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Diagenetic Processes into the Reservoir of the Oil Field of Prinos-Kavala Basin, Macedonia, Greece

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Introduction

Diagenetic processes begin immediately after the deposition of a clastic sediment and continue until the time of anchimetamorphism. All processes are gradual with increasing temperature and pressure. Diagenetic changes depend on the burial depth, the temperature, the chemical composition of the interstitial water and the type of the clastic constituents and cements. The factors that affect the degree of compaction of the components of a clastic sediment are the depth, the size of the grains, the type of clay minerals, the organic matter content, and various geochemical factors. The reduction of porosity and the deposition of cement material restrict the circulation of the fluids, particularly in sandstones, and negatively affect the oil reservoirs. In addition, the burial depth of the sediment is important because it can drastically reduce porosity, especially at depths >5 km (Chamley, 1989; Weaver, 1989; Boggs, 2009).

The most impressive mineralogical conversion during burial diagenesis is that of smectite to illite. The conversion is made in a solid state or by dissolution and recrystallization. At the conversion of smectite into illite dehydration occurs associated directly with the formation of hydrocarbons. The abundance of smectite favours the formation of hydrocarbons. However, the content of a sediment as a storage site in hydrocarbons is inconsistent with the amount of clay minerals found in it. The conversion of smectite into illite begins at temperatures of about 80°C and is accompanied by the production of large quantities of water. The mixed phases chlorite / smectite and chlorite / vermiculite may be formed during early or middle diagenesis. The proportion of chlorite layers in this mixed phase increases with increasing temperature, analogous behaviour to the increase of illite layers in the mixed phase illite / smectite (Tsirambides, 1983; Weaver & Associates, 1984; Nadeau et al., 1985; Chamley, 1989; Weaver, 1989; Lindgreen et al., 1991).

Most of the organic material in the clastic sedimentary rocks is sapropel deposited in lake, lagoon and marine environments with particularly low oxygen levels. Oxygen deficiency leads to anaerobic and reductive conditions which inhibit the oxidation and bacterial degradation of organic matter. This sapropel consists mainly of phytoplankton, zooplankton, seeds, pollen and residual particles of higher plants in rot. During burial diagenesis the organic material undergoes a series of important changes from the combined effect of biochemical and chemical agents. These diagenetic processes destroy most of the organic material and convert the remainder into an insoluble mass, the kerogen. Most of the organic material in shales and mudrocks is kerogen. The average concentration of organic carbon in shales and mudrocks is 1.0-2.2%. Some black shales contain significantly more organic carbon reaching 10% or more, while oil-bearing shales can contain 25% or more organic material (Tissot & Welte, 1984; Boggs, 2009).

From the study of diagenetic processes, significant conclusions can be drawn for the textural, mineralogical and chemical changes that occurred in a clastic sedimentary rock and vice versa. In addition, the extent to which these processes have affected other rock features, such as porosity and permeability, is particularly important when assessing the ability of a formation to function as a reservoir of water, gas or oil.

Results and discussion

Miocene clastic sediments taken from onshore drilling cores (depths 1,780-3,500 m) in the Nestos-Eastern Thassos basin indicated that they have been subjected to early diagenesis (Tsirambides et al., 1998).

The first exploration drilling in the Prinos-Kavala basin took place at the end of 1973 and since then 51 drillings have been carried out with an average depth of 3,000 m (Kiomourtzi, 2016). Today, there are 12 active production wells and 2 intake wells in the region. Crude oil production began in early 1981, initially with 8,000-10,000 barrels / day and peaked at 27,500 barrels / day in 1985. Since then, production has dropped significantly to 1,200 barrels / day. The first filling well, the PA-35, was successfully launched and started production in 2010, at a rate of 1,000 barrels / day to date, confirming the dynamic model of exploitation of the company that manages this field (Ioakeimidis, 2015).

The Prinos-Kavala basin began to form in the Lower Miocene and was gradually filled with clastic materials coming from the regional downfalls mainly in the northern part of the basin, as well as with the deposition of the Nestos River load, that flows to the northeast of the basin. Due to the high pressure of the overlying beds and the presence of cement material, the porosity is gradually reduced and the degree of compaction increases in the clastic sediments of Prinos-Kavala basin. Samples originated at depths >1000 m have been subjected to early diagenesis, while those originated at depths >2,600 m present clear characteristics of middle diagenesis. Late diagenesis processes are completed at greater depths under certain conditions. Such conditions were not detected in the examined basin (Ioakeimidis, 2015).

The total percentage of cement materials in the examined samples ranges between 5.5 wt% and 21.9 wt%. In particular, the carbonates are in the range 3.4 wt% to 14.3 wt%. The sum of organic matter and MnO2 ranges between 1.1 wt% and

4.5 wt% and the sum of Fe oxides and hydroxides ranges between 0.7 wt% and 3.4 wt%. The vertical distribution of the three cement materials measured is similar. The distributions are least differentiated in their intermediate regions, while the maximum and minimum curves are identical. This fact probably reflects the change of the sedimentation conditions (e.g., deposition environment, climate) with intense feeding conditions (minimum curves), alternating with milder conditions (maximum curves), the composition and the texture of the sediments, the physicochemical characteristics of interstitial water and finally the diagenesis conditions (Ioakeimidis, 2015).

The most important changes observed are the progressive conversion of smectite to illite or chlorite through their mixed phases of S/I and S/Ch, as well as the gradual increase in the degree of crystallinity of these two minerals. These changes are more pronounced in the <2 μm grain fraction, where clay minerals prevail. The changes in the percentages of illite, chlorite, sum of smectite + smectite/illite and kaolinite with depth in the clay fraction (<2 μm) are very evident. Illite and chlorite percentages range from 5 wt% to 24 wt% and from 2.7 wt% to 13.2 wt%, respectively, while their trend lines with depth are strongly increasing. The expanded clay minerals (smectite + smectite/illite) percentage ranges between 3.2 wt% and 11.2 wt%, while their trend line with depth is clearly increasing. The kaolinite percentage ranges from 0.1 wt% to 1.3 wt%, while its trend line with depth indicates a clear decrease (Ioakeimidis, 2015).

Clay mineral transformations with depth constitute significant tools in the estimation of the diagenesis stage and in extend in the hydrocarbon potential of the clastic sediments into the Prinos-Kavala reservoir. The conversion of swelling clay minerals into illite requires the circulation of solutions rich in K+ ions, starts at temperatures of 70-95oC depending on the geothermal gradient and is completed at temperatures up to 200oC. Taking into account the average geothermal gradient (30oC/km), this means an average burial depth of 2-4 km. At higher temperatures and depths, kaolinite is converted to illite and chlorite. These observations are in very good agreement with the chart trends of the clay fraction of the examined samples taken from depths of 2,635-2,960 m.

Another important indicator for assessing the evolution of diagenesis of a clastic sediment is the increase in crystallinity of illite structure with depth (Kübler, 1967; Weaver & Associates, 1984; Jaboyedoff et al., 2001). In the studied sediments the illite crystallinity gradually increases with depth with crystallinity index values varying from 8.41 mm to 5.33 mm. The average value of the illite crystallinity index is 7.9 mm, very close to that given by Weaver & Associates (1984) for middle diagenesis (7.2 mm). Two samples with values 3.16 mm and 3.25 mm, respectively, belong to illites that have undergone late diagenesis. The variance of illite crystallinity with depth according to Jaboyedoff et al. (2001) shows a slight decrease, i.e. a gradual reduction in the width of the illite peak (001) at half its height in both parallelly oriented and glycolated samples. The values of this index range between 2.11 and 1.24 (Ioakeimidis, 2015).

Conclusions

The oil-bearing Prinos-Kavala basin is 8 km west of Thassos and has a surface area of about 500 km2. In this basin hydrocarbons are trapped in sandstone and mudstone pores and are found at an average depth of 2,700 m. Among the clay minerals illite is the main phase showing a prominent increase with depth from 5 wt% to 24 wt%. Chlorite exhibits similarly a clear increase with depth from 2.7 wt% to 13.2 wt%. The expanded clay minerals (smectite + smectite / illite) also exhibit an increasing trend from 3.2 wt% to 11.2 wt%. The opposite trend is shown for kaolinite with a noticeable reduction in its content. Taking into account the detailed mineralogical analysis and the degree of illite crystallinity, it is concluded that the studied sediments have been subjected to middle diagenesis processes. This stage coincides with the "oil window" of temperatures 60-120oC (aprox. 2-4 km depth) reinforcing the dynamic formation of hydrocarbons in the Prinos-Kavala basin.

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