tary laboratory work in physics presented by average students must have been impressed frequently by the writer's lack of familiarity with ordinary methods of computation and by his inability to draw rational conclusions regrading the accuracy and significance of his results. Unfortunately, the instruction in these matters presented by many widely used laboratory manuals is very inadequate and frequently misleading. We all admit that the primary object of elementary laboratory work is to put the student in personal touch with the facts and principles of physical science. But every experienced teacher knows that this object is not attainable without more or less formal instruction in the methods of reduction and interpretation of observations. Moreover, the student is seriously handicapped by the long-hand arithmetical processes taught in secondary schools when greater precision and facility can be attained by the shortened methods of computation adopted by every competent physicist.

A number of books designed to fill this gap by a detailed discussion of methods of computation and the theory of errors have appeared during the past few years. Dr. Tuttle's "Theory of Measurements" belongs in this group and it meets the needs of students in elementary physics more adequately than any other text that has come to the reviewer's attention. For the most part, concrete examples are developed to illustrate general principles and the discussions are so clear and well stated that the student can hardly fail to grasp their significance. The treatment presupposes no training in mathematics beyond that usually required for admission to college. In fact capable high-school pupils should find little difficulty in following the discussions.

The most important topics treated in the first one hundred pages of the book are as follows: fundamental ideas, abridged methods of multiplication and division, units and measurements, angles and circular functions, accuracy and the correct use of significant figures, logarithms, computations involving small magnitudes, and the use of the slide rule. The reviewer would be inclined to place more emphasis on the importance of systematic orderliness in computation and exact specification of units in writing numerical results. But on the whole the treatment is very good and guards against most of the common errors of inexperienced computers.

About seventy pages are devoted to a very illuminating discussion of the methods of graphical representation and reduction of observations, including a brief treatment of interpolation and extrapolation. The possibility of emphasizing the significance of the plotted data by a suitable choice of scales is illustrated by numerical examples and the advantages of so choosing the variables that the graph will be linear are pointed out. The uses of logarithmic and semi-logarithmic papers are also illustrated.

The remaining portion of the book deals with errors of observation and measurement, statistical methods, the determination of the best representative value from a series of discordant observations, the estimation of the precision of direct and indirect measurements, and simple applications of the method of least squares. The formulæ of the theory of errors are not derived mathematically but their significance and use are very clearly explained and illustrated by numerical examples.

The book is neatly printed and substantially bound. It should find a place in every physical laboratory devoted to the instruction of students.

A. deForest Palmer

## SPECIAL ARTICLES

### LITHOLOGIC EVIDENCE OF CLIMATIC PULSATIONS

The geologic evidences of changes of climate, as is well known, are numerous and incontrovertible, particularly as regards extremes of temperature and their accompanying variations of flora and fauna. The climatic changes which have produced the most widespread changes in life forms, as well as physiographic features, have been the ones most clearly recognized and easily studied. These changes are known to have been pulsatory or periodic, but with periods or cycles enduring for possibly many thousands of years.

In modern times, and in very recent geologic times as well, there have been minor fluctuations or pulsations in climate in various parts of the earth, as ably demonstrated by Brückner, Huntington and others. The "Brückner cycle," about thirty-five years in length, illustrates one type of pulsation. Hann, Melldrum, Douglass, and others have observed an eleven-year period to be about the average length of time between the maxima of wet or dry conditions. While the length of the cycles or periods may vary, the combinations of these shorter cycles of climatic changes are considered as making up the grand or climatic cycles, which are the ones best known in geology.

If the pulsatory theory of climatic change is a true interpretation of the observed facts of recent times, as seems very probable, then one may naturally inquire if similar pulsations or minor changes in climate have not occurred in the geologic past. If they have, what evidence, if any, is to be found in the rocks? The work of Barrell, Sayles, Case and others, in their studies of sedimentation, seems to definitely correlate climatic fluctuations with various phases of erosion and deposition. It may be of interest to submit some facts which may prove to be additional evidence of climatic pulsations, as afforded by certain "sedimentary" rocks.

The writer, in the course of a study of the sandstone formations in the foothills southwest of Fort Collins, in northern Colorado, came to the conclusion that much of this sandstone is of subaerial, and not subaqueous, origin. The sandstones of this region are commonly referred to as "Red Beds." The stratigraphic names are the Lyons, and the Lykins formations.

In the most prominent ridge of the Lykins outcrop are located a number of quarries from which flagging and building stone have been taken for many years. One prominent feature of much of this stone is its variegated laminations. These are usually alternate layers of white and brown sands, although other colors are occasionally found. These layers vary in thickness from about 0.5 mm. to 30 or 40 mm. In a number of cases the white layers are much thicker than the brown, while in many other cases the two kinds of layers are nearly equal in thickness. Also, the brown layers are often thicker than the white. Very thin alternate layers often occur, and there are usually many of these in a group when they do occur.

Examination of the character of typical samples from these layers shows, essentially, the following facts:

1. The white layers are composed almost wholly of very well rounded grains of white quartz, with scattered specks of iron oxide; the quartz grains are nearly uniform in size, the largest being rarely over 1 mm. in diameter, and the smallest about 0.3 mm. in diameter; the white layers are almost wholly free of any colored cement, and of angular or even subangular grains; many of the grains are pitted; wind ripples are frequently found at the top of a white layer, on exposed bedding planes.

2. The brown layers are composed almost wholly of angular and subangular grains of many different sizes, from very small to over 1 mm. in diameter; comparatively few rounded grains are present; the color is due to a coating of iron oxide on most of the grains.

These differently colored layers of sand, having such markedly different characteristics, would seem to point clearly to rather different origins. The factors and forces contributing to their formation can hardly be said to be identical. The material of the white layers suggests rounding, pitting, sorting, and deposition by the wind. The material of the brown layers has evidently been water-worn and water-borne, coming from a comparatively distant region. The occurrence of these different layers with their implied differences in origin and deposition may well suggest something of the history of this region, especially in regard to the extent and frequency of rainfall.

As these rocks contain no fossils, and in their general lithological character point to deposition by the wind, one may at least tentatively conclude that the climate of this region was rather arid at the time the sands composing these rocks were put in place by the forces of nature. This part of the continent was evidently a portion of the great inland desert which is thought to have existed in Triassic times.

It seems probable that at one season this particular locality was swept by winds carrying a burden of well-worn quartz grains, which was dropped when the force of the wind was checked. When the wind rose again, some of this sand was doubtless moved farther on, but a little remained to add to the accumulating layers beneath. At another season, the surface of this wind-laid sand was covered by a deposit of entirely different material, probably brought from some neighboring zone of alluviation by torrential rains. When the water had flowed on, or evaporated, the red-brown material became exposed to the winds, part of it was doubtless swept away, but some was covered with desert sand which continued to accumulate until the next freshet sent more of the red-brown sediment into the depression in the zone of dunes. That this was approximately the mode of deposition seems likely, when we find the one layer to be characteristically wind-borne, and the other water-borne, when all the accompanying facts are considered, and comparison is made with sand deposits that are being formed at the present time.

The study of this sandstone takes on an added interest if we note further that the frequency of recurrence of the brown or white layers often shows a striking regularity or periodicity. Where we find fairly broad white bands, with very thin brown layers alternating, it would seem that a relatively dry season is indicated. On the other hand, when the brown layers are very numerous and close together, it apparently points to frequent rains, with comparatively little deposition of the white sands by the wind. In the solid rock wall, as observed in the quarries, one can note the more or less regular recurrence of the wider bands of white, and if one could be sure that here a wide white band and one or more narrow brown bands represented the deposit of an arid year, one could determine the time required to produce a given thickness of this rock and also draw some conclusion as to the relative aridity of a given year or a series of years. But one can not at present state, beyond reasonable limits, the amounts of either kind of material that might be deposited in a year, and therefore one may not yet say definitely how long it took for a given stratum to be formed, or whether the aridity indicated by a white band corresponds to one season or to several. It may be interesting to note, however, that the recurrence of groups of brown layers with a

*Quarry "A"*

| White Layer | Thickness of White Layers, in Mm., Bottom to Top | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Section I. | | | | | Section II. | | | |
| Fifteenth | | *22* | | | | | | | |
| Fourteenth | | 2 | | | *14* (top) | | | | |
| Thirteenth | | 5 | | | 13 | | | | |
| Twelfth | | 5 | | | 12 | | | | |
| Eleventh | | 17 | *15* | | 8 | | | | |
| Tenth | | 7 | 8 | | 9 | | | | |
| Ninth | | 4 | 6 | *22* | 8 | *32* | | | |
| Eighth | | 10 | 8 | 15 | 7 | 25 | | | |
| Seventh | *15* | 8 | 4 | 7 | 8 | 28 | *22* | | |
| Sixth | 10 | 8 | 11 | 15 | 10 | 20 | 22 | *15* | |
| Fifth | 5 | 10 | 3 | 17 | 10 | 15 | 15 | 15 | |
| Fourth | 5 | 11 | 12 | 7 | 8 | 13 | 20 | 18 | |
| Third | 5 | 10 | 16 | 5 | 5 | 20 | 16 | 21 | 6 (top) |
| Second | 10 | 8 | 4 | 6 | 7 | 25 | 18 | 15 | 12 |
| First | *15*(*B*) | (*15*) | (*22*) | (*15*) | (*22*) | *25*(*B*) | (*32*) | (*22*) | (*15*) |

corresponding decrease in thickness of the white layers is found, on the average, following every tenth or eleventh layer.

This recurrence, as observed at a number of places on the quarry walls, as well as on detached fragments, ranges from the sixth to the fifteenth white layer. For example, at one place (Quarry "*A*," Section I.) the writer measured the thickness of the series of white layers, the thickest layers recurring as follows: seventh, eleventh (from and including the seventh), fifth (or fifteenth from the seventh), eleventh, ninth, fourteenth. At Section II., Quarry "*A*," the thickest white layers recur as follows: ninth, seventh, sixth. 1, Section I., Quarry "*A*," to the top of column 4, same section, there are a total of 33 white layers. In the section from Quarry "*B*," from the layer at the top of column 4 to the top of column 7, there are 34 white layers; from the top of column 7 to the top of column 11, there are 34 white layers. Likewise, from the top of column 2 to the top of column 6 there are 40 white layers; from the top of column 6 to the top of column 10 there are 38 white layers.

It may be that it is just by chance that these layers are arranged in this way, yet the agreement with known climatic pulsations is so striking as to make one ask whether it is

*Quarry "B," Section I*

| White Layer | Thickness of White Layers, in Mm., Bottom to Top | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Fifteenth | | | | | | *11* | | | | | |
| Fourteenth | | | | | | 3 | | | | | |
| Thirteenth | | | | | | 2 | | | | *10* | |
| Twelfth | | *15* | | | | 9 | | *11* | | 4 | |
| Eleventh | | 5 | | | *15* | 5 | | 7 | | 7 | |
| Tenth | *6* | 6 | *13* | | 4 | 5 | *14* | 9 | | 6 | |
| Ninth | 3 | 3 | 6 | | 5 | 6 | 8 | 10 | | 5 | |
| Eighth | 5 | 3 | 4 | | 10 | 8 | 10 | 10 | | 5 | |
| Seventh | 4 | 2 | 10 | *15* | 10 | 5 | 7 | 8 | | 7 | 6 (top) |
| Sixth | 4 | 2 | 9 | 15 | 10 | 8 | 3 | 6 | *20* | 7 | *13* |
| Fifth | 5 | 5 | 10 | 18 | 4 | 4 | 9 | 10 | 6 | 5 | 13 |
| Fourth | 7 | 4 | 6 | 5 | 2 | 15 | 12 | 11 | 5 | 7 | 10 |
| Third | 6 | 4 | 4 | 10 | 3 | 15 | 10 | 6 | 5 | 6 | 10 |
| Second | 6 | 5 | 3 | 3 | 5 | 10 | 5 | 7 | 8 | 13 | 8 |
| First | *10*(B) | (*6*) | (*15*) | (*13*) | (*15*) | (*15*) | (*11*) | (*14*) | (*11*) | (*20*) | (*10*) |

At another place (Quarry "*B*"), about a quarter of a mile away, the following periods were observed: tenth, twelfth, tenth, seventh, eleventh, fifteenth, tenth, twelfth, sixth, thirteenth, sixth. These three sections are about 2.5, 2 and 4 feet in thickness, respectively. The details of these measurements are shown in the tables above. On about 18 quarried fragments it was found that on the average every eighth to twelfth white layer was thicker than those between. On several such fragments, this recurrence was observed as follows: eleventh; tenth; eleventh and following ninth; eighth; ninth and following eleventh; tenth.

Another striking periodicity may be noticed in the tables. These periods correspond rather well to the average number of years in the Brückner cycle, as from the top of column just chance after all, or a result of natural laws. It is quite evident that the recurrence of layers of a certain character is periodic. Whether one can in this manner safely assign a limit to the yearly deposits seems questionable, but one may certainly inquire into the probability of deducing from a study of these variegated sandstones the conclusion that at the time of their formation the climatic conditions, especially with reference to rainfall, were fluctuating much as they have been within recent times.

It would be distinctly interesting to know whether geologists can find, in more exact and complete studies, further evidence of pulsatory changes of climate having been recorded in the clastic rocks.

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