ART. XXIII.— *Turquois from New Mexico;* by F. W. CLARKE and J. S. DILLER.

AT Los Cerillos, New Mexico, about twenty-two miles southwest of Santa Fé, are mines of turquois which have been worked for centuries. The locality has been repeatedly

described,* from archæological and geological points of view; but, as far as we are able to ascertain, the turquois itself has never been fully analyzed, nor has it been subjected to complete microscopic study. Having at our disposal a very full suite of specimens, collected during the summer of 1885 by J. W. Powell, Director of the U. S. Geological Survey, we have thought it desirable to investigate the subject more thoroughly, and to present our results in such form as to render them readily comparable with the published data concerning turquois from other localities.

The turquois occurs imbedded in its matrix, sometimes in nodules, oftener in seams or veins. It varies in color very widely; ranging from a pure sky-blue, through many shades of bluish green and apple-green, to dark greens which show no blue whatever. The dark green nodules often shade off to nearly white at the center, sometimes resembling in structure, as Blake has observed, certain varieties of malachite. Many of the specimens are seamed or streaked by limonite, which has been derived from accompanying pyrite; and the latter mineral occasionally is found, bright and unaltered, enclosed completely in masses of clear blue turquois.

For analysis, three samples of turquois were selected, representing as nearly as possible, the most definite types of the mineral. They may be summarily described, as follows:

A. Bright blue, faintly translucent in thin splinters.

B. Pale blue, with a slight greenish cast, opaque and earthy in luster, and of sp. gr. 2·805. Blake gives the density from 2·426 to 2·651 for the green variety.

C. Dark green, opaque.

	A.	B.	C.
H_2O	19·80	19·60	18·49
Al_2O_3	39·53	36·88	37·88
Fe_2O_3		2·40	4·07
P_2O_5	31·96	32·86	28·63
CuO	6·30	7·51	6·56
SiO_2	1·15	·16	4·20
CaO	·13	·38	undet.
	98·87	99·79	99·83

Analysis "A" is not quite complete, for enough material could not be obtained without the destruction of too valuable specimens. The silica in it was due to traces of admixed rock from which the material could not well be perfectly freed. "C," however, was free from rock; and the silica in it must be

* W. P. Blake, this Journal, II, xxv, 227, 1858. J. S. Newberry, "Report of the Exploring Expedition from Santa Fé to the Colorado," etc., 1859; printed, 1876. B. Silliman, this Jonrnal, III, xxii, 67, 1881.

accounted for otherwise. Silliman reports the turquois as containing 3·81 of copper, which corresponds to 4·78 of CuO; but he gives no other quantitative data.

In attempting to discuss these results it will be well to compare them with two other published analyses of turquois from different localities. First, we have the figures given by Church* for the well-known variety from Persia; and secondly, the analysis by G. E. Moore† of turquois, pseudomorphous after apatite, from Taylor's Ranch, Fresno County, California.

	Persia.	California.
H_2O	19·34	19·98
Al_2O_3	40·19	35·98
Fe_2O_3		2·99
FeO	2·21	
P_2O_5	32·86	33·21
CuO	5·27	7·80
MnO	·36	
	100·23	99·96
Sp. gr.	2·75	2·798, 2·815

These analyses, leaving temporarily out of account that of the dark-green variety, agree well with each other in their atomic ratios. Dividing the percentages by the proper molecular weights, and treating the bases together, the following ratios appear.

	Total base.	P_2O_5	H_2O
New Mexico, A,	·468	·225	1·100
New Mexico, B,	·479	·231	1·089
Persia,	·492	·231	1·075
California,	·470	·234	1·110

In each case the base stands to the acid in a ratio very slightly in excess of two to one; and that excess may fairly be accounted for upon the supposition that it represents a trifling admixture of limonite. The water is present in a proportion a little under that of five molecules to one of phosphoric acid, the variation here being due to the differences in the percentages of copper. If we calculate the amount of phosphoric acid necessary to satisfy the alumina, and then reckon the phosphate so obtained as requiring five molecules of water, we shall have left over a quantity of copper, acid, and water corresponding to a very simple formula; and the turquois will appear as a variable mixture of the two following salts:

$$2Al_2O_3 . P_2O_5 . 5H_2O.$$
$$2CuO . P_2O_5 . 4H_2O.$$

* Chem. News, x, 290. Dana's Mineralogy, p. 581.

† V. von Zepharovich and G. E. Moore. Zeitsch. für Kryst. u. Min., x, 240.

In the Californian turquois the analytical results fit these formulæ quite sharply, and give the ratio between the two compounds as approximately four to one. The first formula may be regarded as that of normal turquois, and may be written in rational form, halved, as

$$Al_2HPO_4(OH)_4.$$

The copper salt, to which the mineral owes its color, is to be considered merely as an impurity; a view which is emphasized by the analysis of the dark-green turquois, "C." In the latter case the same ratios apply, modified by the presence of silica, which is nearly sufficient to form with the copper a normal metasilicate, similar to if not identical with chrysocolla. This silicate, with whatever blue tinge of color it might have, affected by the yellow or brown of the iron present, probably gives the turquois its green hue. It is exceedingly probable that the purity of tint in gem turquois is due to the copper salt alone; and that degradations of the color towards green are ascribable to admixture of salts of iron. It is noteworthy that, of the three turquoises analyzed, the bluest contains the lowest percentage of copper. This could hardly be the case were not the colors of the other samples modified by some impurities; and compounds of iron would naturally produce an effect in the observed direction.

Sections of the three varieties of turquois were studied under the microscope, and found to be of essentially the same character. Although deeply colored in the hand specimens, the thin sections appeared almost clear and transparent. Between crossed nicols the deep blue and green forms were seen to be composed of minute grains, or short, thick fibers; but in the paler varieties the fibrous structure was more pronounced. The optical properties of both grains and fibers are the same throughout. They are all weakly doubly refracting, but have a rather high refractive index. The finely granular portions have a pale bluish aggregate polarization, less intense than that of chlorite; but when the mineral is distinctly fibrous it polarizes like some forms of serpentine, with light colors of the first order. The fibers are generally somewhat bent and interwoven, but lie approximately in the same direction. Each fiber becomes dark when parallel to the principal section of either of the crossed nicols, indicating that they must crystallize according to either the quadratic, hexagonal, or rhombic system, instead of in one of the inclined systems as was the case with the fibers studied by Bücking* in the turquois of Fresno County, California.

A section was prepared of a distinct vein of pale-green tur-

* See paper by v. Zepharovich and Moore, previously cited.

quois, which showed that the fibrous structure is directly across the vein perpendicularly to its walls. Small fissures, running into or across the veins, have the fibers of turquois arranged perpendicularly along their sides just as serpentine arranges itself along fissures in olivine. Sometimes the fissures are minute and curved; but the resulting arrangement does not simulate the radial fibrous or spherulitic structure described by Bücking* as found in the turquois of California, Nevada and elsewhere.

The perpendicular arrangement of the turquois fibers along fissures crossing the vein, indicates that the mineral may have been derived from the alteration of another substance with which the vein was formerly filled. We would suppose, of course, that the original vein material was itself a phosphate; and the only one after which turquois is known to be pseudomorphous is apatite; a species which not infrequently occurs in veins. The opinion that the turquois has resulted from such an alteration is favored by the presence of other alteration products, to be noted in considering the composition of the country rock in which the turquois is found. It is also suggested by Hermann's analysis of blue oriental turquois, in which the equivalent of 3·41 per cent of calcium phosphate was actually determined.†

The rock in which the veins of turquois occur is described by Blake as "a granular porphyry, yellowish, gray, or white in color, porous and earthy in texture. It decomposes rapidly by weathering, and very much resembles a sandstone." In the collection made by Major Powell there are several good examples of the rock penetrated by the turquois. It is a fine-grained, reddish, feldspathic rock, mostly fresher than that described by Blake, and it has a microgranitic aspect. It contains numerous particles of biotite and pyrite, with stainings of oxide of iron. The hand specimens look as though they had been crushed, and the fissures thus formed so filled as to produce irregular veins and nodules. The veins are small, and mostly composed of turquois, in which are imbedded a few scales of biotite, particles of pyrite, and considerable quartz and oxide of iron. Scales of biotite are found abundantly in the iron-stained cavities, as well as in the solid portions of the rock. Some specimens of rock, containing much pale blue turquois of earthy texture, have been completely kaolinized, and a partial analysis of the kaolin gave the following results:

* Zeitsch. für Kryst. und Min., ii, p. 163.
† See Dana's System of Mineralogy, p. 581.

H_2O	12·88
SiO_2	52·38
$Al_2O_3 + Fe_2O_3$	33·49
P_2O_5	none
MgO	1·17
CaO	trace
	99·92

Although the mineral itself was white, the alumina from it was distinctly reddish with the iron.

Under the microscope the rock is seen to be composed chiefly of feldspar, with a considerable amount of biotite, epidote, pyrite and limonite, and some amorphous substance. It is somewhat microgranitic in structure, and the irregular, interlocking grains of feldspar vary in size from ·01 to ·8mm in diameter. Most of them are considerably kaolinized, so as to appear cloudy in ordinary light; but between crossed nicols the original outlines of the grains become more distinct. Their optical properties indicate that the feldspar is orthoclase; an opinion which is fully borne out by the subjoined analysis of the rock, which shows a remarkably large proportion of potash.

H_2O	3·28
SiO_2	56·68
Al_2O_3	16·62
Fe_2O_3	6·50
P_2O_5	·73
MgO	·79
CaO	·59
CuO	trace, undet.
MnO	1·02
FeS_2	2·21
K_2O	11·18
Na_2O	1·03
	100·63

The porphyritic crystals are generally Carlsbad twins with irregular outlines. There are occasionally small grains of fresh, transparent plagioclase, which has evidently resulted from alteration.

The biotite of the rock occurs in noteworthy quantities, but is very unequally distributed. It is frequently aggregated in groups of scales, and may be seen most abundantly in small cavities. It sometimes occurs intimately associated with the turquois, but unlike the latter it is one of the primary minerals. The small quantity of quartz present is a secondary product, so intimately associated with turquois as to suggest

their genetic connection. Pyrite is scattered rather uniformly throughout the rock in small cubical crystals easily seen in the hand specimen. They are sometimes altered to limonite, but in other cases they have been completely replaced by pseudomorphs of epidote. The specimen of rock which was subjected to analysis probably contained an amount of pyrite rather greater than the average.

One of the most important constituents of the rock, because of its very close association with the turquois, occurs in the form of bright yellow grains. They are not distinctly pleochroic, but have a high refractive index, with strong double refraction, and give brilliant aggregate polarization. The particles are usually very small, and grouped together in irregular compound grains so as to suggest nothing of crystallographic form. In several cases, however, elongated simple grains show inclined extinction; which indicates that the mineral must be either monoclinic or triclinic in crystallization. Judging not only from the properties enumerated, but also from the percentage of lime in the rock, this mineral is in all probability epidote. It is evidently connected genetically with the turquois, for it is almost uniformly found upon the border of the latter, and is most abundant in its neighborhood.

Concerning the origin of the turquois-bearing rock, it may be stated that Professors Newberry and Silliman, both of whom studied it in the field, regard it as eruptive, and probably of Tertiary age. The occurrence of this veritable orthoclase rock in the West is of special interest from the facts disclosed by recent investigations that in many of the rocks previously described as trachytes the predominating feldspar is plagioclase.

The very small size of the veins and their limited distribution show that the turquois is of local origin, and emphasizes the idea that it has resulted from the alteration of some other mineral. In addition to the evidence already cited to show that the turquois has been derived from apatite, we have the fact that epidote, a lime bearing mineral, is present as a secondary product. The oxidation of pyrite may have had something to do with initiating the process of alteration, and the alumina of the turquois was probably derived from decomposing feldspar. The latter suggestion was made by Silliman, who also examined microscopic sections of the rock, and reported apatite as present. No apatite, however, could be seen in the specimens examined by us. A search for it at the locality would certainly seem to be desirable.

U. S. Geological Survey, Washington, April, 1886.

ART. XXV.—*On the Electrical Resistance of Soft Carbon under Pressure;* by T. C. MENDENHALL.

A PAPER by the writer on "the influence of time on the change in the resistance of the carbon disk of Edison's Tasimeter," was published in this Journal in July, 1882. The object of the paper, as its title indicated, was to present the results of some experiments with the carbon disk which appeared to show that, when pressure was applied, the entire diminution of resistance did not take place at once, but that the reduction continued with diminished rapidity through a considerable period of time. At the conclusion of the paper brief reference was made to investigations of the same subject by Mr. Herbert Tomlinson and by Professors Sylvanus P. Thompson and W. F. Barrett.

Only the conclusion reached by some of these physicists was at that time known to the writer, their verdict being that the observed diminution of resistance was really due to the better surface contact of the electrodes and not to any actual change in the specific resistance of the carbon itself.

The last paragraph in the paper contains the following: "without knowing anything about the nature of these experiments the writer desires to record his belief that this theory does not entirely account for the facts stated above."

This, certainly not too rash, declaration of belief in a true pressure effect was the subject of decidedly unfavorable criticism in the columns of one or two European scientific journals; and in this Journal of December, 1882, Professor Sylvanus P. Thompson published an article entitled "Note on the alleged change in the resistance of carbon due to change of pressure," which was an exceptionally severe criticism of the previous paper by the writer. In this article Professor Thompson refers to the investigations of Mr. Tomlinson, Professor Barrett and himself and also to experiments made by Professors Naccari and Pagliani and Mr. Conrad W. Cooke, and he declares that, with the exception of Professor Mendenhall, all who have investigated the point are agreed in their verdict "that this alleged effect was due not to any change in the specific resistance of carbon, but to better external contact between the piece or pieces of carbon and the conductors in contact with them." The truth of this statement is the question at issue. It may be well to remark, however, that although Professor Thompson makes this assertion in December, Mr. Tomlinson had shown, nearly a year earlier, in a paper presented to the Royal Society, on the 26th of the previous January, that the

electrical resistance of hard carbon was diminished by pressure. The amount of the diminution is small, however, and he afterwards expresses the opinion that in such instruments as the microphone transmitter, the greater portion of the observed diminution in resistance is due to variation in surface contact.* Mr. Tomlinson's experiments were made with hard carbon, similar in character to that made use of in experiments to be described presently.

In the summer of 1884, the writer communicated, to the American Association for the Advancement of Science, a brief account of experiments which satisfied him that the opinion which he had previously expressed concerning the nature of the phenomenon was unquestionably correct. Within the past year the subject has been taken up again, and by means of improved methods and instruments, all doubts seem to have been removed.

Innumerable experiments made by physicists of many countries have established, beyond question, the fact that the electrical properties of matter are modified by stress and strain. In carbon the effect of pressure is to diminish resistance. For hard carbon this was established by the investigation of Mr. Tomlinson. In compressed lampblack, as seen in Edison's disks, the effect is very great and that this is for the most part a true pressure-effect is proved, it is believed, by the experiments about to be described.

In the beginning it was desirable to determine, roughly, the magnitude of this effect in the case of hard carbon. For this purpose a copper plated rod, such as is used in the arc lamp, about 12^{cm} in length and $1{\cdot}5^{cm}$ in diameter, was selected and its ends were ground flat at right angles to its axis. The plating was then removed, except that a band about $\cdot5^{cm}$ in width was left near each end of the rod. Two cork rings $1{\cdot}5^{cm}$ thick were fitted to the rod, after which they were tunneled out on the inside, and a hole was made in each so that when they were in place over the copper bands, and mercury was poured in, it would flow around the ring tunnel and make a contact with the carbon as satisfactory as could be desired. The ends of the rod were protected by thin plates of vulcanite, and it was placed between the jaws of a vise. The current from a battery of two or three gravity cells was passed through the rod by plunging wires into the mercury cups formed by the corks. By this arrangement it was possible to apply pressure at the ends of the rod without in any way influencing the contacts through which the current passed.

The terminals of a reflecting galvanometer whose resistance was about 5000 ohms were also introduced into these mercury

* Nature, March 16, 1882.

cups and enough additional resistance was introduced to make a convenient deflection of the spot of light upon the scale. When all was adjusted and the spot of light was at rest, the pressure was applied by turning the handle of the vise. In every instance the deflection decreased showing diminished resistance. This effect was not due to the heat produced by compression as experiment proved that cause to be inadequate. It was found to be necessary to make the carbon rod decidedly warm to the touch in order to lower the resistance by the same amount, besides the effect was not transient as would have been the case if it had been due to the change in temperature. It was also found that compression at right angles to the direction of the current produced a similar effect, but less in magnitude. These facts had been already announced by Mr. Tomlinson.

These experiments with hard carbon or with other rigid bodies are comparatively easy, as there is no difficulty in applying the pressure independent of the contact surfaces, so that possible variation of the latter need not be considered. Unfortunately it appears to be quite impossible to secure this arrangement in the examination of soft carbon. It cannot readily be obtained in forms different from the small disk or button in which it originally appeared, and it is so fragile that it requires the most careful manipulation. Under these circumstances the only thing to do is to secure the best possible surface contact of the poles to begin with. Perhaps the ideal arrangement would be a disk with its two opposite faces electro-plated with copper, through which a contact with mercury can be secured. The electro-plating of two opposite faces of a disk of compressed lamp-black is a work of extreme difficulty and so far as known to the writer has not yet been accomplished, although he is greatly indebted to Mr. Edison for a serious and persistent effort to secure this result, none the less appreciated because, owing to the extremely fragile character of the disk, it proved to be unsuccessful.

It was therefore necessary to depend upon the contact of mercury with the surface of the carbon itself. As this was the contact employed by Professor Barrett in the experiment which Professor Thompson considered "crucial," its use can hardly be objected to in this instance.

The arrangements for the test of the soft carbon were as follows: two glass tubes about 20^{cm} in length were bent at one end into a quarter of a circumference, so that when the two were joined and the straight branches of the tube were in a vertical position the appearance was that of the letter "U," the height being about 15^{cm}. Near the lower end of each a short tube was sealed in, over which rubber tubing could be passed, and at the lower part of the curve, in each, a platinum

wire was passed through and sealed. The ends of the tubes were ground flat, and they were mounted in such a way that while one was fixed in position, the other could be moved toward or away from it in one plane, and so that the ground ends of the curved parts were always exactly opposite to each other. The movable tube was then taken from its place, the ground edge of its curved end was coated with glue, and it was carefully brought down upon the upper surface of a carbon disk which rested in a horizontal plane. The glue causing the disk to adhere to the tube, the latter could then be secured to its sliding stand, ready to move into place. The ground edge of the fixed tube was now coated with glue, after which the movable tube holding the carbon disk was gently moved up until the disk pressed against the end of the other tube, the glue forming the junction. In this way a carbon wall or partition was formed between the two halves of a "U" tube. When the glue had hardened, mercury was introduced on both sides to a height sufficient to entirely cover the faces of the carbon disk. The current was introduced through the platinum electrodes which plunged into mercury cups on either side.

In some of the earlier experiments variations of pressure were produced by the addition of mercury to the two branches of the tube, but vastly better than this was the method latterly used in which the pressure of air was substituted for that of mercury. Glass plates were sealed on the open ends of the two upright branches thus inclosing a space on each side, except at the small side tubes to which short pieces of rubber tubing were attached. These were joined by means of a "T" tube so that equality of pressure on both faces of the disk was secured.

The circuit consisted of the battery, the disk and an additional resistance varying from 3 ohms to 10 ohms for purposes of comparison. The electric ends of the disk and of the resistance were joined to a specially arranged key, by means of which either could be connected with the terminals of a reflecting galvanometer whose resistance was about 7000 ohms. By means of the deflections of the needle of this galvanometer, the resistances were compared and variations noted, the arrangement being substantially the same as that previously used in the experiments with hard carbon. A pressure gauge, sometimes of water, sometimes of mercury, was attached to the apparatus to indicate variations in pressure, and these variations were generally produced by blowing from the mouth into a rubber tube about two meters in length. Very many experiments were made, all without exception, showing great diminution in the resistance of the disk by increase of pressure, and it will be sufficient to quote a few of the results.

The disk is sufficiently sensitive to show very slight changes in atmospheric pressure. On closing the open end of the rubber tube, and slightly pressing any part of it between the thumb and finger, the spot of light instantly moved, showing decrease of resistance. A pressure measured by 5^{mm} of water produced a decided effect. The resistance of the disk, with its mercury and platinum wire connections, under ordinary conditions was slightly greater than 6 ohms. A pressure measured by 5^{cm} of mercury instantly reduced it to less than 3 ohms. If the pressure was maintained, a slow fall of resistance continued for a long time, as found in the previous investigation of the subject. If the initial pressure was small, the recovery would be instantaneous on its removal, but if it was large, so as to greatly reduce the resistance, it was found that the recovery would not be complete on the withdrawal of the pressure, sometimes falling short as much as ten per cent, after which a slow rise would take place. This result is not quite in agreement with the statement made in the first paper upon this subject, which was based, however, upon a much less satisfactory series of experiments.

An examination was made of the effect of the strength of the current upon the resistance of the disk. The weakest current used was a little less than ·001 ampere, and the strongest was about ·37 ampere, so that one was approximately 400 times the other. Throughout this range no sensible differences in the resistance of the disk were observed, the agreement at the two extremes being within the errors of measurement. Under all conditions the effect of variations of pressure was the same.

The faces of a soft carbon disk are always smooth and polished; the surface of hard carbon on the contrary is generally more or less rough and irregular. It would appear, therefore, that, if the reduction of the resistance of soft carbon by increase of pressure is due to better surface contact, this reduction of resistance should be much more marked with hard than with soft carbon. Experiments already described showed that the effect of pressure on hard carbon was very small; so small, in fact, that the pressure of a few centimeters of mercury would hardly produce a sensible effect.

The substitution of a disk of hard carbon for the soft, in the apparatus described, ought to show then whether any considerable part of the resistance variations observed could be attributed to variation of contact between mercury and carbon. A disk of hard carbon similar in dimensions to the soft disk previously employed was accordingly inserted between two similarly arranged tubes. The result of this experiment was to show, as had been anticipated, a small decrease of resistance when the pressure was increased. A pressure of about 7^{cm} of

mercury reduced the galvanometer deflection from 36 to 35 divisions of the scale. This indicates a change of less than three per cent, resulting from a pressure which with the soft disk lowered the resistance by more than sixty per cent. There can be little doubt that this small reduction is due almost entirely to better surface contact produced by pressure.

Throughout all of the experiments with soft carbon, it exhibited more or less irregularity in its behavior. The application of a pressure very largely in excess of the maximum referred to above would sometimes result in a permanent reduction of the resistance of the disk, indicating that a permanent set had taken place. By the exercise of care, however, what may be called the "normal" resistance may be maintained fairly constant for a considerable length of time.

Conclusions.—When carbon is prepared in the form of compressed lamp-black, its electrical resistance varies greatly with the pressure to which it is subjected. A small part of this variation is doubtless to be attributed to change in surface contact between the carbon and the electrodes through which the current is introduced, but by far the larger part (provided any effort is made to secure good surface contact) is due to a real change in the resistance of the carbon itself. The resistance of carbon in this condition is fluctuating and uncertain to a degree that seems to prevent its use as a factor in any device for the accurate measure of pressure.