Geology. — *Synclinal oil and unsaturated strata.* By J. VERSLUYS.

(Communicated at the meeting of December 22, 1928).

Petroleum and natural gas have, as a rule, the tendency to accumulate in the coarser strata, and in particular in the structurally highest parts of these strata. This was observed as far back as 1855 by OLDHAM, who found in a field in British India that wherever possible the oil accumulates on the anticlines. Others soon found an explanation for this phenomenon in the lower specific gravity of gas and oil as compared with that of water.

That oil and gas are mostly found in the coarser strata is to be attributed to the fact that these strata are least reduced in volume by compaction and that they form the drainage channels of the formations. The finer-grained strata, in which presumably oil and gas chiefly arise, are compressed by the burden of the overlying sediments and by orogenetic processes, the liquid (water with a little oil) and gas contained therein being forced out. Probably this is in the beginning only caused by compaction but as soon as so much gas has been generated as to be no more completely absorbed by oil and water, liquid and gas will also be expelled from the finer grained strata without further compaction. The liquid and gas then seek their way through the coarser layers, where resistance is least. Since most sediments, both coarse and fine grained, are composed of minerals which are more easily wetted by water than by oil the latter, once it has entered a coarser layer, will not readily pass out again into a finer grained layer for the area of the interface of the solid particles and water would have to decrease and the area of the interface of solid particles and oil would have to increase, which would require some work.

The same applies to gas. Thus the accumulation of oil and gas in the coarser layers — in which they have not originated — may be a result of compression and of the difference in interfacial tension with respect to the minerals of the sediments. The water pressed out of the finer grained strata by compression finds its way through the coarser layers, thereby easily entraining oil and gas. It will then leave the coarser strata again, principally in the anticlines, and find its way vertically through the finer layers, leaving the oil and gas behind because these as it has been stated heretofore, do not easily go over from a coarse to a fine grained layer, on account of the interfacial tension. In this manner the occurrence of oil and gas accumulations on anticlines can be partly accounted for without the aid of the difference in specific gravity. After anticlinal accumulation has taken place to a certain extension, however, no water can escape at the crest and further accumulation is only due to the difference in specific gravity.

Apart from the deviations from the anticlinal theory which agree with the above, there are also cases of deviations which appear to be contradictory to the generally accepted theory that the difference in specific gravity causes accumulation in the structurally highest parts. This is the not infrequent occurrence of oil in synclines. It has been supposed, however, that this could be made to agree with the theory that accumulation is a result of the difference in specific gravity, by assuming the strata with synclinal oil accumulations as being "unsaturated". By this it is meant that these strata with synclinal oil contain little or no water, so that the oil, instead of floating on the water in the structurally highest parts, precipitates in the dry strata down to the lowest parts, thereby forming accumulations in the synclines.

It seemed highly improbable to the author that at a great depth strata should occur the pores of which are not filled with a liquid or gas under high pressure, and as many data as could be obtained from literature on the subject were collected. "Unsaturated" has a very elastic meaning, but a careful study showed that many writers do, indeed, believe that it is possible for strata originally not saturated with water to be buried by younger layers and be ultimately found at a great depth still in the dry state. It has been presupposed that deposits like f.i. the sand dunes along the coast of Holland may in course of geologic time become deepseated unsaturated layers. The unsaturated state of these strata is called "connate dryness" by some authors. Thus advocates of the unsaturated strata theory assume that these layers may bear oil in the synclinal parts and air under a small (atmospheric ?) pressure in the structurally higher parts. Nevertheless in literature mention is repeatedly made of the occurrence of gas in these layers, and also of the rising of synclinal oil in wells. The supposedly unsaturated strata, therefore in addition to bearing the oil which lies on the synclines, must contain gas under pressure.

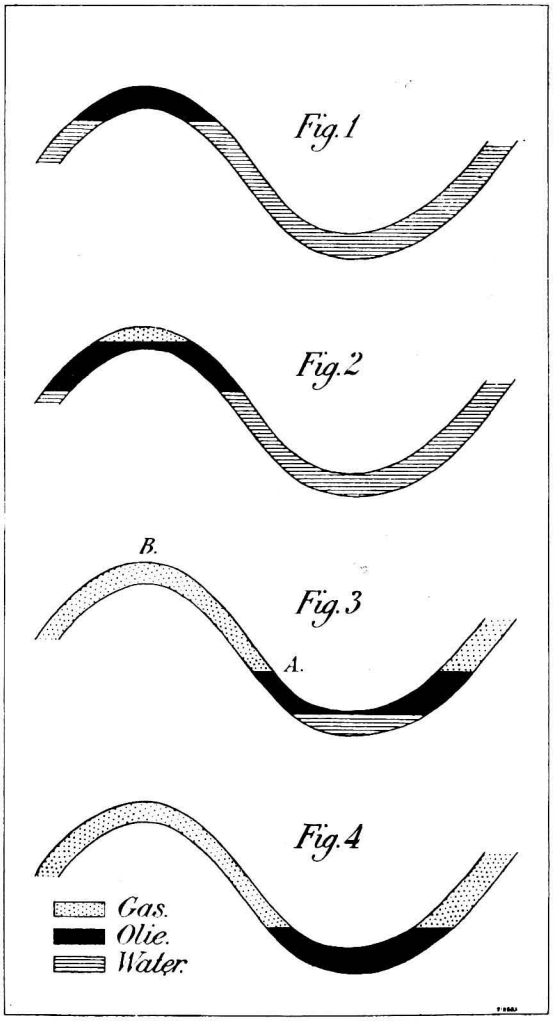
The author's attention was drawn to a description of synclinal accumulations in a treatise by Homer H. CHARLES of the Oklahoma Natural Gas Corporation, Tulsa (Okl.), The author corresponded with this geologist, who most courteously furnished him with all the particulars asked for. It appears that the structurally higher parts of the strata bearing oil in the synclines near Altoona (Kansas) contain gas under a pressure which does not differ much from the hydrostatic pressure which would prevail at the respective depth.

Whilst the anticlinal occurrence of gas and oil may be represented by figs 1 and 2, according whether free gas is present or not, the synclinal occurrence of oil will be represented in the same way by figs. 3 and 4. In synclinal oil accumulations the gas cap is greater and the water is restricted to the syncline, or is entirely absent.

Moreover it occurs that coarser layers, both on the anticline and on the syncline, contain gas exclusively. In such a case in fig. 4 the oil would have to be replaced by gas.

There is, therefore, a transition from anticlinal oil accumulations without gas caps, through those with gas caps, to the synclinal accumulations, next to which are the folded strata which bear nothing but gas.

In addition to gas, oil and water bearing layers, there are also layers



Olie = Oil

which bear only gas and water, whilst, furthermore, there are layers in which the amount of oil separating the water from the gas is of the minutest quantity. Thus in the conditions represented by figs. 1—4 the amount of oil may be very small or entirely absent. A question is whether these conditions are permanent.

The natural gas, which consists mainly of methane, is soluble in petroleum and in water, much more in the former than in the latter.

If the quantities of oil and gas do not change, a variation of the pressure

will cause a change in the volume of the gas, for if the pressure increases, more gas will dissolve in the liquids, and the volume of the not dissolved gas will be reduced by compression.

It is therefore conceivable that if more discordant sediments are deposited the pressure in the deep-seated oil and gas accumulations will increase, and the gas will be compressed. Consequently the gas caps will become smaller, so that the water in the syncline and the slopes will occupy a greater part of the layer. In the case of an oil-bearing layer coming nearer to the surface (through erosion) the gas cap might become larger and a smaller part of the layer on the syncline be occupied by water. This effect is partly counter-balanced by the changes of temperature according to the changes of depth, which also would influence the volume occupied by the gas cap. So the influence of sedimentation and erosion is probably of little importance There are, however, two other grounds for assuming that as a rule the condition in which oil and gas exist is subject to change.

If a gas cap has a considerable height the pressure of the gas will not everywhere balance that of the water in the adjacent finer-grained layers. If, for instance, there is an equilibrium at A in fig. 3, then at B there will be an excess of gaspressure and the interfacial tension will not always be able to prevent the gas from entering the finer grained layers also. Therefore it is not at all certain that gas-bearing layers or oil-bearing layers with a gas cap indeed form a condition which is geologically stationary.

Natural gas is found in very recent deposits, among other places in Holland, Suriname and the Mississippi delta, where it is to be supposed to have originated direct, and is still being developed, from the organic matter enclosed in the respective deposits. This process may also continue in older deposits. Some geologists now believe that in the course of time oil is converted, thereby giving gas. But the gas, coexisting with the oil, as a rule is principally methane and consequently by the generation of gas from the oil, the remaining oil would contain less hydrogen. So it is more probable, that gas is still formed in the finer grained strata and enters the coarser beds. In this manner the gas of the oil and gas deposits would in time increase in quantity. As remarked above, after a gas deposit or a gas cap over an oil deposit has reached a certain height, gas will be lost again in another way.

In support of the theory of the development of gas near or in already existing oil deposits is the fact that here and there the so-called reservoir pressure of the oil and gas deposits may be hundreds of pounds higher than the hydrostatic pressure which should prevail at that depth, without this pressure being accounted for by the proximity of mountains.

It is, therefore, to be assumed on the one hand that in the anticline the gas gradually disappears from the coarser layers in which it is enclosed, but that on the other hand it continues to develop so long as oil and other organic matters are present. Where there is a considerable gas cap or the oil lies in the syncline, the latter process predominates.

Apart from the gas which is found in the coarser layers, and which the American geologists term "reservoir gas", in many cases also shales contain gas. This is called "shale gas" and occurs, for instance, in black shales near the synclinal oil deposits close to Altoona, Kansas (according to a map the author received from Mr. H. H. CHARLES). Therefore there is every reason to suppose that here gas is still being developed. Either it is still formed from the organic components of the black shales, or it continues to develop from the oil which it has already pushed into the syncline. The former of these possibilities is the most acceptable.

According to the above the syclinal accumulations of petroleum show only a gradual difference from the oil deposits with gas cap, and the supposedly unsaturated strata are layers containing natural gas under a pressure governed by the same laws as those of the oil-bearing layers.

An extensive treatise dealing with the literature on the subject will be published elsewhere.

A word of thanks is due to Mr. HOMER H. CHARLES of Tulsa, to whom the author is much obliged for the information with which he was so kindly furnished.