(=7.285), the agreement would be far less satisfactory: 21.64 instead of 24. From this consideration it may also be concluded, that the *tin* in *PtSn* is present in a condition, which is nearer to that of *grey*, than to that of white tin. Contrary to TAMMANN's and ROHMANN's suggestion (loco cit. p. 236), the heat-capacity of *PtSn* is *smaller* than the sum of those of the elements, although its specific volume is *greater* than the sum of the atomic volumes.

Further experiments of this kind now going on in this laboratory, will soon bring still stronger evidence of the fact, that the so-called "law of additive atomic heats" is certainly *not* valid for intermetallic, homopolar compounds. It is most probable then, that, *a fortiori*, it will be neither valid for *heteropolar* chemical compounds. Also this last conclusion will afterwards be tested by experiments.

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Geology. — *Migration and accumulation of oil and gas.* By J. VERSLUYS.

(Communicated at the meeting of April 2, 1932.)

Two points should be borne in mind when considering the occurrence of oil and gas in the earth's crust. Firstly, that they are encountered in the coarse sediments. Secondly, that the majority of the known oil and gas fields are situated in the highest parts of the structures, unless a fault acts as a barrier, in which case oil and gas accumulate in a coarse layer underneath it.

The problem of oil and gas concentration especially in the coarser strata was not at first considered by geologists, nor has it generally been recognized what filled the pores of the finer sediments. Without considering, properly, the reasons for the accumulation of oil and gas in the coarser sediments, the general opinion was that the coarser sediments are the only depositions which have sufficient pore space to contain oil, while the finer sediments were said to be tight. Accordingly the coarser beds, which have no exposures at the surface, are often erroneously regarded as closed reservoirs.

If it is taken for granted that oil and gas rise to the uppermost parts of the coarser strata owing to their lower specific gravity as compared to water [1]), and are retained there, a certain rôle is attributed to the finer grained strata, viz. that they act as barriers to the motion of oil and gas. As it has been remarked already, they were simply said to be tight. In the

[1]) With regard to buoyancy, the so called "shoreline pools" (XXI) and oil accumulations under planes of unconformity are under similar conditions as anticlinal fields.

argillaceous beds, however, there are fine pores and these are waterfilled. The reluctance of oil and gas to penetrate fine pored strata cannot be explained by frictional resistance of flow through such very fine pores, since the energy consumed by friction in liquids and gases when flowing through such strata approaches zero, as the motion becomes infinitely slow. This would mean that oil and gas could not be retained in a coarse bed for a geological period and hence all the oil and gas in the accumulations had not reached a stable state but would be still ascending.

In a former paper (XV) the writer argued that when accumulated oil or gas from a coarser porous medium penetrate a finer one, the pores of which are waterfilled, so that oil or gas would have to displace water which inversely would take the place the other fluids have made vacant, the total molecular energy must increase, so that then a certain amount of work is required to be done. In a similar way fine grained strata act as screens, when water, which has small globules of oil or bubbles of gas in suspension, is forced through them (see XV). A certain pressure is needed to make an accumulated mass of oil or gas from a coarse bed penetrate a fine stratum and a force is needed to push fine globules of oil or bubbles of gas into a finer layer. Thus one can say that under the conditions prevailing in the earth's crust, viz. that all strata are water saturated, except where they are oil and gas bearing, the latter two are adverse to enter fine grained strata.

This aversion of oil and gas, when disseminated in water, may account for their accumulation at certain points in the earth's crust. Such accumulation would occur where a current of subterranean water from a coarser layer enters a fine layer and furthermore where such a current leaves a coarser portion of a layer to enter a finer portion of one and the same layer.

Instead of adhering to the old theory that buoyancy was the only cause of the tendency of oil and gas to accumulate in the highest parts of the structures, the writer in a former paper advanced the principle that the subterranean water which is squeezed out of the strata due to compaction, tends to rise at the anticlines. It flows longitudinally through the coarser strata towards the tops of the anticlines, here it ascends nearly vertically across both the coarser and the finer beds. So at the tops of the anticlines, on account of the aversion of oil and gas to enter a finer pored medium, they are retained in the coarser beds (XV).

Thus the compacting pressure squeezes oil and gas laden water out of the finer grained strata into the coarser beds. In the latter the water migrates longitudinally towards the crests, entraining the confined oil and gas. Near the crests however the upward transversal flow causes oil and gas to be screened out and remain in the coarser strata (XV). An investigation into the problem of subterranean water circulation, however, leads to the conclusion that not only does the water squeezed out by compaction flow longitudinally through the coarser beds towards the crests of the anticlines where it rises across all the strata (except at the anticlines in the mountains or the foothills) but the same is true for the flow of water which could be called "the sub-continental circulation".

Part of the water precipitated from the atmosphere penetrates the earth's crust, percolates through the pores and drains mainly towards the nearby riverbeds. So does all the water percolating in the lowlands. A considerable portion of the water, however, which has penetrated the soil in the mountaneous regions and the highlands, follows a long path through the earth's crust and rises in the lowlands. It unites there with the percolation water of these regions and discharges into the river beds. Part of the percolation water from the continents drains towards the sea. It takes a long time, however, before the percolation water from the mountains or the highlands has displaced all the water which already filled the pores of the strata underlying the lowlands or the sea, so that the stage when percolation water which circulates through the coarser strata under the low lying regions and tends to rise there actually is percolation water, in many cases has not yet been reached. Thus, in many low lying regions, the ascending water is still more or less connate water which was confined in the strata at the time of their deposition. The percolation water of the high lying regions, which starts the „*sub-continental circulation*", does not only enter the outcropping coarser layers but it also enters the outcropping finer layers. The coarse layers however are the real carrier beds, taking care of horizontal, or more properly, of the longitudinal transportation of the water — even when they have no exposures in the highlands or in the lowlands — whereas the water entering the exposed parts of the finer grained strata moves nearly perpendicularly across these layers until a coarser layer is reached.

In the highlands the motion through the finer grained strata generally has a downward trend whereas under the lower lying areas it rises vertically through the finer strata. Not only does the percolation water from the highlands — or the connate water which is pushed ahead of it — in this way ascend in the lowlands, but also does the excess water from compaction at depth as mentioned at the beginning of this paper rise in this way. On account of the pressure head of the water in the highlands and the mountains it often occurs that the water of each deeper coarse stratum tends to rise in a borehole to a higher level than that of the overlying beds, and this phenomenon in many low lying plains gives rise to the occurrence of artesian water (which has sufficient pressure head to rise above the surface of the earth). So one can say that the *potential* [1]) of the subterranean water under the lowlands as a rule tends to increase with depth (XIV). The difference of potential between two adjacent coarse beds may be considerable owing to the great resistivity of the parting finer bed. In one and the same coarse bed, however, the potential, although generally

[1]) This expression has been used by the writer since 1911. (Het beginsel der beweging van het grondwater, Amsterdam 1911). In 1914 it was also used in the report of the first Interstate Conference on artesian water in Australia.

decreasing from the mountains towards the middle of the plains, shows only slight variation over considerable distances. Therefore the potential in each one coarse layer in neighbouring anticlines and synclines is approximately the same. This means that in the anticlines the subterranean water with a certain potential lies nearer to the surface than in synclines, which makes the anticlines the most favourable places for the discharge of the underground water flow. Consequently most water of the sub-continental flow, which follows the coarser beds longitudinally, rises vertically at the anticline across both the finer and the coarser beds. (Probably the fact that water from a syncline following the trend of the layers comes nearer the surface in the adjacent anticline which is farther away from the mountains and the ascension of water across the beds at the anticlines, are responsible for the higher temperatures observed in many anticlines.) Where the water crosses a finer bed, the entrained globules of oil and bubbles of gas are withheld at the base of such a bed and they accumulate at the anticline. This principle — that anticlines are the places where water of underground circulation escapes — was evolved by the writer in 1930 (XV). J. L. RICH in a recent paper on other grounds comes to the conclusion that anticlines are the places where oil and gas from the water in the *„carrier beds"* [1]) accumulate. This geologist, however, lays more stress on an escape of water through fissures.

Probably the final concentration of oil and gas at the anticlines is aided by buoyancy (XV). When a certain amount of oil or gas has accumulated in the topmost portion of a coarse bed, buoyancy causes the oil or the gas to exert a certain pressure on the liquid in the overlying finer grained layer. At the crest of the structure the pressure is proportional to the height of the oil or gas accumulation, i. e. from the plane of contact of the edgewater and oil to the crest of the structure. It is counterbalanced by the intermolecular forces. These forces, however, can withstand but a certain pressure so that the height of the oil or gas accumulation cannot increase indefinitely. It is quite probable that in many cases the oil or the gas may penetrate the caprock and then they may partly or altogether rise to the next overlying coarse bed (see XV and XVII, p. 192). This perhaps explains why the plane of contact of oil or gas and edgewater in some coarse beds, separated by relatively thin shale layers may lie in the same level [2]).

It has already been mentioned, that along with the sub-continental flow of water which is stimulated by the percolation water of the highlands,

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[1]) The term "carrier beds" which was used by J. L. RICH expresses the idea very well.

[2]) The possibility that in some fields the oil is still rising to a higher horizon should not be precluded. The phenomenon that the higher horizons bear lighter oil than the deeper owing to adsorption, described by L. GURWITSCH ("The scientific principles of petroleum technology", London, 1926, pp. 127—128) when occurring is an indication that accumulated oil has ascended across argillaceous strata but it is also possible that this is still taking place.

also some water from the deeper strata, squeezed out by compacting pressure, has to discharge through the anticlinal folds.

In a former paper (XV) it has been set forth that not only are the argillaceous strata compressed, but that compaction also takes place in the coarser sandy strata. The compaction of the argillaceous strata is accomplished very easily and this is reversible. As it was emphasized formerly this compaction of the argillaceous strata is probably the main cause of the oil particles migrating into the coarser strata. It may or may not be finished before the structures are formed.

In the foregoing paragraph reference was made to the reversibility of compaction of argillaceous strata. The reversibility of compaction of clays is not complete, this has been proved by the laboratory experiments of C. TERZAGHI (XII) where clay after having been compressed, on expansion to its original pressure, did not entirely regain its original volume. C. TERZAGHI (XII) ascribed the compressibility of clay to elasticity of the particles, whereas the writer is of the opinion that for clay all phenomena of compression and expansion can be explained on the assumption that the water adsorbed at the surface bears a certain amount of potential energy, which increases when the mass is compressed and decreases when it expands (XIII). The inability of clay to expand to its original volume after compression, that is to say the incompleteness of the reversibility of compression, may be a consequence of a change of arrangement of the particles. The partial reversibility of the compaction of argillaceous strata is observed in boreholes; the shales expand when pressure is released and rise in the hole (the so called "heaving shales" see IV). The compaction of shales, however, has reached an equilibrium only under the prevailing compacting pressure. When water has an opportunity to escape from a shale it may be further compressed by the weight of the overlying strata. This phenomenon was the cause of the subsidence of the Goose Creek oil field (VII). So one can say that the argillaceous strata are in a state of equilibrium as long as the compacting pressure is not very large, and dissolution and recrystallisation have not commenced. Therefore. compaction of argillaceous strata may continue for a long time owing to a continued increase of burden and it is possible that after a period of rest, it will be resumed or reversed. Hence the migration of oil and gas from argillaceous beds into the coarser beds can be continuous, but it can also be interrupted and recommence afterwards.

The compaction of the arenaceous strata on the contrary is a more continuous phenomenon. The grains of sands can be crushed when pressure is sufficiently high but it has been proved experimentally (XIX) that the thickness of the superimposed strata, which could accomplish this, must be so great that before such crushing of the grains would take place, the arenaceous strata have been compacted probably, as described in a former paper, through dissolution and redeposition.

In a former paper (XV) the writer explained that the action of gravity on the superimposed strata performs work, when the grains are dissolved at the points of contact, and at the same time material is deposited on the surface of the grains farther away from the point of contact, which means that compaction in this way will actually be established. This manner of compaction also applies to the argillaceous strata. E. RIECKE's conception (X) of this compaction was somewhat different.

The protracted compaction of the arenaceous and of the argillaceous strata may add some water to the sub-continental flow (XV) and in conjunction with this bring about the ascending motion of water at the anticlines, which in the writer's opinion is the main cause of accumulation of oil at the anticlines. The sub-continental flow however dominates. M. R. DALY (II) attributed the subterranean flow which in the present paper is denoted by "the sub-continental flow" to the "diastrophic" compaction which, however, in the writer's opinion is of less importance than the flow which is sustained by the percolation water of the high lying regions.

In the foregoing pages the theory is advanced, that accumulation of oil and gas at the anticlines has to be ascribed to compaction which forces these fluids from the argillaceous layers into the arenaceous beds.

The sub-continental circulation of subterranean water carries oil and gas through the crests of the anticlines, where the water rises vertically across the coarse and the fine beds both. Owing to the aversion of oil and gas to enter fine strata, they are left in the coarse strata near the crests. This would be the case if the texture of the arenaceous strata were homogeneous. When the texture however varies in one and the same bed, accumulation of oil and gas may occur in the coarser patches of such a bed.

In a former paper (XVI) the problem of the occurrence of oil and gas accumulation in the synclinal regions and on the flanks was treated. The theory that strata bearing oil or gas on the flanks and in the synclines should be dry or unsaturated was contradicted in that paper, and it was stated that such occurrence can quite well be attributed to differences in the texture of the strata. As stated previously, the aversion of oil and gas to penetrate a fine grained strata, tends to keep them in coarse patches of sandy strata. Thus when the sub-continental flow makes its way through a fine grained sand, oil and gas accumulate in the coarser patches. This explains why in most synclinal oil fields the edgewater encroachment as a rule is very slow. The oil occupies the coarser portions of the sand, while the finer grained parts are left to the edgewater. Therefore, in such fields oil may be propelled at a considerable rate towards the wells by the liberated gas, whereas a great resistance is offered to the flow of edgewater on account of the fineness of the pores outside the oil bearing part of the sand. This difference of texture may be accentuated through compaction, as the compaction through dissolution and redeposition stops as soon as the pores become oil or gas filled (see XV and XVII).

In many respects the writer's conception of accumulation agrees with the hydraulic theory of accumulation by M. J. MUNN (VI) and J. L. RICH

(IX). These authors, however, did not ascribe the anticlinal accumulation to the ascension of subterranean water at the anticlines, but they attributed it to an alteration of the velocity and the direction of the motion. Shortly after the writer published his first paper (XV) on the anticlinal discharge of subterranean water, J. L. RICH independently (XX) also brought forward a theory of the rise of water towards the anticline, but based on a different principle viz. that faults were responsible for it [1]).

There is another point which still further emphasizes the correctness of the above principles (see XVIII). D. HAGER (V) drew the attention to the inclination of the plane of contact between oil and water in anticlinal oil fields. He pointed out that the contact of oil and water in an anticlinal structure has a slope and that on the steeper side of the fold the water rises higher than on the flatter side and that oil extends further down the plunges than would be expected from observations on the flanks. HAGER did not refer to any literature, but his conception seems to be derived from C. H. BEAL's (I) description of the Cushing field in Oklahoma.

Very shortly before BEAL, J. L. RICH (VIII) described similar conditions for fields in Birds Quadrangle, Illinois. RICH gave an explanation of the phenomenon, which in the writer's opinion is the most probable and which quite agrees with the theoretical views set forth in the foregoing pages. RICH was of opinion that the inclination of the surface of contact is due to differences of pore sizes in the sand, or in other words, capillarity is an important factor in the shape of oil accumulations. The correctness of RICH's opinion is supported by the fact that the sand in which he observed an inclined plane of contact between oil and water, also contained smaller lenticular oil accumulations. C. H. BEAL in his above mentioned description of the Cushing field (I p. 39) remarks that the oil bearing sand was not of a uniform texture.

M. R. DALY (III) ascribed the deviation of the surface of contact between oil and gas in the Cushing field from a horizontal plane to the differentials of pressure which cause the motion of the water in the sand. These differentials in the opinion of said author are a consequence of diastrophic pressure. The writer believes that such differential pressures respectively differential potentials which in his opinion are caused mainly by differences of altitude at the surface may indeed have some bearing on the shape of the plane of contact, but it seems to him that the influence of capillarity is preponderent. The fact that in certain anticlinal oil fields the productive area is sagged, independent of the structure, may in the same way as the above described phenomena be attributed to differences of texture, if faults cannot account for it.

It often occurs in oil fields that a thin shale parting separates — at least

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[1]) J. L. RICH's principle concerning the ascension of oil and water at the anticline are more fully explained in a new article (see: *Bull, Am Ass. Petr. Geol.*, March 1932, Vol. XVI, N⁰. 3, pag. 265) written by this author, which came to hand after the writer had finished his present paper.

over a limited area — an oil bearing top sand from a water bearing bottom sand. J. S. ROSS (XI) recently described such a case but he mentioned that the bottom sand was calcarious and argillaceous. Perhaps in many such cases it is not exactly the thin parting layer which separates oil from water, but are the different conditions under and above this parting, caused by a difference of texture. Thin layers are liable to be broken, so that they could hardly establish a permanent partition.

It might be worth while to study all phenomena like irregularity of the boundaries of anticlinal oil fields, inclination of the plane of contact of oil and water from the standpoint, that variation of texture is an important factor in all matters of oil and gas accumulation. When such phenomena are encountered, they may indicate that the texture of the formation is irregular, so that accumulations are not of necessity limited to the anticline.

It may be concluded from the above pages:

1. that the most important factors in accumulation of oil and gas are:

a. the intermolecular forces which bring about an aversion of the disseminated as well as of the accumulated oil and gas to leave the coarser strata or the coarser portions of such,

b. the sub-continental groundwater circulation, which is the subterranean flow of water from the mountains and the highlands longitudinally through the coarser beds ascending in the lowlands mainly at the anticlines.

c. the discharge of the excess of water at depth created by compaction of strata: this discharge follows the same paths as the ascending water of the flow mentioned sub *b*,

d. compaction of argillaceous strata which forces the connate water they contain with disseminated oil and gas into the coarser beds;

2. that the rôle to be attributed to buoyancy is mainly to establish the final concentration of oil as well as gas during and after the accumulation by the continental groundwater circulation;

3. that the tardiness of edgewater encroachment during exploitation of certain fields which yield oil and gas quite readily, may be attributed partly to the differences of texture which are responsible for their accumulation, but also partly to the fact that compaction and cementation persist in the edgewater while they are discontinued where oil or gas fill the pores;

4. that synclinal oil and gas can only be expected in sands with tardy edgewater encroachment and an irregular shape of productive areas, where the irregularity is not caused by dislocations.

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Microbiology. — *On some physiological artefacts.* By A. J. KLUYVER and J. K. BAARS.

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§ 1. *Introduction.*

The existence and the wide distribution of thermophilic microbes, i.e. of micro-organisms which only proliferate at temperatures of 30° C. and higher, offer several problems to the physiologist. Mention may be made in this respect of the problem of active life at temperatures of 60—75° C.,