Role of "interlayer" water of clay minerals in origin of subsurface waters

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The formation of the layered waters of the sedimentary basins by the squeezing-out of free and weakly combined water from muds and clays during the compaction of the latter has been highlighted in numerous works (3, 6, 7, 8, 11). However, insufficient attention has been given here to the possibility of participation in the "charging" of collectors by water at the expense of clays, and also the "interlayer" waters of the clay minerals. These waters quite provisionally include the chemically associated, and the so-called zeolite waters, forming a compositional part of individual mineral species in variable amounts.

Certain clay minerals, including those extremely widely distributed, for example, montmorillonite, contain significant amounts of water, the main portion of which consists of interlayer water. At increased temperatures, the clay minerals lose a portion of it, and this loss takes place either without change in the mineral structure, or in association with its reconstruction. The greatest amounts of interlayer water are released during reconstruction of the clay minerals, especially during the conversion of montmorillonite (containing up to 24% water) into illite and other hydromicas (containing not more than 10% water).

It is now considered that a requirement during the conversion of montmorillonite into hydromica is the presence of potassium and aluminum. The reality of such processes has until now been disputed, because of the deficiency of potassium and aluminum in montmorillonite as compared with the hydromicas. According to Savkevich (13), the source of ingress of potassium and aluminum during the catagenesis of clays is the intralayer solution of such clastic minerals as the potassium feldspars.

The processes of conversion of clay minerals during catagenesis and the accompanying release of water have in recent years attracted the attention of many investigators (1, 2, 4, 5, 9, 10, 12-17, etc.). Conclusive proofs have been obtained that montmorillonite is converted into illite and other hydromicas during the process of catagenesis. In particular Khitarov and Pugin (5), using experimental data and information from geologic observations, have demonstrated that the conversion of montmorillonite into hydromicas with the release of interlayer water may take place over a wide depth range, depending on the geothermal conditions. The figure illustrates a scheme devised by these authors for the depths of possible preservation and transformation (with dehydration) of montmorillonite, depending on the geothermal gradient, on which some additions have been plotted. From the figure it is seen that with increased geothermal gradients, the appearance of rejuvenated waters owing to dehydration of montmorillonite is already possible at depths of 2-3 km.

The amounts of water released during the reconstruction of clay minerals may be judged on the basis of calculations. Such calculations have been carried out (10) for the Lower Cretaceous deposits of the central Ob' region of the West Siberian Lowland. A variant of the calculation is presented below.

Let us consider a sequence of deposits of total thickness 1100 m, of which 1000 m is clay, and 100 m sandstone. In a column, 1 km^2 in cross section, the volume of the clays is 10^9 m^3, and the mass is about 2 x 10^9 tons. Let us assume that the clays consist of montmorillonite (50%) (clearly an overestimated value), and that the amount of the water in the montmorillonite is 20%. Then the mass of the montmorillonite in the volume under consideration will be approximately 10^9 tons, and the mass of water in it 2 x 10^8 tons. We note that after some period, 50% of the montmorillonite (i.e., 0.5 x 10^9 tons with a water content of 10^8 tons) has been converted into illite and other hydromicas with a water content of 10%. In such a case, the transformed portion of the montmorillonite has lost approximately half of the water. Consequently, as a result, there appears 0.5 x 10^8 tons of released water.

The water released from the clays under the influence of continuing compaction of the latter will be displaced into the sandy layers occurring in the clay sequence. Their total thickness, as stated, is taken as equal to 100 m, that is, their volume is 10^8 m^3. Let us assume

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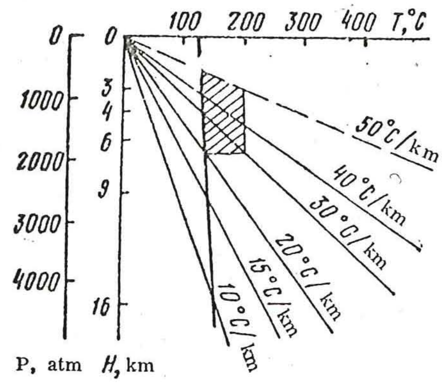

Depths of possible retention of montmorillonite and the formation of hydromicas from montmorillonite in the presence of potassium, depending on the geothermal gradient (after N. I. Khitarov and V. A. Pugin, with additions).

the porosity of the sandstones to be 5% (at depths of 3 km and more, so far as is known, such a porosity is normal). The volume of the layered water occurring in the sandstones comprises in this case 5 x 10^6 m^3, and the mass of water is about 5 x 10^6 tons. Consequently, the amount of water released from the clay minerals is 5 x 10^7 tons, ten times greater. In other words, the amount of released water appearing during dehydration of montmorillonite may greatly exceed the available volumes of the collectors.

Even if we consider that the above accepted amounts of montmorillonite, the amount of water in it, and the degree of conversion of montmorillonite into hydromicas to be overstated, and the porosity of the sandstones to be understated, the amount of water still remains greater than the capacity of the collectors. Moreover, it must be understood that not only is the montmorillonite dehydrated, but also the other clay minerals (although to a lesser degree).

Thus the calculation shows that during the dehydration of clay minerals in the process of catagenesis, masses of released water appear, reaching quite significant volumes, and this means that their hydrogeologic role is very substantial. It is also of importance that the present process is achieved at depths at which compaction of clays and the release from them of weakly combined water is decelerated (as seen from numerous curves showing decrease of porosity of clays with depth). Moreover, judging by the nature of the slope of the curves in the range exceeding 3500 m, it is clear that compaction continues all the same. It is possible that this is associated with the appearance of a new source of filling the pore space of the clays (the "interlayer" water of the clay minerals which has been released into this space). In their turn, these waters are a resource for charging the collectors.

The role of the "interlayer" waters released from the clay minerals in the formation of subsurface waters must be particularly great in the basins characterized by a very great thickness of water-bearing sequence and a high geothermal gradient. An example of such a basin is the South Caspian. It is interesting that in this very place there is an anomalous picture of the appearance and expansion with depth of the zones of development of poorly mineralized waters, clearly not associated with the earth's surface (9, 12, 14). Apparently a significant place here is occupied by those waters being released during the late stages of catagenesis from clay minerals, which waters during their initial existence were almost devoid of dissolved substances.

On the strength of this last situation, and also owing to changes in the structure of the water molecules themselves during the transition from the combined to the free state, the liberated waters possess an increased solvent capacity and aggressive nature (1). These properties create the possibility for transport by the released waters of petroleum hydrocarbons and various petroleum-forming organic substances, which is extremely significant because the phase of release of "interlayer" water from montmorillonite corresponds in general with the main phase of petroleum formation (2).

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