The Properties of Oils*

And Their Relation to Lubrication

George B. Upton¹

THE ordinary users of oils for lubrication of machinery, and many of the sellers, have very little notion of what those properties of oils are which are concerned in lubrication, and how lubrication comes about. Hence the following brief sketch of the meanings and purposes of various tests to which oils may be put.

1. *Test for Acidity.*—Acids in oils, in amounts greater than traces, cause rusting and pitting of metal surfaces, and will soon put shafts or bearings out of commission. Alkalis must also be avoided. Oils should be chemically neutral, neither acid nor alkaline. All oils form acids more or less rapidly in the presence of heat and moisture; more rapidly the greater the heat. With mineral oils this action is usually negligible; with animal and vegetable oils it is considerable. Soaps used to alter the viscosity of oils also decompose by heat. Mineral oils are often bleached during manufacture by the use of sulfuric acid, which may fail of removal or neutralization in the later processes, and so remain in the oil as sold. An oil which is neutral when purchased, and which does not get very hot in use, can be expected to stay neutral.

2. *Test for Ash.*—All pure oils, when heated and ignited in the open air, burn quite completely, leaving almost no ash. Mineral soaps put into the oils leave ash. The ash test, therefore, becomes practically a test for the presence of soaps in the oil. Whether or not these soaps are objectionable depends upon the use to which the oil is put. Soaps usually raise the viscosity of oils. Soaps are used freely in greases, and generally without objection. If the oil is to be used hot, however, the soap is liable to decompose and cause trouble by rusting of metals.

3. *Test for Carbon Residue.*—The oils consist principally or entirely of chemical compounds of carbon and hydrogen (hydrocarbons). About 90 per cent by weight of the oil is carbon in the ultimate analysis. When heated very hot the hydrocarbons decompose partially, forming volatile combustible gases and heavier hydrocarbons, or carbonaceous matter, and even elementary free carbon. Such free carbon (and carbonaceous matter), is always in solution or suspension in oils to some extent, from the processes of manufacture. Heated very hot in closed vessels, without ignition, the oils partially distill unchanged, and partially decompose. When this action is carried to the end point there is left in the flask a thin deposit of "carbon residue." Animal and vegetable oils, and mineral oils loaded with rosins or soaps, leave larger "carbon residues" than pure mineral oils, for which the residue is only a fraction of one per cent.

The "carbon residue" test has practically nothing to do with the amount of "carbonizing" by the oil in the cylinders and on the pistons of internal combustion engines, though it is often so taken. The conditions of the test are utterly different from the conditions in the engine cylinder. In the cylinder the oil is spread out in thin films on hot metal, and exposed to the burning gases of the "explosion." These gases may or may not carry an excess of oxygen to combine with the heated oil. The amount of carbon formed in the cylinder depends on the amount of oil reaching the cylinder and the conditions of exposure in the cylinder. The amount of oil depends on the mechanical fit of piston and cylinder, especially the condition of the piston rings, and on the viscosity of the hot oil on the cylinder walls. The lower the viscosity the more oil will go up past the pistons. After the oil has gone past the pistons a "lean" mixture in the combustion space will have excess oxygen to burn up the oil more or less completely, while a "rich" mixture will not have excess oxygen, the oil cannot burn, and the rich mixture may itself be depositing lampblack carbon.

4. *Oxidation Test.*—Oils gradually oxidize by contact with air at exposed surfaces of oil. The rate of oxidation increases with temperature. The product of the oxidation is resinous or gummy, and spoils the oil as a lubricant if much oxidation occurs. Mineral oils oxidize very little or not at all. Some, but not all, of the animal and vegetable oils oxidize very rapidly. An extreme case is that of linseed oil. The action commonly called "drying" of paint is really the oxidation of the linseed oil. A lubricating oil should be practically non-oxidizing.

An oxidizing oil brings in a considerable fire risk, because when spread out thin on oily waste or cloths it will often oxidize so rapidly at ordinary temperatures as to start "spontaneous combustion." This does not happen with a non-oxidizing oil. Any oily waste will

burn strongly after ignition; but a lubricating oil ought not to be able to start a fire of its own accord.

5. *Volatility Test.*—Oils vaporize without chemical change, just as water does. In some cases, where the oil is kept quite hot, the loss of oil by this vaporization, or volatility, may be perceptible. Usually the vaporization loss is small, and even less than leakage losses from a machine. Mineral oils are generally more volatile than animal or vegetable oils. Volatility of lubricating oils is of little practical importance.

6. *Surface Tension, or Capillarity.*—This, and the adhesion of oil to metal surfaces, are the forces which cause oil to spread over the metal, and to crawl into the thin spaces between bearing and shaft, or piston and cylinder, while the metal parts are at rest. Animal and vegetable oils adhere better to metal surfaces than do mineral oils. This property is especially important in steam engine valve and cylinder lubrication, where the oil must adhere to the metal so strongly that water, and the tendency of oil to float on water, cannot remove the oil film. Mineral oils, pure, may be displaced from a steam engine cylinder wall or valve seat by hot water. The adding of small amounts of animal or vegetable oil to the mineral steam cylinder oil helps the oil film to adhere. The good effect is important enough to counterbalance the bad tendency of the animal or vegetable oil to form acids. Where water is absent the mineral oils stick well enough on metal surfaces. Surface tension of lubricating oils is not usually noticed in testing.

7. *Color Test.*—Color of oil has no connection with lubrication. It results from the details of the manufacturing process. Mineral oils are naturally dark, or dark red, until the carbon and carbonaceous matter are removed by filtration or bleached by sulfuric acid. The removal or bleaching of the carbon and carbonaceous matter probably does little to affect the lubricating properties, though it may make the oil prettier to look at.

8. *Emulsion Test.*—A very simple test to check the purity of a mineral oil is the emulsion test. Fill a clean bottle about a quarter full of clear water (preferably distilled), and another quarter full of the oil. Shake vigorously until oil and water form an emulsion. Allow to stand for 24 hours. A pure distilled mineral oil separates completely from the water, which remains clear. Acids, soaps, rosins, etc., make emulsification easier, prevent the complete separation of oil and water, and leave the water cloudy. There will often be, after the separation, a layer of leathery foam between the oil and the water. The emulsion test is a rough one; it takes a chemical analysis to work out the real reasons for the actions shown. The fact that an oil will or will not readily form an emulsion with water is often of importance in judging whether the oil will feed or not, as an oil pump suction will not work on the foam.

9. *Flash Point, and Burning Point or Fire Test.*—It has been mentioned that when heated to high temperatures oils decompose chemically, the hydrocarbons breaking up into volatile combustible gases and carbonaceous matter, or even free carbon. The flash point is the lowest temperature at which the decomposition of the oil by heat becomes demonstrable through the formation of a combustible, slightly explosive gas mixture over the oil surface. The burning point, or fire test, is the lowest temperature at which the production of combustible gas from the oil is so rapid as to maintain combustion after ignition. The oil does not ignite itself merely because it is at or slightly above the flash point or the burn point; external ignition is necessary.

These tests originally came in because of fire risk. The flash and burn points of lubricating oils were a generation ago often as low as 200° to 300° F. An ordinary hot bearing was potential material for a bad fire, for an oil fire is hard to stop after it gets under way. With improvements in the manufacture of oils, the flash and burn points have been raised so that they now lie usually above 300° F., and often above 400° F.

As regards fire risk, the flash point of lubricating oils is of little consequence; the burn point is the more important of the two. As regards the use of the oil as a lubricant, the flash point is more important than the burn point. The flash point puts an upper limit to the temperature of use of the oil, because the chemical decomposition changes the properties of the oil, and the formation of gas in an oil film will break the film. It is quite possible, even probable, however, that the practical upper temperature limit for the use of an oil as a lubricant occurs below the flash point, from the decrease of viscosity of the oil with rising temperature. We test for flash and burn points, therefore, to catch any oil which might

bring fire risk from having these points too low, and to be sure that the flash point occurs at a temperature higher than the highest temperature at which the oil is to act as a lubricant.

There are a number of places in machinery where oils have to lubricate at decidedly high temperatures. Steam engine cylinder oils must lubricate valves and pistons at the temperature of high pressure steam, somewhere from 300° to 400° F.; with superheated steam even higher. Automobile cylinder oils must lubricate the pistons in the cylinders with a temperature in the oil film of 250° to 350° F. In this case a further requirement is put upon the oil that that portion of it which goes up past the pistons must burn up quickly and cleanly. Hence, the flash and burn points of automobile engine oils must be neither too low nor too high, say not under 400° nor over 500° F. for water-cooled engines. Stationary gas engines and marine engines run colder than automobile engines, and the flash and burn points of their oils may be lower.

10. *Heat Test.*—While the oil is undergoing decomposition by heat we are interested not only in the gases given off, which give the flash and burn tests, but also in the solid or semi-solid products of the decomposition. These substances, carbon or carbonaceous matter, remain in the oil. At present there is no standardized test on this line, paralleling the flash and burn test. It may be suggested that after the flash point temperature is known, another sample of the oil might be held for half an hour at the flash point temperature, without ignition, and then be poured off into a test tube and set away for 24 hours. It should then be examined for quantity and quality of carbonaceous matter and carbon present in suspension or settled out. Some oils form almost no carbon under this action; others will show a carbon deposit of one quarter the volume of the oil in the test tube. Probably these latter oils would be unsuitable for high temperature use.

The accumulation of carbon and carbonaceous matter may choke oil pipes and feed holes, and the carbon may act as a mild abrasive in bearings. The viscosity of oil tends to be slightly raised by the carbon; but the simultaneous formation of light hydrocarbons in the oil counterbalances this. The accumulation of this carbon is one of the reasons why the used oil should be periodically cleaned out of the crank case of an automobile engine. The oil which splashes up to the inside top of the pistons is spoiled on the hot metal, then drops back into the rest of the oil.

11. *Cold tests.*—As oils are cooled they increase rapidly in viscosity, that is, become stiff or sticky liquids. They may become so stiff that they will not flow at a readily measurable rate under the action of gravity. The temperature at which, in cooling, oil first gets too stiff for gravity flow is called the temperature of the pour test. Since gravity flow is very commonly relied upon to move the oil along feed pipes to bearings, cooling below the pour test temperature stops the feeding of the lubricant. On this account the pour test is of considerable importance as a low temperature limit to the use of the oil. Full force feed systems of supply of oil to bearings continue to work below the pour test temperature, down to or near to that temperature where the oil becomes practically a solid substance.

Between the pour test temperature and the solidifying temperature oils are, in appearance and lubricating action, what "greases" are at ordinary temperatures. Some "greases" are in fact merely oils with pour test temperatures above instead of below ordinary room temperatures. Some oils, of animal or vegetable origin, freeze as water does, at one temperature, changing suddenly from a thin liquid to a rigid solid. Most oils, however, become progressively more and more stiff or solid during cooling, with pour test temperatures somewhere between 40° and 0° F., and solidifying temperatures perhaps 40° or 50° F. lower still.

A cold test commonly made, but of no apparent practical application, is the cloud test. Many oils contain paraffin or similar waxes in solution, and in cooling throw this wax progressively out of solution as the temperature goes below a certain point. This point is that of the "cloud test," because the separation of the wax clouds the previously transparent oil. The cloud test is usually at a higher temperature than the pour test. The cloud test may be called the temperature of beginning of the partial solidification of the oil, which partial solidification may be in part responsible for the action (or lack of action) at the pour test temperature.

In many of the present automobile engines the oil

*The Sibley Journal of Engineering, Cornell University.

¹Assistant Professor in Experimental Engineering, Sibley College, Cornell University.

feed piping is internal to the engine. In such an engine even the pour test of the oil becomes of little consequence. If the oil is fluid enough to let the cold engine be started at all, the heat of friction will soon lessen the viscosity of the oil, and the chances are that the oil will be feeding properly by the time the engine will be ready to change from idling to appreciable power production. If the oil feed piping were external to the engine, not engine heat, it would behoove the user of the engine to be very careful in the winter time about the pour test temperature of the oil.

12. **Density.**—Density of oils is probably the property most often misunderstood and misinterpreted. Density is commonly measured and quoted in the oil trade in terms of an obsolescent scale, the scale of "Beaumé light" on a hydrometer. The relation between "Beaumé numbers" and ordinary densities, or specific gravities, with water as unity, is density =

$$\frac{140}{130 + (\text{Beaumé number})}.$$

Thus Beaumé number 29.0 means a density of $\frac{140}{130 + 29} = \frac{140}{159} = 0.880$. In strict

accuracy, Beaumé number 10.0 corresponds to water as 1.000 at 60° F., where the real density is 0.998 on the scientific scale, which takes water as unity at its maximum density (at 4.0° C.)

Fig. 1—Shaft at rest; load on

Density of oils has nothing to do with lubrication by the oils; lubrication does not depend in any way upon density as a specific property of the oil. When we speak of oils as "light," "medium," or "heavy," the property concerned is viscosity. "Light" means low viscosity; "heavy" means high viscosity. These technical usages of the words "light" and "heavy" are extremely unfortunate and highly misleading. They go back historically to a time when it was thought that oils of high viscosity were necessarily also of high density. That there is no such connection between the two properties may be readily brought out by citing liquids other than oils. Three common liquids have the properties at zero degrees Centigrade: water, density 1.00, viscosity, 0.018 c.g.s. units; mercury, density 13.60, viscosity, 0.017; glycerine, density 1.27, viscosity 46.0. It is true that oils made by the same process from the same crude oil have higher densities as they have higher viscosities; but change of process with the same crude oil as base slightly dislocates this relation of density and viscosity, and change of the crude oil entirely dislocates it.

What the density does tell concerning the oil seems to be the source of the oil—what kind of crude oil was used. Thus densities above 0.90 (Beaumé numbers less than 27) indicate in this country that Texas crude oil was used as base; densities below 0.90 (Beaumé numbers greater than 27) indicate Pennsylvania crude oil as base.

Density has an important commercial application when it is used to identify oils. Let it be supposed that a certain firm has by many trials found that one brand and grade of oil is for them the best for one use, saves the most power and gives the least cost of repairs to machinery and time out for repairs. (Cost of oil itself is less important than the value of power saving and repair saving). Before ordering more of this oil from the jobber the firm measures the density of the oil. If they find that the new shipment of supposedly the same oil has very closely the same density as the original, it is practically certain that they got what they ordered.

In the complete testing of oils density determination is necessary as an accessory to the common types (flow types) of viscometers. These instruments measure not viscosity but the ratio of viscosity to density, so that density must be known before viscosity can be computed.

13. **Viscosity.**—Viscosity is the most important property of oils as regards lubricating action. It is practically the controlling factor, so far as the oil is concerned, in the formation and maintenance of the oil

film between metal parts when the parts are in motion. Viscosity is the internal friction of fluids, the force resisting the movement of one layer of oil past the next. A liquid which, like steam engine cylinder oil or tar, is "thick" or "stiff," and does not flow readily, has high viscosity; a liquid which is "thin," flows readily, like water, has a low viscosity. If two parallel metal surfaces of area A , distance x apart, have the space between them filled with oil of viscosity η , and move past each other with the velocity V , then the viscous force F

opposing the motion is $F = \frac{A V \eta}{x}$, or viscous force = (area of oil film) (velocity difference at the two surfaces of the film) (viscosity) $\div$ (thickness of film). Inverting this equation $\eta = \frac{F x}{A V}$. With the forces, distances

areas, and velocities in foot-pound-second or centimeter-gram-second units respectively, this equation tells the measurement. The numerical values quoted above for water, mercury, and glycerine are in c.g.s. units. The equation for viscous force is often written $F = A \eta \left(\frac{V}{x} \right)$, in which the ratio $\frac{V}{x}$ is called the "velocity gradient."

When a shaft is at rest in a bearing, with load on, the shaft and bearing are in metallic contact on the side

Fig. 2—Shaft running; oil film formed

toward the load. The shaft being smaller in diameter than the inside of the bearing, there remains a thin crescent-shaped space between shaft and bearing metal on the side away from the load. This space will fill with oil, while the shaft is at rest, by the action of surface tension or capillarity, even against the action of gravity. The relation of parts is as shown in Fig. 1.

When the shaft starts to turn, oil sticks to the shaft and tends to carry around with the shaft to form a film of oil between shaft and bearing on the side toward the load. The bearing, because of the load, tries to wipe this oil off the shaft, or to prevent the oil from going through. The oil layer in contact with the bearing metal stays stationary in any case. The result of the actions of the moving shaft and the stationary bearing metal is a motion of oil layer on oil layer, a motion which brings in the forces due to viscosity of the oil.

Fig. 3

The viscous force tries to push a wedge-shaped film of oil through between shaft and bearing. The wedge is a bent one, as shown in Fig. 1. The force carrying oil into the wedge increases both with the velocity of the shaft surface and with the viscosity of the oil, or is proportional to the product of velocity by viscosity. This viscous force has against the load on the bearing the mechanical advantage of the wedge, an advantage measured by the ratio of diameter of shaft to clearance of bearing (difference of diameter of shaft and bearing). When the viscous force, or product of viscosity by velocity, becomes large enough, the oil film rather suddenly carries through, and shaft and bearing take the relative positions shown in Fig. 2. The oil film must of course always be thinner on the load side than on the

unloaded side, but with good lubrication the shaft does come appreciably near to running concentric with the bearing. In other words, the thickness of the oil film toward the load, where the film is thinnest, approaches as a limit, but does not reach, one-half the clearance. There is thus a mechanical limit to the thickness of the oil film.

Because of the relationships of forces just outlined, the thickness of the oil film toward the load in any given bearing depends upon the value of the fraction

$\left(\frac{\text{viscosity} \times \text{velocity}}{\text{load}} \right)$. The change of thickness of oil film with change of this fraction is shown in Fig. 3. The curve OCEF has film thickness for its ordinates and values of the fraction $\frac{\text{viscosity} \times \text{velocity}}{\text{load}}$ for its abscissas. OA is one-half the clearance, or the mechanical limit to the oil film thickness. The dash-line HK lies at a distance BC above the base, and represents the heights of the roughnesses of the surfaces of bearing and shaft.

The course of events in lubrication during the starting up of machinery may be followed from Fig. 3. With velocity zero the fraction $\left(\frac{\text{viscosity} \times \text{velocity}}{\text{load}} \right)$ is zero, and there is no oil film (point O, Fig. 3). As velocity increases the fraction $\left(\frac{\text{viscosity} \times \text{velocity}}{\text{load}} \right)$ increases in

proportion. The oil film builds slowly at first, and the bearing and shaft remain in partial metallic contact, with high friction. At some critical value of velocity the oil film becomes thicker than BC, Fig. 3, and metallic contact ceases. Thence onward to higher values of $\left(\frac{\text{viscosity} \times \text{velocity}}{\text{load}} \right)$ the friction of the bearing is

entirely due to the oil. From C to E the oil film builds up rapidly; beyond E further change of the abscissas causes little increase of film thickness. Along CEF and beyond we are dealing with what is often called "perfect" lubrication. The term should more properly be "complete" lubrication. Between O and C lubrication is "imperfect" or better "incomplete."

The formation of the oil film by viscosity and velocity action as described above is known as the "Tower effect."

The fluid friction of a bearing is given by the equation

$$\text{above for viscous force, } F = \frac{A V \eta}{x} = (\text{area of oil film})$$

(velocity of shaft surface) (viscosity of oil) $\div$ (thickness of oil film.) The form of this equation which strictly

applies is $F = \eta V \int \frac{dA}{x}$, since the thickness x of the oil

film varies from one element dA of area to another, both because of roughnesses of surfaces and because the shaft is not concentric with the bearing. This equation, together with the relation shown in Fig. 3 governing thickness of oil film, gives the outline of the variations of fluid friction of bearings with changes of speed, load, and viscosity.

In the region from C to E, Fig. 3, thickness of oil film changes more rapidly than does the abscissa

$\left(\frac{\text{viscosity} \times \text{velocity}}{\text{load}} \right)$. Putting this with $F = \frac{\eta V A}{x}$

shows that while the oil film thickness is rapidly increasing the fluid friction is decreasing, the factor x dominating the function. Beyond E and F, Fig. 3, the oil film has a practically constant thickness, set by the clearance of the bearing. In this region, then, since x cannot vary, increase of velocity or viscosity will increase the friction; but decrease of load will not decrease or increase the friction. Fluid friction in the ordinary bearing is not independent of load because the bearing is working in the region between C and F of Fig. 3, where change of load changes the film thickness. It is possible also that increase of load, and hence pressure in the oil film, causes an increase of viscosity of the oil; but such an effect remains yet to be demonstrated as of practical importance. The seizing of a bearing due to pressure

application comes from squeezing the oil film down till metallic contact occurs.

After a machine is under way the friction causes the film and the bearings to warm up. This complicates the problem, because viscosity of oils decreases rapidly as temperature increases, especially at lower temperatures. The decrease of viscosity decreases the fraction $\left(\frac{\text{viscosity} \times \text{velocity}}{\text{load}}\right)$, velocity and load being now constant, and may affect the film thickness. The viscosity decrease may go so far as to change the film thickness from F to E to C, Fig. 3, allowing metallic contact and seizing of the bearing. If such seizing occurs repeatedly during the operation of a machine, it indicates that an oil of higher viscosity is needed.

Excessive friction in machinery may occur therefore from either too low or too high a viscosity of the oil. Too low viscosity means that the oil film is not maintained. Too high viscosity, while the oil film is "perfect," gives excessive friction in the oil itself. Anyone who has cranked an automobile engine in the winter time appreciates the possibility of having too much viscosity in the oil. Too low a viscosity, with seized bearings, wrecks the machinery; too high a viscosity causes no damage to bearings, but is inefficient. The highest

efficiency comes from going as near to seizing as we dare, while still playing safe.

Because viscosity varies so rapidly with temperature, and the variation is at different rates in different oils, we need in testing the oil for viscosity to find the viscosity as a function of temperature. A knowledge of the viscosity value at one temperature is not sufficient. What we need most to know is the viscosity of the oil at the temperature at which it must operate with the most severe running conditions of the machine in which the oil is used. We must be sure of having enough viscosity to maintain the oil film under the extreme conditions of operation. Then we put up with the higher viscosities when the oil is colder. Usually the range of temperature through which the oil must lubricate is narrow enough so that we can have both enough viscosity at the high temperatures and not too much at the low temperatures. In extreme cases, as the operation of an automobile engine in the winter time, we cannot get enough viscosity left at high temperatures without getting excessive viscosities at starting of the cold engine. The range of temperatures is too wide, considering the unavoidable and uncontrollably rapid change of viscosity with temperature. The ideal would be an oil which did not change viscosity with temperature.

It can readily be shown that the fluid friction of a roughed surfaced bearing is greater than that of a smooth

one, other things being the same. From $F = \eta V \int \frac{dA}{x}$

with η and V the same in the two cases, F varies as

$\int \frac{dA}{x}$. Let the total area in each case be 2, and the

average film thickness be 2. In the rough one let the two halves of the film area have thickness of 1 and 3;

in the smooth one 2 and 2. Then $\int \frac{dA}{x}$ for the rough

one will be $(\frac{1}{1} + \frac{1}{3}) = 1.33$; and for the smooth one $(\frac{1}{2} + \frac{1}{2}) = 1.00$. It should be said, however, that in practice the smoother bearing would probably be made with less clearance than the rougher; and in turn the oil used in the smoother bearing would be of lower viscosity. The change in the automobile engine from hand scraped bearings to reamed bearings will probably bring about all these changes in succession.

The Geology of West Africa*

With Notes on Its Resources and Future Development

By R. Chudeau, Director of the Expedition in French West Africa

THE Geology of Occidental Africa has already been made the subject of numerous works, particularly abundant during the past fifteen years. Many attempts at synthesis have been made. The already old-fashioned studies of Pomel in 1872, and of Du Ronchel in 1879, which were based on too small a number of precise observations, are today of but little interest. In 1891, G. Rolland, who had taken part in the labors of the Choisy Expedition, published a Geological map of the Sahara; it has been reproduced with some modifications in the "FASCE de la TERRE" (Face of the Earth) (Vol. 1, p. 459, 1897) for the central part of the Sahara and the northern of the Soudan, I myself made in 1897 an attempt at a map, a corrected reproduction of which was published by E. Suess in 1911 ("LA FACE de la Terre" (Vol. 3, p. 672). In 1913, subsequent to the expedition for the study of Trans-African railroads, I was able to make certain additions to this document (Bull. Soc. Geol. fr. 4, x 111, p. 173).

All the attempts at maps referred to above are on a small scale. In 1909 H. Hubert published a color map of West Africa on the scale of 1:5,000,000; although this document is already out of date, it is still very useful and sufficiently indicates the main lines of African Geology. More recently, P. Lemoine¹ has made an extensive bibliographical list (333), and a table of twenty-two geological maps relative to West Africa; he has made a résumé of the results obtained. Since then more new notes have appeared, and an analysis of the majority of them will be found in the: *Annuaire et Mémoire du Comité d'Etudes Historique et Scientifique de l'Afrique Occidentale* (Gorée, 1916).

The greater part of the soil of West Africa and of the Sahara consist of granitic massifs and crystalline schists. The first (Granite and Granitoid, Gneiss) sometimes gives birth to peneplains, and more often to granitic chaos, or regions of domes. The regions of granitic chaos are formed by the crumbling of blocks, whose size varies from that of the human head to several cubic meters. In the regions of domes the granite is always porphyroid, with large crystals of Feldspaths; these domes are merely blocks of very large dimensions, of which the portion disengaged from the earth often exceeds 100 meters. This structure of the granitic regions is found throughout the world; it is connected with the nature of the granite which, when in the pasty state formed itself, like most viscous bodies, into harder lumps of varying dimensions. Erosion confined itself to the removal of the least resistant portions, intercalated between the lumps. The aspect of the granitic regions varies with the altitude. In the Sahara, by reason of dryness, vegetation and vegetable earth are rare.

The areas of the granitic chaos present only piled up blocks, which from a distance take on the appearance of mountains, though the length may be only a few meters; analogous landscapes are known upon the Breton Litoral where the vegetation is sparse. Further to the south

the vegetable earth fills all the interstices between the blocks, and during the season of rains, in the midst of the verdure, only a few rounded boulders of granite are to be seen, quite as in the Limousin. As for the granitic domes, their steep walls are everywhere denuded. In the Sahara, as well as in Dahomey, on the Ivory Coast, or in the Vosges, the crystalline schists form a complex ensemble, which certainly represents several stages; in Southern Africa, is found their analogue (pre-Cape formation) which the more complete study of the country enables us to divide into four series. We are less far advanced in Africa where we are as yet able to introduce only two subdivisions, according to whether the schists or the banded gneiss predominates. This classification based on the nature of the rocks is of only mediocre value and may betray a difference in the intensity of the metamorphism quite as easily in the age of the strata.

All these schists exhibit strata which are much tilted, often almost vertical; the out-crops often run nearly north-south along the direction of the meridian. This direction, as we know, plays a part of the first order in the structure of the African earth crust; the great breaks which have given birth to the lakes of East Africa and to the Red Sea are parallel to it.

The crystalline schists offer poor resistance to external forces, they rarely form peneplains, and sometimes true plains, when the phyllades or schists marked by sericity predominate. A few reefs which have been observed there are due to eruptive rocks, especially to the diabases, and are then not strongly marked; or less to quartzites which form long crests towering above the neighboring peneplains (the Atacora chain in Dahomey, + 300 meters; Belia chain near Hombori, + 100 meters etc.).

The age of the crystallophyllian territories is everywhere difficult to fix; in the Sahara it can be affirmed that they are previous to the Devonian and even to the upper Silurian period; in the Soudan, it is believed, merely because of their geographic continuity and, therefore, without sufficient proof, that they are of the same age. These territories are often covered in Africa by mighty masses of sandstone in horizontal layers. These sandstones have grains of very various size and pass through every degree from real pudding-stone to very fine sandstones. They are generally light in color, but covered with a deeper patina. In the Sahara this patina, which is called the desert varnish, is extremely hard and as black as pitch.

These sandstones form three principal bands; the first extends from the northern part of the Ahaggar through Ouallan, as far as the vicinity of Mourzouk, over about 800 kilometers from West to East (Ahnet Moudir Tassili of the Ajers), and fossils are quite abundant there, and it has been known since the voyages of Overweg (1852), and especially since those of H. Duveyrier (1860), that these plateaus are Devonian. The most recent researches have shown lower Devonian, especially well developed there; the Middle and Upper

¹The quartzites alone form an exception; they occupy too restricted an area to play an important rôle.

Devonians are represented towards the north of these plateaus by the clays and the lime-stones. Quite recently M. Doubillé has shown that the basis of these plateaus belongs to the Upper Silurian.

The second band, more discontinuous, begins in Mauretania (Adrar, Tagaut) and reappears around the Adrar of the Iforas and rejoins at Air. It is probable that this also belongs to the Devonian age. In the Adrar of Mauretania and in the neighborhood of the Air the sandstone, which constitute it, is covered at certain points by lime-stones whose fossils permit us to attribute them, without hesitation to the Carboniferous.

As to the third band, it begins in the vicinity of Kayes and extends as far as Hombori, covering a surface of 300,000 kilometers. There is nothing which permits us to connect it with the Devonian except analogy of aspect and a geographic semi-continuity.

Other sandstone plateaus are found in Guinea, in the region of the Tchad (Tibesti and Enedi), without our having any better knowledge as to the period of their formation.³ Whatever be their age these plateaus everywhere play the same rôle in topography and in geography. From the topographic point of view these considerably cut-up plateaus often display abrupt cliffs and the aspect of ruined cities, such as we find in the grit-stone Vosges, everywhere in the Sahara because of the dryness of the air. Their sides bear no vegetation, and are more denuded than those of the European limestone plateaus. Certain gorges form remarkable landscapes, like those of Takounbaret) Moudir, which remind one of the cañons of the Caucasus. The sandstones of the Sahara plateau are covered with a black patina of almost metallic brilliance, quite unknown in Europe. Further south the aspect is more normal.

From an hydraulic point of view these sandstones are of the highest importance. Thanks to their permeability the Saharan Tassili (plateaus) all contain numerous pools of water, frequently quite shallow; sometimes, even, in certain valleys, the water forms little ponds which are almost permanent (Tagergera, Tahount-Arak). In the Soudan wells are frequent at the foot of the plateaus; there are even a few villages built on top of them which possess shallow wells. At some points springs are known. These sandstones are hard and resistant; with the primitive means at their disposal the natives have been able to extricate only a small portion of the reserves of water which they contain.

The marine carboniferous is widely represented in the Sahara by fossiliferous limestones; there are but few of these deposits in Occidental Africa: There is an outcrop from East to West in the Southern part of the Mauritanian Adrar; another constitutes the Hamada el Haricha near Taodeni; there is a third, finally, between the Adrar of the Iforas and the Air.⁴

³Further to the East the age of the Nubian graves displays an analogous lack of definite character.

A coal basin is known in the South Oranais, near Colomb Bechar; in the region of the Rat and in the erg of Issonian, Overweg and Fourcand have collected some remains of vegetation. Up to the present time, in the Sahara of the South the carboniferous is purely marine

*From *Revue Scientifique*.

¹P. Lemoine, Occidental Africa. In *Handbook of Regional Geology*, Heidelberg, 1913.