SCIENCE

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*ADDRESS TO THE GEOLOGICAL SECTION OF THE BRITISH ASSOCIATION FOR THE ADVANCEMENT OF SCIENCE.**

THERE are two circumstances which invest the fact of my presidency of the section this year with peculiar pleasure to myself. The first public lecture I ever gave was in the Town Hall at Birkdale in 1882, and the first of the fifteen meetings of the British Association which I have attended was that held in Southport in 1883.

There is still a third reason that this meeting is in many respects a geological meeting. A paleobotanist is presiding over Section K, and the council has invited, for the first time for many years, one geologist to deliver an evening discourse and another to give the address to artisans. I need hardly say that we are all looking forward to the lectures of Dr. Rowe and Dr. Flett with keen anticipation. To the one for his successful use of new methods of developing fossils and his scientific employment of the material thus prepared in stratigraphic research; to the other for his prompt, daring and business-like expedition to the scene of recent volcanic activity in the West Indies, during which he and his colleague, Dr. Tempest Anderson, collected so many important facts and brought away so much new knowledge of the mechanism of that disastrous and exceptional volcanic outbreak.

* Southport meeting, 1903.

THE FUNCTIONS OF GEOLOGY IN EDUCATION AND IN PRACTICAL LIFE.

At the meeting in 1890, at Leeds, my old friend Professor A. H. Green delivered an address to the section which has generally been regarded as expressing an opinion adverse to the use of the science of geology as an educational agent. Some of the expressions used by him, if taken alone, certainly seem to bear out this interpretation. For instance, he says: 'Geologists are in danger of becoming loose reasoners'; further he says: 'I can not shut my eyes to the fact that when geology is to be used as a means of education there are certain attendant risks that need to be carefully and watchfully guarded against.' Then he adds: 'Inferences based on such incomplete and shaky foundations must necessarily be largely hypothetical.'

Such expressions, falling from an accomplished mathematician and one who was such an eminent field geologist as Professor Green, the author of some of the most trustworthy and most useful of the Geological Survey 'Memoirs,' and above all one of the clearest of our teachers and the writer of the best and most eminently practical text-book on physical geology in this or any other language, naturally exercised great influence on contemporary thought. And I should be as unwise as I am certainly rash in endeavoring to controvert them but for the fact that I think he only half believed his own words. He remarks that "to be forewarned is a proverbial safeguard, and those who are alive to a danger will cast about for a means of guarding against it. And there are many ways of neutralizing whatever there may be potentially harmful in the use of geology for educational ends."

After thus himself answering what is in reality his main indictment, Professor Green proceeds with the rest of an address crammed full of such valuable hints as could only fall from an experienced and practical teacher, showing how much could be done if the science were only properly taught.

And then he concludes by asking for 'that kindly and genial criticism with which the brotherhood of the hammer are wont to welcome attempts to strengthen the corner-stones and widen the domain of the science we love so well.'

I think the time has now come to speak with greater confidence, and, although the distance signal stands at danger, to forge ahead slowly but surely, keeping our eyes open for all the risks of the road, with one hand on the brakes and the other on the driving gear, secure at least in the confidence that nature, unlike man, never switches a down train on to the up track.

Those of us who have been teaching our science for any considerable time have come to realize that there are many reasons why geology should be more widely taught than at present; that there are many types of mind to whom this science appeals as no other one does; and that there are abundant places and frequent circumstances which allow of the teaching of it when other sciences are unsuitable.

To begin with, there is no science in which the materials for elementary teaching are so common, so cheap and everywhere so accessible. Nor is there any science which touches so quickly the earliest and most elementary interests. It was for this reason that Huxley built his new science of physiography on a geological basis. Hills, plains, valleys, crags, quarries, cuttings, are attractive to every boy and girl, and always rouse intelligent curiosity and frequent inquiry; and although the questions asked are difficult to answer in full, a keen teacher can soon set his children to hunt for fossils or structures which will give them part of the information they seek. Of course the teaching can not go very far without simple laboratory and museum accommodation, and without a small expenditure on maps and sections; but the former of these requirements can soon be supplied from the chemical laboratory and by the collection of the students themselves, while the latter are every day becoming cheaper and more accessible and useful. The bicycle and the camera, too, are providing new teaching material and methods, while at the same time they are giving new interests. The bicycle has already begun to create a generation to whom relief maps are not an altogether sealed book, and for whom the laws which govern the relief of a country are rapidly finding practical utility; and the camera, at the same time that it quickens the appreciation of natural beauty, must give new interest to each scrap of knowledge as to the causes, whether botanical or geological, to which that beauty is due. And it is this new knowledge which in turn develops the æsthetic sense. *Mente, manu et malleo* sums up most of what is required in the early stages of learning; but to round off the motto we still require words to express the camera and bicycle.

Another reason is the open-airness of the practice of the science. The delight of the open country comes with intense relief after the class-room, the laboratory or the workshop. In education generally, and especially in geological education, we have reached the end of the period when

> 'all roads lead to Rome
> Or books—the refuge of the destitute.'

Of course I realize fully the vital necessity of laboratory and museum work in the stages of both learning and investigation, and quite freely admit that there is an immense amount of useful work being done and to be done in these institutions alone. But what I think I do right to insist upon is that all work in the laboratory and museum must be mainly preparatory to the field-work which is to follow; every type of geological student must be sent into the field sooner or later, and in most cases the sooner the better. I have generally found that students in the early stages have a great repugnance to the grind of working through countless varieties of minerals, rocks and fossils; but once they have gone into the field, collected with their own hands, and seen the importance of these things, and the inferences to be drawn from them, for themselves—once indeed they have got keen—they come back willingly, even eagerly, to any amount of hard indoor work.

But it is when they leave ordinary excursion work and start upon regular field training that one really feels them spurt forward. As soon as they begin to realize that surface-features are only the reflex of rock-structure and can be utilized for mapping, that to check their lines and initiate new ones they must search for and find new exposures, and that each observation while settling perhaps one disputed point may originate a host of new ones, when above all they can be trusted with a certain amount of individual responsibility and given a definite point to settle for themselves, it is then that their progress is most rapid, and is bounded only by their powers of endurance.

I have often watched my students through the various stages of their field training with the deepest interest as a study of the development of character. At first they look upon it merely as a relief from the tedium of the class-room and laboratory, and as a pleasant country excursion. But gradually the fascination of research comes over them, and as they feel their capacity increasing and their grip and insight into the structure of the country deepening, one can see them growing up under one's eyes. They come into the field a rabble of larky boys; they begin to develop into men before they leave it.

And what is true of students is more than ever true of the working geologist. I hold that every geologist, whatever his special branch may be, should spend a portion of every year in the field. Though a petrologist may have specimens sent to him from every variety, even the common ones, in a rock mass and have their relations and proportions properly explained to him, it is quite impossible for him to feel and appreciate these proportions and relationships so well as if he had studied and collected in the field and gained a personal interest in them. Besides this the conclusions drawn in the field are the crystalline and washed residuum, so to speak, left on the mind after the handling of dozens of specimens, weathered and unweathered, and the seeing them in a host of different lights and aspects. The rock is hammered and puzzled over and its relations studied until some conclusion is arrived at which bears the test of application to all the facts observed in the field.

Again, once a paleontologist is divorced from the field he loses the significance of minute time variations, the proportion of aberrant to normal forms, and the value of naked-eye characteristics which can be 'spotted' in the field. Huxley once asked for a paleontologist who was no geologist; I venture to think we have now had enough of them. What we want above all at the present time is the recognition of such characters as have enabled our field paleontologists to zone by means of the graptolites, the ammonites and the echinids, so that every rock system we possess may be subdivided with the same minuteness and reliability as the Ordovician, Silurian and Jurassic systems and the Chalk.

If this is once done the biological results will take care of themselves, and we may feel perfect confidence that new laws of biological succession and evolution will result from such work, as indeed they are now doing—laws which could never be reached from first principles, but could only come out in the hands of those to whom time and place were the factors by which they were most impressed. It is only by field work that we shall ever get rid of the confusion which has been inevitable from the supposed existence of such so-called species as *Orthis caligramma, Atrypa reticularis* and *Productus giganteus.*

As for the geological result, it is only necessary to read the excellent and workman-like address delivered to this section at Liverpool in 1896 by Mr. Marr to realize how many problems of succession and structure, of distribution and causation, of ancient geography and modern landscape, are still awaiting solution by the application of minute and exact zonal researches.

On the other hand it goes without saying that the more a field geologist knows of his rocks and fossils the better will his stratigraphical work become; but this is too obvious to require more than stating.

Geology, again, is of value as a recreative science, one which can be enjoyed when cycling, walking or climbing, even when sailing or traveling by rail. Indeed, it is difficult to find a place in which to treat the confirmed geologist if you wish to make him a 'total abstainer.' There are others than those who must make use of their science in their professions, those in need of a hobby, those interested in natural scenery, veterans who have seen much and now have leisure and means to see more, and those fortunate ones who have not to earn their bread by the sweat of their brain or brow. Many of these have done and are doing good work for us, and many more would find real pleasure in doing so if only they had been inoculated in those early days when impressions sink deep. Mr. A. S. Reid, who has had much and fruitful experience in teaching, tells me that he has often seen seed planted in barren ground at school spring up and grow and blossom as a country-holiday recreation after school days, or bear the good fruit of solid research after lying dormant for many years.

We may next look upon geology as an educational medium from quite a different point of view. If more than half the work of the man of science is the collection of fact, and of actual fact as opposed to the result of the personal equation, geology is perhaps the very best training-ground. There are such hosts of facts to be still recorded, so many erroneous observations to be corrected, and so much hope of extending observations on already recorded facts, that there is plenty of work even for the man who can snatch but limited leisure from other pursuits and the one who is a collector of fact and nothing else, as well as those

> 'under whose command
> Is earth and earth's, and in their hand
> Is Nature like an open book.'

But in the collection of facts a wise and careful selection is constantly necessary in order to pick out from the multitude those which are of exceptional value and importance in the construction of hypotheses. Nature, it is true, can not lie; she is a perfectly honest but expert witness, and it takes an astonishing amount of acute cross-examination to elicit the truth, the whole truth and nothing but the truth.

There is no science which needs such a variety of observations as field geology. When we remember that Sedgwick and Darwin visited Cwm Glas and carried away no recollection of the features which now shout 'glaciation' to every one who enters the Cwm, it is easy to see how alert must be the eyes and how agile the mind of the man who has to carry a dozen problems in his mind at once, and must be on the lookout for evidence with regard to all of them if he would work out the structure of a difficult country; and who is not only looking out for facts to test his own hypothesis, but wishes to observe so accurately that if his hypothesis gives way even at the eleventh hour his facts are ready to suggest and test its successor. There is no class of men so well up in what may be called observational natural history generally as the practiced field geologist, because he never knows at what moment some chance observation—a mound, a spring, a flower, a feature, even a rabbit-hole or a shadow—may be of service to him. Not only should he know his country in its every feature and every aspect, but he must have, and in most cases soon acquires, that remarkable instinct, which can only be denoted as an 'eye for a country,' with which generally goes a naturalist's knowledge of its plants and of its birds, beasts and fishes.

At the present time many educationists are in favor of teaching only the experimental sciences to the exclusion of those which collect their facts by observation. This attitude may do some good to geology in compelling us to pay more attention to that side of our science which has been better cultivated hitherto in France than in our own country. But whether we think of education as the equipping of a scientific man for his future career or as the training of the mind to encounter the problems of life, we must admit that it would be as wrong to ignore one of the two ways only of collecting fact as it would be to teach deductive reasoning to the exclusion of that by induction. Indeed, this is understating the case, for in the vast majority of the problems which confront us in everyday life the solution can only be reached if an accurate grasp of the facts can be obtained from observation. The training of the mind solely by means of experiments carefully designed to eliminate all confusing and collateral elements savors too much of 'milk for babes' and too little of 'strong meat for men.'

Mr. Teall in his masterly address to the Geological Society in 1901 pointed out 'that the state of advancement of a science must be measured, not by the number of facts collected, but by the number of facts *coordinated.*' Theory, consistent, comprehensive, tested, verified, is the life-blood of our science as of any other. It is what history is to politics, what morals are to manners, and what faith is to religion.

It is almost impossible to collect facts at all without carrying a working hypothesis to string them on. It is easy to follow Darwin's advice and speculate freely; the speculation may be right, and if wrong it will be weeded out by new facts and criticism, while the speculative instinct will suggest others. In hypothesis there will always be an ultimate survival of the fittest.

And it is not only easy but absolutely necessary, because in geology, more perhaps than in any other science, hypotheses are like steps in a staircase: each one must be mounted before the next one can be reached; and if you have no intention of coming back again that way, it does not matter if you destroy each step when you have made use of it. Every new hypothesis has something fresh to teach, and nearly all have some element of untruth to be ultimately eliminated. But each one is a stage, and a necessary stage, in progress.

In physics and in chemistry the chief difficulties are those which surround the making of experiments. When these have been successfully overcome the right theory follows naturally, and verification is not usually a very lengthy process. In geology, on the other hand, theory is more quickly arrived at from the numerous facts; but the price is paid in the patience required for testing and the ruthless refusal to strain fact to fit theory. Every hypothesis leads back to facts again and again for verification, extension and improvement.

Many of the leading conclusions of our science have not yet become part of the common stock of the knowledge of the world; indeed they are not even fully realized by many men eminent in their own sciences. The momentum given by Werner and Playfair, Phillips and Jukes, Sedgwick and Lyell, and other pioneers of the fighting science, has died down, and in the interval of hard work, detailed observation, minute subdivision, involved classification and pedantic nomenclature which has followed, and which I believe to be only the prelude to an epoch of more important generalization in the immediate future, it has been difficult for an outsider to see the wood for the trees. He has hardly yet realized that facts as vital to the social and economic well-being of the people at large, and conclusions of as great importance in the progress of the science and of as far-reaching consequence in the allied sciences, are being wrung from nature now as in the past.

'The unimaginable touch of time,' the antiquity of the globe as the abode of life, the absolute proof of the evolution of life given by fossils, the proofs of change and evolution in geography and climate, the antiquity of man, the nature of the earth's interior, the tremendous cumulative effect of small causes, the definite position of deposits of economic value, the role played by denudation and earth-movement in the development of landscape, the view of the earth as a living organism with the heyday of its youth, its maturity and its future old age and death, to mention but a few of our great principles, furnish us with conceptions which can not fail to quicken the attention and inspire the thought of students of history, geography and other sciences.

Now that these things are capable of definite proof, that they are of real significance in the cognate sciences and of actual economic value, above all now that the nineteenth century, the geological century, has closed, that the heroic age is over, that we have passed the stages of scepticism and religious intolerance and reached the stage 'when everybody knew it before,' it might be expected that a fairly accurate knowledge and appreciation of these principles should form part of the common stock of knowledge, and be a starting-point in the teaching of allied sciences.

Another feature which adds to the attractiveness of geological observations is their immediate usefulness from many points of view. The relief and outline of any area is as closely related to its rocky framework as the form of a human being is related to his skeleton and muscles. The geological surveyor recognizes how every rise and fall is the direct reflex of some corresponding difference in the underlying rocks; he seeks to observe and explain the ordinary as well as anomalous ground-features, every one of which conveys some meaning to him.

A geological basis for the classification and grouping of surface-features is the only one which is likely to be satisfactory in the end, because it is the only one founded on a definite natural principle, the relation of cause to effect. It is not without good reason that the topographic and geological surveys of the United States are combined under one management, and nowhere else are the topographic results more accurate and satisfactory. Landscape is traced back to its ultimate source, and consequently sketched in with more feeling for the country and greater accuracy of knowledge than would otherwise be possible. Geologists were among the first to cry out for increasing accuracy and detail in our government maps, and they have consistently made the utmost use of the best of these maps as fast as they appeared. With the publication of each type of map, hachured, contoured, six-inch, twenty-five-inch, the value and accuracy of geological mapping has advanced step by step. Wherever the topography is better delineated than usual, the facilities are greater for accurate geological work, and the best geological maps, and those in greatest demand, are always those based on the most minute and detailed topographic work. On the other hand geologists are training up a class of men who can read and interpret the inner meaning of these maps, and make the fullest use of the splendid facilities given by the minute accuracy of the ordnance work.

Lord Roberts has recently complained that the cadets at Woolwich are unable to read and interpret maps, and he 'strongly advised them to set about improving themselves in this respect, or they would find themselves heavily handicapped in the future.' I believe that the only training in this subject before entering the Royal Military Academy and the Royal Military College has been that given to those candidates who have taken up geology for their entrance examination. By encouraging these students to study and draw maps and sections of their own districts, and to explain and draw sections across geological maps generally, thus accounting for surface-features, the examiners have compelled this small group of candidates to see deeper into a map than ordinary people. If only this training had been encouraged and advanced and made use of later, the commander-in-chief would have had no cause of complaint with regard to these particular men. Looking at a map is one thing; working at it, seeing into it and getting out of it what is wanted from the vast mass of information crammed into it, is quite another; and geology is the very best and perhaps the only means of compelling such a close study of maps as to enable students to seize upon the salient features of a country from a map as quickly and accurately as if the country itself were spread out before them. The geologist is compelled to work out and classify for himself the features he observes on his maps, such as scarps and terraces, crags and waterfalls, streams and gorges, passes and ridges, the run of the roads, canals and railways, the nature and accessibility of the coast, and all those features which make the difference between easy-going and difficult country. When he has worked his way over a map in this fashion that map becomes to him a real and telling picture of the country itself.

Experience, bitter experience, in South Africa has shown the necessity not only for good maps and map-reading, but for that which is the most priceless possession alike of the best field geologists and of the best strategists, a good 'eye for a country.' It has been said that the Boer war was a geographical war; but it was even more, and, especially in its later stages, a topographic war. Again and again the Boers aroused our astonishment and admiration by the way in which their topographic knowledge and instinct enabled them to fight, to defend themselves and to secure their retreat by the most consummate ability in utilizing the natural features of their country. This was due to two things. In the first place they took care to have with them in each part of the country the men who knew that particular district best in every detail and in every aspect. But in the second place there can be no doubt that they made the utmost use of that hunter-craft by which the majority of them could take in at a glance the character of a country, even a new one, as a whole, guided by certain unconscious principles which each man absorbed as part of his country life and hunter's training. They possessed, and had of necessity cultivated to a very high degree, an 'eye for a country.'

Now the study of the geology of any district, and especially the geological mapping of it, goes a long way towards giving and educating the very kind of eye for a country which is required, partly by reason of the practice in observation and interpretation which it is continuously giving, and partly because it deliberately supplies the very kinds of classification and the principles of form which a hunter-people have unconsciously built up from their outdoor experience.

Any geologist who thinks of the Weald, the wolds and downs of eastern England, the scarps and terraces of the Pennine, the buried mountain structure of the Midlands, even the complicated mountain types of Lakeland and Wales, will remember how often his general knowledge of the rock structure of the region has helped him as a guide to the topography; and as his geological knowledge of the area has increased he will recall how easy it has become to carry the most complicated topography in his mind, or to revive his recollection of it from a glance at the map, because the geological structure, the anatomy, is present in his mind throughout, and the outside form is the inevitable consequence of that structure. Indeed the reading of a good geological map to the geologist is like the reading of a score by a musician.

Surely it would be most unwise if the Committee on Military Education were to cut out of their curriculum the one subject which has exercised and educated this faculty, and one which is at the same time doing a great deal to counteract that degeneration of observing faculties inseparable from a town life. Some cadets at least ought to be chosen from amongst those men who have been trained by this method to see quickly and accurately into the topographic character and possibilities of a country, and provision should be made for educating their faculties further until they become of genuine strategic value.

Then I believe it would be correct to say that no class of men get to know their own country with anything like the minuteness and accuracy of the geological surveyor. The mere topographer simply transfers his impressions on the spot as quickly as may be to paper, and has no further concern with them. The geologist must keep them stored in his mind, watching the variation and development of each feature from point to point for his own purposes. He must traverse every inch of his ground, he must know where he can climb each mountain and ford every brook, where there are quarries or roads, springs or flats; what can be seen from every point of view, how the habitability or habitations vary from point to point; in short, he must become a veritable walking map of his own district. Why not scatter such men in every quarter of the globe, particularly where any trouble is likely to arise? They are cheap enough, they will waste no time, and they will be so glad of the chance for research that they will not be hard to satisfy in the matter of pay and equipment. Thus you will acquire a corps of guides, ready wherever and whenever they are wanted; and when trouble arises they may do a great deal by means of their minute knowledge of topography to save millions of money and thousands of lives, and to prevent the irritating recurrence of the kind of disaster with which we have become sadly familiar within the last five years.

In dealing with the relationship of geology to geography geologists are frequently charged with claiming too much. On this point at least, however, there can be no difference of opinion, that the majority of geological surveyors and unofficial investigators have kept their eyes open to this relationship, and have often contributed new explanations to old problems. They have been compelled to observe, and often to explain, surface features before making use of them in their own mapping, and in doing so have often hit upon new principles. It is hardly needful to mention such examples as Ramsay's great conception of plains of marine denudation, Whitaker's convincing memoir on subaerial denudation, Jukes's explanation of the laws of river adjustment, Gilbert's scientific essay on erosion, Heim's demonstration of the share taken by earth movement in the modeling of landscape features, and the exceedingly valuable proofs of the relation of human settlement and movement to underground structure, worked out with such skill and diligence by Topley in his masterly memoir on the Weald—the jumping-off place, if I may so term it, of the new geography.

No one is more pleased than geologists that geographers have ceased to draw their knowledge of causation solely from history, and that they have turned their attention to the dependence and reaction of mankind on nature as well. But while hoping that geographers will continue to study, so far as they logically can, the relationship of plants, animals and mankind to the solid framework of the globe on which they live, we must draw the line at the invention of new geological hypotheses to explain geographic difficulties on no better evidence than that furnished by the difficulties themselves; on the other hand, we must insist that each new geological principle must take its place amongst geographic explanations as soon as it is freely admitted to be based on a sound substratum of fact.

I must confine myself to a few instances of what I mean. Mr. Marr's geological work on the origin of lake basins has led to some remarkable and unexpected conclusions with regard to the history and origin of the drainage of the lake district. Some of the very difficult questions raised by the physical geography of the North Riding of Yorkshire have received a new explanation from the researches of Professor Kendall and Mr. Dwerryhouse, an explanation which is the outcome of purely geological methods of observation of geological materials. Again, the simple geological interpretation of a well-known unconformity between Archæan and Triassic rocks has made it extremely probable that many of the present landscapes, not only in the Midlands but elsewhere, may be really fossil landscapes, of great antiquity and due to causes quite different from those in operation there at the present day. In mountain regions, too, it can only be by geological observation that we shall ever determine what has been the precise direct share of earth movement in the production of surface relief. Such examples seem to indicate that many of the principles must be of geological origin but of geographic application.

While geology has been of direct scientific utility in topography and geography, there is another domain, that of economic geology, which is entirely its own. The application of geology extends to every industry and occupation which has to do with our connection with the earth on which we live. Agriculture, engineering, the obtaining of the useful and precious metals, chemical substances, building materials, and road metals, sanitary science, the winning and working of coal, iron, oil, gas and water, all these and many more pursuits, are carried on the better if founded on a knowledge of the structure of the earth's crust. Indeed a geological map of this country, showing rocks, solid and superficial, of which no economic use could be made, would be nearly blank. Yet so much has this side of the science been neglected of recent years that our only comprehensive text-books on it are altogether out of date.

But in teaching geology as a technical science, or rather as one with technological applications, one of the greatest difficulties before us is to steer between two opposing schools, the so-called theoretical school and the practical school.

There are those who say that there is but one geology, the theoretical, and that a thorough knowledge of this must be obtained by all those who intend to apply the science. Others think that this is too much to ask—that the time available is not sufficient—and that it is only necessary to teach so much of the subject as is obviously germane to the question in hand.

The best course appears to me to be the middle one between the two extremes. If the engineer or miner, the water-finder or quarryman, has no knowledge of principles, but only of such facts as appear to be required in the present position of his profession, he will be incapable of making any improvement in his methods so far as they depend upon geology. If, on the other hand, he is a purely theoretical man without a detailed practical and working acquaintance with the facts which specially concern him, he will be put down by his colleagues as unpractical; he will have to learn the facts as quickly as he can and buy his experience in the dearest market.

It seems to me that there is certain common ground which must be acquired by all types of professional men. The general petrographic character of the common rocks, enough of their mode of origin to aid the memory, the principle of order and age in the stratified rocks, the use of fossils and superposition as tests of age, the nature of unconformities, the relation of structure to the form of the ground, the occurrence of folds and faults, and above all the reading of maps and sections, and sufficient field work to give confidence in the representation of facts on maps—these things are required by everybody who makes any use of geology in his daily life.

But when so much has been acquired it should be possible to separate out the students for more special treatment. The coal-miner will require especially a full knowledge of the coal-bearing systems, not in our own islands merely, but all over the world; a special acquaintance with the effects of folds and faults, and an advanced training in the maps and sections of coal-bearing areas. The vein-miner should be well up in faulting and all the geometrical problems associated with it, and he should have an exhaustive acquaintance with the vein and metalliferous minerals.

The water engineer needs to know especially well the porous and impervious rock types, the texture and composition of these rocks, the nature of their cements and joints, and the distribution of water levels in them. Further, he must know what there is to be done on the problems of permeability and absorption, the relation of rain to supply, the changes undergone by water and the paths taken by it on its route underground, and the varying nature of rocks in depth. He must also realize the effects of folds and faults on drainage areas and on underground water courses, the special qualities of water-yielding rocks, of those forming the foundation of reservoir sites, and those suitable for the construction of dams.

The sanitary engineer will need to be acquainted with the same range of special knowledge as the water engineer, but will naturally be more interested in getting rid of surface water without contaminating it more than he can help than in obtaining it; he will also need a more detailed acquaintance with superficial deposits than any other class of professional men.

The quarryman and architect ought to know the rocks both macroscopically and microscopically, in their chemical and mineralogical character, their grains and their cements. But he ought to be well acquainted with the laws of bedding, jointing and cleavage, with questions of outcrop and underground extent, and all those other characters which make the difference between good and bad stone, or between one desirable and undesirable in the particular circumstances in which a building is to be erected. Further, he should make a particular study of the action of weight and weather on the rocks which he employs.

The road engineer and surveyor, now that it has been discovered that it is cheaper and better to use the best and most lasting road metal instead of any that happens to be at hand, requires to have an extensive acquaintance with our igneous and other durable rocks. He needs, however, not only petrographic and chemical knowledge, but also a type of information not at present accessible in England, the relative value of these rocks in resisting the wear and tear of traffic, the cementing power of the worn material, and the surface characters of roads made from them, in order that he may in each case select the stone which in his particular circumstances gives the best value for money. It would surely pay the county councils to follow, with modifications, the example of the French and Americans, and carry out a deliberate and well-planned series of experiments on all the material accessible to them in their respective districts.

The teaching of the application of geology should, therefore, take some such form as the following: First, the principles should be thoroughly taught with the use for the most part of examples drawn from the economic side; thus cementing might be illustrated on the side of water percolation, jointing from the making of mine roads and from quarry sites, faulting from effects on coal outcrops and veins, unconformity from its significance to the coalminer; while in teaching the sequence of stratified rocks the systems and stages could be mainly individualized by their economic characters. When this is done the class must be divided into groups, each paying special attention to the points which are of essential importance to them.

The teaching at all stages should be practical and, so far as can be, experimental, and in all cases where possible a certain amount of field work should be attempted. For the field after all is the laboratory of the geologist where he can observe experiments being made on a gigantic scale under his eyes.

The aim of the teaching should be to give to students the equipment necessary to deal with the chief geological problems that they will meet with in their varied professions; it should show them where to go for maps, memoirs or descriptions of the areas with which they are dealing; and in cases of great difficulty should enable them to see where further geological assistance is required, and to weigh and balance the expert evidence given them against the economic and other factors of the problem before them.

From men educated thus geology has the right to expect a valuable return. There is a vast amount of knowledge on economic subjects in existence but not readily accessible. It has been obtained by experts, and after being used is locked up or lost. And yet it is the very kind of knowledge which is wanted to extend our principles further into the economic side of the subject. So well is this recognized that many geologists are attracted to economic work mainly because of the wide range of new facts that they can only thus become acquainted with. It is possible to make use of many of these facts for scientific induction without in any way betraying confidence or revealing the source from which they are obtained; and even if they can not be used directly they are often of great service in giving moral support, or the contrary, to working hypotheses founded on other evidence.

The knowledge of our mineral resources is of such vital consequence to ourselves and to our present and future welfare as a nation, and yet it is a matter of so much popular misconception, that I feel bound to dwell on this subject a little longer. To any one who studies the growth and distribution of population in any important modern state the facts and reasons become as clear as day.

It is easy to construct maps showing at a glance the density of population in any country. Perhaps the most effective way to do so is to draw a series of isodemic lines and gradually to increase the depth of tint within them as the number of people per square mile increases, until absolute blackness represents, say, over 2,000 people per square mile. Such maps are the best means of displaying the geography of the available sources of energy in a country at any particular period. Population maps of England and Wales in the early part of the eighteenth century would be pale in tint with a few rather darker patches, and would show a distribution dependent solely upon food as a source of energy working through the medium of mankind and animals. Such maps would be purely agricultural and maricultural, dependent upon the harvests of the land and sea. Maps made at a later period would show a new concentration around other sources of energy, particularly wind and water, but would not be perceptibly darker in tint as a whole; for although we are apt to think that we have in this country too much wind and water, they are not in such a form that we can extract any appreciable supply of energy directly from them.

But maps representing the present population, while still mainly energy maps, at once bring out the fact that our leading source of energy is now *coal* and no longer food, wind or water. The new concentrations, marked now by patches and bands of deepest black, have shifted away from the agricultural regions and settled upon and around the coal fields. The map has now become geological.

The difference between the old and the new map is, however, not only in kind; it is even more remarkable in degree. The population is everywhere much denser. Not only are the mining and manufacturing areas on the new map more than eight times as densely populated as any areas on the older map, not only is the average population five times greater throughout the country, but the lightest spot in the new map is nearly as dark as the darkest spot on the old one. The sparsest population at the present day is as thick on the ground as it was in the densest spots indicated on the older map, while at the same time the standards of wages, living and comfort, instead of decreasing, have increased.

The discovery of this new source of energy, coal, immediately gave employment to a much larger number of people; it paid for their food and provided the means of transporting it from the uttermost parts of the earth. Under agricultural conditions the map shows that the population attained a given maximum density, and no further increase was possible, the density being regulated by the food supply raised on the surface of the land. Our dwelling-house was but one story high. Under industrial conditions our mineral resources can support five times the number. Our dwelling-house is of five stories —one above ground and four below it.

At the same time the type of distribution is altered. The agricultural areas are now covered by a relatively scanty population, and the dense areas are situated on or near to the coal and iron fields, the regions yielding other metals, those suitable for industries which consume large supplies of fuel, and a host of new distributing centers, nodal points on the new line of traffic, either inside the country or on its margins where the great routes of ocean transport converge, or where the sea penetrates far in towards the industrial regions.

It has been the good fortune of this country to be the first to realize, and with characteristic energy to take advantage of, the new possibilities for development opened up by the discovery and utilization of its mineral wealth. We were exceedingly fortunate in having so much of this wealth at hand, easy to get and work from geological considerations, cheap to transport and export from geographical considerations. So we were able to pay cash for the products of the whole world, to handle, manufacture and transport them, and thus to become the traders and carriers of the world.

But other nations are waking up. We have no monopoly of underground wealth, and day by day we are feeling the competition of their awakening strength. Can we carry on the struggle and maintain the lead we have gained?

In answering this question there are three great considerations to keep in mind. First, our own mineral wealth is unexhausted; secondly, that of our colonies is as yet almost untouched; and thirdly, there are still many uncolonized areas left in the world.

The very plenty of our coal and iron, and the ease of extracting it, has been an economic danger. There has been waste in exploration because of ignorance of the structure and position of the coal-yielding rocks; waste in extraction because of defective appliances, of the working only of the best-paying seams and areas, of the water difficulty, and the want of well-kept plans and records of areas worked and unworked; waste in employment because of the low efficiency of the machinery which turns this energy into work. With all this waste our coal fields have hardly yielded a miserable *one* per cent. of the energy which the coal actually possesses when *in situ*.

Engineers and miners are trying to diminish two of these sources of waste, and geology has done something to reduce that of exploration. This has been done by detailed mapping and study, so that we now know the areas covered by the coal-seams, their varying thickness, the 'wants,' folds and faults by which they are traversed, and all that great group of characters designated as the geological structure of the coal fields. It could not have been accomplished unless unproductive as well as productive areas had been studied, the margins of the fields mapped as well as their interiors, and unless the geological principles wrested from all sorts of rocks and regions had been available for application to the coal districts in question. We no longer imagine every gray shale to be an index of coal; we are not frightened by every roll or fault we meet with underground; nor do we, as in the past, throw away vast sums of money in sinking for coal in Cambrian or Silurian rocks.

We can not afford, hard bitten as we are in the rough school of experience and with our increased knowledge, to make all the old mistakes over again, and yet we are on the very eve of doing it. Up to the present it is our visible coal fields that we have been working, and we have got to know their extent and character fairly well. But so much coal has now been raised, so much wasted in extraction, and so many areas rendered dangerous or impossible to work, that we can not shut our eyes to the grave fact that these visible fields are rapidly approaching exhaustion. The government has done well to take stock again of our coal supply and to make a really serious attempt by means of a royal commission to gauge its extent and duration; and we all look forward to that commission to direct attention to this serious waste and to the possibility of better economy which will result from the fuller application of scientific method to exploration, working and employment.

But we still have an area of concealed coal fields left, possibly at least as large and productive as those already explored and as full of hope for increased industrial development. It is to these we must now turn attention with a view of obtaining from them the maximum amount possible of the energy that they contain. The same problems which beset the earlier explorers of the visible coal fields will again be present with us in our new task, and there will be in addition a host of new ones, even more difficult and costly, to solve. In spite of this the task will have to be undertaken, and we must not rest until we have as good a knowledge of the concealed coal fields as we have of those at the surface. This knowledge will have to be obtained in the old way by geological surveying and mapping and by the coördination of all the observations available in the productive rocks themselves and in those associated with them, whether made in the course of geological study or in mining and exploration. But now the work will have to be done at a depth of thousands instead of hundreds of feet, and under a thick cover of newer strata resting unconformably on those we wish to pierce and work. When we get under the unconformable cover we meet the same geology and the same laws of stratigraphy and structure as in more superficial deposits, but accurate induction is rendered increasingly difficult by the paucity of exposures and the small number of facts available owing to the great expense of deep boring. How precious, then, becomes every scrap of information obtained from sinkings and borings, not only where success is met with, but where it is not; and how little short of criminal is it that there should be the probability that much of this information is being and will be irretrievably lost!

Mr. Harmer pointed out in a paper to this section in 1895 that under present conditions there was an automatic check on all explorations of this kind. The only person who can carry it out is the land-owner. If he fails he loses his money and does not even secure the sympathy of his neighbors. If he succeeds his neighbors stand to gain as much as he does without sharing in the expense. The successful explorer naturally conceals the information he has acquired, because he has had to pay so heavily for it that he can not afford to put his neighbors in as good a position as himself and make them his rivals as well; while the unsuccessful man is only too glad to forget as soon as possible all about his unfortunate venture. And yet in work of this kind failure is second only to success in the value of the information it gives as to the underground structure which it is so necessary to have if deep mining is to become a real addition to the resources of the country.

Systematic and detailed exploration, guided by scientific principles, and advancing from the known to the unknown, ought to be our next move forward: a method of exploration which shall benefit the nation as well as the individual, a careful record of everything done, a body of men who shall interpret and map the facts as they are required and draw conclusions with regard to structure and position from them—in short, a geological survey which shall do as much for hypogean geology as existing surveys have done for epigean geology is now our crying need. Unless something of this sort is done, and done in a systematic and masterful manner, we run a great risk of frittering away the most important of our national resources left to us, of destroying confidence, of wasting time and money at a most precious and critical period of our history, and of slipping down-hill at a time when our equipment and resources are ready to enable us to stride forward.

We do not want to be in the position of a certain town council which kept a list of its old workmen and entered opposite one, formerly sewerage inspector, that he possessed 'an extensive memory which is at the disposal of the corporation.'

Even supposing the scheme outlined by Mr. Harmer can not be carried out in its complete form, a great deal will be done if mining engineers can receive a sufficient geological training to enable them to realize the significance of these underground problems, so that they can recognize when any exploration they are carrying out inside their own area is likely to be of far-reaching geological and economic significance outside the immediate district in which they are personally and immediately concerned.

Turning to our colonies it is true that in many of them much is being done by competent surveys to attain a knowledge of mineral resources, but this work should be pushed forward more rapidly, with greater strength and larger staffs, and above all it should not be limited to areas that happen to be of known economic value just at the present moment. It is almost a truism that the scientific principle of to-day is the economic instrument of to-morrow, and it will be a good investment to enlarge the bounds of geological theory, trusting to the inevitable result that every new principle and fact discovered will soon find its economic application. Further, it is necessary that we should obtain as soon as possible a better knowledge of the mineral resources of the smaller and thinly inhabited colonies, protectorates and spheres of influence. This is one of the things which would conduce to the more rapid, effective occupation of these areas.

With regard to areas not at present British colonies, it seems to me that no great harm would be done by obtaining, not in any obtrusive way, some general knowledge of the mineral resources of likely areas. This at least seems to be what other nations find it worth their while to do, and then, when the opportunity of selection arises, they are able to choose such regions as will most rapidly fill up and soonest yield a return for the private or public capital invested in them.

To sum up, I consider that the time has come when geologists should make a firm and consistent stand for the teaching of their science in schools, technical colleges and universities. Such an extension of teaching will of course need the expenditure of time and money; but England is at last beginning to wake up to the belief, now an axiom in Germany and America, that one of the best investments of money that can be made by the pious benefactor or by the state is that laid up at compound interest, 'where neither rust nor moth doth corrupt,' in the brains of its young men.

This knowledge has been an asset of monetary value to hosts of individuals who have made their great wealth by the utilization of our mineral resources, and to our country, which owes its high position among the nations to the power and importance given to it by its coal and iron. It is surely good advice to individuals and to the state to ask them to reinvest some of their savings in the business which has already given such excellent returns, so that they and we may not be losers through our lack of knowledge of those sources of energy which have made us what we are, and are capable of keeping for many years the position they have won for us.

And in our present revival of education it would be well that its rightful position should be given to a science which is useful in training and exercising the faculty of observation and the power of reasoning, which conduces to the open-air life and to the appreciation of the beautiful in nature, which places its services at the disposal of the allied sciences of topography and geography, which is the handmaid of many of the useful arts, and which brings about a better knowledge and appreciation of the life and growth of that planet which we inhabit for a while, and wish to hand on to our descendants as little impaired in vitality and energy as is consistent with the economic use of our own life-interest in it.

W. W. Watts.

THE TEACHING OF CHEMISTRY IN GRADED AND SECONDARY SCHOOLS.*

Teachers of science are familiar with the noticeable difference in the attitude of a student when beginning the study of chemistry and when beginning the study of the other sciences. In almost every science but chemistry the student has previously had some familiarity, at least with the material things with which the subject has to deal, while in chemistry the phenomena are all of a decidedly new order. It is hard for a student to become interested in an odorless, tasteless, invisible aggregation of molecules called a 'gas,' while he is immediately interested in the leaf of the botanist, the structure of the frog of the biologist, the mechanical models of the physicist and, indeed, the figures of the geometrician are not without interest when compared with the obscurity of chemical theory.

As a result the teacher of the science other than chemistry has a certain foundation to begin building on. It would, indeed, be an unobserving child who had never perceived leaves, insects and the common mechanical appliances of daily life and consequently had not at least a superficial knowledge of these common objects with which the science deals.

It is undeniably true that the fundamental principles of chemistry are of so complex a nature as to require a more mature mind for their comprehension, but can not the child be made familiar with some of the simpler chemical actions even without understanding why the exact order of phenomena appears? By so doing the mind would be prepared to consider at a later period of development the more important principles without having to delay till the simpler phenomena became familiar.

It here becomes an important question as to how early in a child's life this training should begin. It has, indeed, been jocularly said that a certain professor of organic chemistry in one of our large colleges provided his babies with a set of blocks after the nature of the Kekulé models of the carbon atom.

When we consider the thousand and one things crowded into the life of the child of to-day one hesitates considerably before suggesting another. There has been, however, of recent years, a strong undercurrent of opinion in favor of nature study. The teacher in the kindergarten and the primary and grammar school, by developing the powers of observation and drawing attention to the workings of the laws of nature, is rendering incalculable assistance in teaching the sciences. Unfortunately, chemistry profits the least by this preliminary training.

It was formerly recognized that the beautiful phenomena attending many chemical actions were unusually attractive to children and, indeed, to adults. This was attested by the popularity of the chemical lecture in lyceums, lecture courses, churches, etc.

If I may be pardoned in introducing a bit of personal experience, my interest in the subject was first awakened by a popular lecture on 'A Basket of Charcoal.' I had never seen chemical phenomena before. It was a complete revelation. Obviously

* A paper read before the Chemical Club of Wesleyan University, Middletown, Conn., December 7, 1901.