**Geology.** — *The problem of dry or unsaturated strata.* By J. VERSLUYS.

(Communicated at the meeting of May 30, 1931.)

The interstices of the sediments in the earth's crust form one interconnecting network of fine pores to a great depth. These pores are all water filled except where oil or gas have replaced it. In each point of the earth's crust the water has a hydrostatic pressure approximately equal to the pressure exerted by a column of water from that point to the earth's surface above it. [1])

Oil and gas must have the same pressure as the water they have replaced, so that they also have the pressure inherent to the depth where they occur (see however the last page).

No other conception is possible, because most sediments have been deposited under water. The sediments which were deposited on the continents above the water, must have been covered with water or have got into the water saturated regions of the earth's crust before younger sediments have been deposited upon them. Afterwards the volume of the pores may decrease owing to compacting pressure, so that the deeper seated sediments constantly tend to discharge part of their confined water which rises through the overlying beds. Except in volcanic regions, temperature does not increase with depth to such a degree, that the vapour pressure becomes greater than the pressure which is inherent to the depth, so that no water will evaporate at depth and no depletion of the pores can be caused by temperature.

Petroleum and gas are encountered in the coarse sediments and their occurrence is generally restricted to the highest parts of the folded structures of the earth's crust. The fact, that oil and gas tend to accumulate in the highest parts of the strata has for a long time been attributed to the buoyancy of the two lighter substances on water. Thus the fact that oil and gas by preference gather in the highest parts of the structures was ascribed to the segregation of the lighter substances from an emulsion or a foam.

The problem of how oil and gas have been concentrated especially in the coarser strata was not at first considered, it was only taken as a matter of fact. Neither was it considered what filled the pores of the finer sediments. In such sediments the pores may be so narrow, that the motion of liquids through them is very slow; several hydrologists fallaciously consider them to be dry and absolutely impervious. Accordingly the

---

[1]) J. VERSLUYS: "The origin of artesian pressure". These Proceedings XXXIII, pp. 214—222, 1930.

coarser beds, are often erroneously regarded as closed reservoirs, if they have no exposures at the surface. [1])

No real explanation was given of the cause of finer beds acting as barriers to the motion of oil and gas, with the result that they are retained in certain coarse strata. The finer grained strata were simply said to be tight. [2]).

For a long time it was known that there were exceptions to the rule that oil and gas occur in the structural "highs". All discrepancies met with before 1906, however, could easily be explained on the principle of buoyancy; in that year, however, deviations were encountered which could not be explained by buoyancy unless a new principle was adopted to link them with this theory.

In this year in Pennsylvania oil accumulations were found on the flanks as well as in the synclines [3]). The idea that differences in the specific gravity caused the segregation of gas and oil at the top was not abandoned, but in 1907 a new hypothesis was put forward in order to explain these occurrences of oil and gas a consequence of buoyancy. It was therefore assumed that layers bearing oil at the flanks of the anticlines were partly filled with water, while the beds with synclinal oil should be free of water. In ordinary water filled sands oil and gas would ascend to the crest whereas oil would descend to the syncline in dry strata and gather at the top of the water in strata that were water filled to a certain level.

As to the behaviour of gas there would be only one possibility in the author's opinion, viz.: the gas would spread throughout the pores of the layer as far as it was not water filled. This however was not within the scope of the principles at that time. The supposition was ventured that the pores of the dry or unsaturated strata were filled with air under atmospheric pressure. This was supposed to be the case in strata which lay below sea level.

Two distinct conceptions of the origin of dryness prevail. One is the idea of "connate dryness". It was assumed that dry strata had been deposited by rivers in the coastal regions. Successive regressions and transgressions of the sea had alternately exposed the territory to the atmosphere and submerged it, so that beds became dry and air filled and were afterwards covered with marine sediments. The advocates of this "connate dryness" believed that the air under atmospheric pressure would have prevented the penetration of the sand by water when they were submerged.

The second conception was that the so-called dry layers were water

---

1) The writer treated this subject in a former paper: "The origin of artesion pressure", l.c.

2) See J. VERSLUYS: "Compaction an agent in accumulation of oil at the anticlines". These proceedings XXXIII, pp. 990—995, 1930 and: "Can absence of edgewater encroachment be ascribed to capillarity", Bull. Am. Ass. Petr. Geol., XV, pp. 189—200, 1931.

3) Before correcting the proof of this paper the writer found that C. A. ASHBURNER, Science V, p. 43, 1885 and VI, pp. 184 and 185, 1885 stated that several Pennsylvanian gas wells were located in the synclines.

filled when they became buried, but that they were desaturated subsequently. The process of desaturation was explained in three ways. One explanation involved evaporation owing to heat which should make the strata dry at a depth of 450 to 600 metres [1]). The possibility of such an evaporation has been discussed in the foregoing pages. The second explanation was that orogenetic movements of the earth's crust and subsequent denudation had decreased the compacting pressure of sediments so that clays and shales could expand again. During the expansion these fine grained sediments should absorb water which was withdrawn from the coarser sands. These were in this way entirely or partly depleted. The third conception was that water of the deeper strata has been evaporated owing to the circulation of gases, principally methane, (generated at depth) escaping at the surface, mainly through fissures.

Whatever assumption is made, regarding the cause of the supposed dryness of the strata, the idea that dry strata occur at great depth implies the supposition that the overlying and the underlying strata are materially impervious. Otherwise, the dryness could not subsist. As it has been stated above. several geologists actually believe that only the coarser strata are aquifers, and that the shales and clayey strata are absolute barriers to the passage of liquids. The writer, however, does not accept this theory and consequently he does not agree to the principle that beds containing only air at atmospheric pressure can exist at a considerable depth. He admits that oil-bearing layers after most of their oil has been tapped by exploitation have their pores principally filled with gas under a much lower pressure than adherent to their depth, are not allways immediately invaded by water and that mines at a great depth may have a small influx of water, but such conditions could not last for the duration of geologic periods (The Berea sand which is supposed to be dry is of Mississippian age).

A question to be answered is, whether there is any evidence of the occurrence of porous and well permeable beds filled with air under a pressure of one atmosphere at great depth. Some advocates of this principle believe that it is proved by the fact that a borehole in such sands is not immediately filled with water, whereas the shallower sands when pierced by the drill show abundant water. This again can be explained by a great resistivity with respect to the motion of water, owing to the narrowness of the pores. Another argument should be that in certain cases the sands which are supposed to be dry, take up water from the borehole with great avidity. This, however, proves only that sands with little resistivity to motion of liquids or gases have been encountered, in which the pressure of the liquid is perhaps slightly lower than in the borehole.

[1]) Only when the proof of this paper was ready the writer received KEMP's original paper (VII of the list at the end of this paper). It appears that the loss of water from sediments was not entirely attributed to heat; other factors were also assumed to be involved.

If the liquid in the borehole is a mudladen water there may be a considerable excess of pressure in the hole.

Therefore the two mentioned observations which are cited as proofs of the sand being dry and containing only air under atmospheric pressure, do not prove this point at all. The first, that such sands outside the oil accumulations have a great resistivity, on the contrary is in agreement with the writer's explanation of the occurence of oil and gas outside the anticlines, which will be explained hereafter.

Moreover it was stated, that the fact that cores from the oil-bearing part of the so-called dry strata are not saturated with oil when they come to the surface, points to the conclusion that these strata are unsaturated and have low pressures.

One should however not lose sight of the fact, that oil contains dissolved gas, which is liberated when pressure is diminished, so that cores when brought to the surface are never saturated with oil, the escaping gas expelling part of the oil. In coarse sands this may be accomplished sooner than in fine grained sands, but the phenomenon must under all circumstances be perceptible. So in the writer's opinion no proofs of the dryness of certain sands and of the low pressure prevailing in them have been supplied.

The only observation which has lead to the conclusion that certain beds are dry, is that oil therein occurs outside the anticlinal regions. As for the rest the conclusion is merely based on hypotheses. These hypotheses partly concern the way in which the supposed state of dryness has arisen.

Furthermore they are the old theory that oil rises to the anticlines as a consequence of its small specific weight, whilst unconsciously two other principles have been adopted:

1st. that such beds are uniformly porous, and

2nd. that they are overlain and underlain by absolutely impermeable layers.

Regarding the first of these two points the reader may refer to a former paper [1]) in which the writer uttered the opinion that difference in specific gravity of the fluids in the earth's crust is probably not the main cause of accumulation of oil and gas in the anticline. This question he proposes to expatiate on in a future paper.

In his opinion the fine globules of oil and bubbles of gas carried along by the water, which circulates through the pores of the sediments, are left behind in the coarser portions. Generally speaking it can be said that this water moves from the mountains to the lowlands, mainly longitudinally through the coarser layers and tranversally through the finer ones. Principally in the anticlines where all layers come nearest to the surface, water rises across the finer layers from one coarse layer to the next overlying it, so that the anticlines are favorable places for the accumulation of oil

[1]) "Compaction an agent in the accumulation of oil at the anticlines", These Proceedings XXXIII, pp. 990—995, 1930.

and gas. This is not true of the anticlines near the mountains, where the altitude of the surface may be so high, that the reverse takes place. The flow of water from the mountains to the lowlands may partly be caused by compaction, due to orogenic pressure, as suggested by M. R. DALY [1]), but in the writer's opinion it is probably mainly a consequence of the differences of altitude at the surface of the earth. This opinion is supported by the fact that the anticlines in or near the mountains are generally not oil bearing in formations which contain oil further afield. This means that the anticlines are only oilbearing in the lower regions where water rises to the surface. In case, however, the coarser layers are not uniformly porous, but composed of coarser and finer parts, during its longitudinal motion water goes over from finer to coarser portions, so that the accumulation of oil and gas may take place in any coarser patch of the sands or sandstones.

The occurence of oil and gas in the anticlines or synclines could quite well be explained as a consequence of differences of the cross-sections of the pores in the different portions of the sand. If this explanation is adopted, the improbable existence of strata containing air under atmospheric pressure at great depth can be abandoned.

There is some evidence against the theory of strata being partly filled with oil and water and partly with air under atmospheric pressure. The wells in synclinal oil accumulations flow naturally. This means that such oil contains gas which is dissolved under a considerable pressure. If such oil were stored in the deeper parts of a porous bed containing only low pressure air, the oil would first rise in the shape of a foam and then gradually percolate slowly down to the synclines, or to the top of the water filling the lower part of the bed. The gas would then spread evenly through the higher parts of the bed, up to the crests of the anticlines. Moreover in some descriptions of synclinal oil it is stated, that there was high pressure gas above the oil, but yet the authors of such papers asserted that the anticlinal portions are filled with air under low pressure. This is not possible if the bed is porous throughout. The writer's conception is, that oil and gas accumulate at the anticline if the bed may be considered uniformly porous but if there are finer and coarser portions in a sand or sandstone, oil and gas may accumulate in the coarser portions, independent of their place as to the structure. The pores of the finer portions then are water filled.

Besides oil might occur in the syncline in uniform layers should there be sufficient gas to fill the higher parts of the structures. This has been pointed out by the writer in a previous paper. (See No. XXXI of the list at the bottom of this paper.) It appears from the descriptions of several fields that this actually may occur. There are, however, theoretic grounds to believe, that the total height, over which a layer can be gas filled, is

---

[1]) "The diastrophic theory". Am. Inst. Min. Eng. Trans. LVI, pp. 733—753, 1916.

limited. [1]) Even at a considerable depth, the prevailing pressure is not high enough to compress the gas to a specific weight which approaches that of water. Therefore, when at the bottom of the gas filled part of a layer the pressure is equal to the pressure inherent to the depth, at top the pressure of the gas must be considerably lower than of the contiguous water in the overlying finer grainted layer. This difference must be outweighed by capillary forces, which however, are limited. Consequently, if the height of a gasaccumulation exceeds a certain limit, it will penetrate the caprock and rise to the next higher coarse layer.

Several accumulations of oil which are said to be synclinal seem to be situated in small shallow secondary synclines in anticlines, or in the synclinal folds in the flanks of anticlines or domes, so that such oil occurrences can also be called anticlinal.

There are oilfields, in the outcropping part of sands, the top parts of which are sealed with asphalt. If such a layer is tortuous, the sloping synclines may be oil bearing, but this has little to do with the occurrence of oil in real synclinal troughs.

Perhaps the occurrences of true synclinal oil are not so numerous as it might be inferred from literature.

Summarizing the writer would state as his belief that the existence of unsaturated strata at depth, overlain by water filled beds is very improbable and that no actual proof for their existence has been furnished. Such a hypothesis has only been put forward in order to link the observation of synclinal occurrence of oil with the buoyancy theory. In the author's opinion, however, this phenomenon can be explained on the assumption that formations which bear oil outside the anticlines have variable porosity. The main cause of the accumulation of oil or gas in the anticlines as well as in the synclines and on the flanks would not therefore appear to be buoyancy, but might be more logically attributed to the flow of water together with the tendency of oil and gas of not leaving coarser strata or coarser portions of the strata when they have once entered them.

---

[1]) See: "Compaction an agent etc.", l.c.

LITERATURE ON DRY OR UNSATURATED STRATA.


I. A. S. COOPER: "The genesis of petroleum and asphaltum in California". *Cal. State Mining Bureau, Bull.* **16**, Dec. 1899.

II. L. H. WOOLSEY: "Economic geology of the Beaver Quadrange. Pa". *U. S. Geol. Survey, Bull.* N°. **286**, 1906.

III. R. W. STONE and F. G. CLAPP: "Oil and gas fields of Greene County, Pa", *U. S. Geol. Survey, Bull.* **304**, 1907, pp. 79—82.

IV. W. T. GRISWOLD and M. J. MUNN: "Geology of oil and Gas fields in Steubenville, Burgettstown and Claysville Quadrangles". *U. S. Geolog. Survey, Bull.* **318**, 1907.

V. R. ARNOLD and R. ANDERSON: "Geology and oil resources of the Santa Maria. oil District, Cal.". *U. S. Geol. Survey, Bull.* **322**, 1907.

VI. ———————: "Preliminary report on the Coalinga oil district. Cal." *U. S. Geol. Survey, Bull.* **357**, 1908.

VII. J. F. KEMP: "Waters, meteoric and magmatic". *Mining and Scientific Press*, XLVI. pp. 705—708, 1908.

VIII. H. F. BAIN: "Geology of Illinois Petroleum Fields". *Econ. Geol.* III, pp. 481—491, 1908.

IX. W. T. GRISWOLD: "Structure of the Berea oil sand in the Flushing Quadrangle". *U. S. Geol. Survey Bull.* **346**, 1908.

X. M. J. MUNN: "The anticlinal and hydraulic theories of oil and gas accumulation". *Econ. Geol.*, IV, pp. 509—529, 1909.

XI. C. W. WASHBURNE: "The Florence Oil Field, Colorado", *U. S. Geol. Survey, Bull.* **381**, pp. 516—544, 1910.

XII. M. R. CAMPBELL: "Historical review of the theories advanced by American geologists to account for the origin and accumulation of oil". *Econ. Geol.* VI, pp. 363—398, 1911.

XIII. R. H. JOHNSON: "The necessity for a theory of differential cementing in prospecting for oil". *Econ. Geol.* VII, p. 708, 1912.

XIV. M. J. MUNN: "The Menifee Gas Field and the Ragland Oil Field, Kentucky". *Bull. U. S. Geol. Survey* **531**, pp. 9—26, 1913.

XV. D. D. CONDIT: "Oil and Gas in the northern part of the Cadiz Quadrangle, Ohio". *U. S. Geol. Survey Bull.* **541**, pp. 9—17, 1914.

XVI. R. H. JOHNSON: "The rôle and fate of connate water in oil and gas sands". *Trans. A. I. M. E.* LI, pp. 587—592, and discussion by various authors, 1916.

XVII. F. REEVES: "The absence of water in certain sandstones of the Appalachian oil fields". *Econ. Geol.* XII, pp. 354—378, 1917.

XVIII. E. W. SHAW: "Discussion on F. REEVES' paper (N°. XVI). *Econ. Geol.* XII, pp. 610—628, 1917.

XIX. R. VAN A. MILLS and R. C. WELLS: "The evaporation and concentration of "waters associated with petroleum" ". *U. S. Geol. Survey*, Bull. **639**, 1919.

XX. D. HAGER: "Practical oil geology". 3rd edition, pp. 55—57, 1919.

XXI. R. G. MOORE: "General Geology of oil and gas". *State Geol. Survey of Kansas Bull.* **6**, pp. 48 and 52, probably 1921.

XXII. J. L. RICH: "Shoestring sands of Eastern Kansas". *Bull. Am. Ass. Petr. Geol.*, pp. 103—113, 1923.

XXIII. A. BEEBY THOMPSON: "Oilfield exploration and development". *Vol.* I, pp. 191—192, 1925.

XXIV. W. L. RUSSELL: "Relation between isocarbs and oil and gas production in Kentucky", *Econ. Geol.* XX, pp. 249—260, 1925.

XXV. J. L. RICH: "Further observations on shoestring oil pools of Eastern Kansas", *Bull. Am. Ass. Petr. Geol.* VI, pp. 568—580, 1926.

XXVI. B. HARTLEY: "Certain relations between production and structure in Northern Osage County, Oklahoma", *Bull. Am. Ass. Petrol. Geol* VI, pp. 1035—72, 1926.

XXVII. R. D. BUSH and V. H. WILHELM: "Production losses into low pressure oil and gas sands". *Summary of operations in California Oil Fields, Calif. State Mining Bureau.* XII, N°. **5**, pp. 5—12, Nov. 1926.

XXVIII. J. F. ROBINSON: "Geology of the Appalachian Territory". *Oil and Gas Journal*, June 16, 1927, pp. G 12—G 30.

XXIX. H. H. CHARLES: "Oil and Gas resources of Anderson County, Kansas". *Bull. Univ. Kansas* XXVIII, N°. **12**, 1927.

XXX. W. T. THOM: "Synclinal oil occurrence and regional uplift". *Bull. Am. Ass. Petr. Geol.* XII, pp. 554—555, 1928.

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

XXXII. "Structure of typical American Oil Fields", *Vol.* I, 1929 (Symposium).

XXXIII. "Ditto", *Vol.* II, 1929.

XXXIV. C. CRONEIS: "Geology of the Arkansas Paleozoic area". *Ark. Geol. Survey. Bull* **3**, 1930.

XXXV. W. A. VER WIEBE: "Oil fields in the United States". New-York 1930.