Giant Oil Field Found in a Non-Prospective Area Through Integration of Diagenetic Modeling and Tectonics, the Tomoporo Field, Venezuela*

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Abstract

Zulia Oriental is the onshore eastern part of the prolific Maracaibo Basin, Venezuela (Figure 1). A large multidisciplinary study was undertaken with a focus on the deeper portions of the Misoa Formation, which has been subject to both, an intense diagenesis and a complex tectonic history. At the time of the study, all of the deep prospects in the area encountered tightly cemented Misoa Sands, mainly due to extensive quartz overgrowth cement, late calcite cement, and compaction processes (i.e., Perez et al., 1999a).

This paper only summarizes the detailed 4-D diagenetic modeling study that was conducted in order to assess the reservoir quality of the deep Eocene Misoa sands through geologic time, as a function of temperature, overloading, and amount of quartz cement. The studied area, located north of the Venezuelan Andes (Figure 1), was subjected to repeated tectonic activity of various sorts, such as tilting and inversion (Roure et al. 1997), and was recipient of two distinctive hydrocarbon charging events (c.f., Talukdar et al. 1986). The numerical modeling of the quartz cementation was performed considering the regional and local tectonics, as well as well calibrated and available burial and thermal histories (Rodriguez et al. 1997; Perez et al. 1999a). Every stratigraphic unit within the Misoa Formation was studied independently using variable compositions based on representative samples from each of the recognized sedimentological areas.

Approach

The quartz precipitation numerical model (Figure 2) relies on four input parameters, quartz cement quantitatively estimated through cathodoluminescence, thin section based mineralogical composition, expected grain size, and vitrinite reflectance based burial-thermal histories (Lander and Walderhaug, 1999). In addition, we use a conceptual fluid flow model, which indirectly inferred the timing of late non-ferrous calcite precipitation. Locally, late calcite cement completely plugs much of Misoa sandstones. The 4-D modeling was also supported by a local in-house geochemical study that determined the timing of hydrocarbon generation and migration. Obtaining the timing of hydrocarbon migration was a crucial parameter because we worked under the assumption that hydrocarbon emplacement stops diagenetic processes and preserves the remaining porosity from further deterioration. In addition, tectonic restoration was used in order to find early preserved traps filled by the first oil migration event. The importance of having an early hydrocarbon fill to preserve the porosity has been known from a previous diagenetic work in Lake Maracaibo (Chatellier et al 1996). The diagenetic modeling deeply relies on the burial history (Perez et al. 1999) and would have failed if the vitrinite reflectance data had not been locally corrected, especially in the area of intense shale tectonics (Chatellier, 1998a, 1998b).

4-D Diagenetic Modeling

Quartz precipitation and compaction case

The study was based on the assumption that silica exists in excess in the system, that its precipitation is kinetically controlled, and that the time of exposure at high temperature and the surface area are the most important factors (Walderhaug, 1996). The calibration of the modeling parameters using burial histories of samples with measured amount of quartz cement, based on cathodoluminescence image analysis, clearly indicates the viability of the method (Figure 3). After satisfying our check for the best kinetic parameters (i.e., activation energy and pre-exponential parameters), a forward modeling was performed on the various stratigraphic intervals; results are shown in Figure 4. In our forward modeling a series of hypothetic wells were selected with sandstone composition, grain size and burial history adapted to the local settings. The amount of precipitated quartz cement and the porosity decrease were both modeled through time for each of the interval tops (Figure 4). The quantification of quartz cement and porosity in intervals in between the modeled horizons was interpolated from data shown in Figure 4. Sensitivity analysis gave a careful assessment of the effect of grain size in our model (Figure 5).

Late-Calcite precipitation case

Numerical modeling dealing with the precipitation of quartz cement and compaction allowed defining the age of calcite precipitation of many samples with a reasonable accuracy. In Misoa’s paragenetic sequence, late-calcite cement occurred after quartz cementation, and filled pore space left from by compaction and quartz overgrowth. Hence, the method used for timing the calcite precipitation event consisted on matching and timing the available intergranular volume (left by quartz cement and compaction) with the amount of calcite cement present in the sample.

The main assumption made with respect to diagenesis was that quartz cement precipitated through time and the precipitation is a function of temperature and time of exposure at these temperatures, whereas calcite precipitation is expected to correspond to events of much shorter duration and hindered quartz overgrowth. This assumption has been verified by the results of our analyses because all of the samples studied, in any given well, consistently gave the same age for both, the amount of quartz cement found and for the total amount of calcite cement (Figure 7), and calcite cement in various samples of a same well gives consistent values (Figure 6).

Estimation of timing of calcite precipitation yielded consistent age of cementation in all analysed cases, i.e. in single wells, similar precipitation age in samples from different stratigraphic horizons and with different amounts of intergranular volumes and calcite cement. The gradual age change between wells being in line with the tectonic understanding of the area. These results seem to validate three important input parameters used in the diagenetic modeling, which are (1) the burial history, (2) the quartz cement kinetics, and (3) the compaction model.

Tying Basin and Diagenetic History

As we discussed above, one of the most positive factors in our search of potential reservoir was the existence of an early oil migration event, which hindered the quartz and calcite cementation, thus the plugging of the sandstones (Figure 8). The other important factor was the good understanding of the complex tectonic history with the associated reactivation of faults, shale tectonics, and basin tilting (Roure et al. 1997; Rodriguez et al. 1997). In addition, the study of the calcite cement seemed to validate our understanding of the sequence of tectonic activities (Figure 9).

Results of Modular 4-D Modeling

The main result of our study were predictive porosity maps generated on the basis of the combination of real and hypothetical information used to modeled quartz overgrowth, compaction, and calcite cement at each interval and through time. Our results focused more particularly on the reservoir quality at the time of the two known oil migrations (Figure 10 and Figure 11). Additional factors such as variable grain size or the existence of chlorite (impeding quartz cement growth) were added as filters in our risk analysis that was based on a compilation of maps invoking porosity, charge, and trapping. The details of the results of our study are PDVSA proprietary and at this time are not available for publication. However, we believe that the discovery of the deep hydrocarbon accumulation in Tomoporo with a recoverable reserve estimate of more than a billion barrels unarguably demonstrated and validated the method herein presented.

Conclusions

The potential for a deep Eocene play was thus demonstrated for some areas of Zulia Oriental. The recent discovery of an “Oil Giant” in the area confirms the usefulness of the methodology and the validity of the obtained results. The use of a dynamic diagenetic modeling (through time) dramatically reduced the risk of venturing into a deep and costly drilling, the results of which have been beyond expectation. Such a type of study should be more common wherever quartz cementation is an issue.

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Figure 1. Location map.

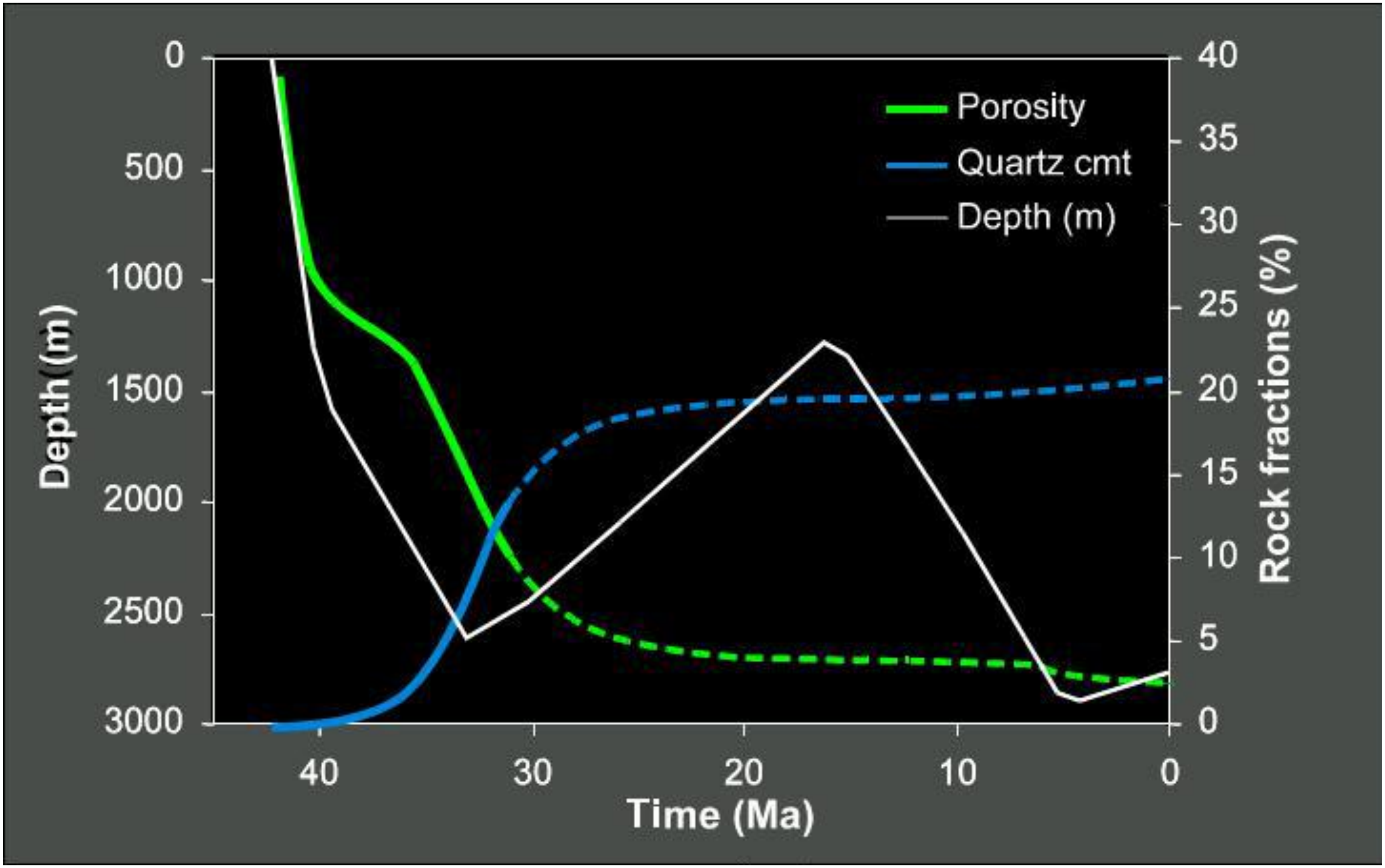


Figure 2. Simulation of quartz cement precipitation and porosity reduction in one well based on the burial history.

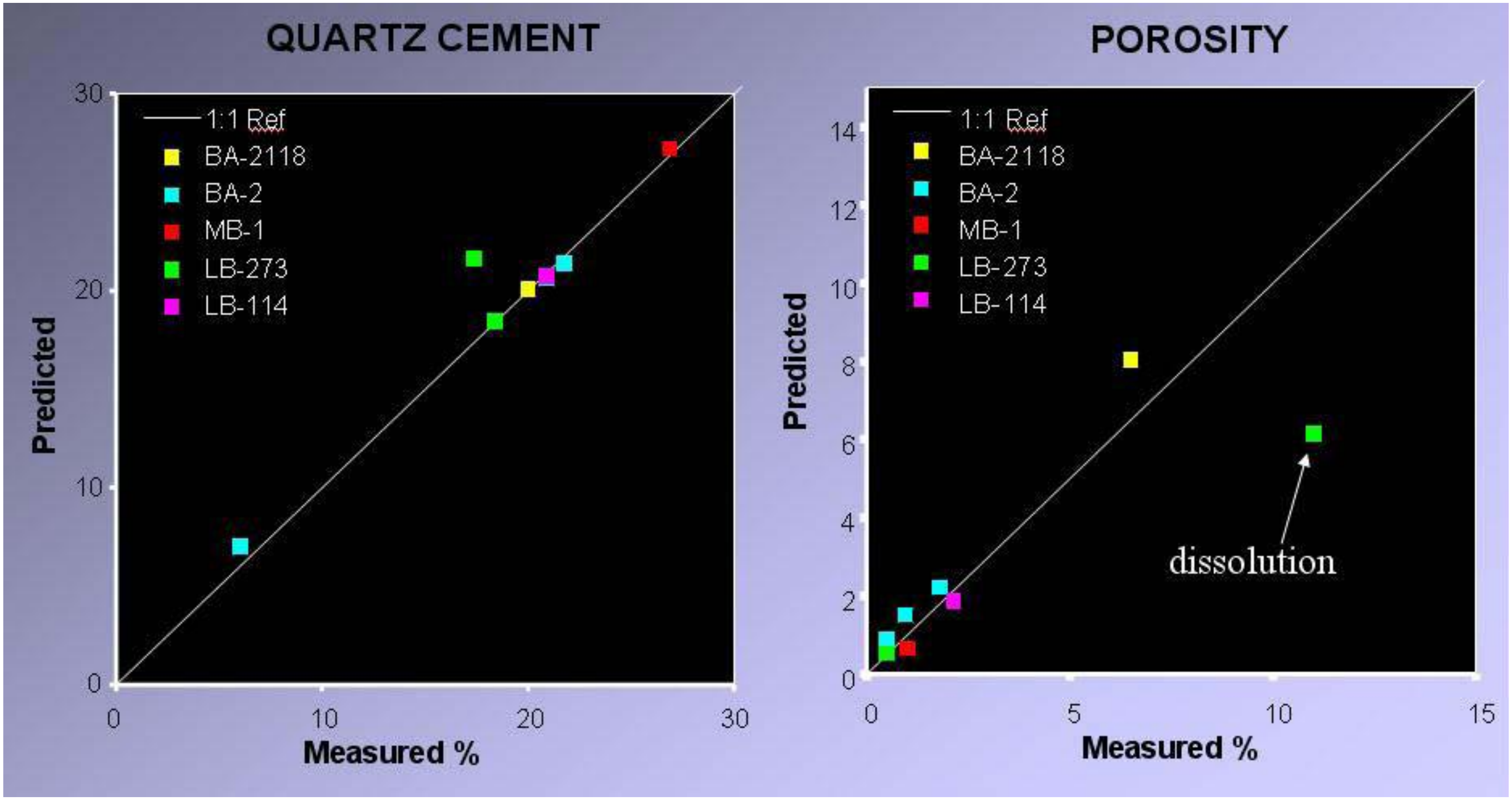


Figure 3. Calibration of the simulation parameters.

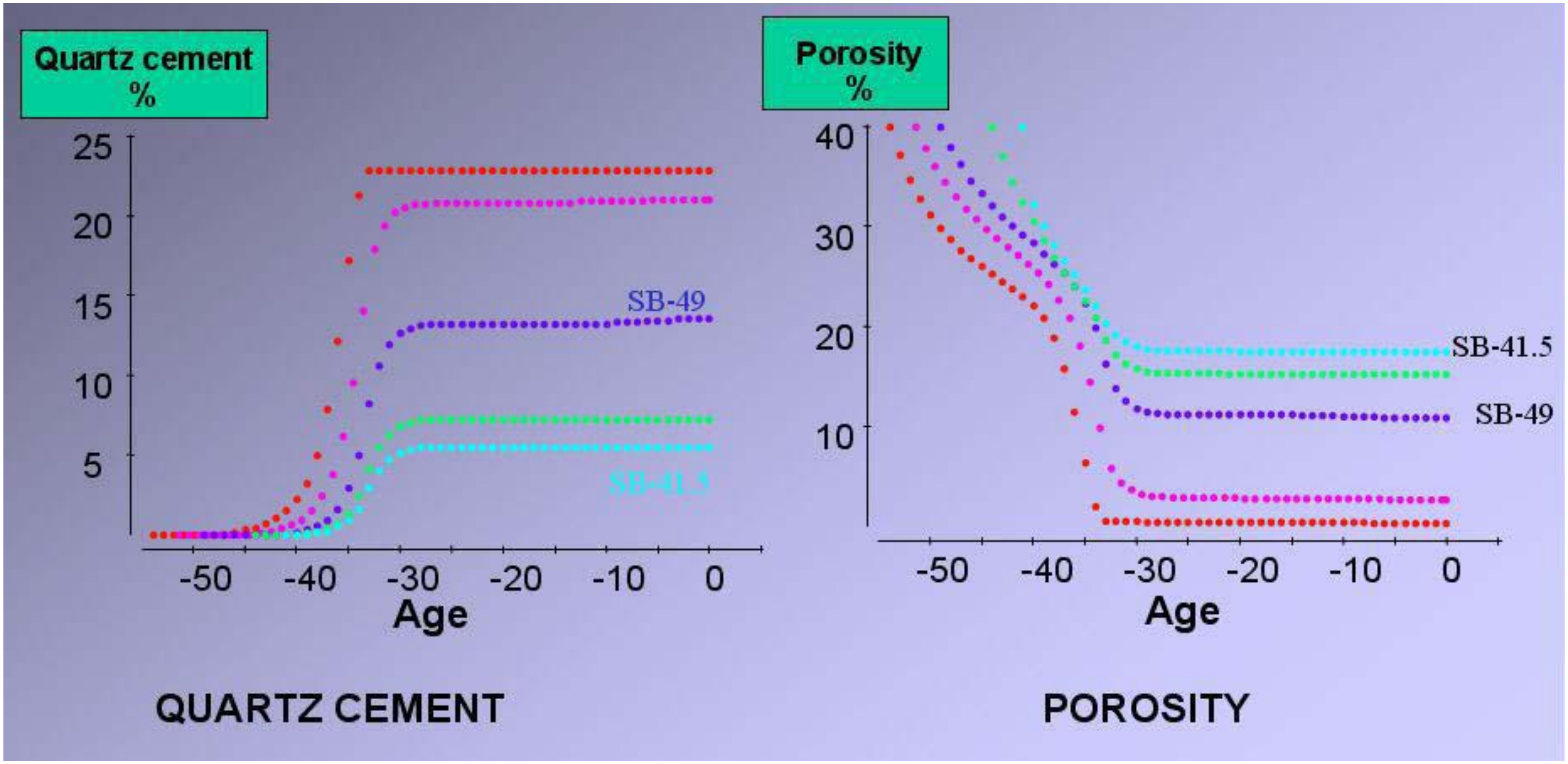


Figure 4. Example of quartz cement and porosity evolution through time for the top of each interval of interest in one well.

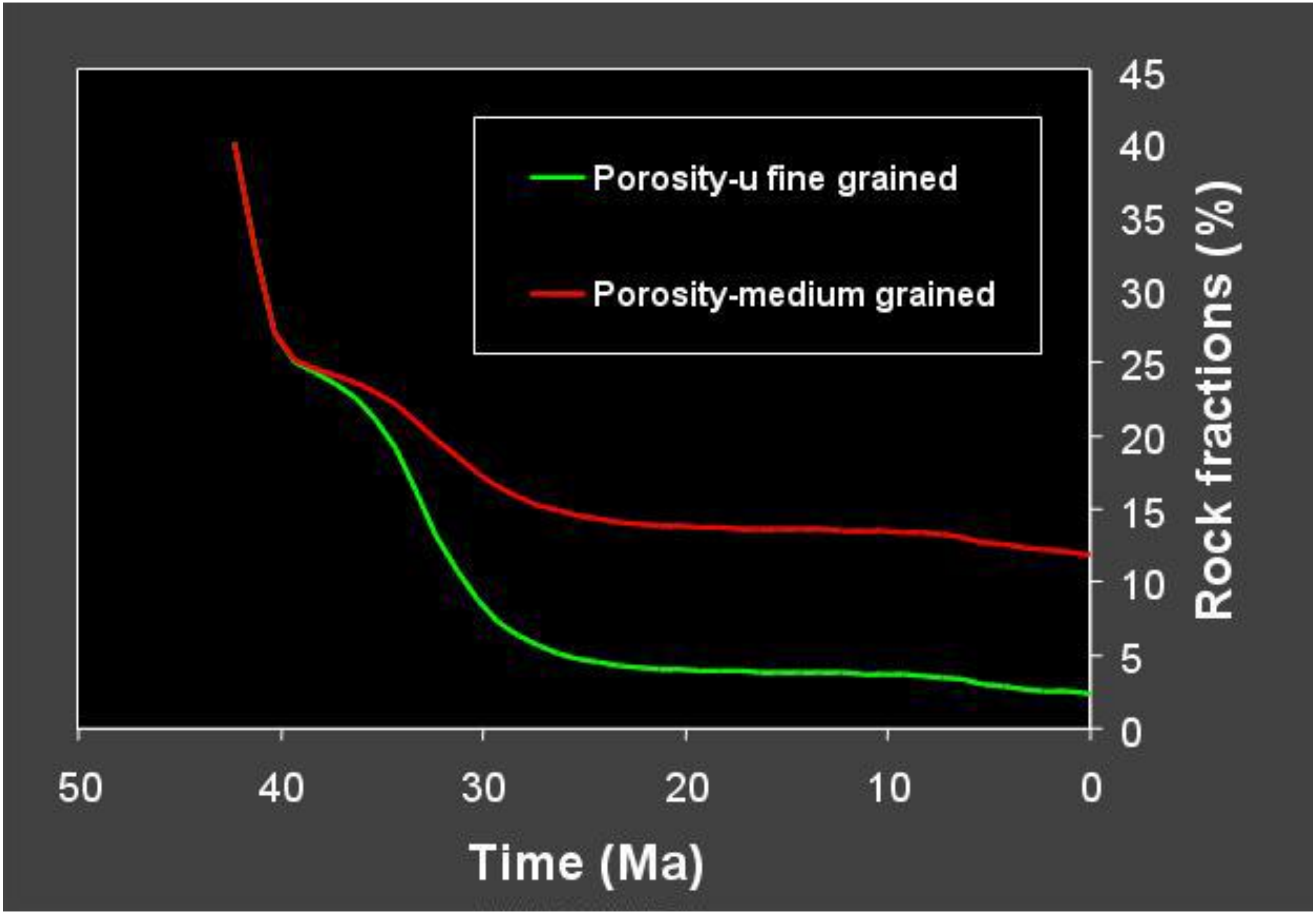


Figure 5. Example of porosity evolution for different grain size lithologies in a given interval.

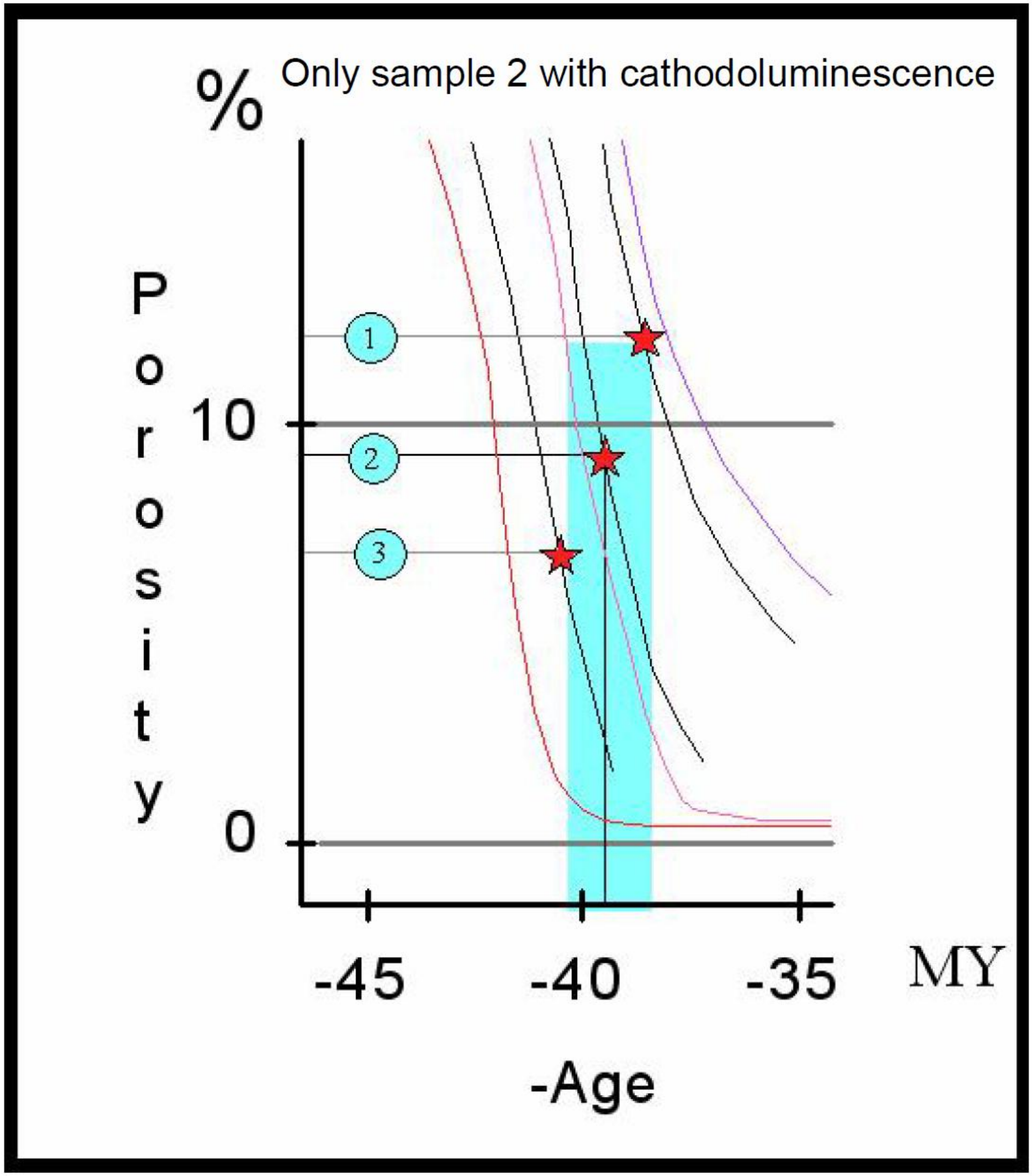


Figure 6. Agreement between amount of calcite cement in and of quartz cement.

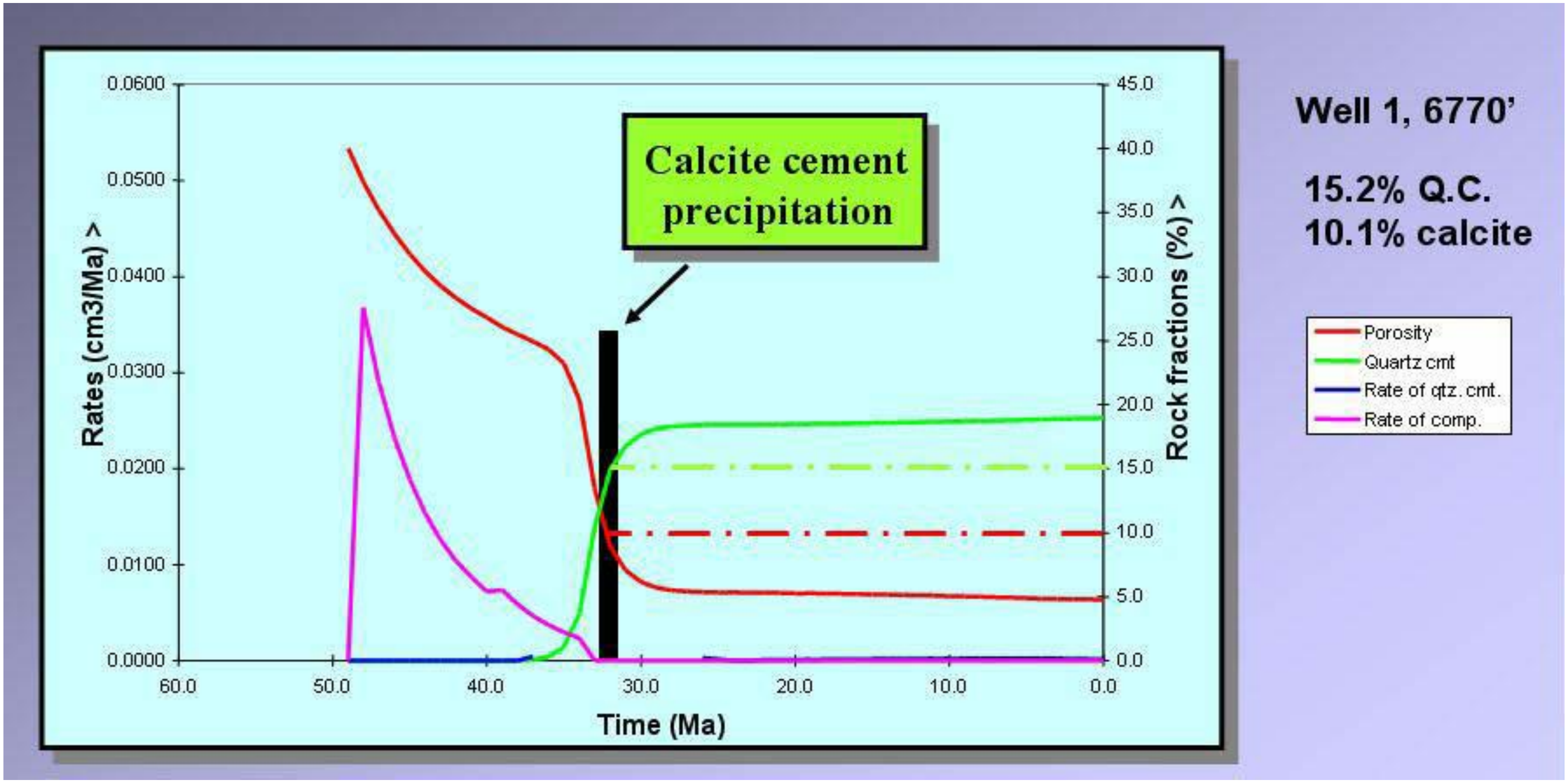


Figure 7. Incorporation of samples with calcite cement confirms the adequacy of the followed methodology.

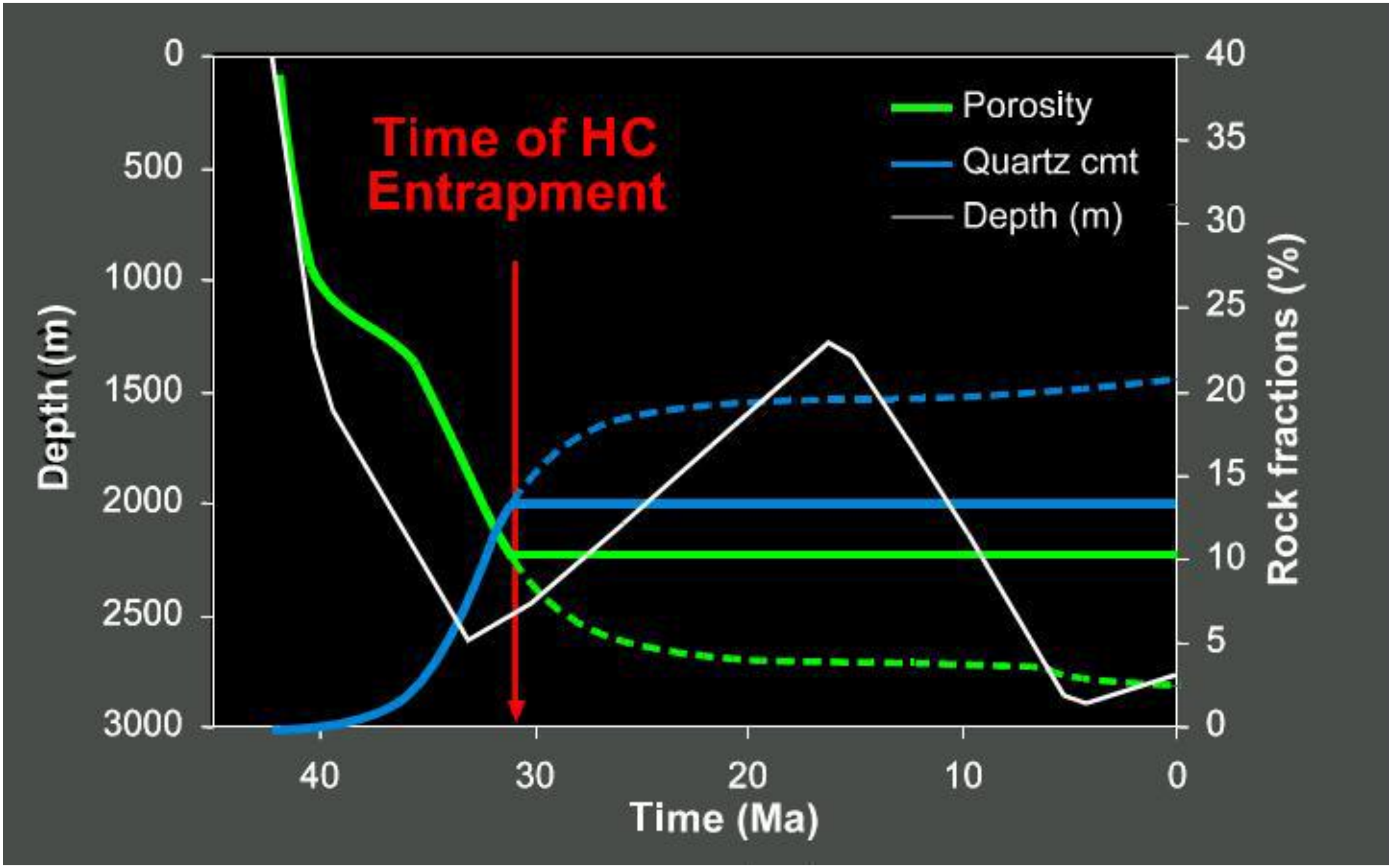
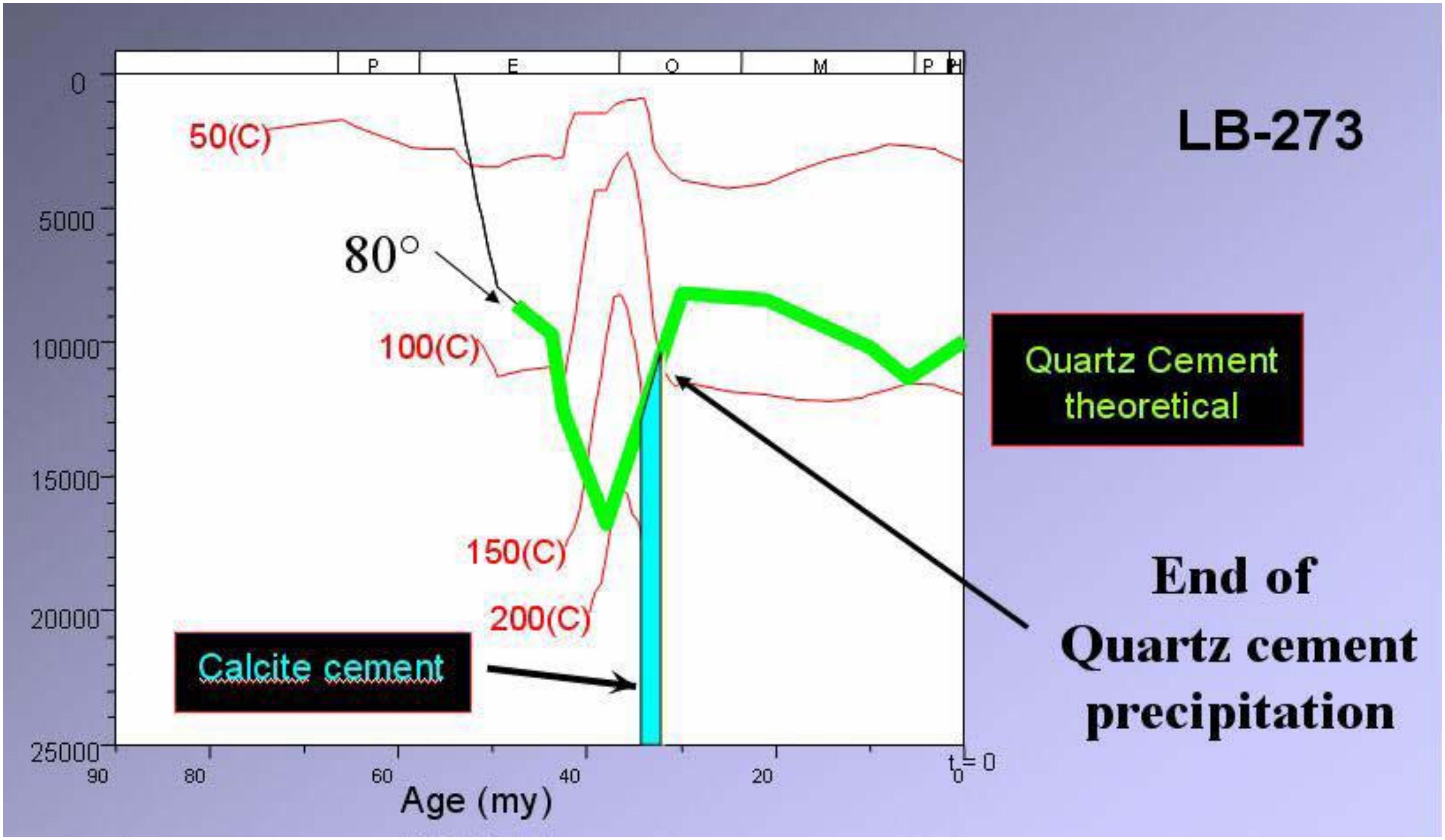


Figure 8. Introduction of hydrocarbon preserves the existing porosity.



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Quartz Cement theoretical

Calcite cement

End of Quartz cement precipitation

Figure 9. A simple view of the burial and diagenetic history in one well.

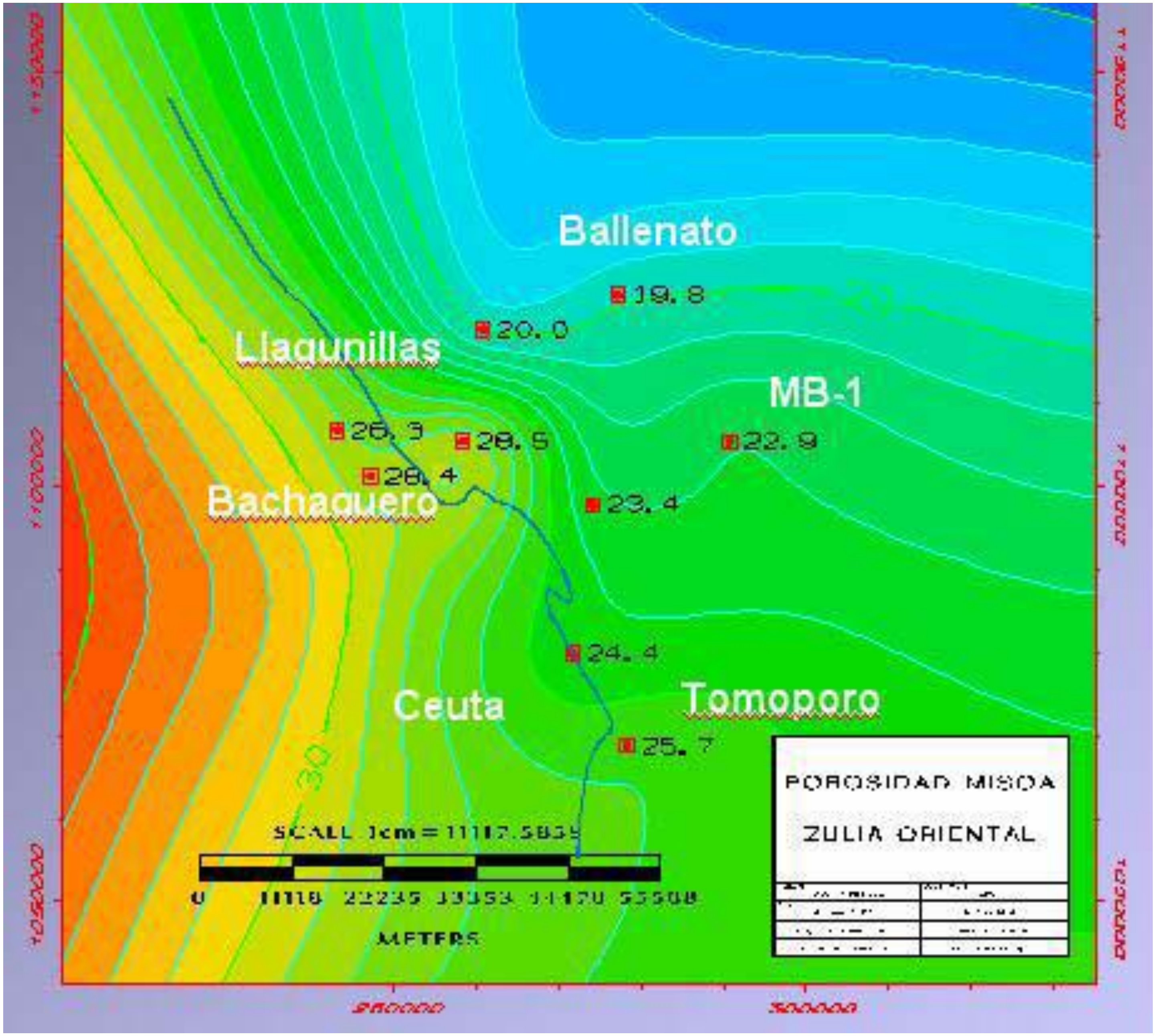

Figure 10. Porosity map based on quartz cement modeling for a medium-grained sandstone at the time of the first oil migration.

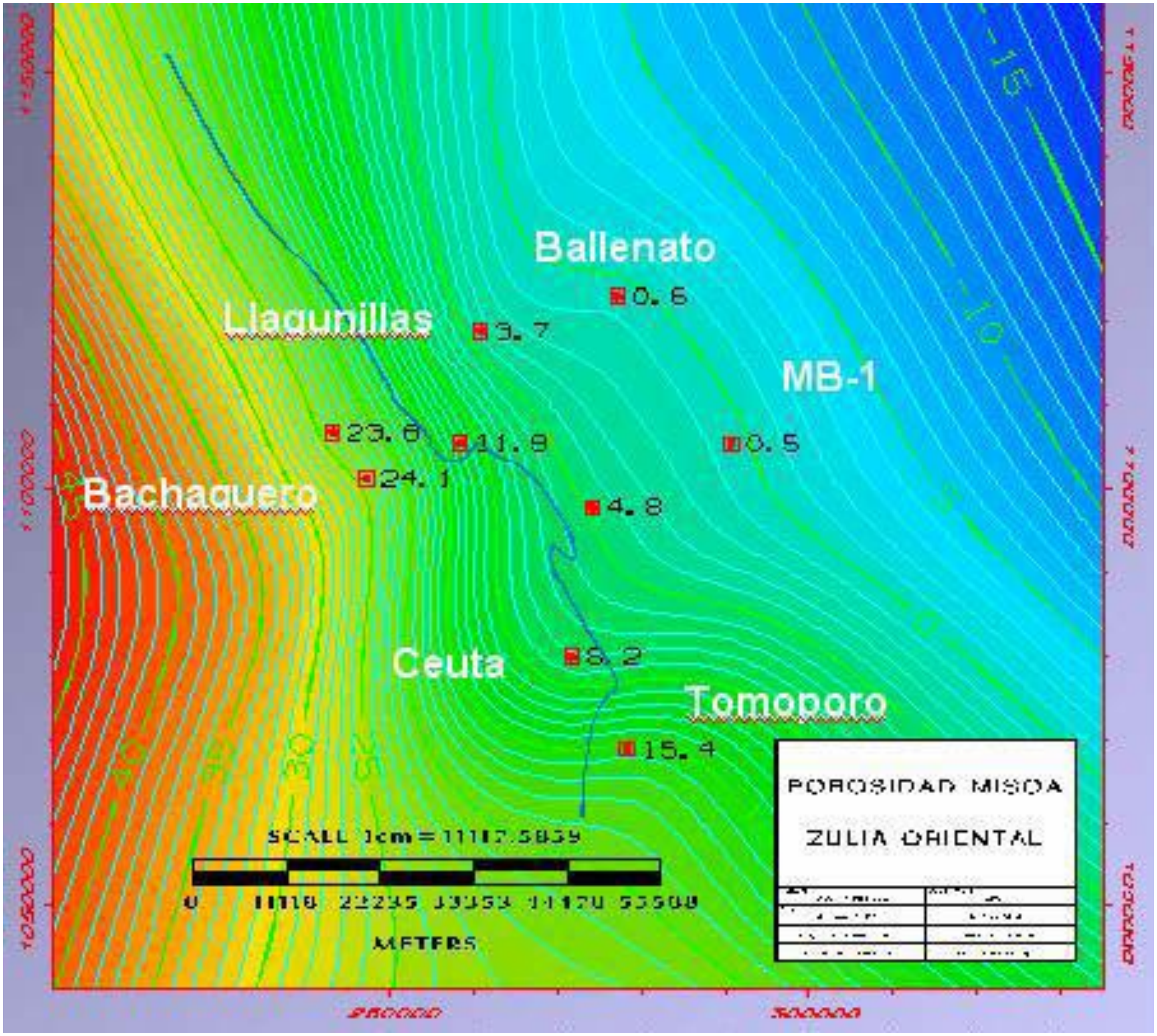

Figure 11. Porosity map based on quartz cement modeling for a medium-grained sandstone at the time of the second oil migration.