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Porosity Structure of a Miocene Reefal Carbonate Complex

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Miocene reefal carbonates provide an important percentage of the worlds exploited oil reservoirs especially in the Middle East. Because they are generally highly transmissive, these carbonates are also frequently used as aquifers for water supply, e.g. on the Balearic Islands. The Miocene reefal carbonate complex of Lluchmajor (Mallorca) has reached a world reputation. Especially the readily accessible outcrops on the cliff coast have been investigated extensively by numerous scientists regarding reef architecture, sedimentology, sequence stratigraphy and reef genesis and led to its status of a world wide reference site.

Understanding the 3D porosity-permeability-distribution of such a complex geological environment is a challenging task. Modern reservoir characterization is based on complex data integration from results of a variety of methods like stratigraphical analysis, surface geophysics, wire-line logs and lab measurements in order to capture petrophysical information on a variety of investigation scales. The geometry of a reef and its according petrophysical rock properties is not only influenced by depositional mechanisms driven by climatic and sedimentological processes, but also post-depositional processes, i.e. diagenetic overprint. Therefore, the analyses and interpretation has to be based on a developed geological understanding of the key depositional and post-depositional processes in order to produce a meaningful 3D subsurface model.

The Mallorca test site, which is one of the two test sites of the EU-funded project “Aliance” lies on the Lluchmajor reefal platform, about 5 km from the coast. The investigated area there consists of a 100 m side length subsurface cube which has been penetrated by 5 fully cored and 2 destructive boreholes, each 100 m deep. Many of the standard methods that are widely used in oil industry have been applied however

some advantages to the situation in oil bearing reservoirs exist. For example borehole spacing on the Mallorca test site lies in the range of several meters to few tens of meters, while in oil industry spacing between individual boreholes is seldom lower than 300 m. The shallow boreholes at the test site imply that there are less restrictions for using a variety of geophysical investigation methods and that their resolution power is higher.

The multiscalar approach for the investigation of the 3D poro-perm-structure chosen here covers the whole bandwidth of scales from micro- to macro-scale. The micro-scale ($<$0.01 m) has been evaluated by multiscalar digital image analysis on thin sections in combination with mercury porosimetry, poro-perm measurements on 1-inch miniplugs and water absorption and desorption tests. Digital image analysis revealed a clear anisotropy of the pore space of grainstones sedimented above wave base level of external lagoon as well as of grainstones and packstones of distal talus. Within this lithofacies types water dynamics led to a preferred orientation of elongated grains like peloids and fossil fragments which directly affected the intergranular pore space. Lowest porosities have been found within isotropic and homogeneous inner lagoon sediments of mainly intergranular porosity and within the framework of recrystallized reef core of vuggy and moldic porosity. Outer lagoon pore structure is anisotropic and homogeneous and consists to a large extent of molds from shells and other dissolved aragonitic organisms. Talus sediments exhibit highest porosity of the whole reef complex. Whereas the upper part was affected by turbidity currents during storm events which lead to an isotropic and heterogeneous pore structure, lower parts were rather affected by a directional and slow deposition which led to the observed anisotropic and homogeneous pore structure.

Meso-scale (0.01-1 m) structure was investigated by gamma, induction, full waveform sonic and televiewer logs. The acoustic and optical televiewer logs were provided by the ISTEEM (University of Montpellier 2). These two logs have been used in order to control lateral heterogeneity changes within individual lithofacies types and the vertical distribution of macroporosity. At meso-scale porosity variations are highest within the reef core where the measured porosity is strongly affected by large dissolution cavities and karstic channels. Therefore within the karstified reef core at this scale high porosity contrasts are present. The distal talus is less permeable than the proximal talus although total porosity is comparable. Observations on thin sections point to a conversion of the predominant pore type from intergrain to a framework-like structure which reduces permeability. On the 10 cm scale distal talus exhibits a very homogeneous lateral distribution of meso-porosity whereas in outer lagoon and proximal talus it is lognormally distributed. A more or less uniform continuous distribution can be observed for the karstified reef core.

Macro-scale (>1 m) structure has been evaluated by electrical resistivity tomography (ERT) and seismic tomography. These two techniques allow for identifying large scale heterogeneities and their distribution between individual boreholes. ERT was very powerful in determining the zones with significant karstic channeling. The high resistivity contrasts observed at several levels in the reef core display the complexity of the distribution of macro-scale primary and secondary porosity, acting as a nucleus for karstic processes. Karst is virtually not restricted to certain levels but is strongly controlled by distribution of lithofacies. The hypothesis that karst developed through postdepositional sea level changes could hence be rejected. The high transmissivities obtained by hydraulic tests and the fact that impeller flowmeter measurements detected the main water flux within reef core points nevertheless to a certain channeling.