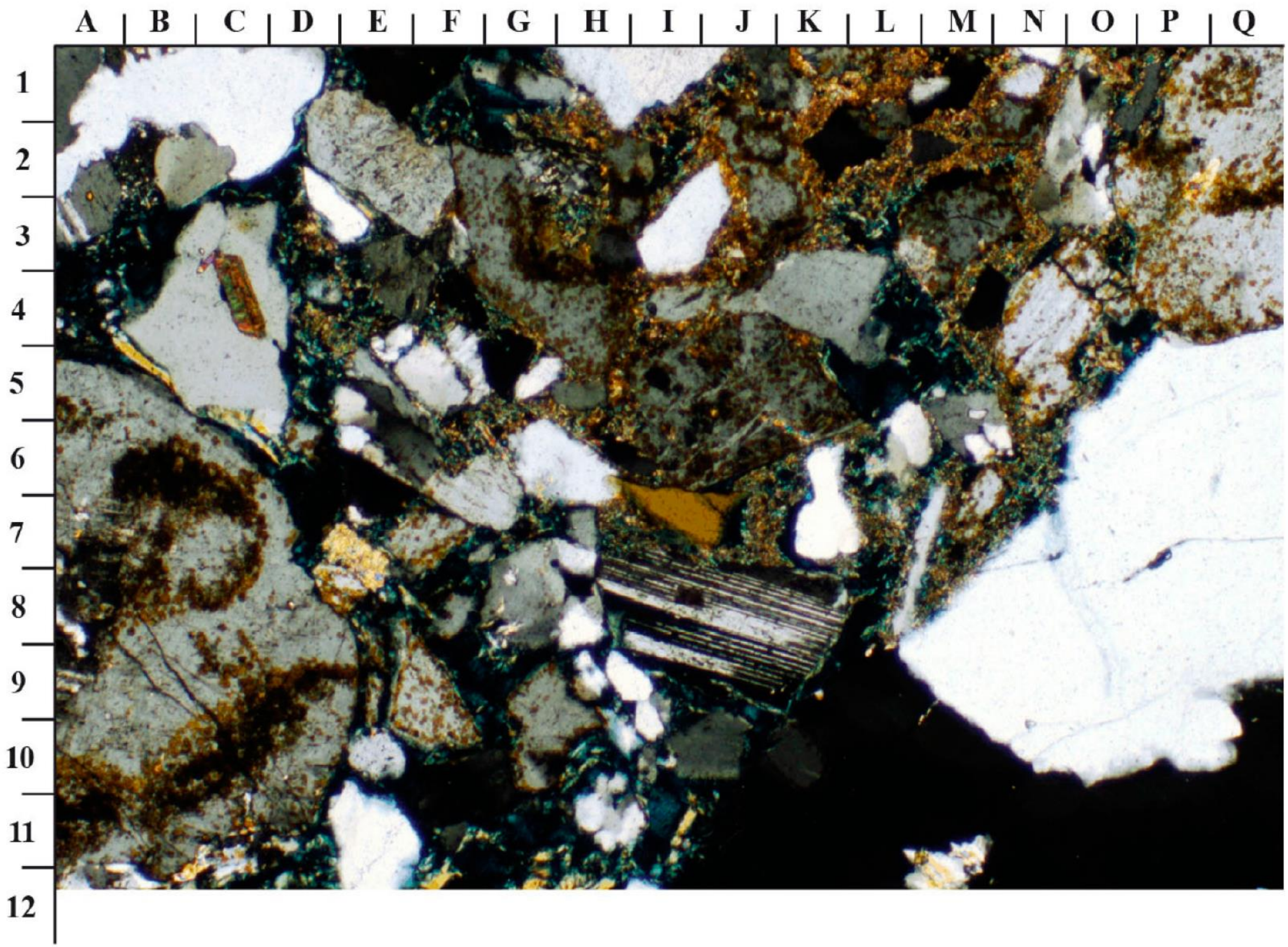

Figure 5. Plagioclase grains altered to sericite.

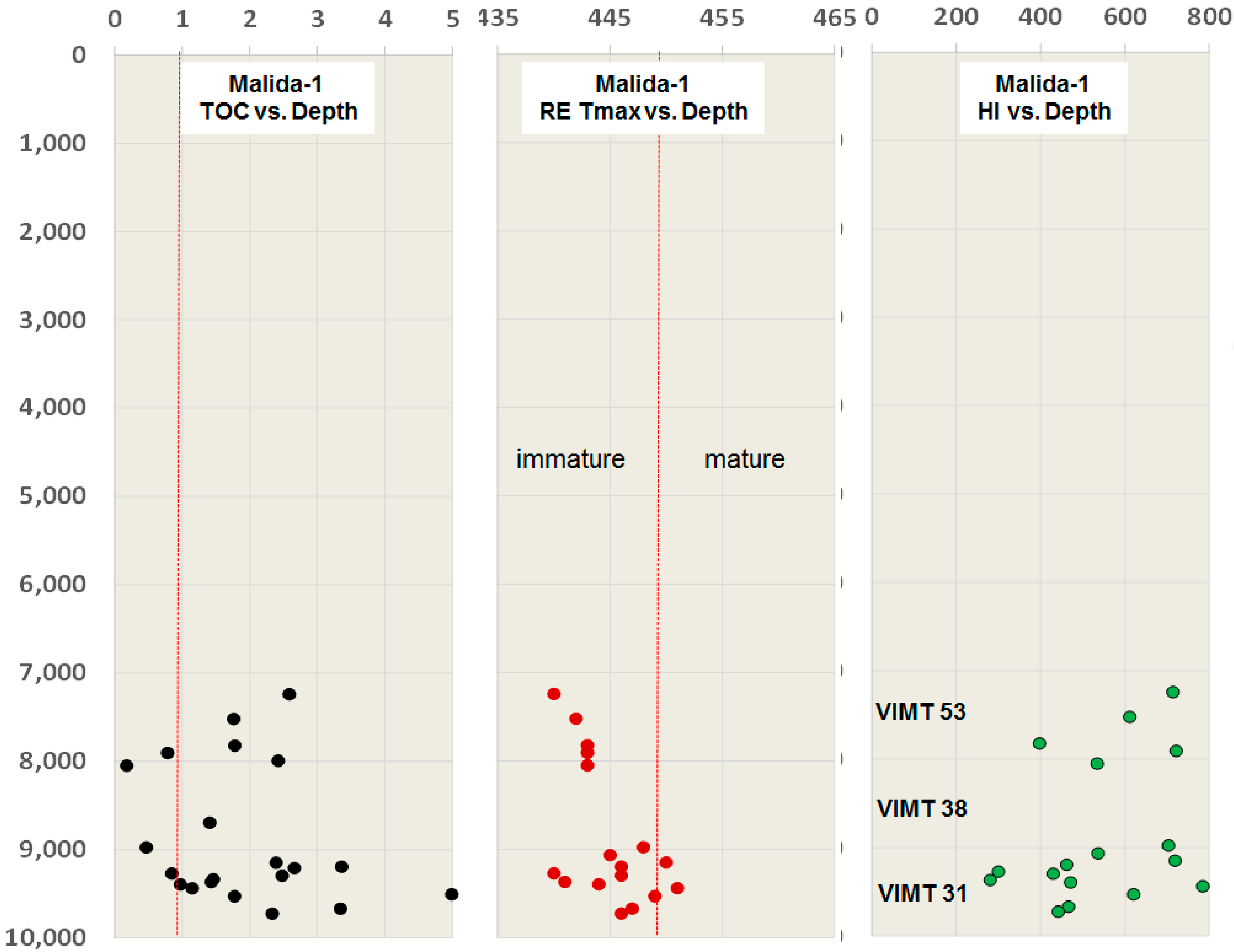

Figure 6. Source rock screening in Malida-1 Well.