Reservoir Characterisation for Field Development, Albertine Graben, East African Rift System*

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Introduction

The Kasamene and Nzizi fields are located in Exploration Area 2 (EA 2) IN Butiaba-Wanseko and Kaiso-Tonya areas, respectively, which are in the central part of the Albertine Graben, Uganda. Both fields are operated Tullow Uganda Operations Pty Ltd. The Albertine Graben forms the northernmost part of the western arm of the East African Rift System (Figure 1). The graben stretches from the border between Uganda and Sudan in the north to Lake Edward in the south, a total distance of over 500 km with a variable width of 45 km, and it straddles both the Democratic Republic of Congo and Uganda borders. The Ugandan part of the graben measures about 23,000 km^2.

The size, complexity, productivity, and the type and quantity of fluids in a reservoir determines field development strategy and ultimately success in production. Therefore, to choose an optimal development plan, the characteristics of the reservoir must be well defined. This is complicated by the fact that often the level of information available is significantly less than that required for an accurate description of the reservoir, and yet estimates of the true subsurface picture need to be made.

This article describes work done in the Albertine Graben, Uganda, to define uncertainties in planning for development, with case studies from the Kasamene and Nzizi fields that are currently under planning for development.

Kasamene Field

Kasamene field measures about 23 km^2. The structure of the field is an extensional faulted 3-way fault-bound horst that is bounded to the north by a W-E fault, to the east by a SSW-NNE fault, to the northeast by the intersection of these faults and to the south-southwest by regional dip into the basin (Figure 2).

Geology

The geology of the area is predominantly fluvial-lacustrine sediments of Pliocene-Pleistocene age. The reservoirs generally consist of fluvial sediments derived from Precambrian gneisses and schists. These consist of several vertically stacked hydrocarbon accumulations separated by thick Pleistocene shale seals, causing vertical compartmentalisation. Oil encountered is waxy with a pour point of 40°C and 30-33° API.

The main structures interpreted are normal faults as shown in Figure 3. In addition, basement palaeo-lows were also identified, were that were later infilled by sediment. Sediment packages can also be identified from the seismic data; a fluvial package with chaotic reflectors overlain by a lacustrine package with more ordered continuous reflectors.

The Kasamene field was discovered in July, 2008, by the Kasamene-1 well, which encountered 31 meters of net oil pay and at least six meters of net gas pay and proved-up 161MMBbl (P50) of oil in-place. Subsequent appraisal was done, among other things to test the vertical extent of the oil leg and gas cap. The Kasamene-2, 3, and 3A appraisal wells were drilled and resource estimates were revised to 116 MMBbl of oil in-place. The field has now been targeted as a candidate for early production.

Well Correlation

Conventional methods of correlation by use of sequence stratigraphy are less easily applied to fluvial successions, especially in closed systems like the Albertine Graben. Instead, systematic changes in facies and sand-body stacking patterns were used in defining the position of key correlatable surfaces (defined below). For correlation, the wireline logs used included gamma ray, Neutron, Density, Resistivity, sonic, porosity and permeability (Figure 4).

Key surface 1: Defines an abrupt change in facies from basement to amalgamated channel patterns. Period of subsidence during onset of rifting. The sediment-basement contact is a known unconformity marking over 400Ma of non-deposition from the Precambrian to Tertiary.
Key surface 2: Switch from amalgamated channel sandstone stories to isolated channel sands.
Key surface 3: Period of tectonic quiescence; marks the onset of deposition of lacustrine sediments, capped by deep lacustrine shale.
Key surface 4: Represents re-appearance of the fluvial channel-fill on top of the lacustrine sediments. This may represent a period of renewed tectonic activity.

The reservoir has been divided into three main zones based on the facies and flow-unit subdivision; the amalgamated channel-fill facies (Figure 5) overlying the basement and having been deposited at the onset of rifting makes up the lower oil zone. These sands form more continuous bodies and exhibit good reservoir quality with very well sorted sands that have high porosities and permeabilities, commonly in the range of 25 to 35% and 600 to 2000mD, respectively. Within this section, two laterally continuous flow units 2 and 3 have been identified, each exhibiting an increasing-upward permeability profile.

The amalgamated channel-fill facies is overlain by the isolated channel-fill facies (Figure 6) that consists of moderately to well sorted sands that are less continuous and have lower porosity and permeability. This section makes up the upper oil zone.

The crevasse splay-dominated facies overlie the isolated channel-fill facies and show the least connectivity, porosity, and permeabilities (Figure 7). This zone contains gas; hence it might not be of much significance in terms of fluid flow. The internal heterogeneity is further increased by clay-drape laminae.

3D Geological Modelling

3D geological modelling was used to adequately capture the different scenarios to represent the distribution of rock and fluid properties in the field. The spatial distribution of reservoir properties was investigated through a number of realisations generated by stochastic statistical methods, and the results suggest that the lower reservoir section has the best reservoir quality. An example of one realisation from property modelling using water saturation data is given in Figure 8.

Nzizi Field

Field Overview

The Nzizi structure, located within the Kaiso-Tonya relay ramp, is an 11km^2, faulted 3-way closure consisting of six individual fault blocks. One exploration and two appraisal wells (Nzizi-1 and Nzizi-2 and -3, respectively) were drilled in three of the fault blocks between November, 2006, and May, 2010. The first well encountered oil, while wells 2 and 3 encountered stacked oil and gas accumulations in sandstones and within fractured basement (Figures 9 and 10). The main gas interval was tested in well 2 and flowed 14MMscf/d dry gas. The reservoirs consist of upper Pliocene fluvio-deltaic sands and channel sands and channel mouthbars, interbedded with lacustrine and fluvio-deltaic claystones. The resources in the field have been estimated at 11 Bcf (P50 GIIP) and 30mmbbl (P10 STOIIP) for the upper and lower oil accumulations in two fault blocks.

Dataset

The Nzizi field dataset contains 2-D and 3-D seismic, acquired between 2005 and 2008, and well data from the following: wireline logs, 47m of conventional core from Nzizi-2, sidewall cores, pressure data, well test (DST) data from Nzizi-2, and PVT reports.

Reservoir Description

Although work is currently on-going to develop a stratigraphic framework for the Albertine Graben, the studies presented here are based on PEPD's working stratigraphic scheme. The main oil and gas reservoir intervals are found within the Nkondo Formation (Figure 9). Oil was also encountered within fractured basement in wells 2 and 3.

The overall environment of deposition of the Nkondo Formation is interpreted to be shallow lacustrine cut by fluvio-deltaic channels and mouthbars (Figure 10). The shallow lacustrine nature of the environment was confirmed by palynological work on Nzizi-2 core which indicated abundance of fresh water algal types (Pediustrum and Botryococcus). This is in addition to intense bioturbation in shales and rootlets interpreted from the cores (Figure 10).

Although generally thinly bedded, with relatively poor net to gross ratio, the Nzizi reservoir sands are fine- to medium-grained, moderately to well sorted with good porosity and permeability. Core porosity ranges from 25-35%, while permeability in the tested main gas reservoir is in excess of 10 darcys. The upper oil zone was tested, but did not flow to surface, possibly due to low reservoir pressures. However, permeability of this interval is estimated from injectivity test as 250mD.

The tested main Nzizi gas reservoir is lean gas with about 98% methane, while the upper oil reservoir has the following crude properties: 23-24^{o} API, viscosity of 40cP, wax content of 19%wt, and 36^{o}C pour point.

Petrographic analyses including XRD, SEM, sieve analysis, and thin-section preparation were carried out on core plug samples from Nzizi-2. Analysed samples include fine- to medium-grained sandstones, silty shale, and shale. Framework grains are moderately well to poorly sorted, varying widely with depth, and are typically subangular in finer sandstones and subrounded in coarser ones. Depositional clay-rich matrix, noted in several samples, is abundant in the shales and shaly sandstones. Other sandstones are matrix-free and contain authigenic clay as the only pore-filling or pore-lining variety. The authigenic clays in the sandstones typically commonly have associated ineffective microporosity (Figure 11). Cleaner sandstones tend to be quite porous, with framework grains lightly cemented by a variety of secondary components. XRD results reveal a wide variety of clay types. In terms of the overall clay fraction, kaolinite is most common (avg. 31%), followed by mixed-layer illite/smectite (avg. 28%), chlorite (avg. 22%), and illite (avg. 19%). Mixed-layer clays are dominant in cleaner sandstones. SEM results show the characteristic booklet morphology of authigenic kaolinite in several samples, and the bladed morphology of authigenic chlorite cement and replacement is also observed at many depths. Effective interpretation of log response must take into account this variable mineralogy and lithology, as well as bound water within clay microstructures.

Reservoir Modelling and Development Strategy

Work is being undertaken to develop 3-D static model realizations of the field. The static models will be taken through to simulation to aid development planning.

The Nzizi development is planned to be based initially on the delivery of gas from two wells situated in fault blocks 2 and 3 to a 50MW power plant. Depending on the data acquired during the initial production phase, additional production wells may be drilled to drain gas from other fault blocks in the field. The development of the oil reservoirs is expected at a later stage to coincide with availability of facilities in the greater Kaiso-Tonya area. The effect of producing gas prior to oil is currently being evaluated.

Conclusion

Reservoir characterisation is illustrated for two fields, Kasamene and Nzizi, from the Albertine Graben, East African Rift System. As part of the on-going work to help with development planning, 3-D static geological models have been built for the fields.

Reference

Njabire, N., 2007, Structural evolution and its control on the sediment fill of Albertine Graben: Unpublished M.Sc. thesis, Royal Holloway, University of London.

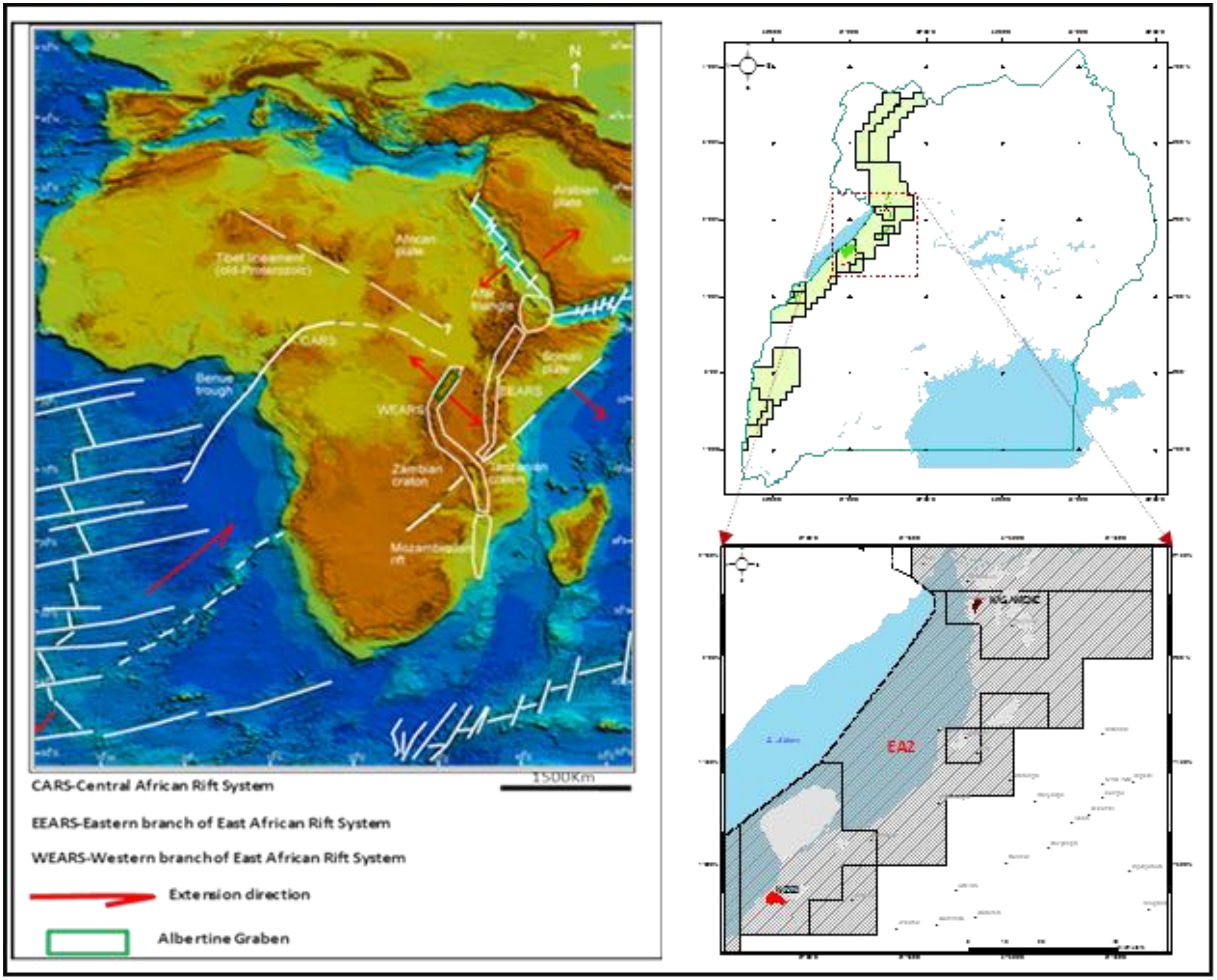

Figure 1: Location map of the East African Rift System and Albertine Graben, modified from Njabire, 2007 (left) and the Albertine Graben showing the location of Kasamene and Nzizi fields (right).

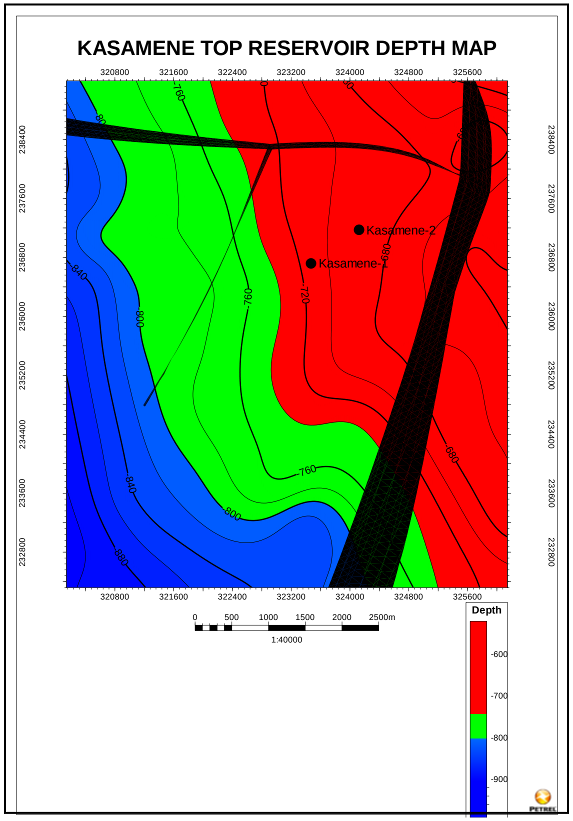

Figure 2: Kasamene top reservoir depth map.

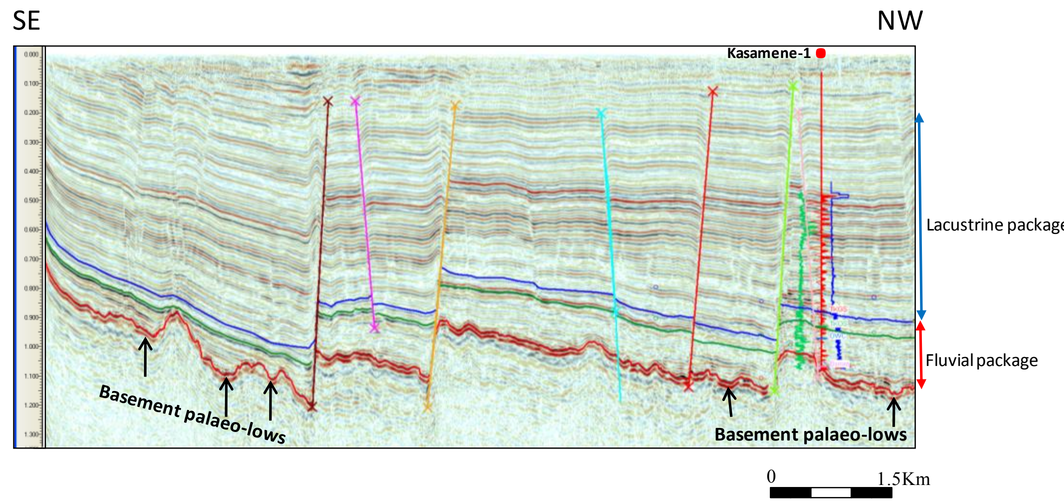

Figure 3: Seismic line on which Kasamene-1 was drilled.

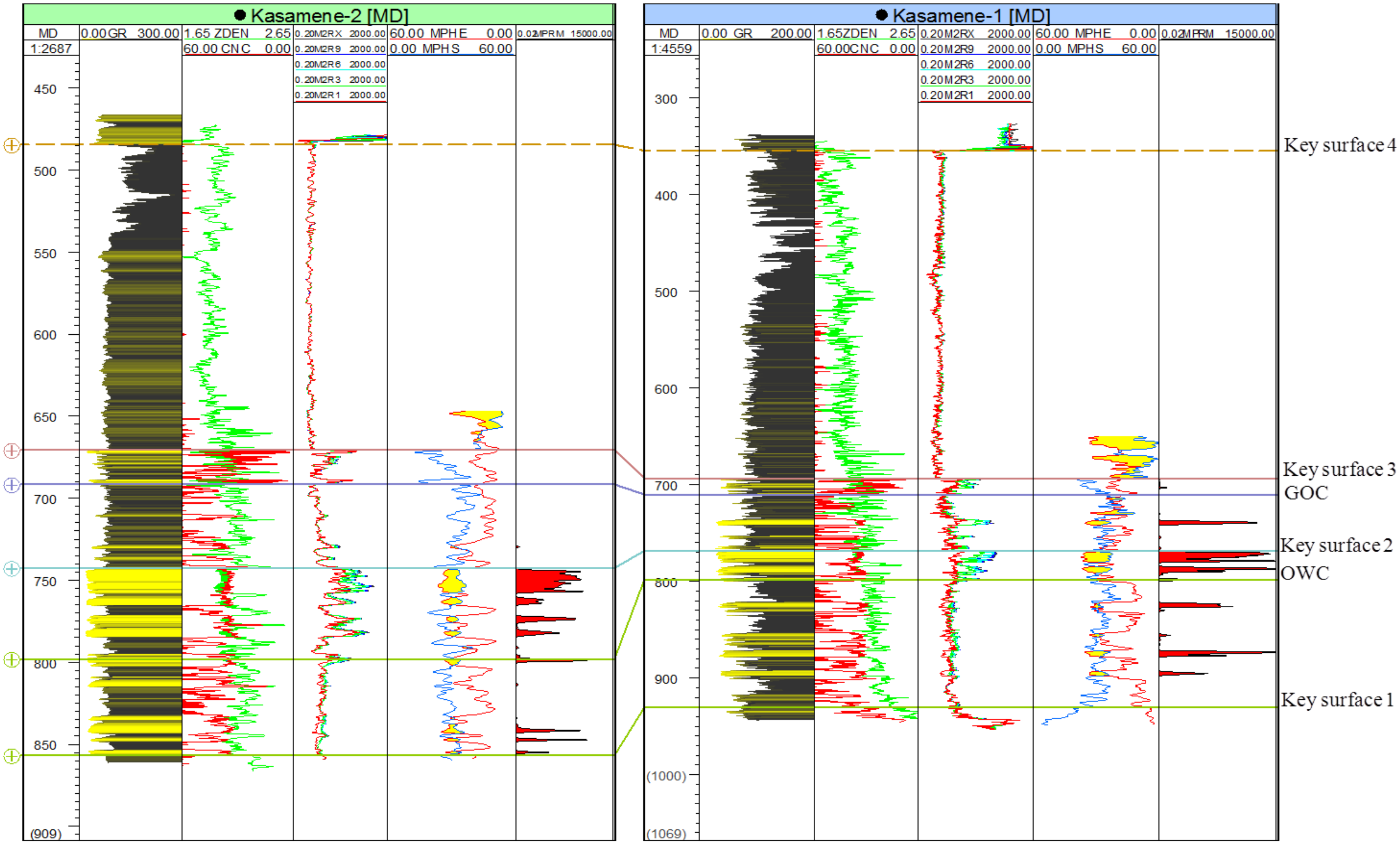

Figure 4: Kasamene correlation panel.

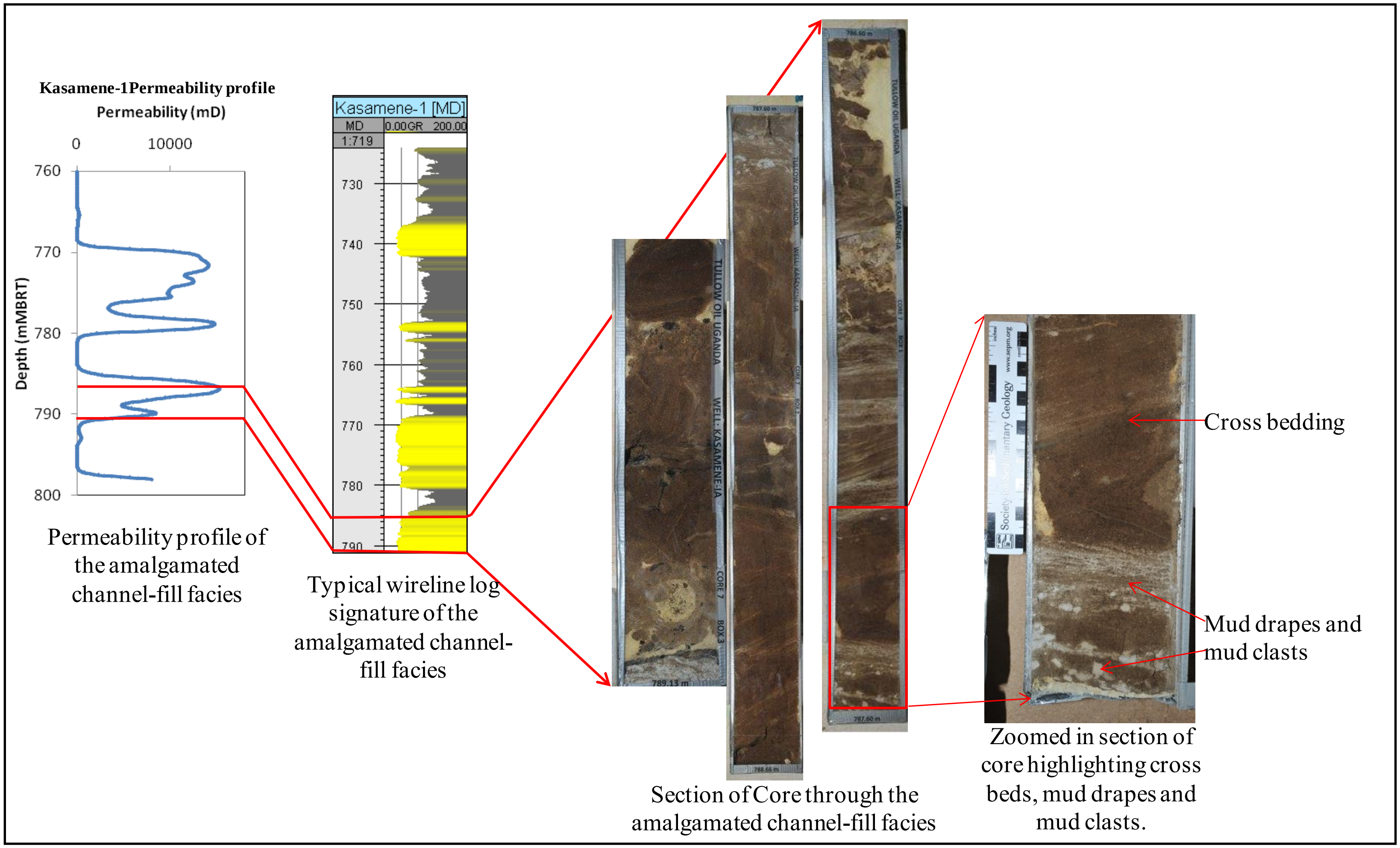

Figure 5*:* Core, log, and wireline log permeability profile (uncalibrated), showing a typical section through the amalgamated channel-fill facies.

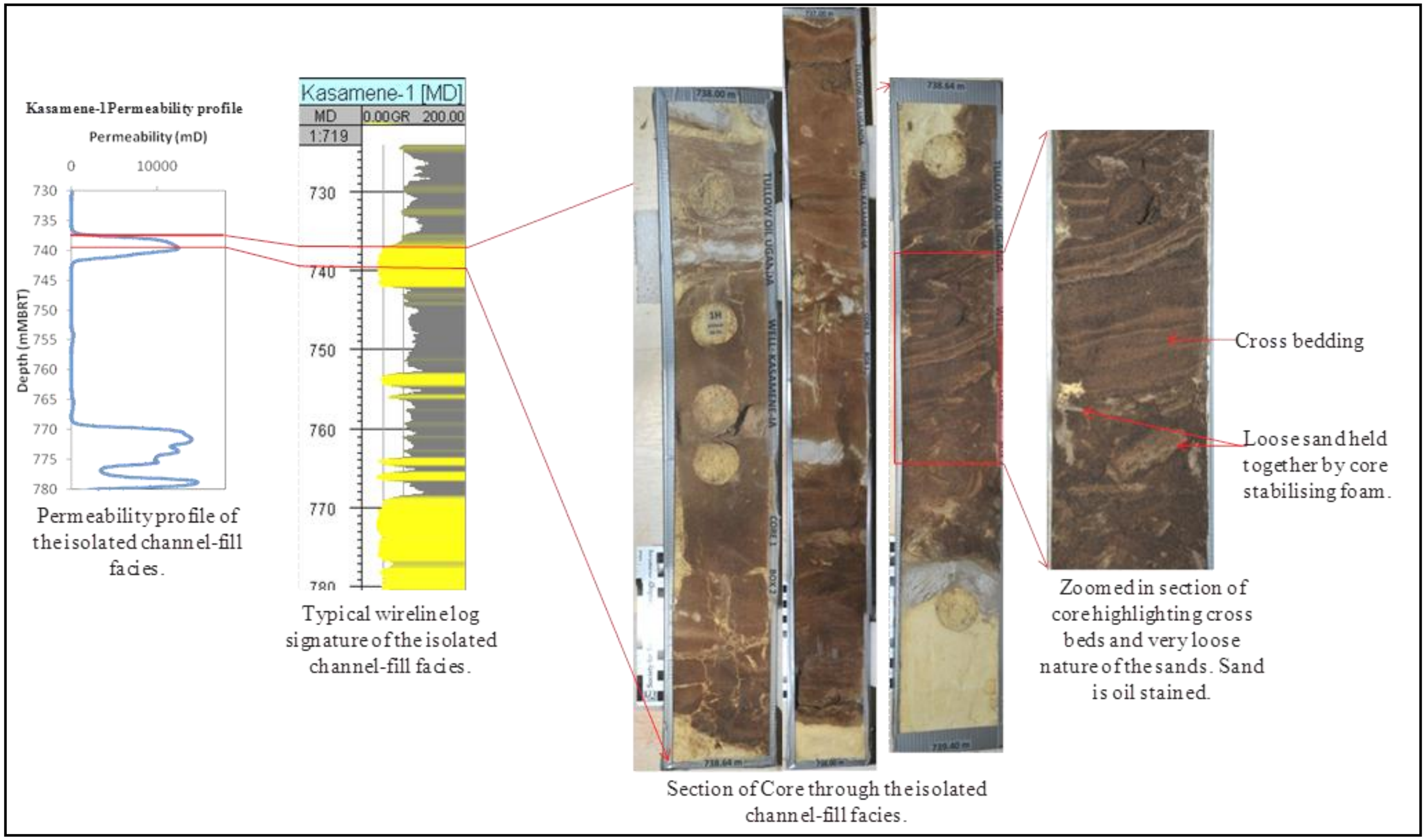

Figure 6: Core, log, and wireline log permeability profile (uncalibrated), showing a typical section through the isolated channel-fill facies.

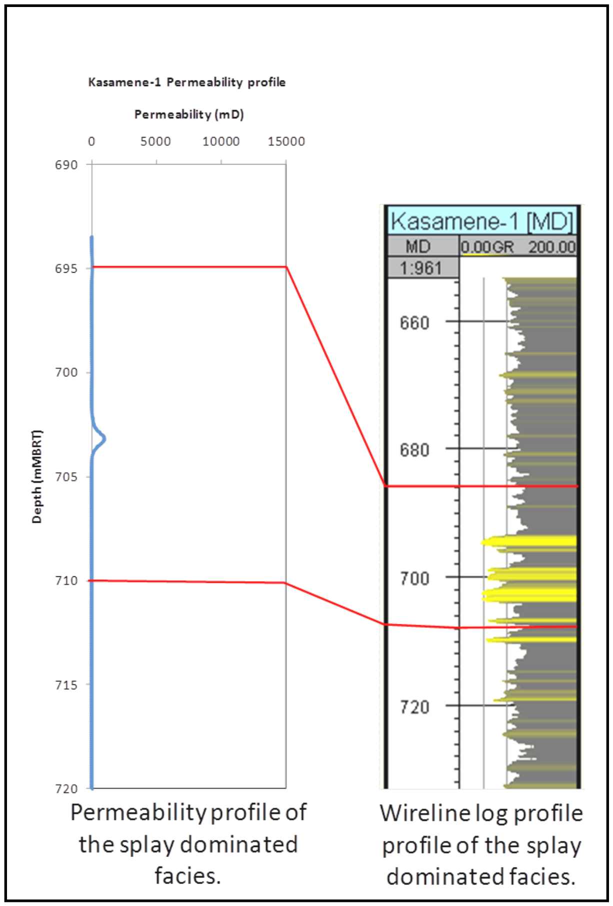

Figure 7: Log section and wireline log permeability profile (uncalibrated). through the flood plain facies.

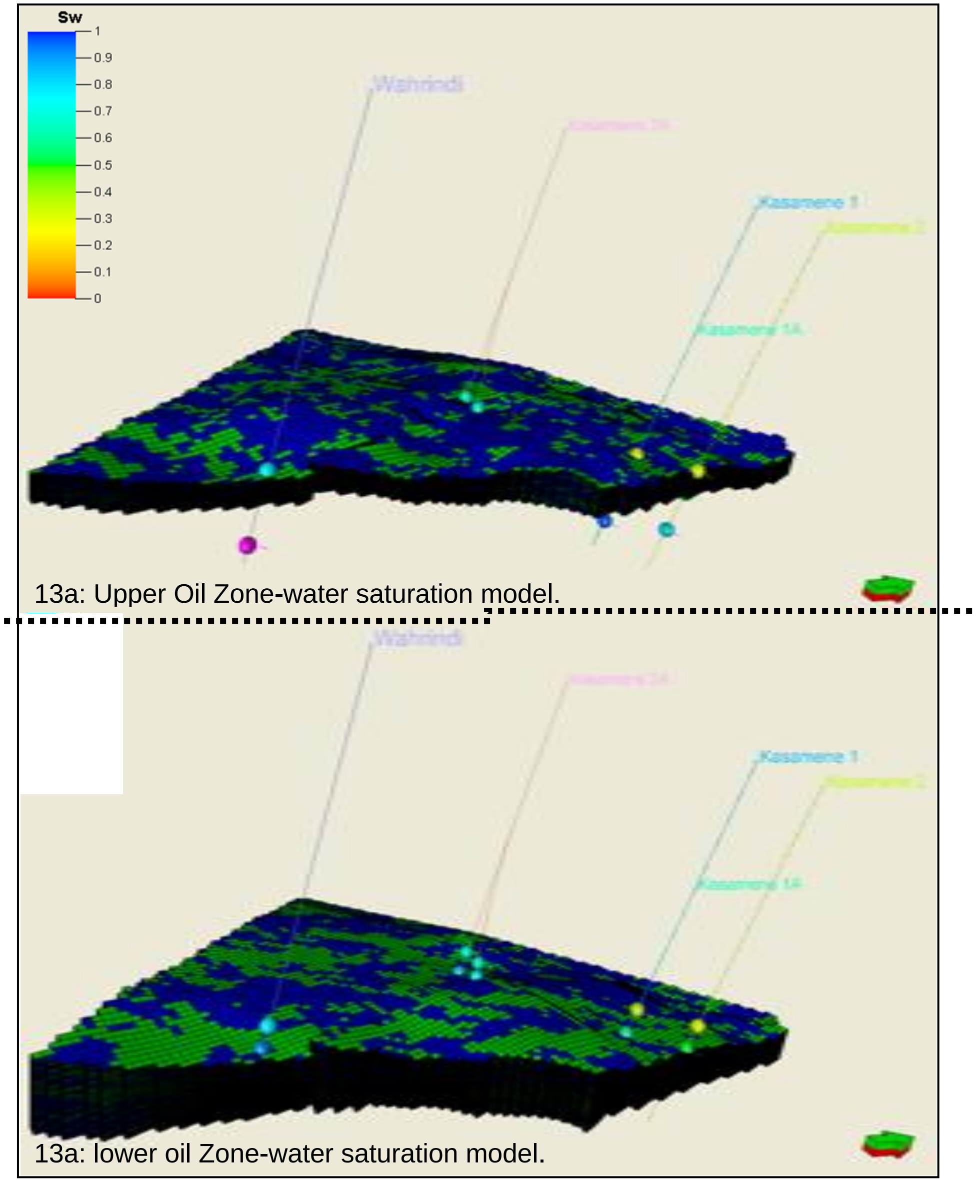

Figure 8: A realisation from the Kasamene water saturation modelling—13a: Upper Oil Zone-water saturation model (upper); 13a: Lower oil Zone-water saturation model (lower).

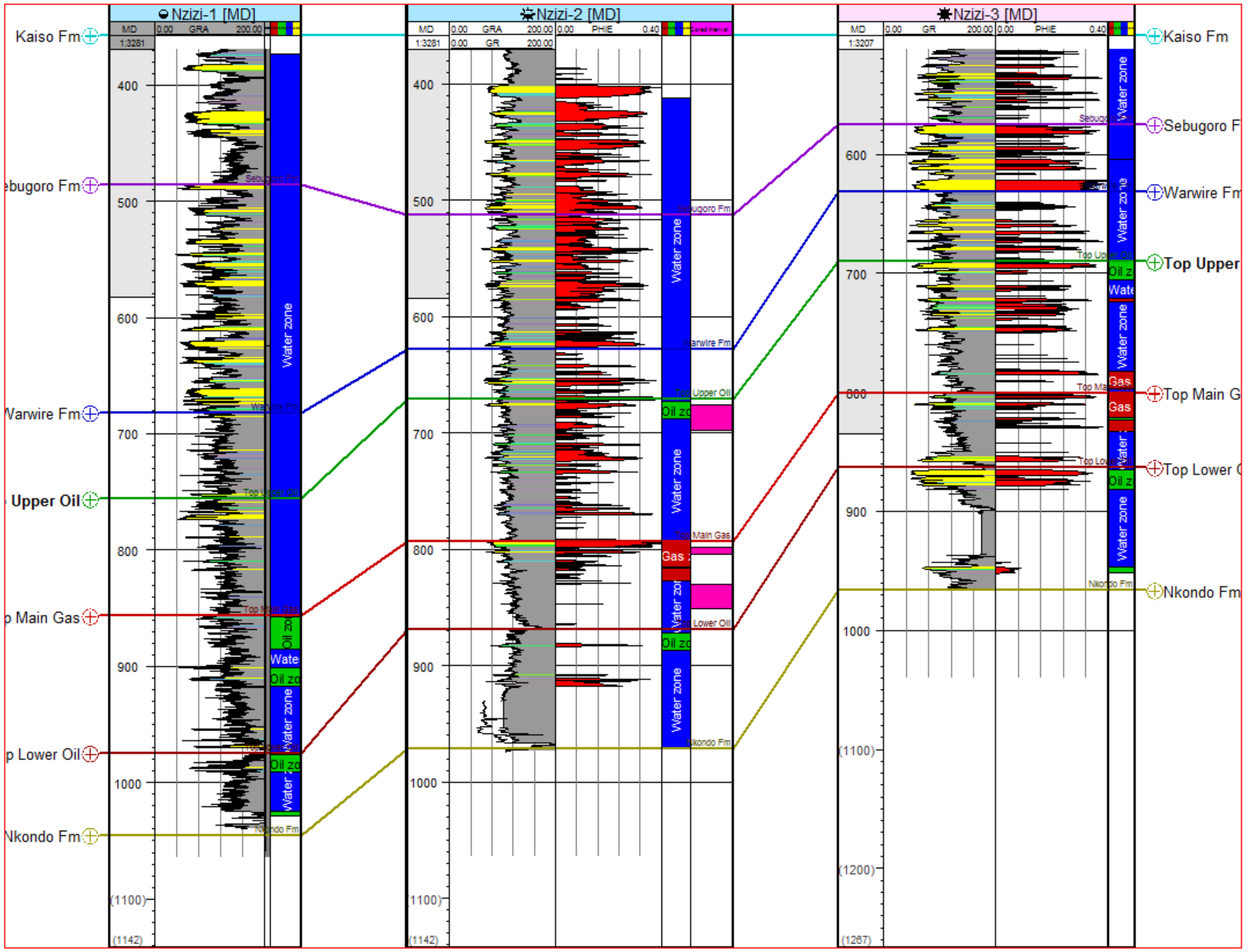

Figure 9: Nzizi field well correlation, showing the main reservoir intervals and formation tops.

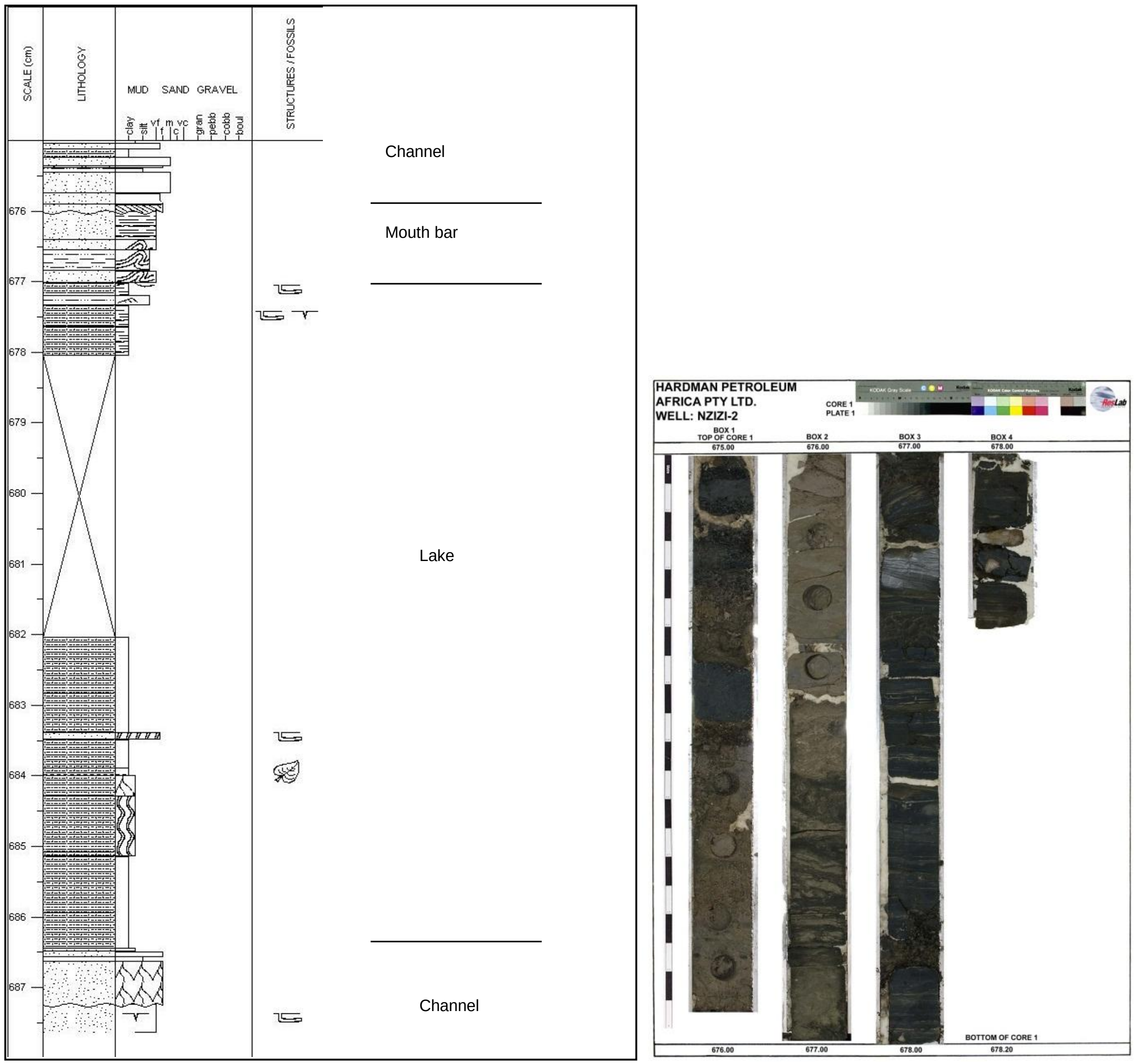

Figure 10: An interpretation of core data, showing depositional environments (left) and core image from the upper oil zone in Nzizi-2 well (right).

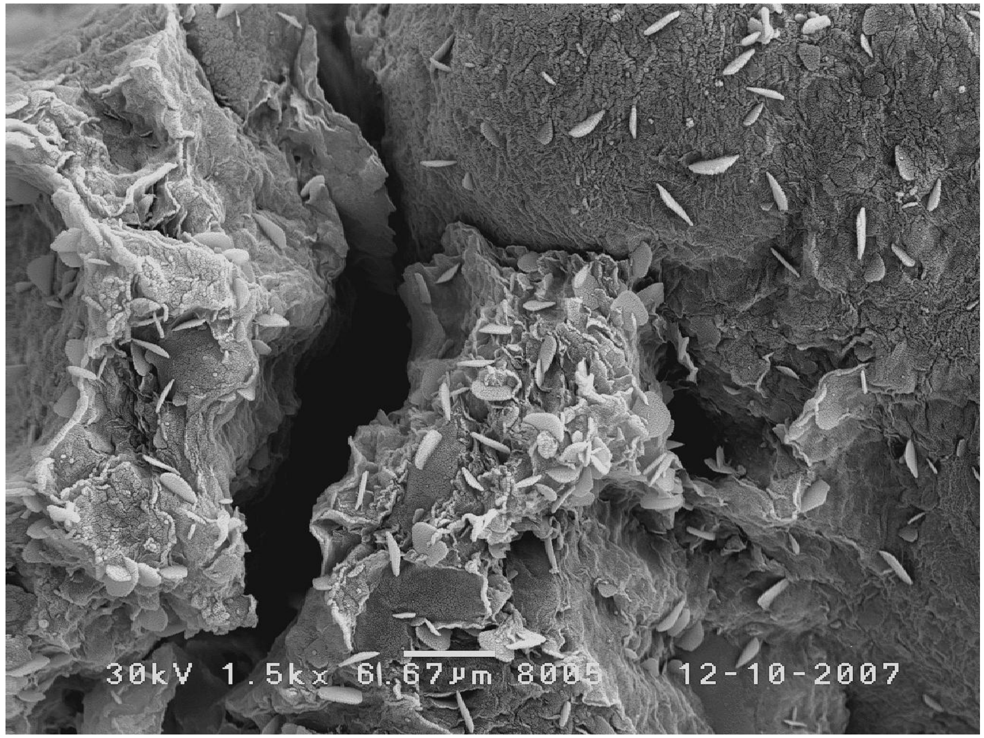

Figure 11: Authigenic chlorite clay occurring both as grain-coating and grain-replacing material in the main Nzizi gas sand. Primary intergranular pores are present in minor amounts. Micropores associated with these clays are likely to contain irreducible water.