

Geology. — *Compaction an agent in the accumulation of oil at the anticlines.* By J. VERSLUYS.

(Communicated at the meeting of November 29, 1930).

It is generally accepted that accumulation of oil has some connection with structure. In most cases accumulation has taken place in the structurally high portions of the coarse strata.

Various reasons are given for this accumulation in the top of the structures. Most geologists ascribe it to the difference in specific gravity between oil and water, although this has not yet been confirmed by experiments. Experiments as a rule have not given much evidence as to the opinion that small globules of oil, disseminated in the water which fills the pores of a sand, are able to rise along an overlying layer of clay which has a gentle slope. Such experiments, however, are not quite conclusive, as the time factor is too small to be comparable to the time available for accumulation in the earth's crust. On the other hand, in the earth the distances are so much greater than in the experiments that much more time would be required to bring about the accumulation. The author does not reject buoyancy as an important factor in oil accumulation at the anticline, but in his opinion other factors may also have a considerable influence.

There are different opinions as to the origin of oil. Most geologists, however, agree inasmuch as they accept that oil must have migrated, as it is very improbable that so much organic matter has been originally enclosed by the sediments within the limit of the present oil accumulations as to give rise to the existence of all the oil. It is more plausible that oil has been formed as small globules throughout the water in the voids of the sediments. It is a question whether oil has been formed in all the strata or only in part of them. In the opinion of several authors it is mainly formed in the finer grained strata. These, however, are generally clay and are easily compressed by the weight of the overlying sediments. The water is partly squeezed out and makes its way mainly through the coarser strata ¹⁾. The small globules of oil are entrained on to the coarser strata, from which, however, as will be explained below, they will not easily penetrate finer grained layers again.

In 1898 F. H. KING ²⁾ mentioned motion of underground water owing to compaction. Since the relation of such motion to carrying oil and gas

¹⁾ J. VERSLUYS: "Synclinal oil and unsaturated strata" Proc. Royal Academy Vol. XXXI pp. 1086—1090, Amsterdam, 1928.

²⁾ "Principles and conditions of the movement of ground water" Nineteenth Annual Report of the U. S. Geol. Survey, II, p. 77.

on to the coarser strata was dealt with by R. W. JOHNSON¹⁾ and by R. VAN A. MILLS and R. C. WELLS²⁾. These authors however do not give an explanation as to how oil and gas are left behind in the coarser strata and they did not realize that the flow caused by compaction may be an agent in accumulation in the structurally high portions of these strata.

The water, although mainly having a longitudinal motion through the coarser sheet sands and lenses, at certain points rises to the surfaces across the finer grained and the coarser layers both. These points of escape, where the water has its most intensive vertical motion, are the crests of anticlines and domes.

Not only are the clayish strata compressed, but compaction takes place also in the coarser, sandy strata, and it is perhaps more the flow of water due to the compaction of the sandy than of the clayish strata that brings about the accumulation of oil in the anticlines. The clayish sediments are very easily compressed by the weight of overlying strata and this compaction may nearly be finished when the structures are formed. This compaction may be supposed to take place according as the weight of sediments increases³⁾.

The sands can be compacted in two ways. The grains may be crushed when they are submitted to a very high pressure. Such pressure, however, cannot be brought about until the thickness of superimposed strata is about 10.000 metres according to VAN HISE and HOSKINS⁴⁾. Although the calculations of these authors are not claimed to be exact, a great depth is required to fulfil the condition of the crushing of the sands. There is, however, another way in which sands may be supposed to be compacted gradually. The water in the voids is a solution which tends to be in equilibrium with the minerals of the formation. Such equilibrium can not exist because in the points of contact of two grains the stress on account of the compacting pressure is greatest and this stress performs work when these corners give way, that is to say, when some substance is dissolved. So the total potential energy of the gravity action on the sediments decreases when the grains are dissolved or corroded at the points of greatest stress, and the same material is precipitated in the neighbourhood on the surface of the grains, which means that this phenomenon will take place⁵⁾. In this way the centres of gravity of the grains approach one another and porespace decreases, so that water is squeezed out. This

¹⁾ "The rôle and fate of the connate waters in oil and gas sands". *Am. Inst. Min. Eng. Trans.* LI, p. 975, 1915.

²⁾ "The evaporation and concentration of water associated with petroleum and natural gas." *U. S. Geol. Survey Bull.* 693, 1919, pp. 68 and 69.

³⁾ J. VERSLUYS: "An hypothesis explaining some of the characteristics of clay." *Proc. Royal Academy* Vol. XXX, pp. 104—112, Amsterdam, 1927.

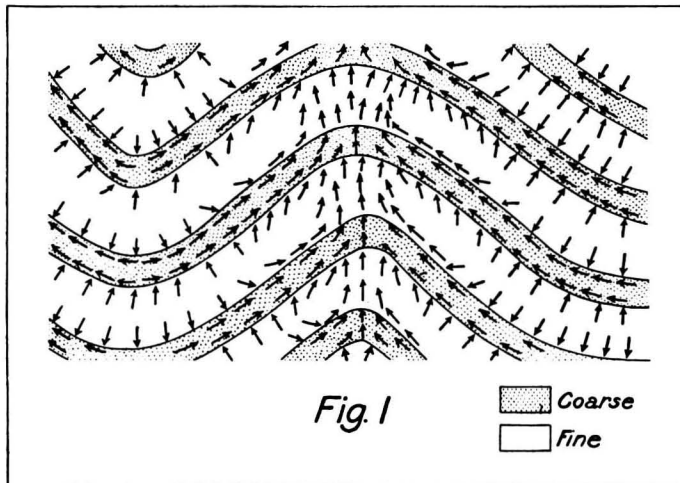
⁴⁾ C. H. VAN HISE, *Sixteenth Ann. Rep. U. S. Geol. Survey* 1896, pp. 571—843 and L. M. HOSKINS, ditto, pp. 845—874.

⁵⁾ J. VERSLUYS: "The compacting pressure of sediments." *Proc. Royal Academy* Vol. XXX pp. 1004—1009, Amsterdam, 1927.

compaction ultimately brings about cementation. The rate at which this compaction takes place depends on the amount of weight, but it is quite different from the compaction of clayish strata. In the latter, when part of the water has been squeezed out, an equilibrium may be established which is only disturbed when the pressure is changed. In sandy strata, however, the compaction by solution and recrystallization, takes place slowly and it does not counterbalance the increase of the burden. Perhaps it would continue until the voids are entirely filled with secondary minerals, or till they are divided into disjointed compartments.

The compaction of the clayish sediments which takes place according as the burden of overlying sediments increases is presumably nearly finished before the strata are folded and if this is the case it mainly causes the concentration of oil in the coarser strata. The compaction of the coarser strata which goes on at a slower rate almost indefinitely, may be the main cause of the accumulation at the anticlines. In the later stages of compaction the phenomenon of recrystallisation will also take place in the finer grained strata.

The direction of the motion of water in alternating coarser and finer sediments after folding, if it is accepted that both finer and coarser sediments are still being compacted, is shown by the arrows in fig. 1. In



this plate the coarser sands are supposed to be sheet sands. If they are more or less lenticular the flow conditions are not materially altered.

As it has been stated above and is expressed in figure 1, the water rises across the finer grained strata at the anticlines. This can be conceived as follows. In a coarse stratum, the differences of pressure head are small due to the fact that resistance against motion is small in such layers. Hence pressure head in a coarse layer does not differ much in the syncline and the anticline. The resistance opposed by the overlying strata to the rising motion of water however is smallest at the crests of the structures, so that here water will mainly rise as long as it is submitted to compaction pressure.

If the water in the pores of all the strata is supposed to be littered with small globules of oil as mentioned above, then in the coarser strata they will not be directly in touch with the minerals and they will be spherical. They are separated from the grains by a film of water owing to the fact that the minerals are better wetted by water than by oil, as already mentioned. (At the end of this paper it will be explained that if there were an oil in the formations for which the minerals had a greater affinity than for water, such oils would never accumulate. Therefore, without hazarding an opinion on the question whether or not such oils might exist, they can be discarded, as they would never collect in certain parts of the formation so as to be discoverable and exploitable.) In coarser strata the globules can easily be entrained and follow the motion of water, as they are small, compared with the dimensions of the voids of the sediments.

In very fine grained sediments the globules will also be separated from the grains by a film of water, but they may be of the same order of magnitude as the voids of the sediment, so that their form may depend on the shape of the pore in which they lie. Consequently they will, as a rule, not be spherical, often oblong, if the voids have the form of channels. Except for the film of water which separates them from the wall, the globules cover the whole cross section of a pore and will be propelled by the water.

With the spherical form the area of the surface is smallest and consequently the potential energy of the intermolecular forces has its smallest possible value. Hence a globule can pass easily from the fine layer into a coarse one, as then the intermolecular forces come into action as they perform work. If, on the contrary a globule has to be pushed from a coarse stratum into a finely grained one, work has to be done to counterbalance the increase of potential energy of the intermolecular forces. Thus a force is needed to make the globules pass from a coarse into a fine layer.

In the former pages it has been explained, and it is shown in fig. 1 that the water, charged with small globules of oil will flow across the finer strata at the crests of the structures. Intermolecular forces however will retain the globules of oil, so that they accumulate under the fine grained strata in the anticlines and domes. The fine grained layers thus become the "*caprocks*" of the oil.

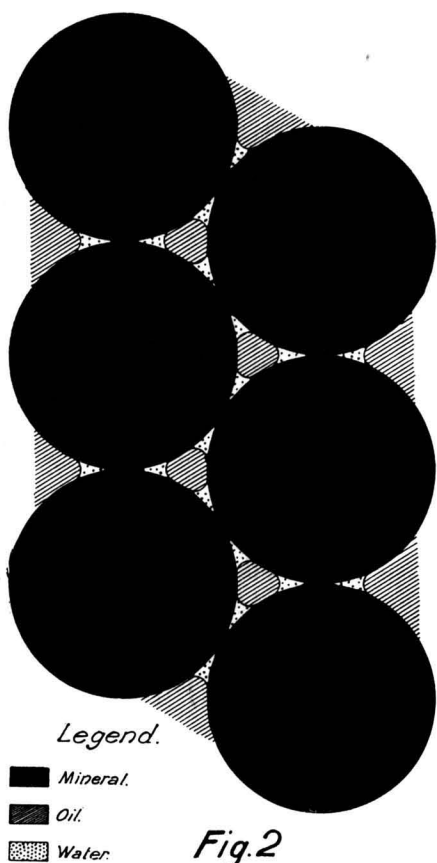
Where the oil accumulates under the caprock, the globules unite and gradually the pores of the coarse layer are filled with oil. An oil-filled layer of sand arises under the caprock at the crest. This seals off the upper part of the sand under the caprock and no more water can pass, so that accumulation would cease. Then, however, accumulation must take place farther down the slope. As soon, however, as a continuous layer of oil is formed, this can move updip due to buoyancy. There would be no other resistance than internal friction of oil, which approaches zero, as the motion is infinitely slow.

When a certain amount of oil in this way has accumulated in the structurally high portion of a coarse layer, the buoyancy tends to make the oil rise and consequently the oil exerts a pressure on the water in the caprock, which equals the product of the difference in specific gravity and the height from the border of the edgewater to the crest of the stratum. This pressure is counterbalanced by the intermolecular forces. These forces however can only withstand a certain pressure, so that the height of the oil, although it may be great, can not increase infinitely. It is quite probable that in some cases the oil may penetrate the caprock and perhaps all the

oil may migrate to the next higher coarse sand. This will not be treated in all details.

When the coarse layer is filled with a continuous mass of oil, it may be assumed that the film of water covering the grains will disappear. Independent of the question whether when the coarse layer is filled with a continuous mass of oil there are still films of water covering the grains or not, the intermolecular energy would increase if the oil penetrated a finer grained layer, because if the oil replaces water in the finer grained layer the interface either of oil and mineral matter or of oil and water must increase, so that there is a resistance opposed to oil penetrating finer layers.

Probably minute particles of water will remain at the contacts of the grains in loose sands, in the oil after its accumulation, as a consequence of the fact that the grains are more easily wetted by



water, than by oil. The condition of the remaining water would be represented schematically by fig. 2. This condition corresponds to the "pendular condition"¹⁾ of sand wetted with liquid. Then the liquid forms small pendular bodies at the points of contact of the grains. In the case of water and oil the pendular bodies would also be water.

It is to be stated here why oil that wets the minerals better than water would not accumulate. Soon after they have been formed, the globules of

¹⁾ J. VERSLUYS: „De capillaire werking in den bodem", Amsterdam 1916 and: "Die Kapillarität im Boden" Int. Mitt. für Bodenkunde, Munich 1917 pp. 117—140.

oil would attach themselves to the grains of the formation and gradually take a position as shown in fig. 3. There would be pendular bodies of oil



Fig. 3

in water. They would remain at the spot and the formations would contain erratic small bodies of pendular oil, which would not be detected. The author does not mean to say that such oil exists; he merely wishes to make sure that all accumulated oil must have less affinity for the mineral grains than water, because otherwise it would not have migrated. Moreover, oil with such a great affinity for the minerals would

tend to enter the more finely grained strata if it could migrate at all.

The occurrence of oil in stray sands can be explained by the above theory. When there are only isolated coarser lenses, the water, when moving on account of compaction, makes its way through these lenses and where it leaves them, the oil is retained by these lenses due to the filtering action as described above.

The opinion that compaction of the coarser sediments is one of the factors involved in the process of oil accumulation is perhaps supported by the fact that many sands yield the oil quite liberally without this being followed by a flow of water at a considerable rate. Perhaps this may be explained as follows. Compaction of the coarser strata takes place through dissolution and recrystallization. This is impossible after the pores are filled with oil, so that after the accumulation of oil the compaction can continue only outside the oil; consequently in the water-filled portion the pores become narrower than the oil-filled portion of the sand.

The writer admits that the above theory is speculative. Another speculation may be added as to the question of pendular bodies of water in the oil accumulation. As far as the authors knows, there is no indisputable evidence of pendular water remaining in the oil after accumulation in loose sands, unless the water mentioned by MILLS and WELLS ¹⁾ may be regarded as such which, however, is not sure. Anyhow, the percentage of water, in this way suspended amidst the oil, would be very small and it is not sure that it would be entrained by the oil when this flows to a well. But even within such bodies dissolution and recrystallization might continue. Then, however, the angles of the pore space around the point of contact of the grains would gradually become less favourable for the suspension of water. The pendular water then must sink and segregate from the oil and unit with the water of the underlying fine grained layer.

Anterior to F. H. KING, above mentioned, R. HAY ²⁾ in 1890 explained some properties of ground water as caused by the burden of superimposed strata. This author's conception however was static.

¹⁾ R. VAN A. MILLS and R. C. WELLS: "Opt. Cit. pp. 26 and 27.

²⁾ "Artesian wells and the causes of their flow". The American Geologist V, pp. 296—301, 1890.