PS Characterization of Low-Permeability Reservoir Rock Using Petrography and Depositional Studies — Case Study: Optimizing Production from Low-Permeability Bekasap Sandstones in Central Sumatra, Indonesia*

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Abstract

An integrated petrographic [i.e., thin section, x-ray diffraction (XRD) and scanning electron microscopy (SEM)] and depositional environment study is one of many methods available, which is relatively cheap, giving quick and accurate results to support reservoir characterization.

The objective of this study is to identify Bekasap Sandstone production optimization. This study also documents geologic factors that control the development strategy and production optimization for the Bekasap Sandstone. This sandstone was deposited in an estuarine, tidal dominated delta system. According to lithofacies, the sandstone can be divided into upper and lower parts. The lower part consist of medium grained, conglomeratic, cross-bedded and massive sandstone, slightly bioturbated, mainly arenite type that has horizontal permeability up to 1900 mD. On the other hand, the upper part is composed of fine- to very fine-grained, medium-highly bioturbated sandstone, greywacke type dominantly, with horizontal permeability from tens up to 200 mD.

In general, reservoir quality development, especially horizontal permeability, is more controlled by depositional environment factors (i.e., grain-size, bioturbation and mud matrix content) rather than diagenetic processes (i.e., cementation and dissolution). However, at several depths, both permeability and porosity reductions are significantly controlled by cementation.

Permeability reduction is significantly controlled by decreasing grain size and sorting and increasing both matrix and bioturbation content. On the other hand, decreasing both matrix and bioturbation volume, coarser grain size and better sorting increase permeability. Precipitation of dolomite cement dramatically destroys both permeability and porosity whereas dissolution slightly increases both porosity and permeability.

Both technically and economically, horizontal drilling technology is an optimum strategy to increase production for low permeability caused by the depositional environment aspect.

General Statement

Integrating petrography with environment depositional information as well as core petrophysics, log and well test data in reservoir rock characterization has proved useful in improving quality and reliability of overall results. This article demonstrates one of the available methods in how to make an integrated approach that will affect the cost efficiencies as well as giving quick and accurate results to support preliminary recommendations for exploitation of a reservoir.

Based on lithofacies identifications, the Bekasap sandstones (1900-2200 ft-ss), in Central Sumatra, Indonesia (Figures 1 and 2), display a fining-upward trend. Its mineral composition is mostly monocrystalline quartz with additional feldspar and rock fragments. It was deposited in an estuarine tidal dominated delta system and can be divided into upper and lower units of Bekasap Sandstone. Their characteristics are significantly diverse in grain-size, sorting, clay matrix content, permeability and gamma-ray and resistivity logs.

Description and Results

The upper part of Bekasap Sandstone, known as the low permeability case, is composed of very fine- to fine-grained, medium-highly bioturbated sandstones, with 18-22% clay matrix and horizontal permeability of up to 200 mD. The sandstones are mostly feldspathic greywacke and lithic greywacke. Their log characters are identified by gamma-ray of 60^0-90^0 API and low resistivity of 8-12 ohm-m. Whereas the lower part has better reservoir quality with 55-60 API units (gamma-ray log)and 20-60 ohm-m (resistivity log). This sandstone mainly consists of massive-cross bedded, medium- to coarse-grained with <5% clay matrix content. These beds are classified as sublitharenite, with horizontal permeability up to 1900 mD (Figures 3 and 4).

As a general view of Bekasap Sandstone, major reservoir parameters in development stages, such as permeability, are significantly controlled by depositional factors (i.e., grain size, bioturbation and mud matrix content) rather than diagenetic processes (i.e., cementation and dissolution). Although those diagenetic products had been observed to occur at several depths but those are limited in quantity. It is should be noted that use of basic geologic factors resulted in development strategy and production optimization. For example, the upper part of Bekasap Sandstone, known as low-permeability sandstone, is characterized by very fine- to fine-grain size with low to high bioturbation.

The permeability reduction for Bekasap Sandstone is significantly controlled by decreasing grain size and sorting. It is also correlated with increasing clay matrix and bioturbation content. That was verified by petrography and routine core analyses. Whereas very fine- to fine-grained, moderate-highly bioturbated sandstones with high clay matrix content have horizontal permeability of up to 200 mD, the sandstones that is fine-grained and slightly bioturbated have horizontal permeability from 200 to 600 mD. Medium- to coarse-grained sandstones with cross-bedding and <5% clay matrix have a horizontal permeability of up to 3000 mD (Figures 5 and 6). Dolomite cement in the sand also dramatically destroyed both permeability and porosity, whereas dissolution slightly increased both porosity and permeability (Figure 7).

As a consequence of the variability in permeability, better management of the field, the low-permeable upper-Bekasap sandstones have undergone carefully planned exploitation and horizontal drilling. The use of horizontal drilling is acknowledged as a success story of its own. Production history reveals that horizontal-wells (Figure 8) can produce 10 times more oil than vertical-wells (Figure 9). These successes would not prevail without the application of the integrated approach in interpretation of core, well-log, and well-test data in reservoir characterization. In this approach, petrography and depositional environment play an important role.

Structural, porosity, and thickness maps are shown in Figures 10 and 11.

Conclusion

Low permeability in the Bekasap sandstones are mainly controlled by depositional factors, and horizontal drilling is the best strategy to optimize oil production. Petrography and depositional studies constituent an important approach in reservoir characterization.

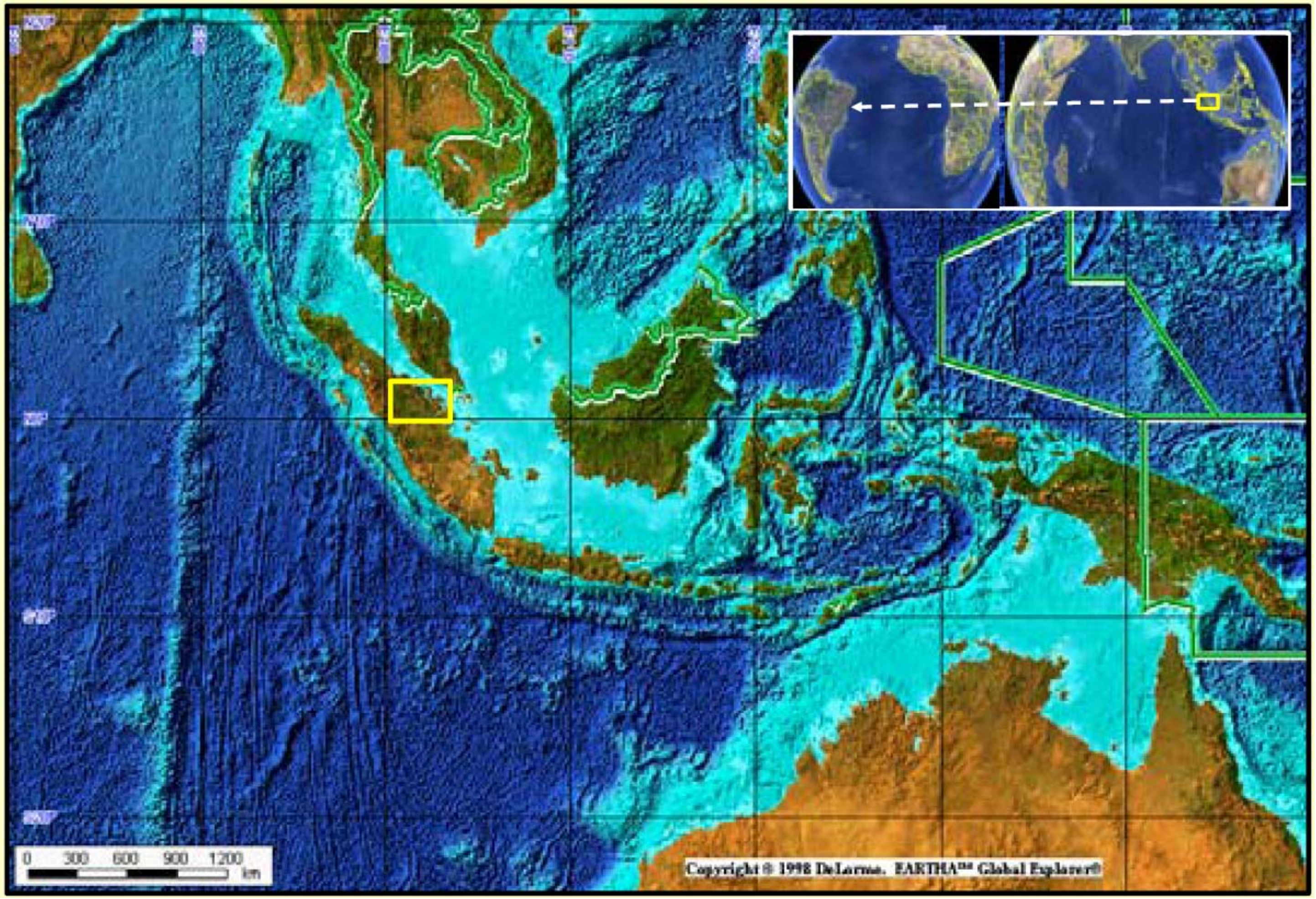

Figure 1. Location of the study area.

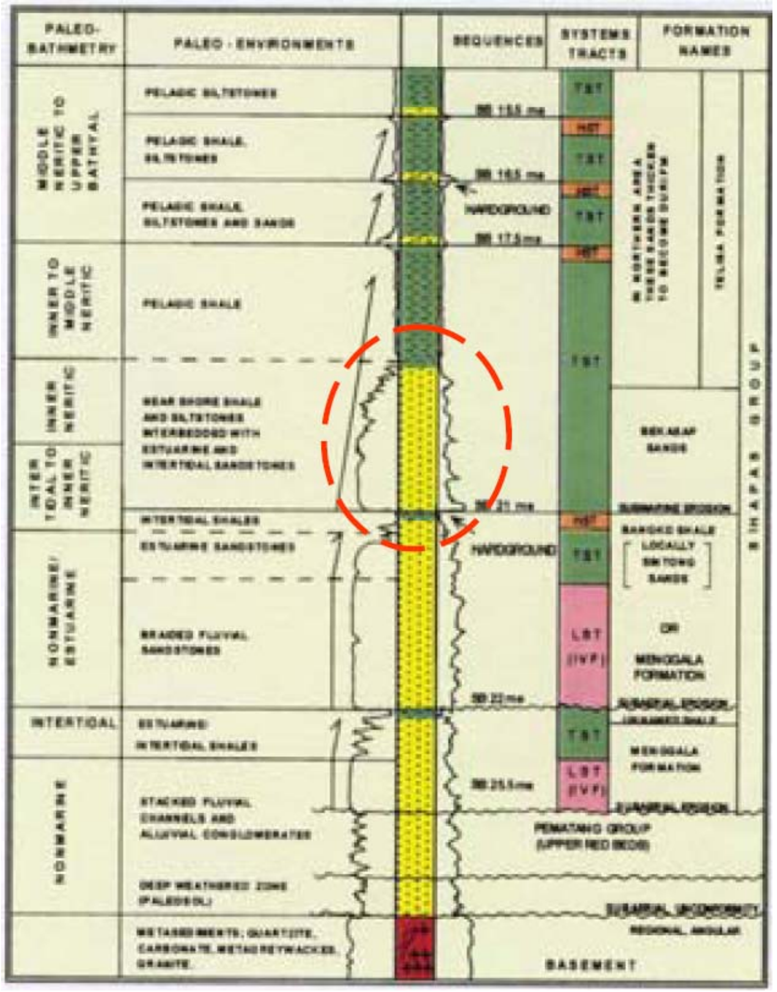

Figure 2. Sequence stratigraphy of Central Sumatra Basin (Dawson et al, 1993).

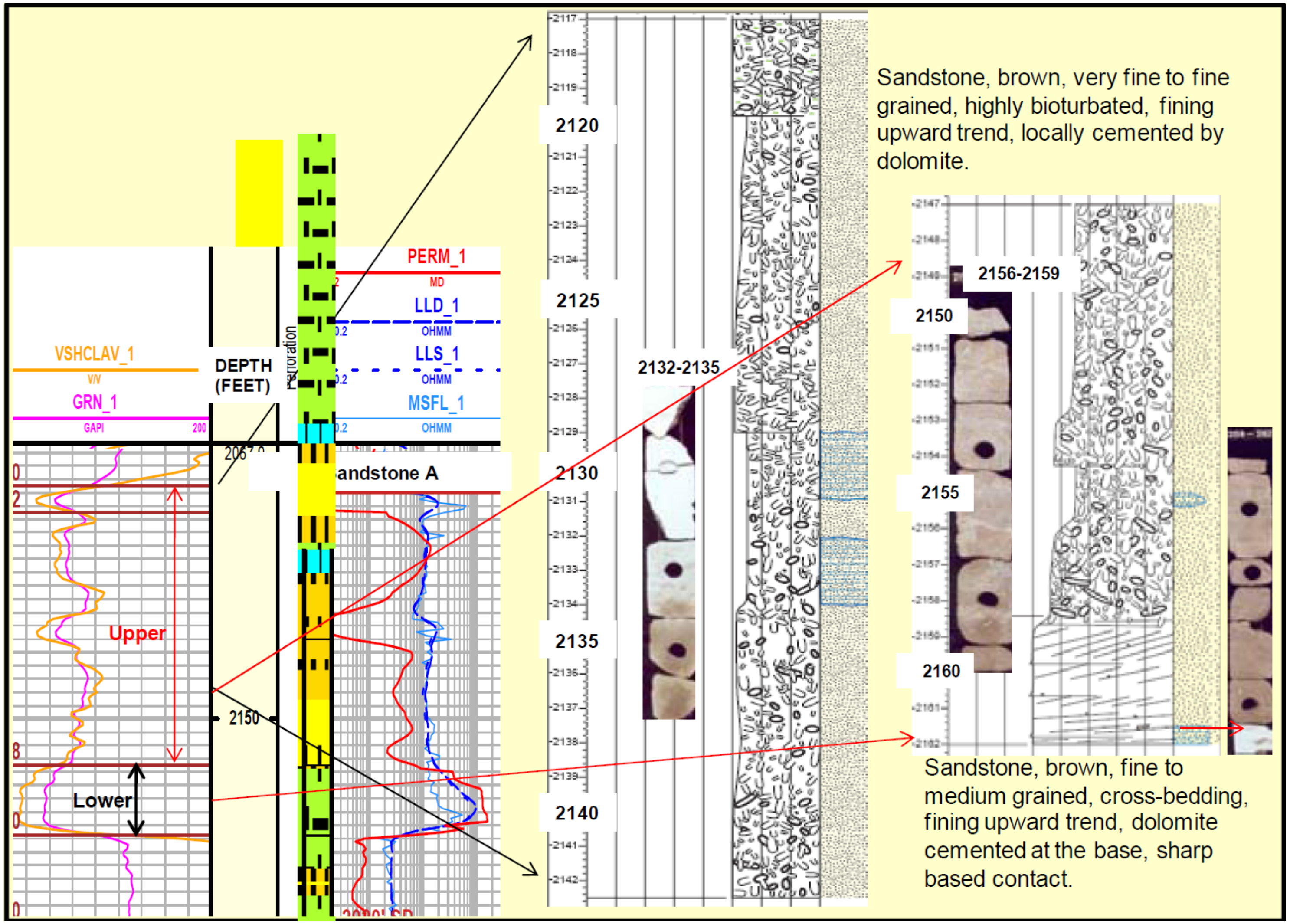

Figure 3. Visual characterization of the Bekasap sandstone, illustrating two different parasequences. The lower part consists of cross-bedded conglomeratic sandstone as an incised valley deposit, but the upper part is mainly composed of bioturbated sandstone.

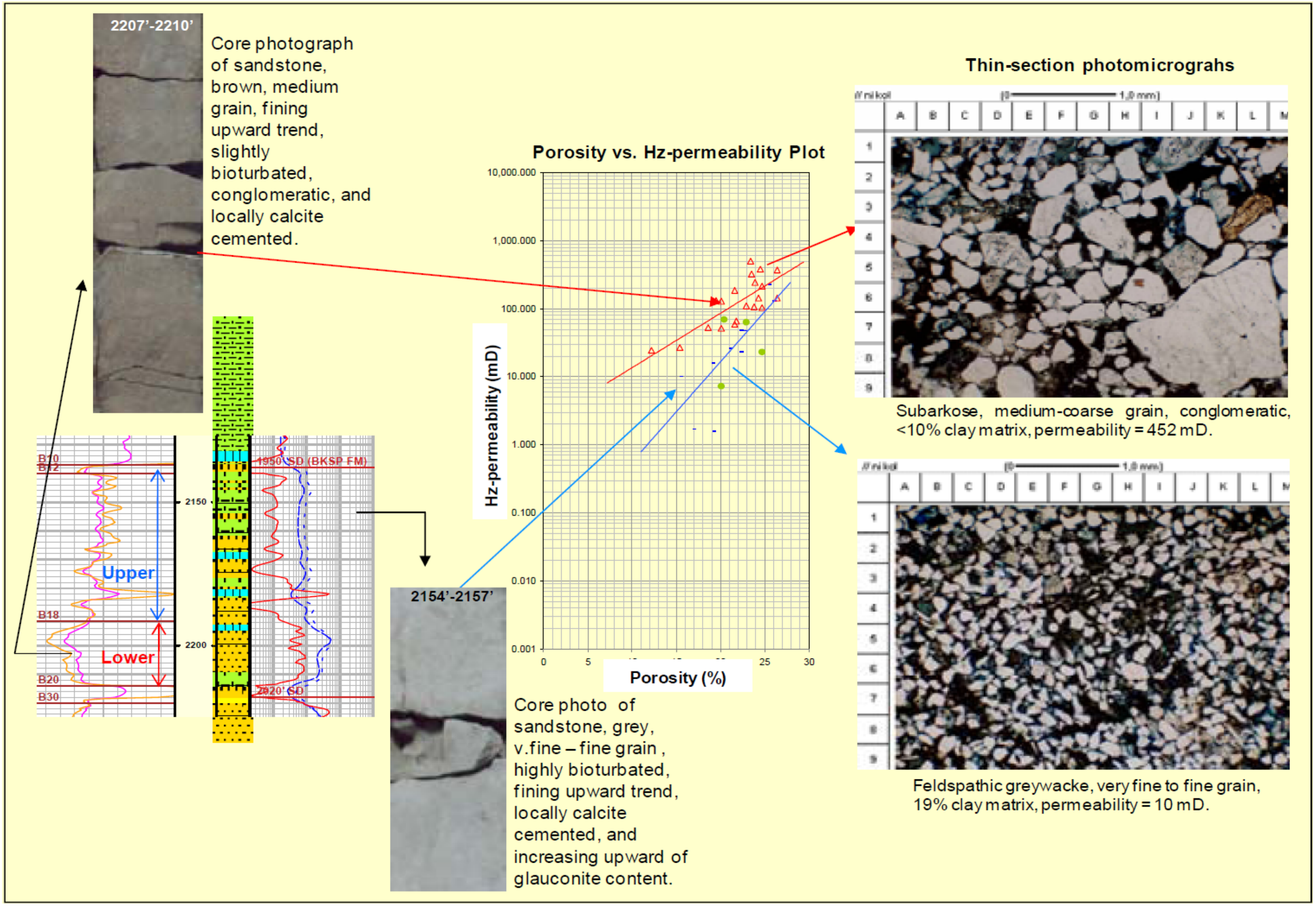

Figure 4. Features of the Bekasap sandstone, demonstrating two different patterns in porosity vs. permeability plot(especially permeability). These differences are controlled mainly by depositional features (sedimentary structure, grain-size and clay matrix content).

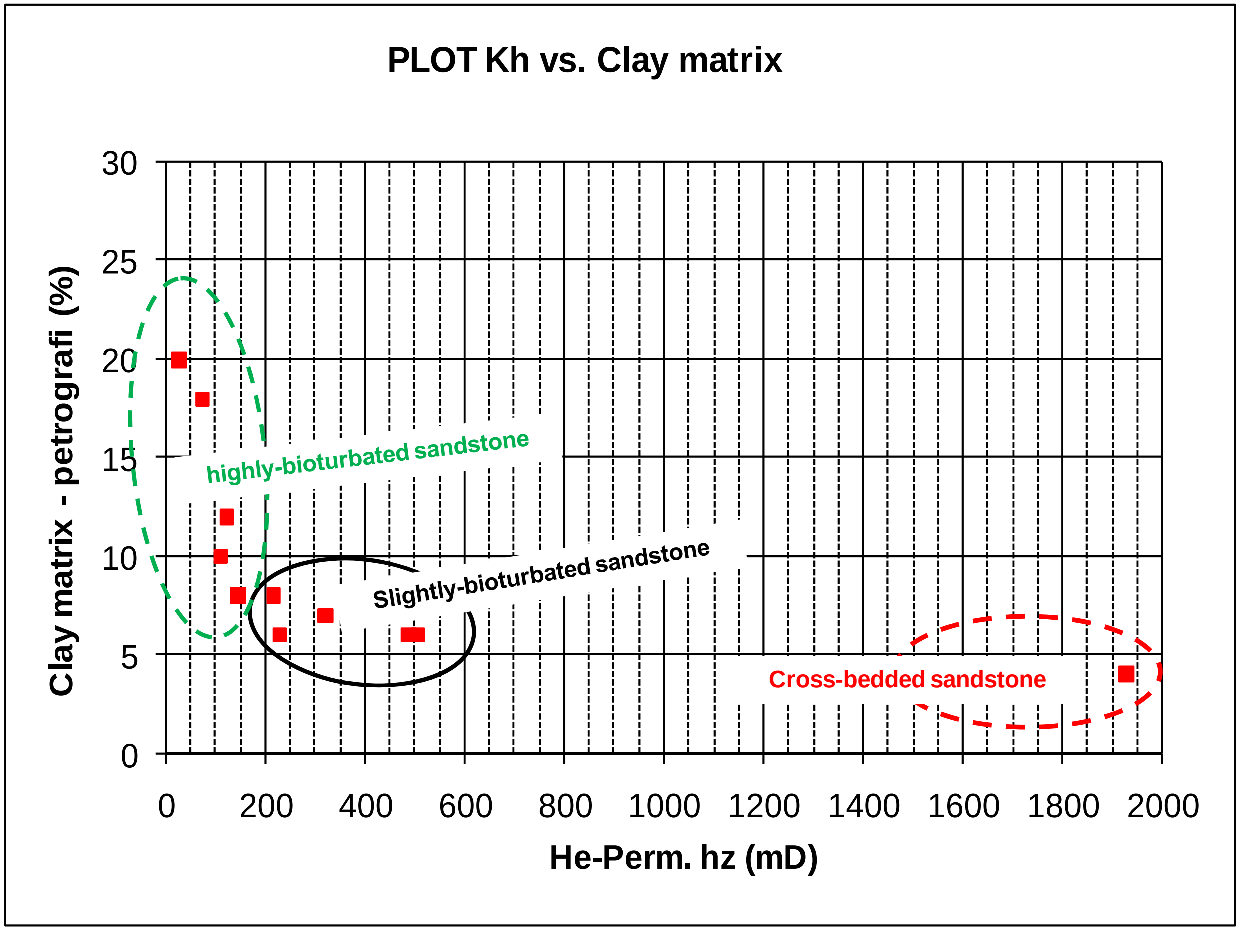

Figure 5. Relationship between clay matrix content, sedimentary structure, and horizontal permeability. Increasing clay matrix content and bioturbation intensity result in lower permeability (close to 50 mD). The sandstones with 5-10% clay matrix and slight bioturbation have permeability from 200-500 mD. Sandstones with cross-bedding and <5% clay matrix have permeability up to 1900 mD.

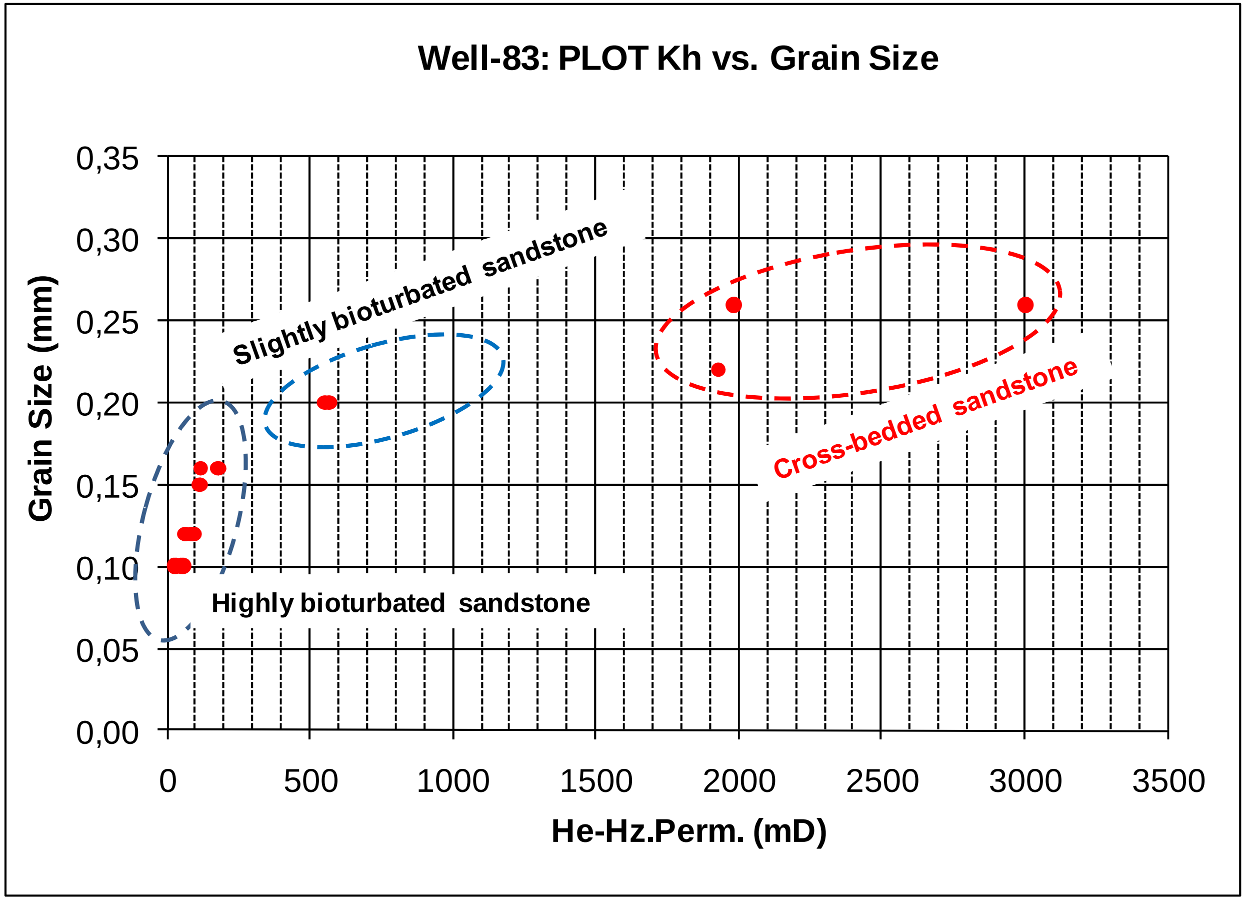

Figure 6. Relationship between grain-size, bioturbation intensity, sedimentary structure and horizontal permeability. Very fine- to fine-grained (0.06-0.14 mm) sandstones that are highly bioturbated have permeability of up to 200 mD. Fine-grained (0.20 mm) sandstones that are slightly bioturbated have permebility of up to 600 mD. Cross-bedded, medium-grained sandstones have permeability of up to 3000 mD.

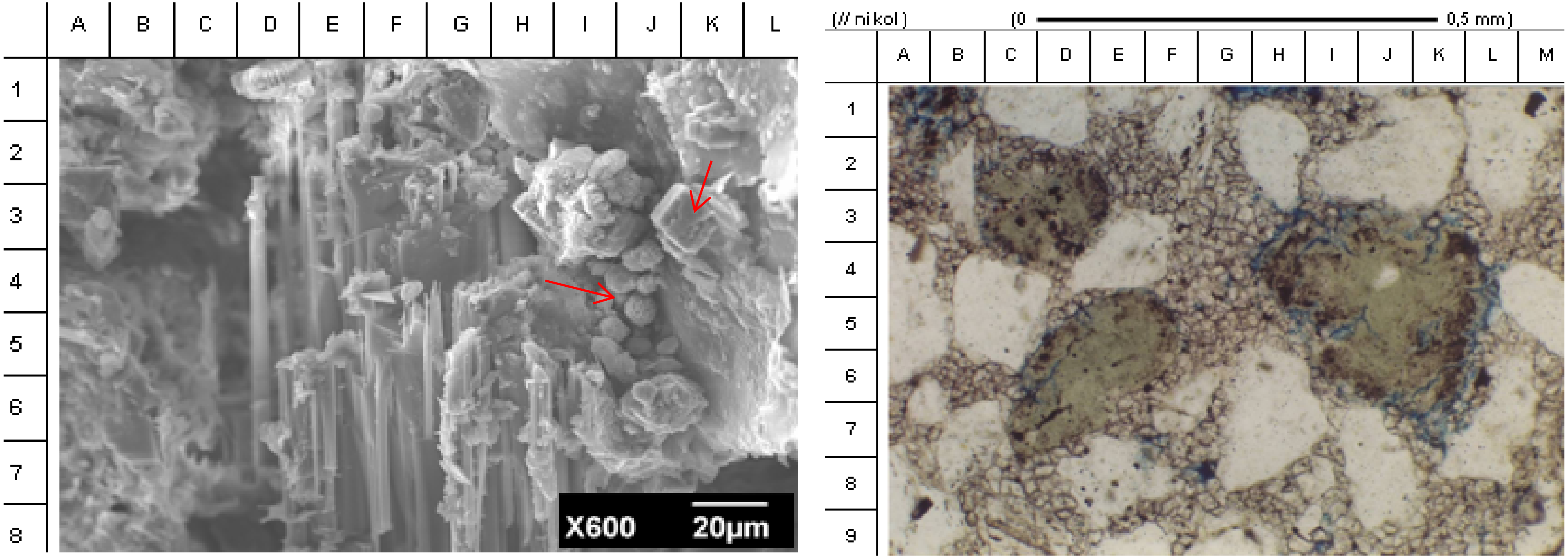

Figure 7. **Left:** Scanning electron microscope (SEM) micrograph illustrates little precipitation of pyrite (I,4), dolomite (K,3) cements and slightly increasing porosity due to partially dissolution of feldspar (D-H, 2-8). **Right:** Photomicrograph demonstrates extensive precipitation of 'sucrosic' dolomite cement (brown, e.g.: G, 4) that reduced both porosity and permeability.

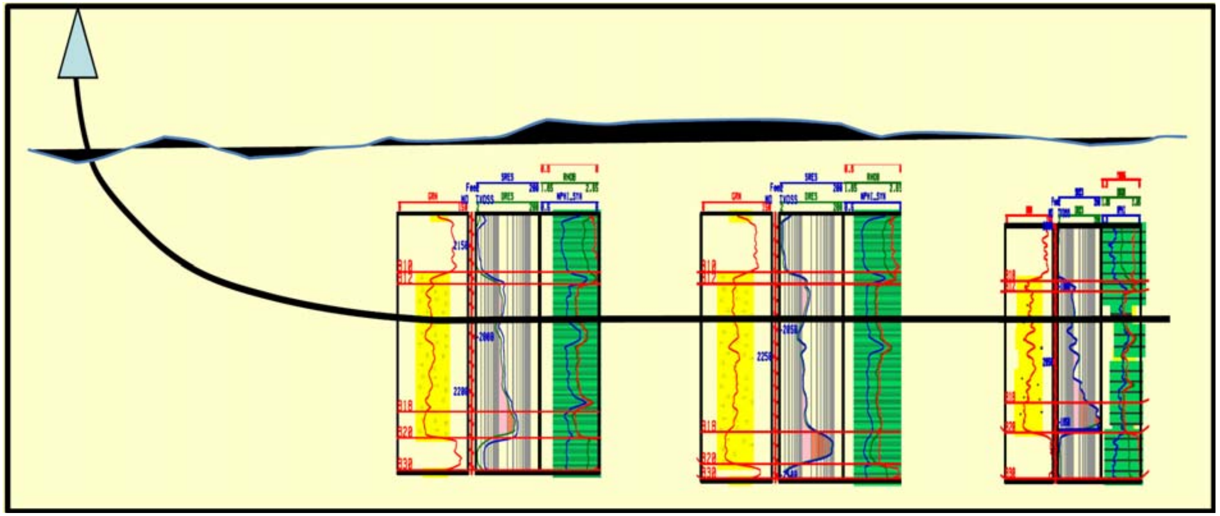

Figure 8. Sketch of horizontal well as the best technology for optimizing production of the low-permeability Bekasap Sandstone.

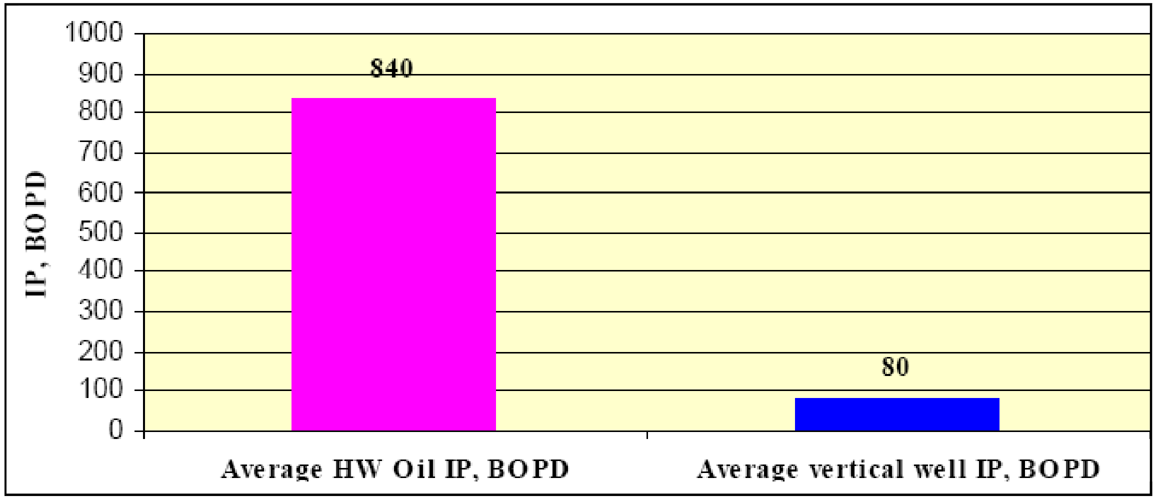

Figure 9. Diagram showing average initial production of horizontal and vertical wells.

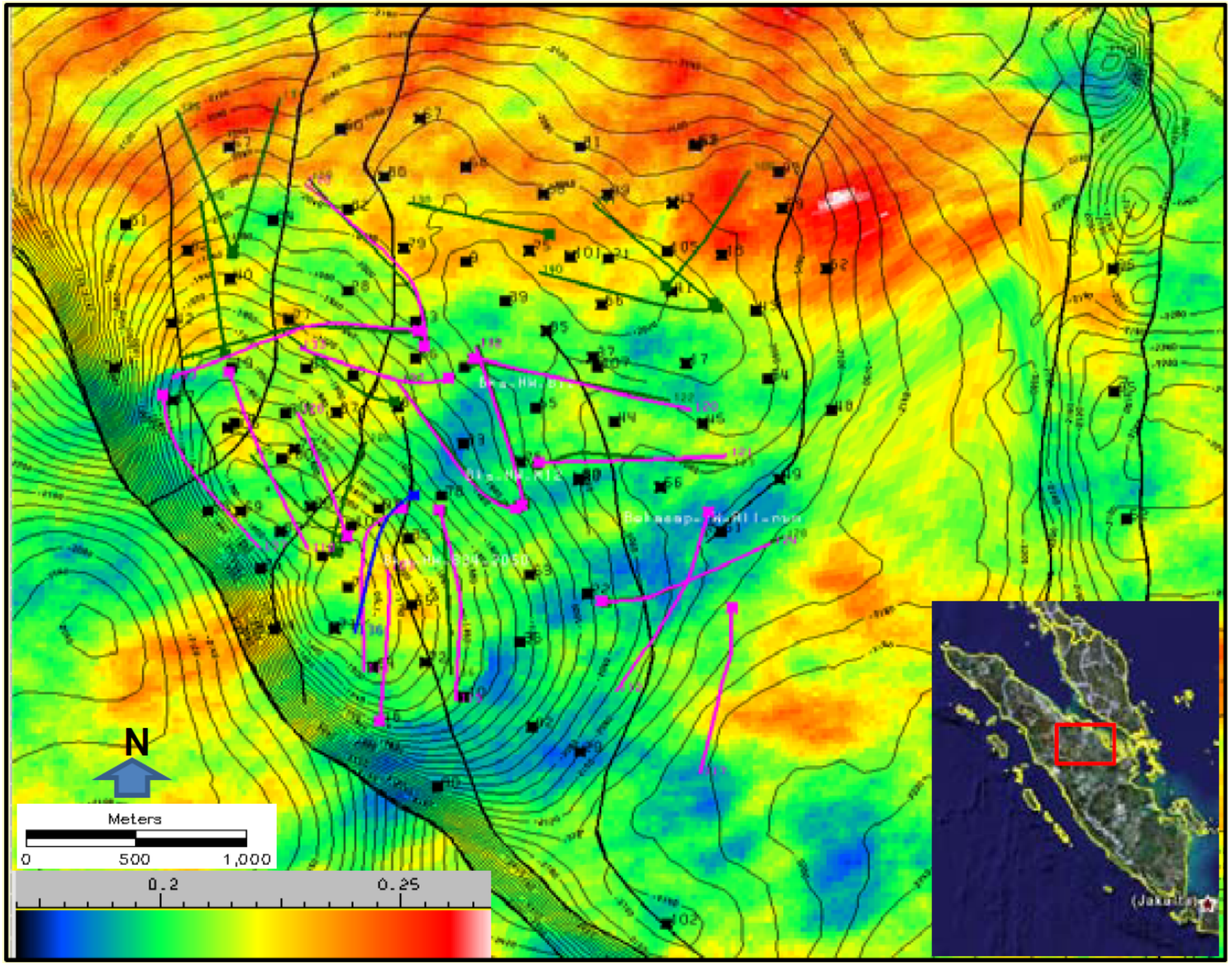

Figure 10. Combination of top depth structural and iso-porosity maps of the Upper Bekasap sandstones. Red – yellow represents good porosity area.

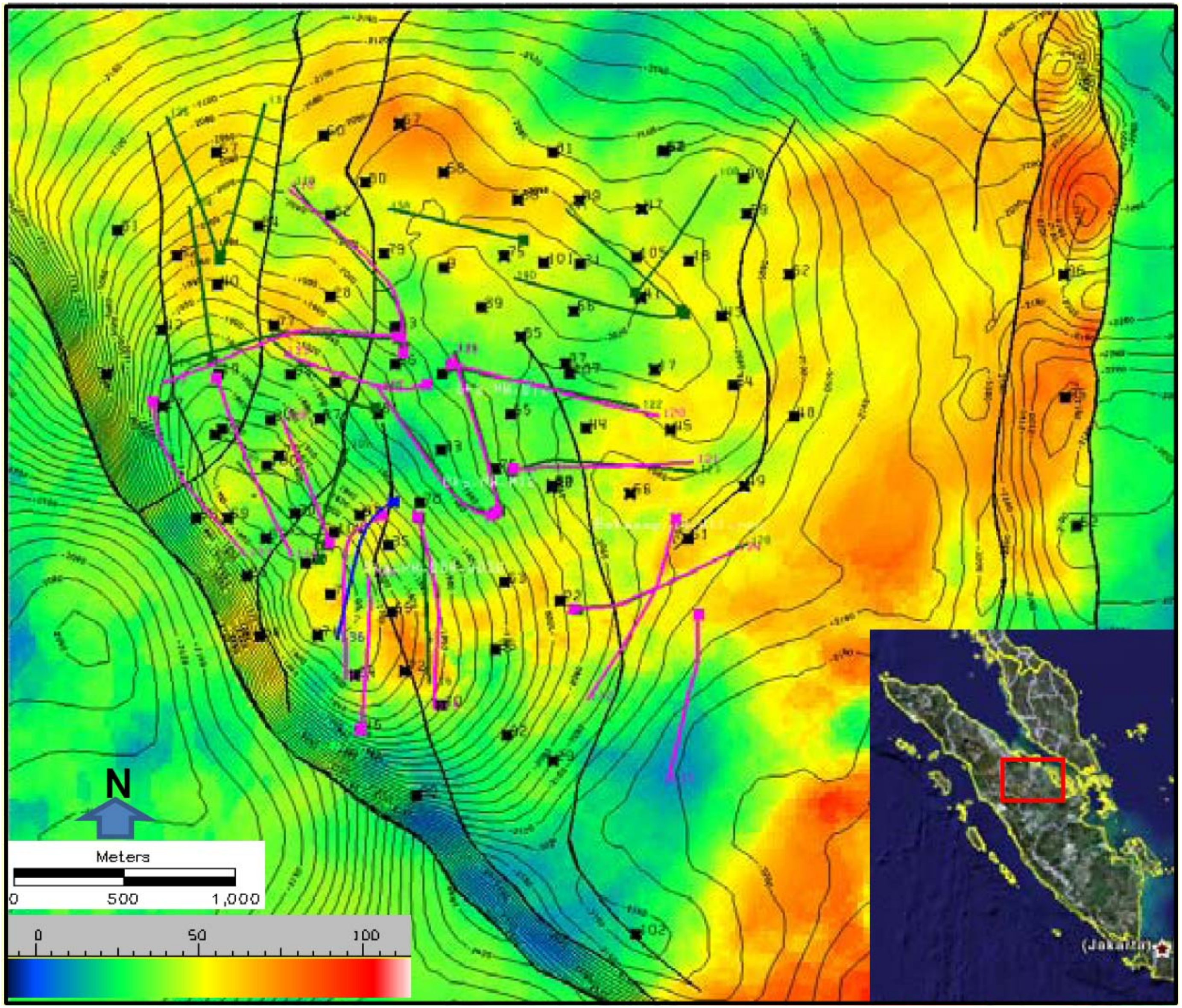

Figure 11. Combination of top depth structural and thickness maps of the Upper Bekasap sandtone. The reservoir rock thickens to the east (yellow-brown)