THE USE OF GEOLOGY ON THE WESTERN FRONT.[1]

By Alfred H. Brooks.

INTRODUCTION.

Before the end of the war nearly all active American geologists were engaged in work directly or indirectly connected with military problems. The many fields of activity opened to geologists by the emergency included service with troops, administration of war activities, national economics, relief work, military education, and, above all, applied geology. The success achieved by the American geologist in such strongly contrasting duties bears testimony to his broad interests and wide experience and shows that he did his full part in the great struggle. This record also shows the educational value of geologic training, for it has made clear that such training develops the mental power necessary to success in new fields of endeavor. It is also true, as shown by the record, that while the geologist has the mental equipment and experience to render valuable service during war in many different capacities, yet his most important duties will be to determine the sources of minerals which the military situation renders especially necessary. This fact is here emphasized because it has been assumed by some that the application of geology to war is limited to the work done on the battlefield. As a matter of fact, the work in economic geology done on this side of the Atlantic contributed more to the successful termination of the war than that of the geologists in France. The Germans, too, recognized this fact, for a large part of the geologists they called into military service were engaged in the investigation of mineral resources. Many geologists in both France and England were engaged in a similar service.

The following is a partial list of publications in which reference is made to the war work of American geologists:

Alden, W. C., The country around Camp Albert L. Mills (text on back of topographic map), New York: Map of Camp Mills quadrangle, U. S. Geol. Survey, 1918.

Alden, W. C., The country around Camp Upton (text on back of topographic map), New York: Map of Moriches quadrangle (Camp Upton edition), U. S. Geol. Survey, 1918.

Bastin, E. S., War-time mineral activities in Washington: Econ. Geology, vol. 13, pp. 524–537, 1918.

Bateman, A. M., Military and geologic mapping—a plane table: Geol. Soc. America Bull., vol. 30, pp. 405–414, 1919.

——— The geologist in war time—the training of artillery officers: Econ. Geology, vol. 12, pp. 628–631, 1917.

Berkey, C. P., Engineering geology during and after the war (abstract): Geol. Soc. America Bull., vol. 30, p. 81, 1919.

Bliss, E. F., Some problems of international readjustments of mineral supplies as indicated in recent foreign literature (abstract): Geol. Soc. America Bull., vol. 30, pp. 101–102, 1919.

Brooks, A. H., Influence of geography on the conduct of the war (abstract): Educational Congress, Dept. Public Instruction of Pennsylvania, 1919, Proc., pp. 540–547, Harrisburg, 1920.

——— Military mining in France: Eng. and Min. Jour., vol. 109, pp. 606–610, 1920.

——— The application of geology to war (abstract): Eng. and Min. Jour., vol. 109, p. 764, 1920; Washington Acad. Sci. Jour., vol. 10, pp. 331–333, 1920.

——— TheLorraine iron field and the war: Eng. and Min. Jour., vol. 109, pp. 1065–1069, 1920.

Butts, Charles, The country in and around Camp Taylor (text on back of topographic map): Map of Camp Taylor and vicinity, Ky., U. S. Geol. Survey, 1918.

Campbell, M. R., The country around Camp Sherman (text on back of topographic map): Map of Camp Sherman quadrangle, Ohio, U. S. Geol. Survey, 1918.

Cross, Whitman, Geology in the World War and after: Geol. Soc. America Bull., vol. 30, pp. 165–188, 1919.

Davis, W. M., Handbook of northern France, Cambridge, 1918.

Day, A. L., Annual report of the Director of the Geophysical Laboratory: Carnegie Inst. Washington Yearbook, 1917, pp. 135–137, 1918.

DeWolf, F. W., The outlook for geology and geography: School Science and Mathematics, vol. 19, pp. 391–397, Chicago, 1919.

Gregory, H. E. [editor], Military geology and topography, New Haven, Conn., 1918.

——— Geology in the Student Army Training Corps (abstract): Geol. Soc. America Bull. vol. 30, pp. 81–82, 1919.

Hewett, D. F., Manganese ore as a war mineral (abstract): Geol. Soc. America Bull. vol. 30, pp. 97–98, 1919.

[1] Presented in abstract before the Geological Society of America Dec. 31, 1919.

JOHNSON, D. W., Topography and strategy in war, New York, 1917.

——— Some recent books on military geography: Geog. Review, vol. 9, pp. 60–63, 1920.

LEE, C. H., Water resources in relation to military operations: Military Engineer, vol. 12, pp. 285–289, 1920.

LEITH, C. K., Internationalization of mineral resources (abstract): Geol. Soc. America Bull., vol. 30, pp. 107–108, 1919.

LEVERETT, FRANK, The country around Camp Custer (text on back of topographic map): Map of Camp Custer quadrangle, Mich., U. S. Geol. Survey, 1918.

LOUGHLIN, G. F., Rock products and the war (abstract): Geol. Soc. America Bull., vol. 30, p. 97, 1919.

MATTHES, F. E., The country around Camp McClellan (text on back of topographic map): Map of Anniston quadrangle, Ala., Camp McClellan edition, U. S. Geol. Survey, 1918.

——— The country around Camp Gordon (text on back of topographic map): Map of Camp Gordon and vicinity, Georgia, U. S. Geol. Survey, 1918.

MERTIE, J. B., jr., Present status of phototopographic mapping from the air: Eng. News Record, vol. 82, pp. 996–999, 1919.

MOFFIT, F. H., Methods used in aero-phototopographic mapping (review): Eng. News Record, vol. 82, pp. 1000–1004, 1919.

MOORE, R. C., The environment of Camp Funston, with a chapter on the western theater of war, by Maj. D. W. Johnson: Kansas Geol. Survey Bull. 4, Topeka, 1918.

PAIGE, SIDNEY, United States Geological Survey as a civic institution during war (abstract): Geol. Soc. America Bull., vol. 30, pp. 78–79, 1919.

POGUE, J. E., Mineral resources in the war and their bearing on preparedness: Sci. Monthly, vol. 4, pp. 120–124, 1917.

——— Military geology: Science, vol. 46, pp. 8–10, 1917.

SALISBURY, R. D., and BARROWS, H. H., The environment of Camp Grant, Ill.: Illinois Geol. Survey Bull. 39, 1918.

SHAW, E. W., Mexican petroleum and the war (abstract): Geol. Soc. America Bull., vol. 30, pp. 109–110, 1919.

SMITH, G. O., Our mineral reserves, in American problems of reconstruction, edited by E. M. Friedman, pp. 59–97, New York, 1918.

——— U. S. Geol. Survey Thirty-eighth Ann. Rept., pp. 7–9, 1917.

——— U. S. Geol. Survey Thirty-ninth Ann. Rept., pp. 7–10, 1918.

——— U. S. Geol. Survey Fortieth Ann. Rept., pp. 7–10, 1919.

——— The strategy of minerals, New York, 1919.

——— Economic limits of domestic independence in minerals (abstract): Geol. Soc. America Bull., vol. 30, pp. 98–100, 1919.

——— Military contributions of civilian engineers, Geol. Soc. America Bull., vol. 30, pp. 389–404, 1919.

SMITH, P. S., The geologist in war times: The United States Geological Survey's war work: Econ. Geology, vol. 13, pp. 392–399, 1918.

SMITH, W. D., War work by the department of geology at the University of Oregon (abstract): Geol. Soc. America Bull., vol. 30, p. 83, 1919.

SPURR, J. E., War minerals: Econ. Geology, vol. 13, pp. 500–511, 1918.

——— Commercial control of the mineral resources of the world (abstract): Geol. Soc. America Bull., vol. 30, pp. 108–109, 1919.

——— The commercial control of the mineral resources of the world; its political significance: Sci. Monthly, vol. 6, pp. 73–82, 1919.

STEPHENSON, L. W., and MISER, H. D., Camp Pike and the adjacent country (text on back of topographic map): Map of Little Rock quadrangle, Ark., Camp Pike edition, U. S. Geol. Survey, 1918.

STONE, R. W., Phosphate rock an economic army (abstract): Geol. Soc. America Bull., vol. 30, p. 104, 1919.

UMPLEBY, J. B., World view of mineral wealth (abstract): Geol. Soc. America Bull., vol. 30, p. 107, 1919.

VAUGHAN, T. W., Geologic surveys and the eradication of malaria: Southern Med. Jour., vol. 11, pp. 569–572, Birmingham, Ala., 1918.

——— Presentation of geologic information for engineering purposes (abstract): Geol. Soc. America Bull., vol. 30, pp. 79–80, 1919.

WRIGHT, F. E., War-time development of the optical industry: Optical Soc. America Jour., vol. 2-3, pp. 1–7, 1919.

Although geologic investigations in areas far behind the front must always be of great importance during war, yet it is now definitely established that the geologist can render an essential service at and near the front. The fact that a knowledge of geology may prove to be the decisive factor in a given military operation was made evident only during the late war and by no means found general acceptance among military leaders.

An exposition of the use of geology during the war should be prefaced by the statement that while the science was definitely recognized in several of the armies, it was by no means developed to its full usefulness, not so much because of the failure to organize geologic staffs or to give support to geologic investigations, as because of the failure to apply the results achieved and to seek the advice of the geologist on problems that clearly lay within his field. Relatively few officers of the high commands of the several armies that employed geologists had any adequate conception of the application of geology to military and engineering problems. So far as geology was thought of at all, it was regarded by many as a purely speculative and abstract rather than as a practical and concrete science. The geologic officers of all the armies had to spend much time and energy in combating such ignorance and prejudice. This made the service particularly hard, for it was discouraging to see the cheerful undertaking of impossible projects, involving the needless expenditure of time and energy and only too often useless sacrifice of lives, which could have been avoided by a little elementary knowledge of geology. These conditions can best be emphasized by citing a few examples.

During the great battle of Verdun a body of troops was ordered to intrench itself on the high plateau of the Côtes de Meuse. Even a casual examination of the geologic map would have shown that the plateau was underlain by hard limestone with less than a foot of soil. This material could not be excavated with the light tools furnished or even with proper equipment in the time available. As a consequence there was a large and needless loss of life.

In part of the Lorraine sector the front-line dugouts were located by the French without any consideration of the underground-water conditions. As a consequence a large part of the dugouts constructed at great labor were quickly rendered useless by filling with water. We did the same thing. I recall an attempt at dugout construction at a locality where the responsible officer had been warned that he could not excavate to the depth required to obtain shelter. The location was in an exposed position, and a number of lives were sacrificed before the project was abandoned because of water.

In the early part of the war, when transportation facilities were crowded to the limit, the British brought road metal from England in ignorance of the fact that a geologist was able to designate readily accessible sources in the theater of operations. A responsible officer in our own service made a requisition for filter sand to be transported across the Atlantic, though the geologists of the American Expeditionary Force had already found localities where such sand could be procured in France.

During 1915 the German troops in the St. Mihiel sector were giving official recognition to the use of the witch-hazel stick in locating sources of underground water. The first duty of the geologist detailed to this sector was to collect data on the results achieved by this implement, so as to shake the confidence of the authorities in its efficacy. In our Army many large plants, such as hospitals and flying fields, were located without any definite knowledge of the source of needed water. In the British Army, after the first year, no well drilling was permitted without the approval of the geologist in charge of water-resource investigations. There was no such rule in the American Expeditionary Force, and many wells were drilled with no adequate knowledge of the underground-water conditions. In many instances it was not until hospitals or other large plants actually had a shortage of water that the geologist was called into consultation.

In the early part of the war neither the British nor Germans recognized the need of geologic knowledge as a preparation for military mining. The success of the British in gaining control of the underground situation must in large measure be credited to the refinement of the geologic studies and their interpretations made by Lieut. Col. T. Edgeworth David. The attitude of the British is illustrated by a personal experience. Soon after reaching France I was sent to the British front to investigate military mining. When I was presented to Brig. Gen. R. N. Harvey, who commanded the British mining troops, and stated my mission, he said, without knowing my profession: "The first requisite for success in military mining is to secure the services of experienced geologists. I wish I had known that at the start."[2] Although, as will be shown, the French Army probably made a more general use of geologic maps than any other, yet there was a school of French officers who had no conception of the application of geology to military affairs. One of these, in a confidential and authoritative report on mine warfare, says: "It may be well in complex cases [that is, underground conditions] to make borings and consult geologists." His attitude is also indicated by this sentence among his final conclusions: "The discoveries of experts do not count for much. Science has the habit of taking back with one hand what she gives with the other."

A large part of the German secret official manual of military geology[3] is devoted to an attempt to convince army officers of the usefulness of geology in war. During the first two years of the war the German technical publications contained many articles advocat-

[2] Gen. Harvey has recently repeated the same thought: "From the military miner's point of view geological advisers must always be indispensable during war" (King, W. B. R., Geological work on the western front: Geog. Jour., vol. 54, p. 217, London, 1919).

[3] Kriegsgeologie, herausgegeben im Auftrage des Chefs des Generalstabs des Feldherres durch den Chef des Kriegsvermessungwesens am 15 Januar 1918, Brussels, 1918.

ing the use of geologists in the army and pointing out the various applications of the science to war problems. This propaganda was finally stopped by the censor under the plea that military secrets were being published. It is evident, therefore, that Germany, with all her use of applied science, had not then recognized the military utility of geology.

The examples above given will serve to illustrate the difficulties with which the military geologist had to deal on the western front. There were, of course, physical obstacles to observation and record, and, above all, his investigations were hampered by the fact that when geologic results were demanded at all, they were demanded at once. Many of the responsible officers of the several belligerents had no idea of the necessity of field studies. A geologic officer might be ordered to make a geologic map overnight, without any preparation, very much as a draftsman would be ordered to make a tracing. The necessity of giving the geologic officers opportunity to do field work and study the terrain was often completely ignored.

The American Expeditionary Force, profiting by the experience of the Allies, organized geologic work from the start. Although many American officers failed to recognize the utility of geologic knowledge, there were exceptions to this rule. The work could not have been carried out without the strong support given to it by many of the officers, especially by those of the Corps of Engineers. It is worthy of note that the plan for employing geologists in the American Expeditionary Force did not originate with geologists but with regular officers of the Engineer Corps of the United States Army. The strongest support of the geologic work throughout the war came from the same source.

As a class the persons most difficult to convince of the utility of geology were those who in civil life had failed to recognize the application of the science to problems of engineering. As a result of my experience I am convinced that the average American civil engineer is sadly lacking in elementary knowledge of geology as well as in the application of geology to his profession.

In the following pages the history of the application of geology to war will be briefly traced, and the organization of the geologic staffs of the different belligerents will be presented. This will be followed by the principal theme of this paper, namely, the application of geology to war as developed on the western front. In this presentation the attempt will be to make the subject clear to the reader who is not conversant with geologic science. For this reason some concepts of geology which are well understood by professional geologists will be elucidated.

DEVELOPMENT OF MILITARY GEOLOGY.

It is evident that as great military leaders must take into account the physical features within the theater of operations, they have made at least a subconscious use of geologic facts. Most of them have not realized, however, that in many regions the use of geologic facts will make it possible to predict accurately the physical conditions that influence military operations. Military engineers as a class have also ignored geology, to their disadvantage, though their work brings them into closer contact with geologic phenomena than that of any other service.

The many references in technical publications to the application of geology to engineering projects [4] must be counted as a recognition of the use of the science in military art. Yet direct references to the military value of a knowledge of geology are exceedingly scant in prewar publications. This lack is due in part to the fact that only during the present generation has the science reached a sufficient degree of precision to make its conclusions generally applicable to engineering projects. Engineers as a class, except those in the branch of mining, have not yet taken cognizance of this evolution of geology toward greater accuracy. It can not be expected that military engineers will be in advance of those in civil life in a recognition of the application of geology.

Maj. Gen. Portlock, soldier and geologist, was one of the first to recognize that a knowledge of geology would be of aid in war. In his discussion, published in 1868,[5] of various applications of the science, he says: "Geology is now a true science, being founded on facts and reduced to the dominion of definite laws,

[4] Ries, Heinrich, and Watson, T. L., Engineering geology, New York, 1914. Sorsbie, R. F., Lieut. Col., R. E., Geology for engineers, London, 1911.

[5] Portlock, J. E., Maj. Gen. R. E., A rudimentary treatise on geology, 5th ed., London, 1868.

and in consequence has become a sure guide to the practical man. * * * The soldier also may find in geology a most valuable guide in tracing his lines both of attack and defense."

Before the war the only very definite application of geology to military problems was that made by the French military geographers. The study of military topography is as old as the art of war, but it had no very definite scientific basis until the genetic relation between land forms and geologic history had been recognized. So long as land forms were regarded as unrelated features, without order of arrangement of form, their influence on military operations could not be presented systematically.

French soldiers have long been leaders in the study of military topography, and with the development of physiographic science they were quick to see its application in their field. This was in part due to their environment, for it has long been the duty of French military leaders, in the interests of national defense, to study the terrain of their own land, which has been the battle ground of Europe since the dawn of history. Here the broader features of relief are clear-cut and of simple pattern. Nowhere is the genetic relation between topography and drainage, on the one hand, and stratigraphy and structure, on the other, more evident than in northern and eastern France. The many wars of the past afforded innumerable examples of the control of military movements by the highlands, scarps, and watercourses, and these examples have been noted by generations of military geographers. It is therefore not surprising that the French, who have so long maintained a leadership in the art of war, should have been the first to recognize the use of geology in the field of military topography, but it is remarkable that other nations have failed to give any attention to this subject. A generation before the present war the physiographic features of the Paris Basin and of much of the rest of Europe had been described and their influence on strategy and tactics set forth by French officers. There is a dearth of similar treatises by the military geographers of other nations.

It is not pertinent to this paper to discuss the development of physiographic science, or to search out its earliest applications to military problems. Suffice it to say on one hand that the geologic interpretation of some land forms is so evident that it was recognized early in the evolution of geologic science, and on the other that the empirical description of topography has dominated most treatises on geography up to very recent years.

In this connection it is perhaps worthy of record that the geographer Guyot during the Civil War prepared a description of a part of the southern Appalachian region for the use of the military authorities.[6] He was probably the first American geographer to make use of his science in military problems. His description is very largely empirical and presents for the most part a bewildering mass of detail without orderly arrangement. Here and there are suggestions that Guyot had profited by Lesley's great work, "Manual of coal and its topography" (1856), and had some inkling of the geologic basis of land forms.[7] Though physiographic science has been developed chiefly by American students, yet not until the outbreak of the recent war was its military application recognized in this country. This is all the more remarkable, for, as will be shown, the French have for many years been publishing works on this subject. Maj. Johnson's work [8] has directed attention to a field of research which should prove of fascinating interest to both the American geologist and the professional soldier.

Of the many French treatises on military topography, that of Commandant Marga, published 35 years ago,[9] may be cited as one in which the physiographic control of military operations is clearly set forth. Furthermore, Marga recognized the influence of geology in the matter of controlling troop movements by its determination of the physical character of soil. Of this he says: [10]

> The character of the soil, which is known by the geology, greatly influences the passability of a region, and therefore indicates the difficulties which armies must overcome in their marches. In a granitic country the roads are good at all seasons, whereas in a region of argillites they are muddy after the rains of autumn or spring and dusty

[6] Guyot, Arnold, Notes on the geography of the mountain district of western North Carolina (manuscript), Princeton, N. J., Feb. 22, 1863. Copy in library of U. S. Geol. Survey.

[7] Lesley's students gained a clear conception of the need of geologic knowledge as a basis of understanding topographic forms. Among the military papers of one of them, Maj. T. B. Brooks, I find many references to the need of a geologic basis for an understanding of military topography.

[8] Johnson, D. W., Topography and strategy in war, New York, 1917.

[9] Marga, A., Commandant du Génie, Géographie militaire, pt. 1: Généralités, La France, 2 vols. and atlas, 4th ed., Paris, 1885; pt. 2, Principaux états de l'Europe, 3 vols. and atlas, Paris, 1885.

[10] Op. cit., pt. 1, vol. 1, p. 18.

in summer. * * * Physical geography, also using the science of geology through the data furnished by geologic and topographic maps, determines the types of terrain which are unfavorable. It determines the position of lines of defense and the places that should be fortified.

In his discussion of the military geography of France, Marga presents briefly the geology of the region, and points out its influence on the terrain. The control of military operations exercised by the Vosges, Ardennes, and other highlands and by the outward-facing scarps of the Paris Basin, as well as by the watercourses, are set forth in detail. In this connection he says:[11] "Between the Triassic plateau of Langres and Paris there are six concentric ridges which present more or less serious obstacles to invasion." The influence of all these physical features on the wars of the past and the future are analyzed in considerable detail. This exhaustive treatise indeed covers the whole field of geographic influences on war, including the commercial, political, ethnologic, and industrial factors.

The more purely physiographic phase of the military geography of France and of many other countries of Europe has been elaborately presented by O. Barré, commandant du génie, in his lectures at the École d'application de l'artillerie et du génie, Fontainebleau.[12] Barré is not only a professional soldier but also an eminent geologist. Though his treatment of military topography is physiographic, yet he has laid greatest emphasis on the tectonic history and has perhaps presented the geology in greater detail than his thesis required. His principal work on this subject, published 20 years ago, forecasts with a remarkable degree of accuracy the control exercised by the physiography on the military operations of the late war.

There are other publications by French officers which treat military geography from the standpoint of the physiographer. The two above cited clearly indicate that the French have been the pioneers in this field and for a generation have recognized its importance. They long ago presented complete analyses of the military physiography of France and accurately predicted its control on the campaigns of the war. Moreover, the interest of French officers in physiography has been by no means confined entirely to the application of the science to military problems. Several have made notable contributions to geology.[13] There can be no question that interest in and knowledge of geology was more widely disseminated among French officers than among those of any of the other belligerents.

Though geology has in the past received little recognition in military textbooks, the science was by no means ignored in the training of officers. At West Point a brief course in general geology has long been a part of the curriculum but apparently was given for the purpose of general culture, with little or no recognition of its application to war. French officers have also received training in geology, and its application, especially to military topography, has been recognized in the French military schools. Less is known of the German officers' training in geology, but it is certain that some of them were at least required to attend brief lecture courses in the science.

British officers formerly received instruction in geology both at the Chamberly Staff College and at the Chatham Engineer School, but these courses were abandoned many years ago.[14] Between 1886 and 1898 Lieut. Col. Charles Cooper King gave the course in military geology at the staff college. He was an artillery officer, a man of broad culture, and a geologist of some standing. He seems to have been the first professional soldier to recognize the wide application of geology to military problems.

[11] Idem, p. 155.

[12] Cours de géographie, Croquis géographiques, par le chef de bataillon du génie O. Barré, École d'application de l'artillerie et du génie, Fontainebleau, 1897–1900:

Section 1, Introduction à l'étude de l'Europe centrale, January, 1897, pp. 1–27.

Section 2, France, frontière du nord frontière du nord-est, August, 1898, pp. 1–89.

Section 3, France, système des Alpes, frontière du Jura, frontière des Alpes, November, 1899, pp. 1–70.

Section 4, France, frontière des Pyrénées, frontières maritimes, massif centrale, June, 1900, pp. 1–78.

Section 5, Belgique et Hollande, Suisse, Autriche-Hongrie, June, 1897, pp. 1–75.

Section 6, Italie du nord, Allemagne, January, 1898, pp. 1–85.

Sections 1 and 2 were republished (two pamphlets) under the general title "La géographie militaire et les nouvelles méthodes géographiques," with part of the maps from the atlas, Paris, 1899. The atlas was also issued in six sections, covering the same areas as the text, as follows: Section 1, January, 1897, 5 plates of maps; section 2, August, 1899, 7 plates of maps and sections; section 3, July, 1900, 5 plates of maps and sections; section 4, July, 1900, 5 plates of maps and section; section 5, January, 1901, 5 plates of maps and sections; section 6, July, 1898, 5 plates of maps.

[13] Noe, G. de la, Lieut. Col. du Génie, and De Margerie, Emmanuel, Les formes du terrain, Service géographique de l'Armée, Paris, 1888.

Barré, O., Commandant du Génie, L'architecture du sol de la France, Paris, 1903.

Berthaut, Gen., Topologie; étude du terrain, Service géographique de l'Armée.

[14] King, Capt. W. B. R., Geological work on the western front: Geog. Jour., vol. 54, p. 218, London, 1919.

In his teaching, which included field work, he pointed out the influence of geology on military operations.[15]

The above statements indicate that geology has not been entirely ignored in military education, though the use of the science does not seem to have been widely accepted. Above all, there was before the war an almost complete ignorance among military men of the fact that professional geologists could render valuable service during a campaign. This is all the more surprising because there are many examples in military history where ignorance of geology has been a serious handicap. A few exceptions to the general neglect of the use of geology by military authorities should be noted.

When Napoleon invaded Egypt in 1798 he included in his expeditionary force a commission of scientists, among whom were two geologists. This was part of a plan for a scientific investigation of a little-known region and was in no sense a recognition of the military value of geology. At that time, in fact, no geologic maps had been made and the students of earth science were primarily mineralogists and paleontologists. Some of the elaborate topographic surveys made by the military authorities in different parts of Europe during the Napoleonic régime included the collection of information about the distribution of minerals and other scientific data.[16] The plan of having scientific investigations made in connection with military and semimilitary expeditions, originated by Napoleon, has since been widely adopted. Much of the first knowledge of the western part of the United States was gained in this manner.

In 1898 Dr. George F. Becker went to the Philippine Islands to make a reconnaissance of the geology and mineral resources of the islands. He was attached to the Army and was there during the Philippine Insurrection. On occasions he was called upon to give geologic advice bearing on military subjects. Dr. H. H. Hayden accompanied the Younghusband expedition into Tibet as geologist, and geologists have been attached to many other military and semimilitary expeditions. These can not, however, be claimed as indicating recognition of the military value of geology.

During her war with Russia Japan made a geologic survey of Chosen, and it is quite possible that some of the results may have been put to immediate military use. The evident purpose of this survey, however, was to determine the resources of Chosen.

Certain geologic maps and studies of parts of Germany and Austria appear to have been made in the past by order of the military authorities with the desire of obtaining information about water supply. In fact, the use of geologists during peace times to determine sources of underground water for military posts and fortifications has been not uncommon. This must be regarded as a civilian rather than a military use of geology.

Except in the field of military topography, Col. Cooper King was probably the first professional soldier to recognize the application of geology to war, but apparently little attention was paid to his pioneer work in this field. The subject was entirely ignored until shortly before the outbreak of the World War, when Capt. Kranz, of the corps of fortification engineers of the German Army, called attention to the use of geology in war.[17] In his article Kranz, who was himself a trained geologist, briefly sketched the several fields of usefulness of military geology. He pointed out that while three or four German engineer officers were each year given a few hours a week of instruction in geology at Charlottenburg Politechnik, this did not meet the situation. He recommended that a few selected officers be trained as professional geologists by a three years' course, including field work at one of the universities. Kranz advocated the recognition of military geology as a special profession. The work of these specialists, he stated, could be supplemented in time of war by calling into the military service other geologists from civil life.

Kranz's recommendations, published a year before the war, attracted little attention among geologists and apparently none at all among the military authorities. Therefore, when the war came German geologists were mobilized with their unit without regard to the possible value of their services in their own profession.

[15] Obituary notice of Lieut. Col. Charles Cooper King: Geol. Soc. London Jour., vol. 54, p. lxxxvi, 1898.

[16] Berthaut, Col., Les ingénieurs de géographie militaires, 1624–1831, vol. 1, pp. 404, 420, 426, 429, 430; vol. 2, pp. 14, 104, 334, 477, 480, Paris, Service géographique de l'Armée, 1902.

[17] Kranz, Capt. W. (retired), Militargeologie: Kriegstech. Zeitschr., vol. 16, pp. 464–471, Berlin, 1913.

This was at a time when scientists of some other professions were excused from service with troops on the plea that they were more valuable in other fields. At once there arose a great clamor among German geologists for a similar recognition of the utility of their science. The German technical journals and even the daily press contained many articles showing the application of geology in war, and Kranz's article, previously almost ignored, was cited as presenting the views of a trained soldier. Soon controversies arose as to the best military use of geology and its limitations. This continued until public discussion was stopped by the military censor in 1916.

While this battle in printer's ink was raging and at least one German army was using the witch-hazel stick, the British expeditionary force had quietly acted in May, 1915, by calling into the service Capt. W. B. R. King, of the British Geological Survey, to determine underground-water resources.[18] Capt. King, therefore, so far as known, was the first geologist to receive a military assignment for work in his own profession. During the summer of 1915 a staff of geologists was organized for a part of the German front and appears to have been specially charged with the examination of water resources. Both the British and the German geologic investigations were extended during the following year, and gradually more or less definite geologic organizations were formed, as will be set forth below.

The first recommendations for the employment of geologists by the American Expeditary Force were made in July, 1917, by Brig. Gen. (then Col.) S. A. Cheney, and Col. (then Maj.) Ernest Graves, both of the Engineer Corps. These officers, after a visit to the British front, independently came to the same conclusion. Gen. Cheney had been investigating water-supply equipment and Col. Graves military mining. This report was approved by Brig. Gen. Harry Taylor, chief engineer of the American Expeditionary Force, and orders were issued to Maj. E. C. Eckel and me, which took us to France in August.

French geologists of military age, like those of Germany, were mobilized with their units. No geologic staff was organized in the French Army during the war, and but little definite recognition was given to the military application of the science. There was, however, probably a larger use of geologic maps among French officers than among those of any other Allied army. The geologic map of France was completed many years ago, and French engineers have long been trained to use it as a source of certain kinds of information. Most of them are sufficiently versed in geology to apply the information contained on the map and in the explanatory text, though the text is expressed in very technical language. It is indeed not uncommon to find French engineers who have sufficient knowledge of paleontology to make their own stratigraphic determinations.

The fact that the French were fighting in their own land, with whose physical features they were thoroughly familiar, made the service of geologists less important to them than to their allies. Nearly every French officer had at least a subconscious knowledge of the local geology in his field—an advantage entirely lacking among the officers of the other armies. In spite of this fact the French made certain blunders because of their ignorance of the geology.

It has been shown that the French have long been the leaders in military physiography, and that more of her officers had been trained in geology than those of any other country. It is difficult, therefore, to understand why France made no professional use of geologists during the war. One reason for it lies in the fact that in comparison with other countries France has not to any great extent applied geology to industrial problems. The ideals of her leading geologists have been to advance the science rather than to show its practical utility. Moreover, the French geologic maps, completed many years ago, are not of the same standards of detail and accuracy as those of more recent date issued by other countries. The lack of refinement in the geologic maps is due to the fact that there are but few good base maps of French territory. Except for areas chiefly along the old German frontier, there were at the beginning of the war no good topographic base maps of France. The standard map (scale 1:80,000) is hachured, and the topography was surveyed before the middle of the last century. Therefore, though the features of culture are admirably shown, the map is of little use as a base for detailed

[18] King, W. B. R., Geological work on the western front: Geog. Jour., vol. 54, pp. 201-221, 1919.

geologic surveys. It should be added that the above criticism of lack of detail in some of the French geologic work does not apply to the investigations in the coal fields.

As a result of the conditions above set forth French engineers and men of affairs have not always realized the practical value of detailed surveys and exhaustive studies. In general, the attitude of the engineer is that the geologist has completed his researches many years ago and presented final results. If additional geologic information or interpretation is needed the engineer and not the geologist must be called upon. In other words, the average engineer knows little of the precision of results attained during the recent development of geologic science. As the military authorities held the same view, it was natural for them to turn to the engineer rather than to the geologist, both for more precise information and for a practical application of the science.

In one field of applied geology, namely, hydrology, the early leadership of French geologists must stand without question. Yet in spite of this the French Army drove thousands of wells without consulting a geologist, so far as can be learned, and certainly without definite recognition of the hydrologists as a class. It should be added, however, that many of the engineers of the water-supply service of the French Army were close students of geology and hence were entirely competent to make their own geologic examinations. I also found many French engineer officers using the geologic maps in connection with the siting of dugouts.

Though the French Army gave no recognition during the war to the use of professional geologists, it by no means entirely ignored the application of geology to military problems. As already noted, French officers received geologic instruction,[19] including a study of the terrain in the field, before the war. During the war some lectures were given to French officers on the application of geology to military engineering.[20]

The French were the first to issue a map showing the passability of the country as governed by the physical character of the surface formations. During the summer of 1918 plans were formulated by the Service géographique for the preparation of "tank maps," which were to take cognizance of the physical conditions imposed by the surface materials. A number of the prominent French geologists were also attached to the Service géographique during the war and performed valuable services in preparing descriptions of the physical features of the theater of operations, as well as in summarizing the mineral resources and mining industry of Germany.

I learn through Dr. A. Renier[21] that Gen. Greindle, chief engineer of the Belgian Army and long secretary of the Geological Society of Belgium, had a very intimate knowledge of the geology of the country where operations were carried on and made full use of it. In September, 1918, Dr. Van Strachen was appointed geologic adviser to the engineering commission (conseil de génie) of the Belgian Army.

It appears that geologists were attached to the Austrian Army during the war. This action probably followed the organization of the geologic corps in the German Army. As to the Italian or Russian use of geologists during the war, no facts are at hand.

GEOLOGIC STAFF OF BRITISH EXPEDITIONARY FORCE.

In May, 1915, Capt. W. B. R. King was detailed as geologist to the engineer in chief, British Expeditionary Force, and took over as his principal task the determination of water resources in the areas occupied by the British Army. He was the official adviser on all matters relating to water resources but also had to do with other applications of geology to military affairs. It also fell to Capt. King to devise the system of surface-water control in the plains of Flanders and in northern France, which had an important use in both offensive and defensive warfare.

In May, 1916, the first use of geologists for mine warfare was made by the British Expeditionary Force,[22] and Lieut. Col. (then Maj.) T. Edgeworth David was assigned to this duty, first as geologic adviser to the engineers of the armies and later at general headquarters, where

[19] Lemoine, Paul, Compte-rendu de l'excursion dirigée par M. le Général Jourdy aux environs de Rouen les 8 et 9 avril 1906; Soc. amis sci. nat. Rouen Bull., 1905, pp. 453-466, 1906.
Joly, H. D., Conférence de géologie: Rev. génie militaire, vol. 34, pp. 50-78, Paris, 1907.

[20] Charra, Capt., Géologie appliquée aux travaux du génie, Groupe des armées du Nord, Cours du génie, Mar. 29, 1918.

[21] Personal letter, Sept. 23, 1919.

[22] King, W. B. R., Geological work on the western front: Geog. Jour., vol. 54, pp. 201-202, 1919.

he served on the staff of the inspector of mines. Col. David was assisted throughout the war by Lieut. Loftus Hills, and at different times by other geologists detailed from among the officers of the mining troops. Although the British geologic staff at no time exceeded five officers, this was not so much of a handicap as would appear, for there were among the officers of the mining troops ("tunneling companies") many mining engineers who had been trained as geologists and were well qualified to extend the observations and deductions of the headquarters staff. Col. David and Capt. King shared the investigations relating to other fields of applied geology. Though for much of the war these two officers were attached to different branches of the chief engineer's staff, they worked in perfect harmony, and the geologic investigations were carried on as a unit. Toward the end of the war the obvious mistake of having, in theory at least, two independent staffs was rectified. The two geologic offices were then united under the deputy engineer in chief,[23] and Lieut. Col. David became chief geologist.

GEOLOGIC STAFF OF AMERICAN EXPEDITIONARY FORCE.

The geologic section of the American Expeditionary Force was established as a part of the office of the chief engineer in September, 1917. It then included two officers and was not enlarged until April, 1918, when another officer was added for temporary duty only. The geologic section was first made a part of the division of front-line engineering, which was under Col. G. A. Youngberg. Col. Youngberg's strong support of the geologic work throughout the war was the decisive factor in gaining for it what recognition it received. Later the section was transferred to the division of engineering intelligence, which was administered by Col. F. B. Wilby, and he too did much to help the geologic investigations. At a still later date the chief geologist reported directly to the assistant to the chief engineer at general headquarters. All the assistants to the chief engineer, including Gens. M. L. Walker, S. A. Cheney, and Charles Kellar, did everything in their power to advance the geologic work and to gain recognition for it.

In July, 1918, plans were approved providing for five geologic officers for each army, which allowed one for each corps. These were to be members of the staffs of the chief engineers of the armies. Provision was also made for two geologic officers for work in the line of communication. This plan also provided that the senior geologic officer at general headquarters should be designated chief geologist and should have technical supervision of all geologic work in the American Expeditionary Force. This designation carried with it the technical control of the geologic investigations then being made by an officer of the water-supply section. Meanwhile the geologic work done at general headquarters, in part for the Engineers and in part for the intelligence section of the General Staff,[24] had so greatly increased in amount that authority was finally obtained in August, 1918, to increase the geologic section to a total of six officers.

Therefore, in midsummer, 1918, a total of 18 geologic officers had been authorized, distributed as follows: Six at general headquarters, five with each of the two armies, and two in the line of communications (designated the service of supplies in the American Expeditionary Force). Though requisition had been made on Washington by cable in July, 1918, for additional geologists, but one arrived before the signing of the armistice. For this reason and because the armies did not ask for their full quota of geologists the complete authorized geologic staffs were never organized.

To provide the needed personnel a careful search was made in the American Expeditionary Force for professional geologists, and a number were found engaged in other duties. The following were ordered to general headquarters as fast as conditions permitted: Maj. Morris F. Lacroix, then instructor in the Army Engineer School; Lieut. R. S. Knappen, who was serving as topographic officer in a railroad regiment; Lieut. H. F. Crooks, who was serving as a master engineer in a road regiment; Lieut. Wallace Lee, who commanded a munition train in the Field Artillery; and Lieut. Kirk Bryan, who was a private serving as draftsman at a corps headquarters.

At the time of the signing of the armistice there was a total of nine officers engaged, at least in part, in the geologic work of the

[23] King, W. B. R., op. cit., p. 217.

[24] The cooperation with the intelligence section of the General Staff was brought about through the influence of Col. K. T. Riggs, Cavalry, one of the first to recognize the application of geology to war.

American Expeditionary Force, five at general headquarters, two with the First Army, one with the Second Army, and one with the water-supply section.[25]

The influence of geology on field fortifications was also developed in the engineer training schools of the American Expeditionary Force. This result was due largely to the teaching of the late Capt. John D. Irving, who was in charge of the course on mining and dugouts at the Army Engineer School and lectured at the corps schools. A few geologic lectures were also given at army and corps schools by the chief geologist of the American Expeditionary Force.

GEOLOGIC WORK OF GERMAN ARMY.

The beginning and organization of geologic work in the German Army have not yet been fully set forth in any publication now available. As already shown, it is certain that at the outbreak of war the German Army had no geologic staff, nor any definite policy for the use of geologists. The Germans have, however, so long made use of applied geology in connection with engineering works that there can be little doubt that they called geologists into consultation on engineering problems long before the need of geologic assistance in the more purely military field was seriously considered. It is also generally believed that Prof. Albrecht Penck has long been an adviser of the German general staff on matters relating to geology and geography. The evidence obtained from technical journals and captured documents makes it possible to outline, in brief, the development of the German military geologic organization.

It appears certain that as late as the spring of 1915 practically no use had been made of geology in the German Army, and that during the following summer the development of military geology in that army began. At this time Van Werveke,[26] then director of the Alsace-Lorraine Geological Survey, paid a professional visit to the Lorraine front, with a view of determining underground-water resources. The first geologic work by any one in the army appears to have been done by Prof. Hans Phillipp, of Greifswald. During the summer of 1915 Phillipp, then serving as a private in the Lorraine sector, made some water-supply investigations in the Bois de Prêtes region of the Moselle Valley. By November of that year [27] the army staff of this sector had given definite recognition to these investigations, which then occupied four geologists. By February, 1916, this staff had been increased to twenty geologists.

About the time that Phillipp started work, Capt. Kranz opened a geologic office at the University of Lille.[28] In August, 1915, Dr. August Leppla,[29] of Berlin, started library and laboratory work on the geology of Belgium at Brussels. This was followed in 1916 by the advent of other geologists at Lille and Brussels, and gradually a military geologic organization was established. This organization, it appears, was not definitely incorporated into the German Army until late in 1917. In the later part of 1916, however, there began to appear in the German military manuals instructions on the use of geologists. For example, instructions [30] on position warfare issued December 15, 1915, include the following paragraph:

> In the organization of the ground much labor can be saved by appealing to geologists and other competent persons to choose favorable positions, principally relating to the evacuation of water, the driving of tunnels and galleries, the location of wells, and the collection of the necessary material.

This is in strong contrast to the manuals on similar subjects issued before and early in the war, in which there is no reference to geology.

The geologists of the German Army were a part of the department of military surveys,

[25] The following is a complete roster of officers connected with the geologic work of the American Expeditionary Force during the war: Lieut. Col. Alfred H. Brooks, chief geologist at general headquarters; Maj. E. C. Eckel, at general headquarters for about one month and in the water-supply section of the line of communication for about four months; Maj. Morris F. La Croix, at general headquarters and with First Army; Capt. Charles H. Lee, at general headquarters and in line of communication; Lieut. R. S. Knappen, at general headquarters and with Second Army; Lieut. T. M. Smithers, at general headquarters for three months; Lieut. Harold F. Crooks, at general headquarters; Lieut. Kirk Bryan, at general headquarters; Lieut. Wallace Lee, at general headquarters, and with First Army; Lieut. A. W. Diston, a few weeks at general headquarters; Lieut. Sidney Powers, arrived in France on day of armistice. Capt. O. E. Meinzer and Lieut. K. C. Heald were on the way to France at the time of the armistice.

[26] Van Werveke, Leopold, Anregung zur planmassigen geologischen Untersuchung des besetzten feindlichen Gebiet: Geol. Landesanstalt von Elsass-Lothringen Mitt., vol. 10, pp. 241-255, Strassburg, 1916.

[27] Van Werveke, Leopold, Die Ergebnisse der geologischen Forschungen von Elsass-Lothringen in ihre Verwendung zu Kriegswerken: Wiss. Gesell. Strassburg Schriften, No. 28, p. 27, Strassburg, 1916.

[28] Information from Prof. Charles Barrois, then detained by the German military authorities at Lille.

[29] Information from Dr. A. Renier, then detained at Brussels.

[30] Règlements allemands relatifs: La guerre de position, p. 7, Paris, Grand quartier général des armées des Nord et Nord-est, 1917.

controlled by an officer (Chef des Kriegsvermessungwesens) who was a member of the general staff. At the headquarters of each army, or possibly group of armies, in the field there is a survey staff officer (Stabsoffizier der Vermessungwesens) with the rank of major. Under him is a geologist with the rank of captain (Gruppen Leiter), who has charge of geologic investigations and surveys. The geologists are divided into small sections (Geologen Stellen) and distributed according to the needs of the service.[31] These sections were commanded by experienced geologists, some of whom were lieutenants, some noncommissioned officers, and some privates. There appears to have been a special class of privates created, known as Kriegsgeologen. The low rank of the German military geologists is but a reflection of a general policy. In general, officers of equivalent responsibilities were ranked much lower in the German Army than in the armies of the Allies. The discrepancy is specially noticeable when comparison is made with the American and British armies. In the German technical journals there are numerous references to the low rank given to military geologists, and complaint is made that in consequence they had not sufficient authority and influence.

In addition to the above-mentioned organization, which did the field work, there were geologic intelligence sections or information bureaus (Geologische Arbeitstelle or Geologische Beratungstelle), of which there was one at Lille, one at Brussels, and one at Metz. These were manned by the older geologists and did only office work. They furnished the field geologists with summaries of literature, compiled maps, and made determinations of rocks and fossils.

During the period of trench warfare, the geologic sections (Geologen Stellen) were provided with comfortable, well-equipped offices, located conveniently to the front line. One of these offices is described by Maj. Lawrence Martin as being

> a well-built hut in the woods east of the Côtes de Meuse, well equipped, having stained-glass centers leaded into the windows, and better drawing tables, shelves, drawers, and filing arrangements than in most offices of American general headquarters. There was an illuminated paleontological poem on the wall, and outside a concrete rain gage with a 5-inch cast of a fossil (ammonite) embedded in the side. A signboard on the road read "Geologen Stelle No. 3." There was every appearance of permanence and comfort.

Lieut. R. S. Knappen, who visited another one of the geologic offices, found it still more elaborate. It is worthy of note that these offices were in the St. Mihiel sector and were the first places from which we chased the Germans. In that sector there are known to have been five of the geologic offices, and they were about 20 kilometers apart and all connected by telephone.

There is no exact information as to the number of military geologists in the German Army. At the outbreak of the war, it is said,[32] 176 geologists were mobilized with different units for active service. It seems quite likely that before the armistice most of these were assigned to geologic duties. There are known to have been about 20 in the St. Mihiel sector. Prof. Barrois estimates that about 60 geologists were working under Capt. Karl Regelman, who had headquarters at Lille. In addition to this force about 5 or 6 were stationed at Brussels for much of the war, but these were chiefly older men, not directly connected with the military problems. Captured documents and information from Prof. Barrois and Dr. R[illegible]r have revealed the names of 34 geologists connected professionally with the German Army. It should be noted, however, that many of these geologists were occupied in investigating the mineral resources of Belgium and northern France and not working directly on military problems. It is probably safe to assume that about 100 geologists of the German Army were investigating military problems on the western front.

APPLICATION OF GEOLOGY TO WAR.

OUTLINE.

Geology finds its principal application to war in forecasting the physical conditions that will be encountered in the execution of certain military projects, such as the construction of fortifications, the maneuvering of troops, and the erection of engineering structures, and in determining the sources of water, road metal, and other mineral supplies. The value of geology to the military commander is directly proportionate to the accuracy of the deductions

[31] Kriegsgeologie, Brussels, 1918.

[32] Steinman, Gustav, Geologie und Kriege: Geol. Rundschau, vol. 6, pp. 94-95, 1915.

made by the geologist. This accuracy will evidently be controlled by the simplicity or complexity of the problem presented and by the opportunity afforded for detailed observations. The nature of the problem will be inherent to the theater of operations; the opportunity for observations will depend on the military situation. It is evident that if the geology is simple and opportunities are afforded for exhaustive field studies, the results will be more accurate than if the geology is complex or the military situation prevents extensive field observations. For example, the underground-water resources available for use in the line of communications on both sides of the western front could be determined with great precision, owing to the relative simplicity of the stratigraphy and structure and to the ample opportunities in the rear areas for detailed examinations. On the other hand, the conclusions reached on the geology of the areas within the zone of shell fire, where observations are always more or less limited, were usually less accurate than those relating to rear areas. Still greater difficulties are encountered in times of rapid advance, when the facts must be gathered under extraordinary difficulties except in so far as they can be obtained from published maps and reports.

The problems of the military geologist are in general among the simpler problems of geology, and deal primarily with (1) the physical character of the surface formations, (2) the depth to hard rock, (3) the lithology and structure of the formations to depths of less than 100 feet, except in deep-well drilling, (4) the depth of the ground-water level, (5) the distribution of water-bearing beds, including their surface outcrops, (6) the geologic control of run-off as affecting stream volume, and (7) the distribution of rock suitable for road metal and of gravel, sand, and materials for concrete.

Though the geologic facts needed would under ordinary conditions be readily determinable, the zone of fighting is of course unfavorable for field work, and the investigator must often perforce be content with very meager observations or even rely entirely on compiled data. Although the military situation may prevent detailed examinations, the facts and interpretations sought for demand a high degree of refinement, such as is usually necessary for engineering projects. For example, a difference of 1 or 2 feet in the depth to hard rock may determine whether or not trenches can be made at a certain locality by the use of only the standard infantry equipment. Again, accurate deductions as to the kind of alluvial filling of a valley at a locality within the enemy lines may control its passability for infantry, artillery, or tanks and thus be the decisive factor in determining the feasibility of a given maneuver. It is evident that the military geologist must often come to a decision on problems when facts are exceedingly scant. Such a decision may be little more than a "scientific guess" and must then be frankly stated as such. Of two men who are familiar with the general conditions in the theater of operations a geologist will, however, be better qualified to make such a guess than one who is untrained in the science. It will be evident that the military geologist must be one of broad training and experience and preferably one who has applied his science to engineering problems.

The use of geology on the western front was greatly favored by two circumstances: (1) The entire theater of operations was covered by the official geologic maps of the French and Belgian surveys, and (2) the geology of the region was relatively simple. Some of these geologic maps were old and not up to the present standards, yet all were invaluable to the military geologists of the belligerents on both sides. The information presented by these maps was supplemented by numerous publications treating of the geologic problems arising in the field of operations.

The formations along the western front between the Vosges Mountains and the English Channel consist of little-altered sediments ranging in age from late Triassic to Quaternary. The lithologic units are fairly persistent over broad areas, and the beds are but little disturbed. This simplicity of stratigraphy and structure favored the definite determination of the physical conditions that influence military operations. Closely folded and highly indurated Triassic formations, together with metamorphic Carboniferous rocks and large masses of intrusives, make up the Vosges Mountains. The geologic complexity of this range did not interfere greatly with the solving of the problems presented by warfare, for a detailed knowledge of areal and structural geology was here not absolutely essential. Springs occurring along the numerous zones of fracture afforded an ample supply of pure water, and the depth to hard rock could in most places be forecast with a fair degree of accuracy. The geology on the lines of communication was also simple. It is no doubt true that there was a larger use of geology on the western front than there would have been if the scene of operations had been in a region of greater complexity.

Though the problems of military geology are usually not complex, yet their solution demands the attention of highly trained professional geologists who have had extensive field experience. It will be shown below that in certain fields where the geology is very simple the experienced engineer can often make his own geologic observations and deductions. This procedure, however, as indicated by the experience of the war, is safe only where the professional geologist has determined the general conditions and the necessity of giving consideration to geologic facts has become well established.

All higher staff officers and military engineers should know some geology. It is equally important that the military geologist should have some knowledge of engineering. Unless the geologist has the capacity and experience to make the practical application of his science, he will be unable to render the service demanded. To develop full usefulness in war a geologist should have some military training, especially in military engineering. Kranz's suggestion that military geology be recognized as a distinct profession is not without merit. The basal training should, however, be geologic and not military. It can not be too strongly emphasized that the view held by some that all problems in military geology can be solved by those who have made geology only a side issue to another profession is entirely erroneous. This is eminently not true, for there is no place for amateurs in war, be it in geology or in any other subject relating to military science.

Therefore, in making a choice of geologists for problems of war, thorough military training must be given due weight, yet it is essential to procure men who have had broad professional education and above all wide field experience. The military geologist must be capable, on one hand, of solving the most detailed geologic problems and, on the other, of reaching trustworthy conclusions on the basis of only inadequate field observations and on a study of literature. In other words, he must be trained in both detailed and reconnaissance surveys. His success will depend on his ability to grasp and coordinate the salient geologic features of the theater of operations, and to make the practical interpretations of them demanded by the military situation.

In military geology, as in all other branches of applied geology, the geologic map is the first essential. If none is available, one must be prepared. The geologic map once made, with the necessary structural sections and tables of sequence, can be interpreted for the various military uses. A military geologic map can not be too detailed, and the ideal to be sought is the highest scientific accuracy. Lacking such a map or the time to prepare it, the geologist must make reconnaissance and compile maps. The known facts relating to the areal distribution of geologic formations must be shown on the map, and even a greatly generalized map is better than none at all. Should warfare continue to develop on the scale and with the scientific refinement witnessed during the last five years, geologic maps will in time be considered almost as essential to the offensive and defensive operations as topographic maps are now.

FIELDWORKS.

INTRODUCTION.

Any engineering project involving excavation must take account of the underground physical conditions, or, in other words, the geology. This is especially true of modern fortifications, which require a large amount of excavation. The experience of the war has shown that protection against modern high-power artillery can not be obtained by surface structures, no matter how strong they are built. Adequate defense against artillery is possible only by the excavation of deep works protected by undisturbed earth or rock. The deeper the excavation the greater the influence of the geology. Therefore, there is no branch of military art to which the application of geology is more definite than in the location and construction of fortifications. This is true of both permanent and field fortifications.

Permanent fortifications are built during peace times, when there is ample time to explore exhaustively the underground physical conditions by test borings and other excavations. The facts thus determined can often be correctly interpreted by an experienced engineer who has little geologic knowledge. Nevertheless, there are some localities where the conditions are so complex as to call for greater geologic knowledge than that possessed by the average engineer. The experienced engineer should recognize such conditions and know when to call for professional geologic advice. Capt. Kranz[33] has cited an illuminating example in which the engineer recognized his own limitations. Some works forming a part of a permanent fortification had to be built on marshy ground. The engineer officer in charge, not being sure that his own interpretation of the test borings was correct, called a geologist into consultation. As a result of the geologic examination modifications of the project were made, and this, as it proved, prevented an important part of the structure from sinking into the mud, as it would have done had the original plan been followed.

Fieldworks consist of trenches, dugouts, and subways, used in defense, and mines, which may be either defensive or offensive. In siege operations approach trenches or saps are also used in the offensive. Trenches are surface excavations and range from hastily constructed breastworks, giving only partial cover to a man lying down, to excavations 6 feet or more deep, giving complete protection except against shell and trench-mortar fire. Dugouts range from cave shelters, excavated usually to a depth of not exceeding 30 feet, to shelters constructed at or near the surface. Military mines range from those not having sufficient cover to give protection against shell fire to those which are 100 or even 200 feet below the surface. It is evident that even shallow trench excavation is more or less affected by geologic conditions, such as depth to hard rock and permeability of the soil, while for deeper works geology may absolutely control the feasibility of the project. Under front-line conditions it is seldom possible to use anything but the simplest mechanical equipment, and therefore projects that presented no difficulties in peace may be impracticable in war. Moreover, it is of very great advantage for the military commander to know in advance what physical conditions he will meet in executing any given project for field fortifications.

[33] Kranz, Capt. W., Militargeologie: Kriegstechn. Zeitschr., vol. 16, p. 468, Berlin, 1913.

Field fortifications, in contrast with permanent fortifications, are almost always built in a hurry and often under shell fire. In general such works must be constructed without taking time to make underground tests. Yet in many localities the underground conditions are clearly indicated by the surface formations or can be determined by the correct interpretation of a geologic map. Scientific warfare demands that every possible source of pertinent information be drawn upon in advance of an undertaking. The engineer charged with the construction of field fortifications must make it part of his duty to become acquainted with and make use of the geologic facts. The desired result may be in part accomplished by training the military engineer in the principles of geology that affect his profession; in part by furnishing him with geologic maps and teaching him their use.

Although field fortifications are usually built in a hurry, the time available and the character of the work required vary greatly according to the military situation. They may consist of only the cover dug hastily by the infantryman with his intrenching tools under front-line conditions, or they may involve the deliberate organization of a defensive position, with the use of engineer troops and their equipment. Under the first condition the application of geology will be limited to the use of such facts as can be gleaned by a hasty reconnaissance or from the geologic map. Such use may prevent the commanding officer from making the blunder, of which there were only too many examples during the late war, of choosing defensive positions where excavation was impracticable, when not forced to do so by the military situation. Furthermore, if the higher commander, who is not at the scene of operations, has information at hand about the local geologic conditions, either from a map or from a military geologist, he will not be likely to issue intrenching orders which are impossible of execution.

The deliberate organization of a defensive position usually allows more time for planning and execution than the rapid intrenchment described above. In such projects the army, corps, or division commander usually gives orders for the defensive position, the site of the works being designated only in a general way. The details of location are left to the engineer officer in charge, who adjusts them so as to take advantage of favorable topographic conditions within the zone designated by his orders. In certain regions it is of equal importance to adjust the fieldworks so as to take advantage of favorable geologic conditions. Therefore the engineer should have a geologic map, and it will save time if he is accompanied by a geologic officer who can give him the detailed facts about geologic conditions. Attention to the geology is especially important if the fieldworks are to include deep dugouts.

SITING OF FIELDWORKS.

There has been some controversy as to whether favorable or unfavorable geologic conditions can be regarded at all in the siting of fieldworks. Some hold that this is a purely tactical problem; others that the local geology must be the decisive factor. It is evident that the military situation may demand some form of defensive works where the geologic conditions are all adverse, and it is then the duty of the engineer to overcome the obstacles as best he may. Thus fieldworks have been constructed in the water-soaked ground of Flanders, and underground shelters have been hewn out of the solid granite of the Vosges Mountains. These operations were possible, however, only under long-stabilized conditions of position warfare which made it possible to overcome the physical obstacles by equipment that is usually not available at the front. Even in these operations knowledge of the geology was invaluable by indicating in advance the conditions that would be met and therefore the equipment and time necessary for the construction.

In many localities the geologic conditions may practically prohibit the construction of fieldworks. In such localities geology rather than tactics will be the decisive factor. If the bedrock is such that troops can not intrench themselves in a given position with the material and time available, field fortifications can be constructed only by choosing a more favorable site, and in making this choice the tactical commander must be guided by the geology.

To take another example—that of an underground offensive—military mining, as a rule, can be carried on only where it is favored by the geology. Obviously a plan for a mine attack must give heed to the geology, or it may be doomed to failure. Therefore the tactical commander who does not avail himself of geologic knowledge before siting his fieldworks is neglecting an important source of information, and this neglect may lead to disaster. It is equally true, however, that geology is only one of several factors that influence the choice of sites for fieldworks.

Once the general site of fieldworks has been selected, a knowledge of geology again comes into play in helping to make choice of the detailed locations. Often a slight change of position that will be entirely in accord with their tactical requirements will yield more favorable geologic conditions. Thus, a trench may by a slight shift avoid hard rock or danger from flooding, and a dugout that would be difficult to construct at one place may easily be built at another near by.

The experience of the war has shown that although the location of the front line will be controlled by the tactical situation, the works of the second and third positions may often be so adjusted as to take full advantage of favorable geologic conditions. Consciously or unconsciously, such adjustments were made by both sides on the western front, notably in the Lorraine sector. In many places the adjustment was brought about by elimination, the unfavorable localities being successively abandoned after futile attempts to fortify them. Much of this useless work could have been avoided by taking cognizance of very simple geologic facts.

The most essential element in the correct siting of fieldworks is a comprehensive knowledge of topography. Here, too, evidently, a knowledge of the geology is an important factor. Topographic maps can evidently be read much more intelligently if the reader has some acquaintance with the genesis of land forms and hence with their relation to the bedrock structure and lithology as well as to the recent geologic history. This application of geology was but little developed during the war, except by the French.

It can not be expected that all future wars will be fought in regions of which topographic maps are available. In the absence of such maps the geologist can perform important service by determining in advance the topographic types that will be found in the field of operations, and he will be able to gain a better conception of the relief than those who are unversed in geologic science.

TRENCHES.

The character of the material in which a trench is to be constructed is evidently the first consideration, and this can often be accurately foretold for any particular locality from the geologic map without further field examination. Is the material loose or consolidated? If loose, can it be excavated with intrenching tools, or is the engineer's equipment of larger picks and shovels necessary? If the geology is known, it will be possible to estimate closely the rate at which trenches can be constructed. For example, heavy clay takes about five times as long to excavate as loose soil or sand and gravel. Again, if the material is hard rock, trench construction is possible only by blasting. Evidently these considerations will enable the tactical commander to determine in advance the feasibility of a project, taking into account the man power, equipment, and time available for its execution.

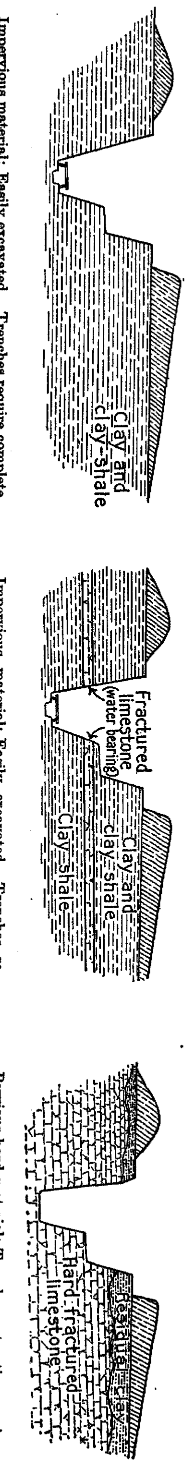
I recall an instance in a training camp showing the need of some knowledge of elementary geology by field officers. During a certain maneuver a battalion was ordered to intrench itself on a ridge, using the standard infantry equipment. This locality, of which there was a good geologic map, had been reconnoitered by the commanding officer, but he had overlooked the fact, which would at once have been evident to the merest tyro in geology, that the ridge selected was made up of hard limestone hardly covered with a few inches of soil. Intrenching in the time and with the equipment specified was of course impossible, and the maneuver failed. In time of war such a blunder might be very serious.

The geologic information needed for planning trench construction demands a knowledge of the depth of soil and subsoil, as well as of the weathering of any hard rock that may underlie the surface material. The depth of weathering will depend on the lithology of the rock, the climate, and the topographic location. Of these factors the first two will be fairly constant for a given formation, but the last will vary from place to place. In general, if the unconsolidated material extends to a minimum depth of 4 feet, this will satisfy the conditions of ordinary trench construction. The average depth of the seasonal ground frost may also in time of emergency have an important bearing.

The lithology and structure of the hard-rock formations within 4 feet of the surface must also be considered. If the rock is friable or fractured so that it can be excavated with hand tools, it will be as well adapted to rapid trenching as unconsolidated material.

The permeability of the material excavated is also an important consideration. (See fig. 7.) Trenches dug in impervious material, such as clay, require draining or, if the topography will not permit that, pumping during the wet season. On the other hand, if the floor of the trench consists of porous material, such as gravel or fractured limestone, no surface drainage will be necessary. Drainage is a very important consideration in a region of heavy rainfall. Because the physical conditions were ignored many a trench was dug during the war only to become a ditch during the wet season. In this connection it should be emphasized that in the application of geology to the construction of fieldworks and especially of trenches due consideration must be given to the quantity and seasonal distribution of the rainfall.

The physical character of the formation in which trenches are constructed not only determines the ease and rapidity of excavation but also the stability of the slopes and hence the need of revetment. Here, again, the seasonal climatic variations must be taken into account, for a trench wall which will stand with-



Impervious material: Easily excavated. Trenches require complete revetment and drainage for surface water.

Impervious material: Easily excavated. Trenches require complete revetment and ample drainage for both surface and underground water.

Pervious hard material: Trench construction requires blasting but little revetment. No drainage required, as surface water runs into the ground.

FIGURE 7.—Diagrams illustrating geologic control of trench construction.

out support during dry weather may quickly begin to slide during heavy rains. The amount of revetment will vary in accordance with the angle of slope adopted. Firing trenches will always have at least a nearly vertical wall toward the enemy, and these, except where blasted out of solid rock, will require revetment. (See fig. 7.) The strength of the revetment necessary will vary with the character of the ground. Communicating trenches, which are usually made broad and open, with slopes determined by the angle of rest, generally require but little revetment. Where such trenches traverse plastic clay formation, however, revetment is usually necessary to hold the ground during the wet season. A knowledge of geologic conditions will make it possible to determine in advance the amount of revetment to provide for any given project.

The position of underground water must also be considered in trench construction. If the ground-water level is near the surface trench construction may be entirely impracticable, and defensive works may have to be limited to breastworks with little or no excavation. (See fig. 9.) This was true in much of the Woevre lowland of the St. Mihiel sector. Here the Oxfordian clay is water-soaked, and excavation of trenches is practically impossible. Another source of water that has to be guarded against consists in water-bearing strata whose outcrops may be loci of seeps or springs. A trench crossing one of these outcrops is in danger of being flooded with water. If such a location of a trench is necessary, provision must be made for evacuating the water. Such conditions existed on both slopes of the Moselle Valley and also on the eastern scarp of the Côtes de Meuse of the St. Mihiel sector. (See fig. 8.)

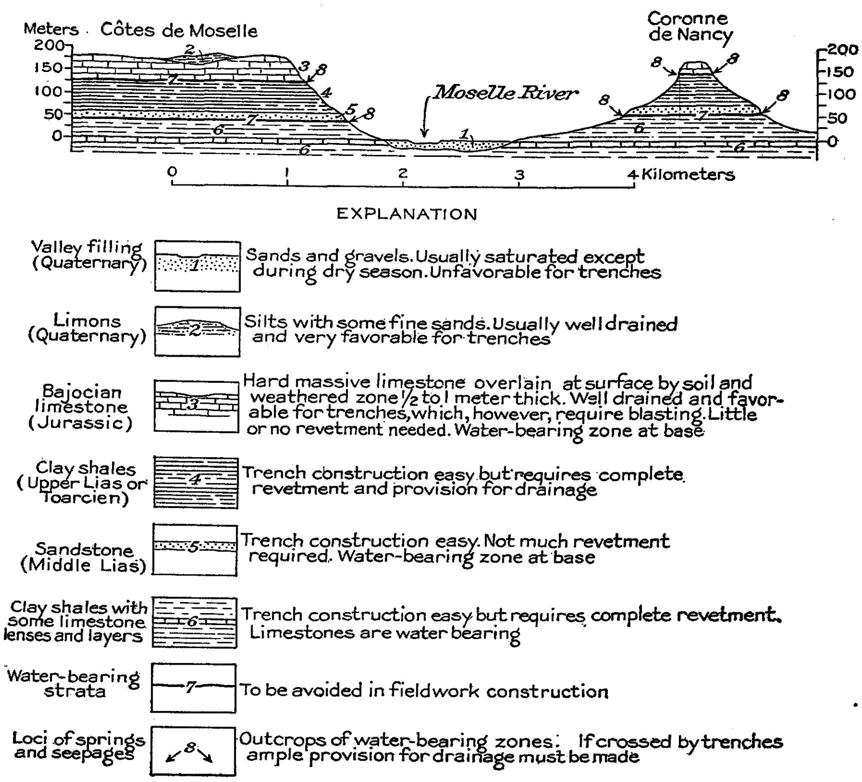


FIGURE 8.—Diagrammatic cross section of Moselle Valley near Pont-à-Mousson, France.

In certain localities underground water-bearing strata may be cut by trenches and lead to flooding. (See fig. 7.) Such conditions occurred, for example, in part of the St. Mihiel sector in areas covered by a formation made up of marl and clay shales with interbedded limestones. The limestones are fractured and in places water bearing. In some of the Tertiary areas of the British front the underground-water conditions were even worse. Here loose sands carrying artesian waters were in places mantled by only a thin cover of impervious clay.[34] Piercing of the clay by excavation would lead to flooding of the trenches. It was found that many of the fault planes in the Lorraine sector were water bearing, and hence on the military geologic maps (Pl. XV) issued by the American Expeditionary Force these features were marked as a possible source of trouble. An example of such a feature is found in a belt of limestone which roughly paralleled the front just north of Beaumont, in the St. Mihiel sector (Pl. XV). This limestone was admirably adapted to dugout construction, but the belt was bounded

[34] Information from Col. T. Edgeworth David.

on the north by a water-bearing fault. To avoid flooding, it was therefore necessary to site the dugouts so as not to cut the fault plane.

The application of these principles can be illustrated by citing some of the geologic features of the Lorraine sector. The Moselle Valley is floored in part by gravel, usually saturated and unfavorable to trenches and also in places subject to inundation by floods. The lowest formation exposed in the valley walls (fig. 8) consists of the Middle Lias clay shales with some thin limestone beds. The shales weather deeply to a clay that is easily excavated for trenches, which, however, require more or less complete revetting and provisions for getting rid of surface water. Moreover, some of the limestone lenses carry enough water to interfere with fieldworks. This formation is succeeded by a porous sandstone (Middle Lias) from 20 to 40 feet thick, whose outcrop is usually marked by a small bench on the valley slopes. The top of this sandstone affords a good position for defensive works, provided they are not excavated deep enough to cut the bottom of the formation, where there is a strong water-bearing zone. On account of a slight westerly dip of all the formations there is less trouble with water on the west side than on the east side of the Moselle Valley. Above the sandstone is another clay-shale formation (Upper Lias or Toarcian), which affords easy trench construction but calls for full revetment and ample provision for the drainage of surface water. The Toarcian is capped by the heavy fractured limestone of the Bajocian (Jurassic). The outcrop of this limestone is marked by bold bluffs and cliffs that mark the margin of the Moselle plateau (Côtes de Moselle), and its top furnishes an admirable defensive position. At its base, the site of the famous minette iron ore of Lorraine, there is a strong water-bearing zone which must be avoided in fieldworks.

As a rule the soil and weathered material overlying the Bajocian limestone is not deep enough for trenches, and in many places they must be blasted out of the hard rock but require no revetment and are self-draining. Locally the Bajocian limestone is capped by deposits of loam or silt, the so-called Limon of the French geologists. This formation in many places is deep enough for trenches, can be quickly excavated, needs little revetment, and is well drained and admirably adapted to trench construction. Therefore the distribution of the Limon was a rather important military factor, as it permitted rapid trench construction with only infantry equipment in a region which in general was underlain by hard limestone with only a thin covering.

The section described above covers less than a mile in a horizontal direction. It serves as a good illustration of the variety of physical conditions affecting construction that may be found within a short distance in a region where there are no great differences in the character of the formations.

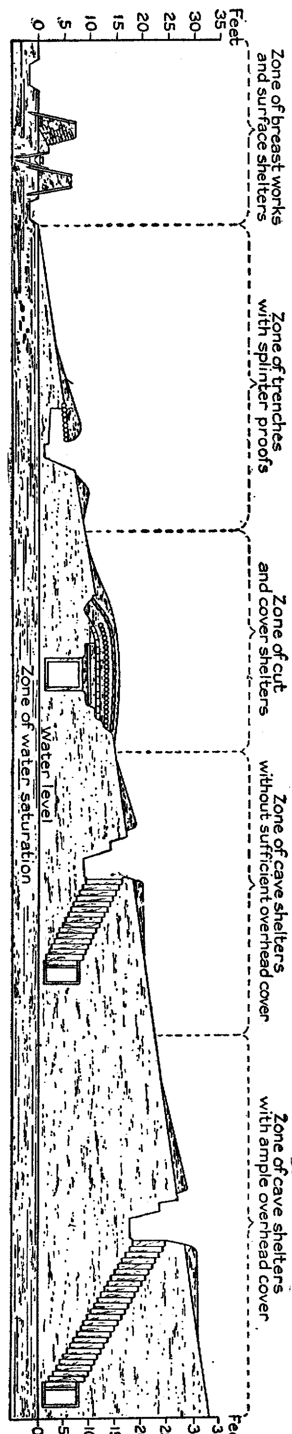


FIGURE 9.—Diagram showing control of depth of fieldworks by ground-water level.

DUGOUTS.

"Dugout" is used as a general term to designate any form of shelter against rifle or shell fires, having an overhead cover and in part or entirely underground. Dugouts range from a shallow recess under the parapet of a trench (splinter proof), affording protection only against small missiles, to one excavated to sufficient depth to withstand the shells of the heaviest artillery (fig. 9). If the dugout is entirely underground and undisturbed earth and rock are the sole cover, it is called a "cave shelter." A dugout consisting of an open excavation subsequently provided with a protective roof, the greater part of the structure underground, is called a "cut and cover shelter." A shelter of another type, not properly a dugout, is constructed entirely above ground, whose sole protection is the thickness of walls and roof; this is called a "surface shelter." Surface shelters are usually built of reinforced concrete, but even the strongest can not withstand a direct hit from powerful artillery. Moreover, their construction requires much time and the use of much heavy material. Therefore, surface shelters are in general used only where the underground conditions do not permit deep excavation. Exceptions to this rule are found in exposed machine-gun positions, especially those built in the rear lines, where ready egress from shelter is more important than absolute protection. In general, however, if time is available, deep cave shelters will be built in all defensive positions where the underground conditions permit.

As a well-organized defensive position, including dugouts, is usually established only where time and other conditions permit the excavation of any material, whether it is loose or hard rock, the lithology and structure of the material is not so important in the construction of cave shelters as in that of trenches. On the other hand, the presence of underground water usually precludes the use of deep shelters, except where natural drainage is possible. A small quantity of seepage water can be controlled by hand pumps, but the use of pumps entails a heavy duty on front-line troops, which must be avoided if possible. As a general rule cave shelters will not be used if they require excavation below ground-water level or the intersection of water-bearing beds.

It is evident, therefore, that the position of the ground-water table will control the type of shelter that may be constructed. If it lies at or near the surface only surface shelters are possible (fig. 9); if it is within 10 or 15 feet of the surface, cut and cover shelters must be used. The depth of cave shelters will depend on the size of the artillery against which protection is sought and the character of the material affording cover. For example, the amount of undisturbed cover necessary to protect the occupants of a shelter against light field artillery (77 millimeters) is 5 feet of compact, undisturbed earth or 2 feet of indurated rock such as hard sandstone or granite. Protection against the heaviest artillery used during the war (420 millimeters) required 48 feet of compact earth or 24 feet of hard rock. Therefore, cave shelters with sufficient cover can be built only where the water table is at least 30 feet in depth, except that where the surface relief permits natural drainage dugouts may be excavated below the water table. The control of the type of shelter exercised by the relation of the water table to the surface of the ground is roughly shown in figure 9. Evidently not only the position of the ground-water table but also the presence of water-bearing strata will determine the feasibility of cave shelters. Many of the failures in dugout construction have been due to ignorance of these facts. It will be shown below that the distribution of underground water is of even greater importance in military mining.

No problem is of greater difficulty to the military geologist than the accurate determination of underground-water conditions. Even after the general law controlling the ground-water table in any particular province has been determined by field examinations, there may be sufficient local variations from this law to invalidate its application to a certain locality. A few feet of additional overhead cover may determine the practicability of a project. In the Lorraine sector the problem of ground water varied with each formation. Impervious formations like the Toarcian and Oxfordian clays were free of water once the water-soaked surface had been penetrated. (See fig. 12.) Fractured limestone, like the Bajocian (fig. 8), is always well drained, except at its lower contact with clay shale, where there is a strong water-bearing stratum. On the other hand, certain formations that are made up of interbedded shale and limestone and are very common in the Lorraine sector were a constant source of trouble because of the irregular distribution of their water content. In these formations the only safe method of procedure was to determine the underground-water conditions by bore holes[35] in advance of dugout construction.

It has been shown that the amount of protection against shell fire is dependent on the lithol-

[35] Made with hand-drilling apparatus. The British made a total of 28,000 feet of test bore holes during the war to determine underground conditions for dugouts and mines. See King, W. B. R., Geological work on the western front: Geog. Jour., vol. 54, p. 202, 1919.

ogy of the formations and on the fact that earth has only about half the resistance of hard rock. Therefore in this phase of the problem also geology has a service to render, for the depth of loose material over hard rock must be determined. Knowledge of the lithology and structure of the hard rock is also necessary to determine in advance the ease of excavation and the mechanical equipment required. These factors also control the amount and character of timbering. For example, the fractured Bajocian limestone required heavy timbers, but the cave shelters hewn out of the Vosges granite stood without support. The chalk formation was the most favorable for dugouts, as it could usually be mined without blasting and required little timber. The clay-shale formations were easily excavated but, on account of the plasticity of the weathered zone, needed close timbering.

MINING.

Military mining during the late war was done on a scale which completely dwarfed all previous operations of this kind. In no field did the military geologist perform a greater service than in determining the physical conditions that affect underground warfare. A large measure of the success of the British mining is due to the detailed geologic work of Col. T. Edgeworth David.

Though the French have long been the acknowledged leaders in military science, they appear to have failed to realize fully the application of geology to military mining. Many of the French officers were trained in geology, but some of their mining operations were more or less hampered through failure to make full use of the science by the employment of professional geologists. In spite of this handicap, some of the most brilliant mine attacks of the war were made by the French, and French methods and equipment were used by all the belligerents.

Mining is more or less controlled by all factors that affect military operations, such as relative strength and morale of the opposing forces, distance of objective, means of transportation, and availability of material. In mining, however, the underground conditions are of first importance and in the interest of success must be determined before any project is undertaken. In many positions the geologic conditions, such as ground water, tough bedrock, or broken or loose strata, may be such as to make military mining impracticable. Mining is feasible only when an army is in close contact with the enemy[36] and must therefore be carried on under the most adverse conditions, such as shell fire, infantry attack, and difficulties of transportation. As a general rule all matériel such as mine timbers and machinery must be transported to the scene of operations on men's backs, so that usually only the simplest form of mechanical equipment for pumping, ventilating, and excavating is available. Adverse physical conditions that would prove little or no obstacle to mining in civil practice may therefore be absolutely prohibitive in war.

The principal geologic facts influencing mine warfare can be grouped as follows: (1) Distribution, thickness, and structure of formations; (2) physical character of formations; (3) underground water.

The country rock of the area to be mined may consist of only a single formation, with little or no variation in composition below the weathered surface zone. More commonly, especially in deep mines, variations in the country rock will be found. In such places the sequence and thickness of the different rock strata should be accurately determined. Any variation in the thickness of individual beds within the zone of operations should also be noted.

If the sequence includes beds of different composition some of the strata will be more favorable to mining than others. For example, a bed of soft clay shale may be included between strata of hard sandstone, and the shale can be easily excavated with pick and shovel, but the sandstone will require blasting. (See fig. 11, p. 107.) At the siege of Sebastopol the Allies by accident encountered a shale bed underground which permitted rapid advance of gallery construction, whereas before they had been driving in hard limestone and the advance had been very slow. Military writers who have described the mining operations of this siege have commented on the "good luck" of the Allies in finding this bed of shale. They have entirely overlooked the fact that the very simple geology of the region made it possible to determine accurately in advance the position of this stratum favorable to mining. It is evident also that if a particu-

[36] This is, of course, not true of defensive mines prepared in rear positions.

lar bed is selected as the site of a mine gallery there must be a reasonable degree of certainty that it will maintain a thickness great enough for the gallery throughout the distance it is to be followed. On a part of the British front mining was limited to a bed of clay occurring between two water-bearing strata. (See fig. 13, p. 109.) This formation, though several hundred feet thick in Belgium, thinned out to the south in France. When underground operations were necessary near the southern margin of the deposit it became a matter of the greatest consequence to determine in advance the thickness of the clay.

In general mining will be impracticable in all areas where the country rock is igneous (granite, diorite, basalt, etc.), for such rocks can not be excavated with the mechanical equipment available. It may happen, moreover, that even in a region made up essentially of sedimentary beds igneous rocks in the form of dikes or larger masses crosscut the country rock. A mine gallery that abuts against such a dike, unless the dike is narrow, will usually have to be abandoned. (See fig. 10.) It is important, therefore, to know in advance whether dikes occur in the region to be mined, and this can usually be determined from a knowledge of the general geology. If dikes are likely to be encountered, as detailed an examination of the area to be mined must be made as the military situation permits. The outcrops of dikes can frequently be recognized in photographs taken from aircraft.

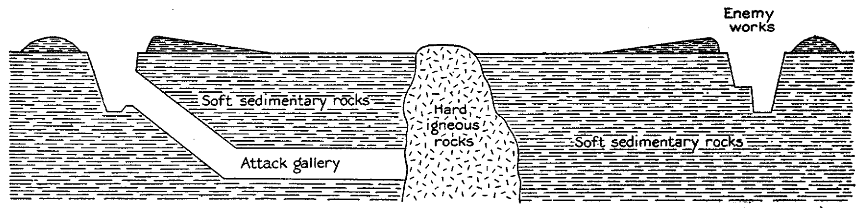


FIGURE 10.—Diagram showing an igneous dike that prevents the advance of an attack gallery driven in soft sediments.

Most successful military mining has been done where the galleries follow individual strata. This is possible where the rocks have been little disturbed and are therefore practically horizontal. If the rocks are badly crumpled the operations of mining are usually impracticable. On the other hand, low dips of beds may be of advantage in providing for better drainage of galleries. It is evident that the attitude of the beds—the structure—must be determined in advance of mining operations. Horizontal beds are in many localities broken by displacements or faults, and these may be a serious if not insurmountable obstacle to driving a gallery. (See fig. 11.) So far as possible the presence or absence of faults should be determined in advance of mining. If one is reached in the gallery an examination of the plane of the fault will often reveal the direction of the throw and may make it possible to "pick up" the same bed beyond the dislocation. In the example illustrated in figure 11 the fault brings the bed so near the surface that there is not sufficient head cover for mining.

The physical character of the formations penetrated by the mine workings will control the speed of excavation and the type and quantity of timbering and will indicate the mechanical equipment required. The underground transmission of the sound of excavation, an important consideration in mine warfare, varies with the character of the strata.

The physical character of the rocks to be mined will depend both on their original mineral composition or lithology and on the amount of alteration they have undergone. A sandstone, originally deposited as a sand, may be only slightly cemented and be very friable and easily excavated. Again it may be highly indurated or altered to a hard quartzite and thus be very difficult to mine. If a hard sandstone has been subject to earth stresses it may be so fractured and sheared as to be readily broken in mine excavation. What has been said of sandstone is also in general true of limestone and other rocks. The ease of excavation will depend, therefore, not only on the degree of hardness and toughness of the strata but also on the presence or absence of bedding planes, fractures, joints, cleavages, and schistosity.

In the following classification the most common geologic formations are grouped in accordance with their relative ease of excavation under such conditions as are usually imposed by military mining. This classification is not intended to be complete but will serve to indicate the kind of information needed in mine warfare.

1. Excavated with little or no picking; examples, gravel, sand, and silt.

2. Easily excavated with pick and shovel; examples, clay, shale, soft sandstone, and chalk.

3. Difficult to break with pick; examples, siliceous chalk, hardpan, sandstone, and schist.

4. Broken only by blasting and hand drilling but not so hard as to make excavation impracticable; examples, limestone, medium hard sandstone, slate.

5. Excavated rapidly only by machine drilling; example, granite, diorite, quartzite.

The first three of these groups afford favorable conditions for military excavation, the fourth group is decidedly unfavorable, and the fifth is ordinarily prohibitive. Mine warfare has, however, been carried on even in the hardest rocks. In 1916 the French and Germans did extensive mining near the north end of the Vosges Mountains, not far from St. Dié, in quartzite, highly indurated sandstone, and conglomerates. Both sides used air drills supplied from power stations located near the front line. This was possible because the topographic conditions were exceptionally favorable. The deep-cut valleys and heavy timber gave almost complete shelter from observation, and hence there was but little artillery fire on either side. The noise of the operations was so great, however, that both armies had fairly definite information about the operations of their opponents. In general, the plan was ill conceived and led to no decisive results.

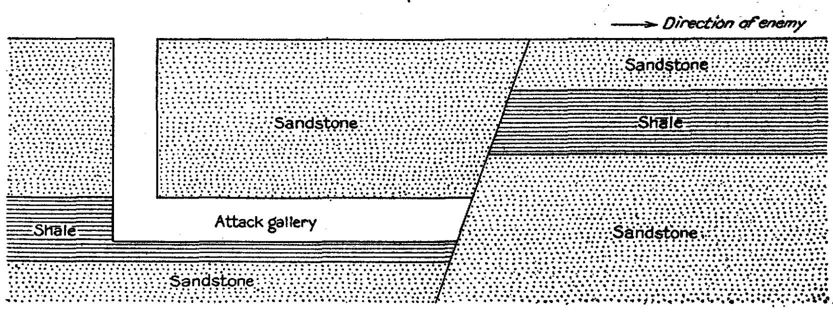


FIGURE 11.—Diagrammatic cross section showing a fault that prevents the advance of an attack gallery driven in beds of soft shale lying between beds of hard sandstone.

One of the first principles of underground warfare is that operations should be carried on with as little sound as possible, so as not to reveal the position of the mines to the enemy. It is evident that the audibility of mine operations will depend on the hardness and toughness of the rock as well as on the mechanical means used in excavation. Sound is transmitted more rapidly by solid formations than by those that are incoherent, and mining of hard rocks will be heard at far greater distance than that of soft material like clay or sand. The records show that the use of the pick can be heard more than twice as far in chalk as in clay. In general the above grouping of the rock formations according to relative ease of excavation also serves as a rough indication of the relative distance at which the noise of excavation can be heard.

The charges of mines and camouflets[37] are carefully gaged to bring about the desired radius of destruction and no more. If the mines are undercharged their purpose is not acccomplished; if they are overcharged the consequent shattering, or even cratering, of the ground will necessarily hamper further mining progress. The determination of the charge is based on the composition of the explosives, the depth of the mine chamber, and the physical character of the formation. The last factor involves the use of geology.

Even the color of the excavated material, determined by its lithology, should be known in advance, so that provision can be made for the camouflaging of the surface dumps. This is necessary because the success of a mine attack is largely dependent upon its secrecy, and a conspicuous dump of rock, such as white chalk, is a sure indication to the enemy of the position of the shaft or entry.

The amount of fracturing that the rocks have undergone not only has an important effect on the ease of excavation but also determines to a large extent the amount and kind of timber required. If, for example, the formation is a plastic or semiplastic clay, complete timbering or casing will be necessary. In contrast to this, a solid limestone or chalk will stand with very little timber. Some of the most difficult ground is that formed by highly fractured hard rocks, such as limestones, which require the use of heavy timber. This fractured condition may be caused in areas of active mine warfare

[37] A camouflet is a small mine whose charge is so gaged that its effect does not reach the surface.

by the discharge of explosives in defense and attack.

Water is the most serious obstacle with which the military miner has to deal. If there is any chance of countermining, the attack will be made at as great a depth as possible, for it is a decided advantage to have the adversary above. Very frequently the depth of operation is determined by the water conditions; hence these must, so far as possible, be determined in advance, and in many places this is the most difficult problem of the geologic engineer. When, however, the general features of the underground water have once been established for a geologic province, it will only be necessary to determine the local features of the geology that may cause variations from the normal conditions.

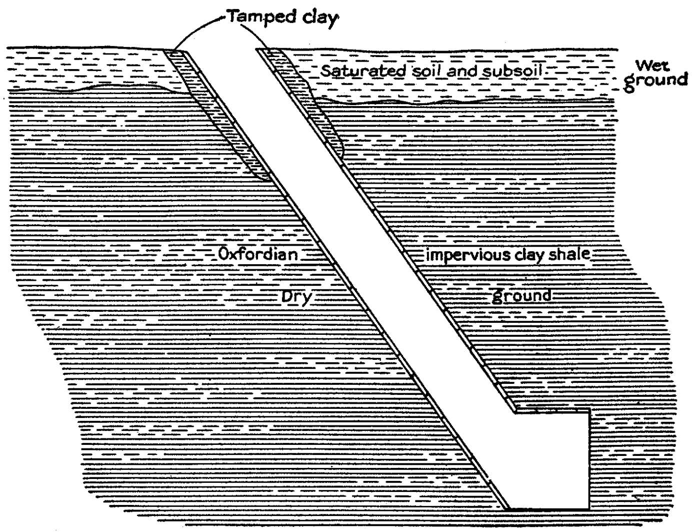


FIGURE 12.—Section in Woevre lowlands, Lorraine, showing underground conditions and entrance to cave shelter.

There are three sources of ground water to be considered in military mining—(1) the surface water that may penetrate to a considerable depth in quantities large enough to interfere with mining (see fig. 12); (2) the ground-water level, which occurs at varying depths in accordance with geologic and topographic conditions; (3) water-bearing strata in which the water may or may not be artesian.

Surface waters do not usually occur in sufficient quantity to interfere seriously with military mining. In regions of excessive precipitation, especially during the rainy season, they may hamper the sinking of shafts. In some parts of the British fronts, for example, the surface formation was a loose sand underlain by clay. Here the upper bed was heavily charged with water and presented serious difficulties to the sinking of shafts. (See fig. 13.) In the Woevre district of Lorraine the surface formation is clay, which during the rainy season is heavily charged with water to a depth of 1 or 2 meters. This also interferes seriously with the sinking of shafts. (See fig. 12.) Conditions of this kind are usually determinable by surface observation and by a consideration of the seasonal distribution of rainfall, or if not test borings will have to be made.

The ground-water level usually has a greater effect on military mining than the surface water. In general, military mines must be kept above the ground-water level. Exceptions, however, are found where natural drainage to the surface can be obtained through galleries, or where power pumps can be operated. In any particular province the depth of the ground-water table usually varies between certain fairly definite limits. Information about it can be obtained by studying the distribution of springs and seeps and the sequence of strata, or by direct observation in wells or shafts or in drill holes sunk for the purpose. In many places the ground-water level has a sufficient seasonal fluctuation to affect underground warfare. One of the most valuable services performed by Col. David was the accurate determination on the British front of the ground-water level at different seasons of the year. By his advice the British mines were located above the high ground-water level of the spring, while the Germans, who attempted to drive at a lower level, were flooded out of their workings.

If a water-bearing stratum is penetrated, the mine will be flooded and entirely lost. Information about buried water strata can often be obtained from existing well records; in the absence of these it must be inferred from the general geology and topography of the region under investigation.

The underground conditions on a part of the British front are illustrated in the accompanying diagrammatic section (fig. 13), which shows a bed of impervious clay overlain by quicksand and underlain by chalk carrying artesian water. To meet these conditions shafts were sunk through the quicksand by the use of tubing, and the mine galleries were driven in the clay. If these galleries broke into the sand above, they would be flooded by surface waters. If, on the other hand, they were placed too low in the clay the artesian water of the chalk would break through and flood the mine works from below. A gallery properly placed in this section evidently had a strong tactical position, for it could not be countermined at a lower level. This presents an excellent example of the necessity of close adjusting of the mine works to the geologic conditions.

Though the factors governing military mining are very largely geologic, yet their interpretation in terms of excavation, equipment, etc., are problems of the mining engineer. Therefore, the geologic engineer will be called upon for the geologic facts and deductions, and the mining engineer will apply these data in formulating the plans of underground operation.

The geologist not only must determine the facts in regard to his own side of the front but must also forecast, so far as possible, the conditions which the enemy will meet if he countermines. Evidently mine warfare calls for the most detailed geologic information. It is to the great credit of the British geologic staff that they procured this information in spite of the fact that all the investigations had to be carried on under front-line conditions. The surface observations were supplemented by a large number of test borings.

SUMMARY.

The use of geologic facts in the siting and construction of fieldworks can be summarized as follows:

1. Geology will make it possible to take advantage, so far as the tactical situation permits, of the most favorable physical conditions.

2. A knowledge of the geology will, to a large extent, prevent the undertaking of projects that are impossible on account of the physical conditions underground.

3. The information gained about the depth of the ground water or of water-bearing strata by the use of geology will determine in advance the type of cave shelter which can be constructed and whether mining is practicable.

4. By the use of geologic facts it will be possible to forecast the kind and quantity of matériel necessary to execute any project of fortification. This will include the tools and other mechanical equipment, such as ventilators, boring machines, and pumps, revetting material for trenches, and timbers for dugouts and mines.

5. A knowledge of the geology will make it possible to learn in advance the character of the material to be excavated, and this is one of the factors determining the time needed to complete the project.

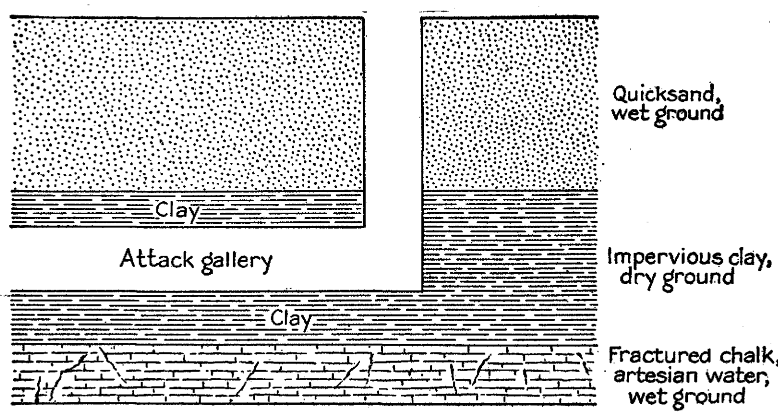


FIGURE 13.—Diagram showing location of mine gallery in dry ground between two water-bearing formations.

GEOLOGIC MAPS AND REPORTS.

The geologic information needed as a guide to the location and construction of fieldworks was furnished by all the armies of the western front in the form of maps, sections, and reports, and to some extent by personal inference. In the earlier stages of the work the maps were chiefly adaptations of the existing French and Belgian geologic maps. Later more detailed geologic surveys were made and the results were shown on color maps printed for general distribution. The standard scale of the British military geologic maps was 1:10,000, and they were printed on the new Ordnance Survey base without the contours.[38] These geologic maps are pre-

[38] The maps examined covered areas in the plains of Flanders, where there is little relief. It is possible that others were issued in which the relief is shown by contours.

sented as being a "General classification of ground according to its suitability for dugouts, etc." The information shown by colors is supplemented by overprinted descriptions. The locations of all bore holes are indicated, thus giving a measure of the reliability of the information about any particular locality. For the mining work of the British Army geologic maps on a still larger scale were prepared, but these appear to have been issued only in manuscript form. The British also printed geologic cross sections with brief explanatory texts conveying information of the same kind as that shown on the maps.

These graphic data were supplemented by the British geologists by brief reports in which the geologic sequence was described and its relations to the construction of fieldworks set forth. These reports were usually issued in mimeographed form and were illustrated by geologic sections. The British geologists, unlike those of the American Army, were frequently called into consultation on the ground, and thus gave much help orally of which there is no record.

The first military geologic maps prepared by the American Expeditionary Force were colored by hand on bases without relief and on a scale of 1:80,000. When the work of issuing geologic maps of the entire front was undertaken these were printed on a scale of 1:50,000, with a contoured base. They were termed engineering geologic maps and the classification was lithologic. In the legend the lithologic units were described with reference to the construction of fieldworks. Seeps and springs were indicated by red lines. A part of the Montsec map, originally printed in colors with contoured base, is here reproduced (Pl. XV).

The German Army issued some geologic engineering maps on the French hachured base of the 1:80,000 scale, but their standard map was on a scale of 1:25,000, on a contoured base, with the geology indicated in great detail. The map explanations were practical rather than scientific and presented in full detail the features of each geologic formation that could be of military value. It is probable that not very many of these detailed maps were printed during the war, for less than half a dozen were captured.

In addition to these maps the Germans printed many reports dealing with the relation between geology and field fortifications. In these reports an evident attempt was made to avoid all geologic nomenclature that would not be comprehensible to the layman. Some, indeed, were clearly intended for the use of men having little or no technical education. In spite of this attempt the German map legends and reports are in general so elaborate and comprehensive as to tend to defeat their own purpose.

All the belligerents followed the practice of issuing preliminary geologic maps and reports before more complete information was available. These would be corrected in later editions. Thus a geologic map might run through several editions within a few months. The exigencies of military operations may evidently demand some information before the field examinations have been completed. This situation is a difficult one for the average geologist to meet, for his inclination is to wait until he has all his facts before coming to a decision. It is hard for a geologist from civil life to grasp the important fact that some information is better than none at all.

The geologic engineering maps of the American Expeditionary Force differed from most of those issued by the other armies in the fact that they were extended far within the enemy lines. It was held that information about the physical conditions in enemy territory was of value even if only approximately correct. These maps could of course not have been prepared had the French official maps (1:80,000) not been available. In drawing the boundaries on a scale larger than the original some use was made of aero-photographs. The base of the heavy cliff-forming Bajocian limestone could, for example, be rather accurately delineated from the photographs. The same results could probably have been attained without the photographs if a better contoured base had been available. Another feature that favored the drawing of this contact for part of the Moselle Valley was the fact that the vineyards of this area, which were outlined on the base map, are all on the Bajocian limestone. Spring lines were also a useful guide in determining some of the contacts.

The geologic section of the American Expeditionary Force prepared a number of reports dealing with the geologic control of field fortifications, military mining, mining troops, and related subjects. These reports are listed below. All except one were issued only in

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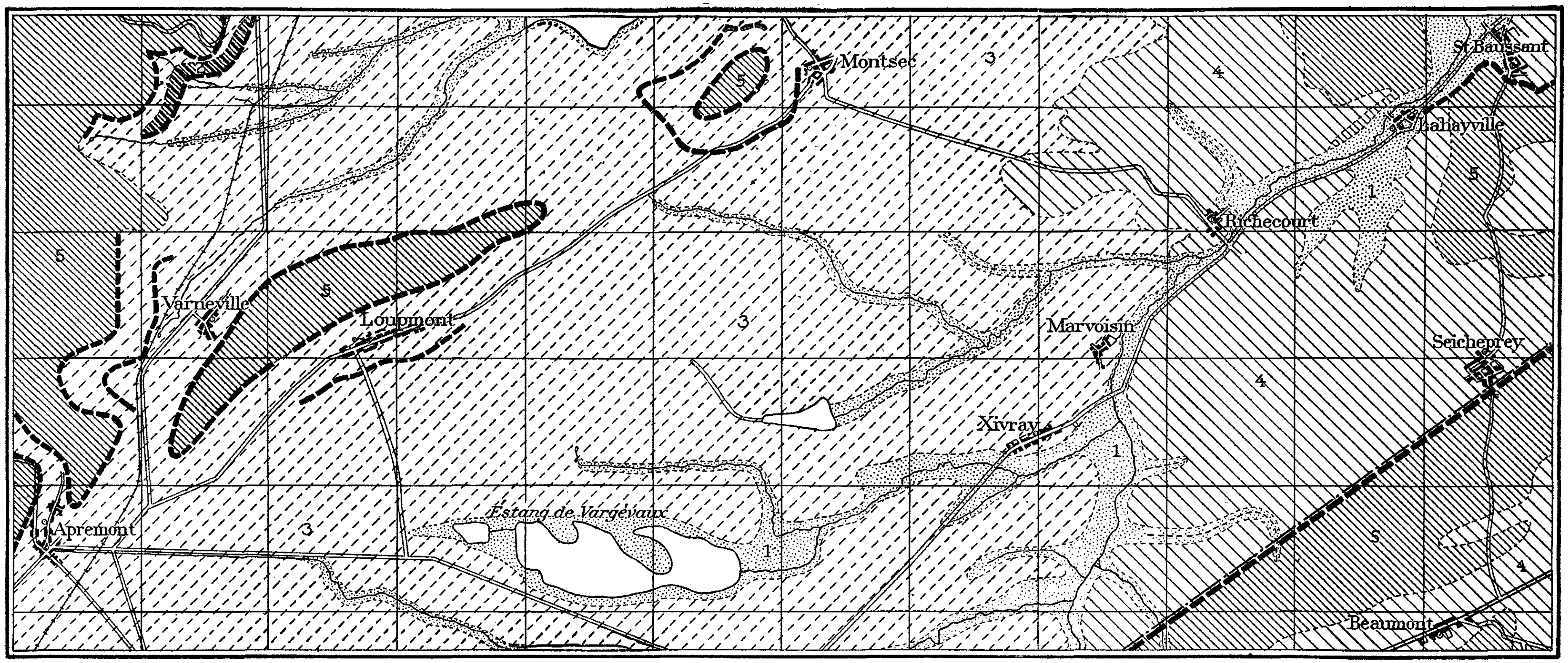


Scale $\frac{1}{50,000}$

1 0 1 2 3 4 Kilometers

DESCRIPTION OF FORMATIONS

1 — Silt, clay, and mud

Usually saturated, except during dry season (April to August), and subject to flooding. Unfavorable for trenches and dugouts.
These deposits range in thickness from ½ to 2 meters in small valleys to 2 to 8 meters in large valleys such as that of Meuse River.

2 — Loose material on slopes (talus)

Made up of clay at surface and angular limestone débris below. Usually well drained; favorable for trenches and, where thick enough, for dugouts. In many places water occurs along the bottom of these deposits.

3 — Clay at surface; clay shales with some thin limestone layers below

Surface zone usually saturated for a depth of 1 to 2 meters except in very dry weather. Deep trenches usually impossible, and even shallow trenches likely to be filled with water. Defensive works will be principally parapets revetted on both sides. Cave-shelter construction usually impracticable unless means are provided for sinking through saturated zone into the dry ground underneath. Cut and cover shelters most practicable form of shelter. In certain localities the terrain permits sufficient drainage for cut and cover shelters.

4 — Surface formation usually clay 1 to 2 meters in depth. Below this formation is soft clay shale or soft limestone

Seepages are likely to be found in limestone. In general favorable for trenches and locally favorable for cave shelters.
In many places underground water prevents cave-shelter construction. The presence or absence of underground water should always be determined in advance of dugout construction by test shafts or bore holes.

5 — Surface formation consisting of weathered zone ½ to 1 meter thick made up of clay with limestone fragments and broken rock. Below is compact limestone formation

Usually well drained, and trenches require little revetting. Very favorable for cave shelters but requires hard-rock excavation. A few beds of clay are found in the limestone, and at these places water is likely to occur. Where a limestone formation rests on clay, as near Apremont, a line of springs or seepages is usually found. Such localities should be avoided, or the fieldworks placed above the line of springs or seepages.

Principal lines of dislocation

Water is likely to occur along these lines, due to the zones of fracture.

Locus of springs and seepages

These should be avoided as far as possible in the location of fieldworks, especially of dugouts. Fieldworks should be placed above the lines of springs.

MILITARY GEOLOGIC MAP OF MONTSEC, FRANCE, AND VICINITY.

manuscript form and hence had no wide circulation. Reports were prepared covering the front between the Swiss frontier and Meuse River and including a description of the military engineering features and their relation to the geology. A special report on underground water and its relation to fieldworks was also prepared for the use of the engineers. Detailed reports were also made on the geology and topography of the enemy positions in the Lorraine sector and their relation to and control of the enemy fortifications. These reports were prepared for the use of the intelligence section of the General Staff.

Geologic engineering maps prepared by geologic section, American Expeditionary Force.

Quadrangle.	Scale.	Notes.
Commercy	1:80,000	Hand colored; not printed.
Montsec	1:50,000	Printed.
Cheminot	1:50,000	Do.
St. Mihiel	1:50,000	Do.
Etain	1:50,000	Do.
Lunéville	1:50,000	Hand colored; not printed.
Amelecourt	1:50,000	Do.
Schirmeck	1:50,000	Not completed.
Chateau Thierry	1:50,000	Do.

Reports prepared by geologic section, American Expeditionary Force, relating to field fortifications, etc.

Mining troops of British Expeditionary Force.

Notes on British mining practice.

Notes on British mining schools.

Engineer reconnaissance on French front from Belfort to St. Mihiel.

Geology and topography as affecting military engineering, Nomeny-St. Mihiel sector.

Mine-rescue apparatus.

Notes on cover for shelters.

Underground water and its relation to fieldworks. (Printed in Engineer Field Notes, No. 27, A. E. F.)

Notes on shelters for infantry.

Geology and topography as affecting military engineering of German position, St. Mihiel and Pont-à-Mousson sector.

The German defenses of the Lorraine front.

MANEUVERING.

The influence of swamps and marshes on strategy and tactics is of course well established. On many occasions skillful leaders have defeated an opponent by taking advantage of impassable ground. Present tactics and modern equipment in artillery and tanks have led to a revision of the old classification of passable and impassable ground for troop maneuvers. This revision has been necessary because of the colossal scale of modern operations, involving not only tremendous concentrations of men but also enormous unit weight of mobile equipment, such as artillery and tanks. A land surface that would have been no obstacle to maneuvers in former wars, with their relatively small numbers of troops and light equipment, might prove almost impassable for the great bodies of men and the heavy equipment demanded by present tactics. There were, of course, plenty of exceptions to the new requirements during the late war, for much fighting was done in swampy lowland and even among rugged snow-clad ranges, where the great concentration of infantry in attack and the use of heavy equipment was impossible. The decisive battles of the war, however, were fought in areas where the passability of the ground was an important element. The question whether a certain hill slope is made up of slippery clay or of hard ground may be the decisive factor in a tactical movement. Again, the success of an operation may hinge on the quick traverse of a certain valley bottom. If the valley floor is silt or clay, it will be soft and muddy during the wet season and difficult to traverse; if it is sand and gravel it will be hard and dry and easy of passage by troops and equipment. Again, the successful fording of a stream may depend on the physical character of the stream bottom. A knowledge of the geology of the region will make it possible to forecast the physical conditions of the surface, and this will often be of immense service in formulating plans for tactical movements.

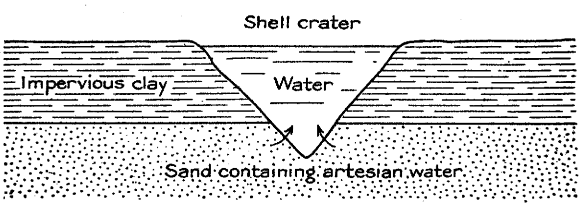
The feasibility of a maneuver depends, as shown above, on the physical condition of the soil, as well as on the topography.[39] Complete understanding of the topography of the scene of operations is clearly of first importance to the tactician. It has been emphasized in many publications,[40] notably by the French, that a thorough knowledge of military topography can best be obtained by understanding its relations to the bedrock geology and to the recent geologic history of the region. This subject relates to the training of officers and, though important, need not be further discussed here. The influence of topography on tactical move-

[39] There are other conditions, such as distribution of forests, character of roads and railroads, that influence tactical movements, but these need not be considered here.

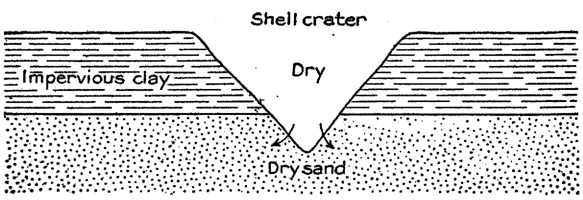
[40] This subject is admirably presented in "Military geology and topography," edited by H. E. Gregory, pp. 162–252, New Haven, 1918.

ments has, however, been emphasized to the exclusion of almost any consideration of the effect of soil conditions. An escarpment may afford an admirable defensive position, but a lowland underlain by clay may during a wet season be even a still greater obstacle to an attack. Ground that could be readily traversed by a light skirmish line might, after being crossed by repeated waves of infantry, be so churned up as to become practically impassable for rapid forward movement. Even if passable by infantry it might be impassable for artillery and tanks.

Another aspect of the problem is the effect of modern artillery fire, with its penetration in unconsolidated material to a depth of nearly 50 feet. A barrage may so churn up the ground as to make it a serious obstacle to rapid infantry attacks and impassable to heavy equipment. It is evident that the shell craters will be much larger in unconsolidated material than in hard rock, and which kind of ground will be reached by the shell fire can be determined in advance by the use of geology. Moreover, underground conditions may lead to the shell craters being filled with water from below and thus add still greater obstacles to advance. (See fig. 14.)



Shell crater in clay overlying sand containing artesian water; filled with water from below



Shell crater in clay overlying dry sand; surface water drains into ground

FIGURE 14.—Diagrams showing influence of geologic conditions on the presence of water in shell craters.

The location of outcrops of hard, brittle rock within the enemy lines, especially in their fieldworks, may also be of some local importance. Artillery fire that hit such outcrops was more effective because of the splintering of the rocks.

Whether ground will be hard or soft at any particular time depends principally on the physical character of the soil and subsoil and on the amount of precipitation. Therefore the determination of the physical conditions of the surface as a guide to planning troop maneuvers involves the use of data on geologic conditions and rainfall. A knowledge of the areal geology is of first importance, and hence a geologic map is indispensable.

The lithology of the formations immediately underlying the surface must be known, as well as their products of weathering including soil and subsoil. An essential element to the problem is the depth to hard rock, for obviously if bedrock occurs near the surface, with only a thin cover of soil, the ground will be dry and hard at all seasons. On the other hand, if there is a heavy cover of soil and subsoil that have certain physical properties the ground will become soft and water soaked during the wet season. If the surficial material is pervious, as, for example, in a sandy soil, the rain water will soak deep into the ground and the surface will remain dry and hard, but where there is an impervious surficial deposit, such as clay, it will hold the water and form soft, muddy ground. Other geologic factors, such as depth of ground-water table and degree of saturation of soil and subsoil at the time of rainfall, also affect the problem.

The dip of the strata determines in a large measure the areal distribution of the formations and this of course holds true of the soils derived from them.[41] In areas of horizontal strata there will evidently be less variation in type of soil from place to place than in regions of close folding.

In the practical application of these principles no great refinement will be necessary. Having a geologic map of an area with which he is familiar and data on precipitation, an experienced geologist will be able to forecast the soil conditions of any formation with a sufficient degree of accuracy for use in maneuvers.

The whole problem is closely tied to the quantity and seasonal distribution of rainfall. A certain formation may afford hard footing and hence be easily passable during the dry season, only to become soft and practically

[41] In glaciated regions other factors are evidently involved, which will not be discussed here.

impassable during wet weather. Therefore monthly data on precipitation are absolutely essential, and information about evaporation is desirable. In northern latitudes the seasonal distribution of ground frost may have a bearing on the passability of the terrane at times.

The permanent ground frost of polar and subpolar regions introduces another element. In these regions the soil and subsoil thaw only to a depth of 1 foot to 3 feet during the short summer. This condition produces a swampy character in the ground even on hill slopes, and as a result much of the country is almost impassable for modern armies.

An area in which the character of the soil and the precipitation are such as to form muddy ground during the wet season may be artificially drained. Locally the plain of Flanders has been so drained as to give relatively hard ground, but the great plain of western Russia, with similar natural physical conditions but not drained, is wet and muddy.

In arid and semiarid regions the considerations above set forth are of less importance, for the terrane, except for talus slopes, is likely to be firm at all seasons. As the greatest concentrations of the population of the world are in the humid regions, however, these are likely to continue to be the scenes of important wars. Therefore the use of geologic maps in forecasting the physical conditions of the surface of the ground deserves attention by tactical leaders. This military use of geology need not be overemphasized, for evidently in many regions it will have little practical application. Moreover, its important effect in military maneuvers will be confined chiefly to the wet season of the year.

Though geologic maps may be only occasionally of service to the tactician, yet he can not afford to ignore any source of information about the physical character of the terrane in the scene of his operations. Advance knowledge that the soil conditions in this or that part of the battlefield will slow down an infantry attack or make the advance of artillery or tanks impossible may give a decisive advantage in a given movement. Some instances from the late war, showing the influence of geology on troop maneuvers, can be cited.

In the Lorraine sector of northeastern France strongly contrasting physical conditions were found between the areas underlain by hard limestones (Jurassic) and sandstones (Triassic) and those underlain by clays and marls (Liassic and Jurassic). The former afford hard footing at all times; the latter during the wet season were in many places impassable for heavy equipment such as artillery and tanks or even for quick movements of large bodies of infantry. The wet country may be provided with hard roads, but in time of advance the enemy will destroy the roads in whole or in part, so that they are likely to be impassable. Moreover, a general attack is made over a broad front, and the advance of heavy artillery or tanks must be possible without counting on the use of roads.

The Germans had planned their withdrawal from the St. Mihiel salient in October, when the water-soaked clays of the Woevre lowland (Pl. XV) are in their worst state so far as the movement of troops is concerned. (See fig. 12.) Captured documents showed that they had formulated very elaborate plans for the demolition of roads and bridges. Fortunately, our attack was made in September, both before the physical conditions were at their worst and before the plans for demolition could be accomplished. Had the attack been deferred until October and the roads been destroyed as planned, a part of the new positions would have been almost impregnable to attack until after the rainy season. Evidently the Germans had taken into account the physical conditions of the surface formation and its seasonal variations.

The physical character of river bottoms and banks may also be an important factor in carrying out any particular movement. A shallow watercourse bottomed by mud or silt will be impassable for large bodies of infantry, not to mention artillery and tanks. The presence of a bedrock reef on such a stream, affording a hard bottom, will provide a feasible crossing. For example, the streams traversing the Woevre lowlands, underlain by the Oxfordian clay shales, had muddy bottoms that could not be crossed by artillery, tanks, or large bodies of infantry. In places, however, as shown by the geologic maps (Pl. XV), the streams traversed limestone reefs where crossings could be made. Geologic information of this kind was used in the planning of the St. Mihiel attack, principally in choosing routes for tanks. Again, the gravel-filled valleys of the streams whose sources are in the hard rocks of the Vosges Mountains afford dry, firm footing, but the Meuse and its tributaries, traversing areas of soft limestones and shales, are bottomed with silt and mud and are very difficult to traverse during the wet season. The ground underlain by the Cretaceous chalk usually remained hard during all seasons. Many of the Tertiary formations became water soaked during the wet season and furnished a difficult terrain for troop movements. Much the larger part of the success in the use of tanks during the war was attained in the chalk areas, but attempts to take tanks across areas underlain by clay formations, such as the Oxfordian, in the St. Mihiel salient, failed.

The study of the physical conditions affecting troop movements must sometimes take account of the effect of barrage fire. In the Tertiary formations of the British front there were places where an artesian water-bearing sand was capped by impervious clay. As a result of a heavy barrage the ground was pitted with innumerable shell craters filled with water from the underlying strata.[42] Advance over such ground was exceedingly difficult for infantry. The designation of the areas where these conditions existed, so that they might not be chosen as scenes of attack, was one of the duties of the British geologists. On the other hand, where an impervious clay overlay a dry sand the effect of shell fire was to drain the surface. Such types of terrain might be of local importance in affording a series of dry shell craters to organize as defensive positions.

The use of geologic maps to forecast the physical conditions of the surface was of slow development during the war. In this field the French did the pioneer work. A map of a part of the Reims sector, making a classification of surface deposits according to degree of passability, was issued by the Fifth French Army in July, 1917. It is called a soil map and is on a hachured base on a scale of 1:80,000. The physical character of the surface outcrop of each formation in its relation to infantry and artillery movements is described for both the wet and dry seasons. This appears to have been the first and probably was the best of this type of geologic maps. The French also issued "general information maps," on some of which the soil was outlined and classified in a crude way according to passability. Toward the end of the war the Service géographique started on a project to make a series of maps for the use of tanks, but none of these were issued.

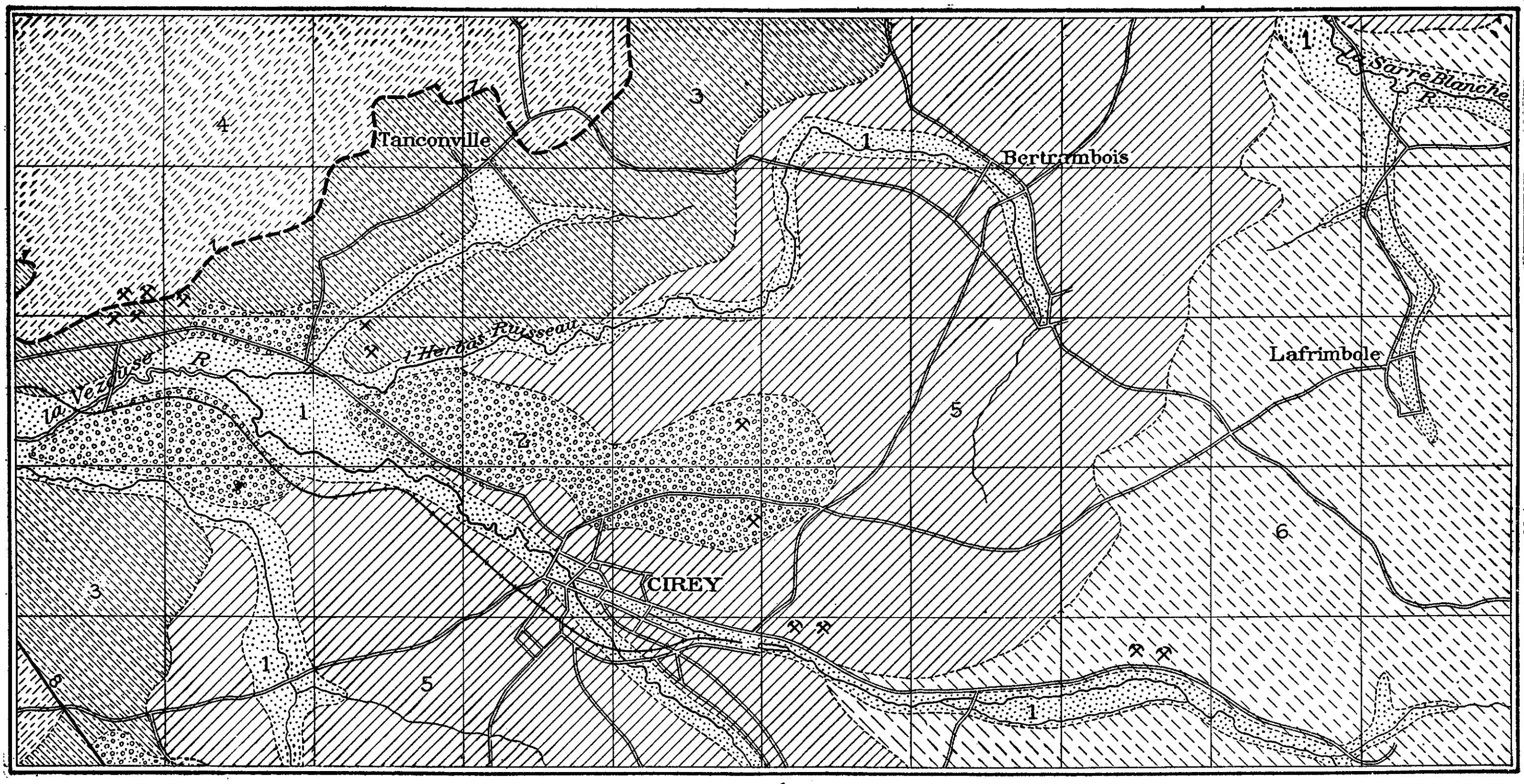
As has been shown, the British geologists were consulted on questions relating to physical conditions of the surface, especially in regard to the effect of barrage fire. They also prepared some maps, giving a broad classification of their entire front with reference to the use of tanks.

No special maps giving a classification of soils as affecting the maneuvering of troops were issued by the American Expeditionary Force. Information of this kind was, however, given on some of the geologic engineering maps. In these the explanations included a description of the surface conditions of each formation for both the wet and dry season. An example of this type of map, the original of which was in colors, is given in Plate XVI.

It also fell to the geologists of the American Expeditionary Force to collect and make available information about river crossings. This had largely to do with the fluctuations of stream volume but also took into account the character of the river bottom. The description of the topography and geology of the enemy's lines, prepared by the geologists of the American Expeditionary Force, included mention of the areas in which hard or soft footing would be found on the uplands and slopes as well as in the valley bottoms. Just before the armistice the Tank Corps of the American Expeditionary Force developed a plan to make use of a geologist in the selection of area suitable to the maneuvering of tanks. By that time experience had shown that a proper use of tanks is possible only if heed is given to the physical conditions of the soil.

It appears that in the German Army the use of geology in forecasting the conditions to be encountered in an advance was only a late development. Not much space is devoted to this application of the science in the German secret manual of war geology published in January, 1918. Through the courtesy of Dr. A. Renier I saw at Brussels a German map giving information of this type, issued in June, 1918. This was called a military geologic map and is published on a scale of 1:50,000. The legend is of the same general type as those of the

[42] Information from Col. T. Edgeworth David.



Scale $\frac{1}{50,000}$

1 0 1 2 3 Kilometers

DESCRIPTION OF FORMATIONS

1

Silt, mud, sand, and gravel, with some clay

The valleys of the Meurthe and parts of the Sanon (Parroy to Mouzy) and the Vezouse up to Blamont, as well as those of the small streams within the sandstone area, are chiefly floored with sand and gravel. In the other valleys the floor is chiefly silt and mud. The thickness of these deposits ranges from less than 1 meter in small valleys to 2 or 3 meters along Sanon and Vezouse rivers.

They are usually saturated, except during the dry season (June to September); in part subject to flood and unfavorable to trenches and dugouts.

The silt and mud floored valleys usually afford soft footing, even during the dry season. They are for the most part impassable during the wet season (October to May), except when frozen. The gravel and sand floored valleys are better drained and are passable except during floods. Floods are likely to occur in any month but are most frequent and highest between November and April.

2

High gravel and sand deposits with some clay (½ to 20 meters thick)

Well drained near surface but contain much water at bottom. Trench construction easy but requires complete revetment. Cave shelters possible where deposits are thick enough but require heavy timbering to maintain roof.

The surface is usually firm, even during wet weather.

3

Clay 1 to 3 meters thick resting on limy shale

The clay is thinnest at the crests of deep slopes, thickening toward the summits of divides and toward the bases of slopes, where it may exceed the thickness given above by accumulation of slide material. During the wet season the surface zone is more or less saturated, and the ground is muddy to a depth of 1 meter or more. Ground water usually within 3 or 4 meters of surface, except at crests of slopes, where it is deeper. The formation also contains some thin beds of limestone, usually water bearing. The presence or absence of underground water should always be determined in advance of cave-shelter construction by test shafts or bore holes.

Trench construction easy but requires complete revetment and ample provision for surface drainage. Trenches located on clay slopes are liable to be destroyed by slides and need strong revetment. Cave shelters can be built only where the terrain permits drainage tunnels.

The surface of this formation is usually soft and except where well drained on crests and slopes is likely to be muddy during the wet season (October to March); except when frozen, slopes are slippery during the wet season.

4

Clay with weathered limestone ½ to 1½ meters; compact limestone below, with some shale beds

Surface usually well drained, but some water may occur along shale beds.

Trenches difficult to excavate but require little revetment. Formation is favorable to cave shelters but requires hard-rock excavation and where rock is fractured heavy timbering.

Surface of ground usually firm, but during wet weather (October to April) some mud found on limestone. Limestone forms steep cliffs where capping hills.

5

Sandy clay soil with weathered sandstone 1 to 3 meters; medium-hard sandstone containing some clay below

Usually well drained; trench construction in weathered zone easy but requires heavy revetment on account of swelling. Cave shelters in sandstone require heavy rock work; some seepage water, and drainage tunnels usually necessary.

Surface of this formation usually well drained and firm.

6

Sandstone and conglomerate, in most places weathered to a depth of only ½ meter or less

Rock below soil very hard and requires blasting for trench construction. Cave-shelter construction requires use of power drills and blasting. In most places not much seepage water.

Surface ground firm and in places hard throughout the year.

7

Locus of springs and seepages

These should be avoided as far as possible in the location of fieldworks, especially of dugouts. Fieldworks should be placed above the lines of springs.

8

Line of dislocation (fault)

Water is likely to occur along these lines, due to the zones of fracture.

⚒ Quarry (in part abandoned)

× Sand and gravel pit

MILITARY GEOLOGIC MAP OF CIREY, FRANCE, AND VICINITY.

French and American maps already described. Its purpose is evidently to guide the tactical commander in planning a forward movement. While intended primarily to describe the surface formations, it also contains geologic information bearing on fieldworks. The areas of natural and possibly artificial inundation are indicated. Like all the other German military geologic publications, the map is confusing because of the attempt to show too great a variety of facts on a single base. Dr. Renier told me that a number of other maps of this type had been prepared, but this is the only one captured, so far as I know. In one respect it was different from all other German geologic maps that I have seen, inasmuch as it covered areas held by the Allies and was therefore in part based on compiled data.

The sources of information needed for geologic maneuvering maps will be field observations within an army's own lines and compiled data on areas occupied by the enemy. Geologic and soil maps will be the best sources of information. The facts furnished by these maps must be interpreted in terms of firmness and stability of soil at different seasons of the year. A proper interpretation will be possible only if the geologist has a personal familiarity with the region, and he should also know by observation the effect on the soil of a given type of the passage of large bodies of troops and heavy equipment. He should also know the unit weight of the heaviest equipment which is used.

River and stream crossings should be marked on the same maps, with a statement of whether bottom is hard or soft and the seasonal fluctuations in depth. Maps of this type should be made on a contoured base and on a scale not larger than 1:50,000.[43] It is very desirable that the same maps also show distribution of forests,[44] which is important to maneuvers.

WATER RESOURCES.

The supplying of a huge modern army with water is one of the largest tasks that falls to the military engineer. It is difficult enough to develop the water supply needed in rear areas and under stationary conditions of trench warfare, but the task becomes far more complex and serious in time of advance and mobile warfare. During the recent war both the British and the French estimate of minimum water requirement when troops were massed for advance was about 150,000 gallons a day for every 20 square miles of territory occupied.

The water supply provided for civil consumption in most regions is not sufficient for military needs. Therefore, it is usually not only necessary to make available to the armies the water already developed but also to seek new sources of supply. The determination of possible sources of water in any particular region is largely a geologic problem. Nevertheless, during the early part of the war none of the opposing armies appear to have made any use of professional geologists in this field. Part of the German forces were then using the witch-hazel stick to find water, and the well drilling done by the British was largely haphazard and without heed to the geologic facts.[45] The British were the first to recognize the error of such happy-go-lucky methods. By the time the United States entered the war the use of geologists in determining the sources of water was well established in both the British and German armies. The French water-supply service was also making much use of geology in selecting locations for wells but failed to recognize the economy and efficiency of calling on professional geologists to solve geologic problems, rather than having the work done by water-supply engineers, many of whom were at best only partly trained in geology and all of whom must perforce give the greater part of their attention to questions of development and mechanical equipment.

In view of the experience gained by the blunders of our allies there is less excuse for our not having made full use of geologic science in its application to water resources. Though reforms were instituted during the war in these matters, yet in the aggregate many wells were drilled by the American Expeditionary Force without any knowledge of the underground water conditions. It is rather surprising to find experienced engineers who in their own field will not start a project without the most careful investigations and planning, yet who will cheerfully begin drilling for water while

[43] The standard geologic maps of the U. S. Geological Survey (scales 1:62,500 and 1:125,000) are well adapted for this purpose if a proper explanatory text is prepared to accompany them.

[44] Forests could be shown, as on the French maps, by a black pattern; the geologic information being indicated by overprints in transparent colors.

[45] King, W. B. R., Geological work on the western front: Geog. Jour., vol. 54, p. 219, 1919.

utterly ignorant of its underground occurrence. The explanation of this anomaly lies largely in the fact that engineers have not kept pace with modern advance in applied geology sufficiently to realize that the location of water-bearing strata is almost an exact science. Fortunately the hit or miss method did less harm in this field than it might elsewhere, because underground water-bearing strata are rather widely distributed on the western front. Therefore a policy that would have been disastrous in many other fields in general led here only to a waste of time and energy.

A determination of the sources of underground water demands a knowledge of the areal, stratigraphic, and structural geology. The French official maps formed admirable guides in this field, and in some places an interpretation of these maps and their accompanying explanatory text sufficed to determine the positions of water-bearing strata. More commonly, however, some local surveys and supplementary investigations were necessary. Most of the well drilling done in the American zone was in the line of communication. At the front we depended largely on water supplies already developed by the French military authorities, and during the advance we made much use of sterilized surface water.

It fell to the geologists in large measure to report on the resources of the surface waters. Where good stream measurements were available [46] or where the conditions permitted field examinations the questions of surface water supply were passed on by engineers. Even in this field they were not always entirely successful, because many engineers who are expert in water-supply construction failed to realize the necessity of a careful scrutiny of the seasonal variations of rainfall and more especially of the control of run-off by the geology as well as by precipitation. As a result some attempts were made to utilize surface water without adequate knowledge of the quantity of water available during the dry season. When it came to estimating stream volumes within the enemy's lines the task proved to be beyond the engineers and fell to the geologists of the American Expeditionary Force. With this went the determination of the location of springs, depth to underground water, and similar facts, which, of course, requires a knowledge of structure and stratigraphy.

[46] There has been no systematic gaging of streams in northern and northeastern France.

In the British Expeditionary Force the geologist, Capt. W. B. R. King, acted as adviser to the chief engineer on all matters relating to water resources. No well drilling was permitted without his sanction, and he supervised the collection of all data relating to water resources. His duties were distinct from those of the water-supply officers, who took his results and interpreted them from the standpoint of the engineer. The line was therefore clearly drawn between water resources, belonging to the field of the geologist, and water supply, belonging to that of the engineers.

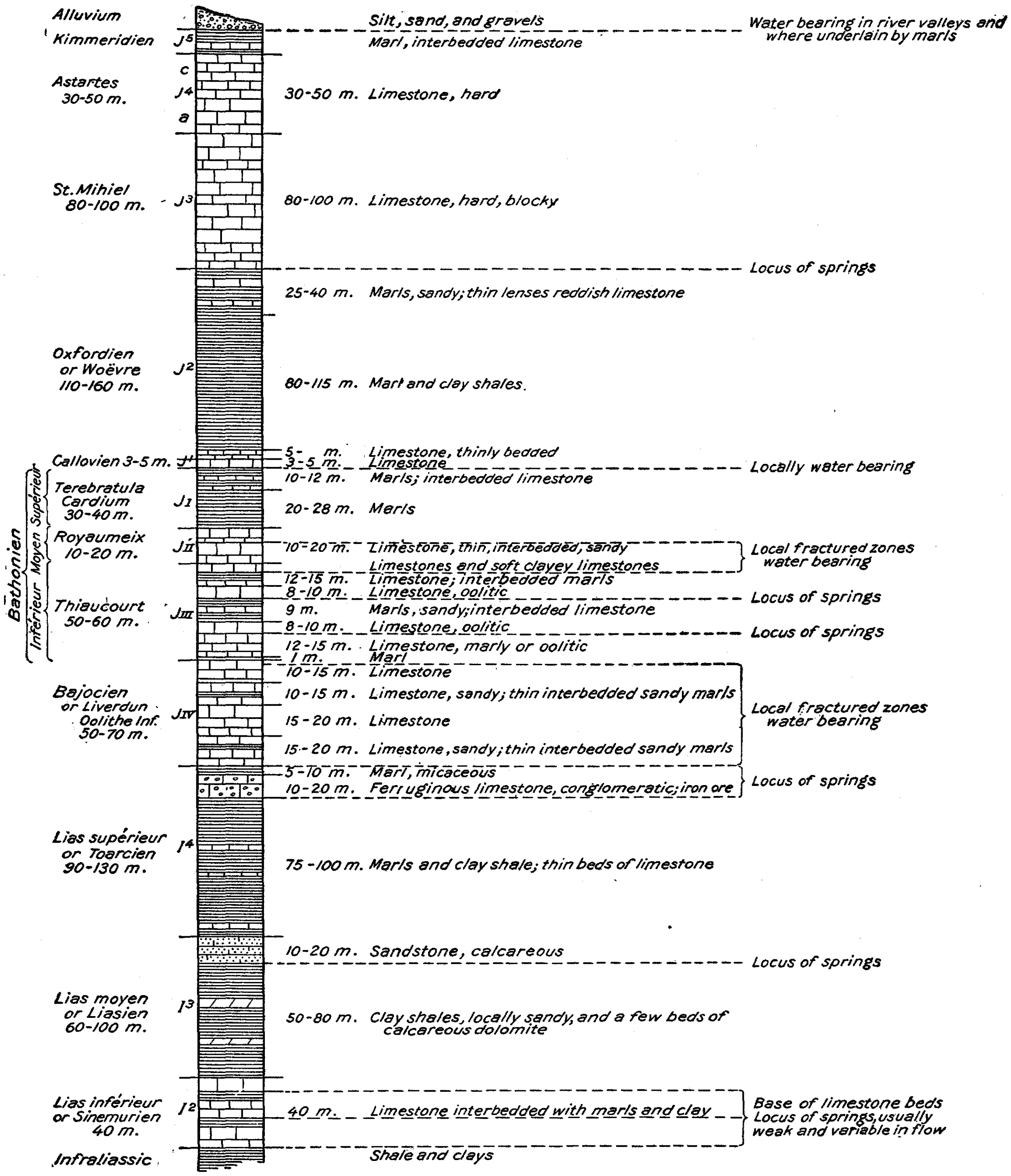
The lack of surface water in part of the area lying in front of the British lines necessitated the drilling of wells during the advance. One of the most valuable services rendered by Capt. King consisted in selecting sites for these wells within the battle area and forecasting the depth to water. In commenting on Capt. King's paper,[47] Brig. Gen. Liddell says:

> In this connection it would give you some idea of the problem with which the geologists had to deal when I instance the advance of the Third Army. * * * We had to cross practically a desert area * * * in which there was practically no surface water. We got across this desert area largely owing to our accurate geological knowledge of the ground. * * * To take 300,000 men and 100,000 horses across an area like that is a feat which I think has seldom been equaled. Of course, we depended largely upon borings. During the advance and in the face of the enemy we made 13 bores 250 to 300 feet in depth; in some cases the boring plants were in line with the field guns, and the crews unfortunately in this case were knocked out by shell fire. The bores were most successful, and as a result the Army was well supplied with water.

This statement well illustrates the necessity of having an exhaustive knowledge of the geology of the theater of operations. Had it not been for Capt. King's professional attainments and knowledge of the terrain, which enabled him to predict the underground water conditions, this advance would not have been made in the time allotted to it. It brings further proof of the necessity of having the geologic investigations in the hands of experienced professional geologists. To rely on amateurs in such an emergency would have been the height of folly.

In the French Army both the water-resource and water-supply work was done by the

[47] King, W. B. R., op. cit., p. 215.



GENERALIZED SECTION OF COMMERCY QUADRANGLE, FRANCE, SHOWING SEQUENCE OF GEOLOGIC FORMATIONS AND OCCURRENCE OF WATER.

116-1

same men. Though it was very evident that greater use of geology would have been beneficial to the French service, yet it must be remembered that many of the French engineers had a complete knowledge of the underground water resources of the country. Indeed, some of them were highly competent geologists. Nevertheless, the service would have been benefited if professional geologists had been employed to determine the water resources and the engineers had been free to devote their time to the engineering problems.

In the American Expeditionary Force the distinction between the work of the geologist and that of the engineer was recognized but not very sharply defined. Some of the engineers engaged in water-supply development gave small heed to geology, and insufficient control was exercised to compel the determination of underground conditions in advance of well drilling. As a consequence during the dry season there was an unnecessary shortage of water at a number of hospitals, aviation fields, and other military establishments. On the other hand, some of the geologists were detailed to water-supply work that clearly belonged to the domain of the engineers. These matters were being rectified at the end of the war, when a definite system of responsibility for the different fields was being established.

The function of the military geologists of the German Army in the matter of water resources seems to have been similar to that of the British geologists. They acted as advisers in all matters relating to water resources but were not responsible for the engineering problems of water development. It appears that they performed some of the duties of sanitation, which in all the other armies were left to the medical corps.

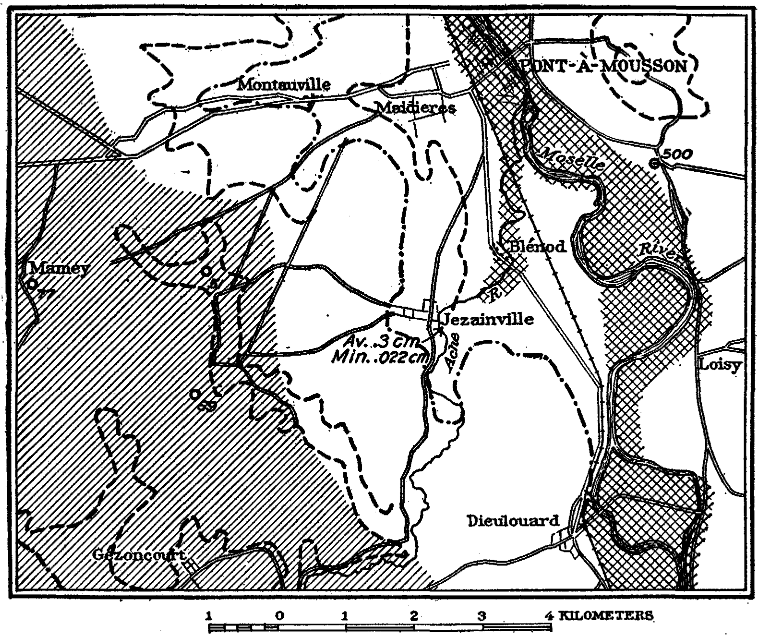
Many of the geologic data and conclusions relating to water resources must necessarily relate to special localities where water developments are under consideration. In the American Expeditionary Force reports of this character were made concise and, so far as possible, shorn of all geologic terminology and speculation. The aim was to put into the hands of the engineer a statement of conclusions, with a brief summary of the facts upon which the conclusions were based. In addition, some reports and sections were prepared for the use of those versed in geology. (See Pl. XVII.) The purpose of such a report was to present the geologic facts bearing on the water resources of a particular region, to serve as a guide to those making local examinations. It would have been well to have had these reports prepared before the war, as a part of the military preparation. Though there is a vast literature dealing with the underground waters of France, it consists for the most part of detailed descriptions of special localities, and but few attempts have been made to summarize the facts bearing on larger regions, as has been done for many parts of the United States.

Exceptions to this are the publications of Dr. Ed. Imbeaux, of Nancy, ingénieur en chef des ponts et chaussées, which give much information about the underground waters of France and especially of Lorraine.[48] Information about the run-off of streams of northern and northeastern France is exceedingly scant, as there has been no systematic gaging of the watercourses. Data of this kind were collected from various sources, and in the absence of exact measurements estimates were made on the basis of precipitation and knowledge of the geologic conditions.

The American Expeditionary Force printed some maps showing the facts relating to distribution of water as determined by geology. On these maps were indicated the locations of springs, the areas of possible shallow dug wells, and the areas of deeper underground waters and also the available information about stream volumes. (See fig. 15.) They proved to be of great service to the water-supply engineers, but unfortunately the force available for their preparation was not large enough to permit covering the entire front with these maps. To be complete they should have shown also the depth of the principal underground water horizon by subterranean contours. This would have greatly enhanced the value of the maps but could not be done for lack of sufficient field force to make the necessary local examinations.

It also fell to the geologists to compile reports on the water resources within the enemy lines. These reports were printed as small pamphlets, each accompanied by a map (fig. 16) graphically summarizing the information contained

[48] Imbeaux, Ed., and others, Annuaire statistique et descriptif de la distribution d'eau de la France, 2d ed., Paris, 1909. Imbeaux, Ed., Les eaux potables et leur rôle hygiénique dans le Département de Meurthe et Moselle, Paris, 1897.



EXPLANATION

Water-bearing river deposits 1-10 meters deep. (More or less water also occurs at moderate depths below bottoms of smaller valleys)

Principal areas of underground water at depth of 30-225 meters. This water occurs along irregularly distributed fissures in limestone and at base of fractured limestone on strata of clay shale. Water under varying hydrostatic pressure

Av. .3 cm.
Min. .022cm

River discharges (approximate) average and minimum flow in cubic meters per second

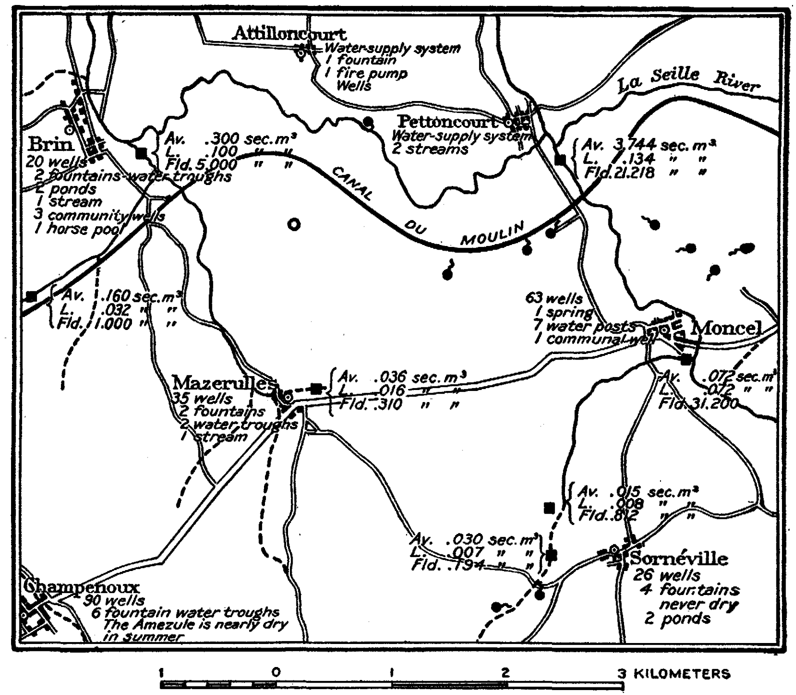
Loci of springs

Loci of strong springs

Deep wells: (approximate or minimum depth in meters)

Deep drill holes cased through artesian water horizons in hard sandstone. Depth in meters to water horizon

FIGURE 15.—Map showing water resources of Mamey, France, and vicinity.



EXPLANATION

Spring
Dug well
Stream believed to carry water throughout the year
Stream believed to be dry in summer

Note.-The data on springs and wells are incomplete. There are shallow wells in nearly all towns and at many farm houses

APPROXIMATE STREAM VOLUMES

■ Gaging stations

Av. .036 sec. m^3 = Average run-off in cubic meters per second
L. .016 " " = Low-water run-off in cubic meters per second
Fld. .310 " " = Flood-water run-off in cubic meters per second

Note.-.001 cubic meter per second is equal to 22,800 gallons of water per day. Stream volumes based in part on incomplete data. Therefore use 50 per cent factor of safety for minimum run-off

FIGURE 16.—Map of Pettoncourt, France, and vicinity, showing developed water supply.

in the text. They included a brief nontechnical statement of the physiography and geology so far as it affected the water resources. The character of the developed sources of water was briefly described, and information on stream volumes was tabulated. In the description of the watercourses information was given not only as to their volume but also as to their depth and other features that affected stream crossings.

A glossary of English water-supply terms, with their German and French equivalents, was also included in these publications. In the back of each pamphlet was an alphabetic list of the towns with a full statement of the developed water supply. All this information was summarized on the map, on which all wells, springs, and reservoirs were indicated by appropriate symbols. These reports, prepared in the office of the chief engineer, of which the geologic section formed a part, were issued and distributed by the intelligence section (G 2) of the General Staff. A list is given below.

General water-supply reports and maps prepared by geologic section, American Expeditionary Force.

[* Indicates printed reports.]

Notes on water supply, Nomeny–Pont-à-Mousson–St. Mihiel sector.

Notes on underground water supply, St. Dié–St. Mihiel sector.

Note on deep water-bearing horizons in southeastern part of Commercy quadrangle.

Hydrogeologic map of French front from Commercy to Thann, scale 1:320,000.

Water-supply map of Nancy, scale 1:80,000.

Water-supply map of Commercy, scale 1:80,000.

*Water supply of Commercy quadrangle, with map, scale 1:80,000.

*Water supply of Metz S. W. quadrangle, with map, scale 1:50,000.

*Water supply of Metz S. E. quadrangle, with map, scale 1:50,000.

*Water supply of Metz N. W. quadrangle, with map, scale 1:50,000.

*Water supply of Metz N. E. quadrangle, with map, scale 1:50,000.

*Water supply of Verdun N. E. quadrangle, with map, scale 1:50,000.

*Water supply of Verdun N. W. quadrangle, with map, scale 1:50,000.

*Water supply of Mézières S. W. quadrangle, with map, scale 1:50,000.

Water supply of Mézières S. E. quadrangle, with map, scale 1:50,000.

*Water supply of Lunéville N. E. quadrangle, with map, scale, 1:50,000.

*Water supply of Sarrebourg S. W. quadrangle, with map, scale 1:50,000.

Water supply of Sarrebourg N. W. quadrangle, with map, scale 1:50,000.

*Water supply of and geological notes on the Rhine Valley.

The above-listed reports were modeled on those issued by the British geologists, each of which contained an alphabetic list of towns with a statement on their developed water supply and were accompanied by a map on which the same information was graphically summarized. For use in the studies of underground water of northwestern France a summary of the geology relating to this subject was compiled for the use of the British Expeditionary Force by the Geological Survey of the United Kingdom. This summary relieved the geologist at the front from much examination of literature, which could be done better in the libraries at London.

One of the tasks of the British geologic staff was to prepare maps showing the territory occupied by the enemy divided into regions according to type of water supply. The map explanation indicates the sources of water in each region and the type of mechanical equipment needed to develop it. These maps served both for general strategic purposes and to guide the engineer in making choice of the proper water-supply equipment to provide for an advance.

The kind of information furnished by these maps is indicated by the following extract from an explanatory text:

AREA I.

Horses.—Plenty of surface water. Water in ——— Canal bad during flax-soaking operations. Shallow wells a few feet deep will give horse water anywhere on low ground.

Drinking water.—Scarce to very scarce. Will have to depend on sterilizing lorries or alum sedimentation, or chlorination. Boring is not used for "Thanet sand." Water is saline.

Equipment needed.—Surface pumps only. Sterilizing lorries. Alum installation.

AREA IV.

Clay overlying "Thanet sand" on old rocks. Springs in valleys at junction of old rocks. Borings could get some water from "Thanet sand."

A fair number of running streams for horse watering.

Equipment needed.—Surface pumps for springs. Tube well pumps, not air lifts. Ashford steamers.

AREA XV.

Oolitic limestones overlying clays with some sands. Some springs in valleys from limestone, but on the whole area is dry. Borings could get water from sand.

Equipment needed.—Surface pumps and tube well pumps; air lifts.

Another type of British water-supply map of the region held by the enemy was one on which the relative abundance of water in the several regions is indicated, as well as its purity. Using as a unit 150,000 gallons a day for each 20 square miles, the colors on the map show whether water is "abundant, medium, or scarce," also whether it is "good, fair, or bad." These maps were prepared for strategical and tactical purposes.

The regional reports[49] of the French General Staff include brief statements on water supply and some short but very admirable summaries of the geologic and physiographic features, prepared by Dr. Emmanuel de Martonne and other geologists. The several French armies also issued maps showing the distribution of sources of water developed for military use within their own lines. Outside of these there seem to have been no maps or other publications relating to water resources issued by the French Army. The engineers of the Service d'eau had, however, in their files many data relating to the hydrology of the army sectors.

The Germans issued very elaborate maps showing the water resources of the areas within their own lines. All their geologic military maps contained some reference to underground water. In addition, special maps were issued on scales of 1:25,000 and 1:50,000 which contained a great variety of information on water resources and water supply. On these maps the distribution of loci of springs and areas of deep and shallow waters were indicated by colors. In addition the quantity and quality of the water supply of each town was shown by symbols, and all the military supply systems, including reservoirs, pipe lines, and pumping stations, were indicated. This information was so complete that the capture of one of these maps made it possible to select important targets for artillery fire. None of these maps contained any information about quantities of surface waters. No captured documents revealed evidence that the Germans prepared maps showing water resources of the areas within the Allied lines.

In addition to maps the Germans issued some reports dealing with underground waters and their methods of development. So far as could be learned, the German geologic staff was the official source of all information about water resources, and the engineers were charged with the developments.

The experience of the war has clearly shown that matters relating to the provision of water for field armies are of two kinds—(1) the determination of water resources, which includes the collection of data in field and office and relates chiefly to geology; (2) the furnishing of water supply, which pertains to the development of water and is solely a matter of engineering. An effective organization will clearly differentiate between the two fields. The geologist will make the necessary field examinations and compilations of data, so as to obtain full information as to the sources of water. The results of the geologist's investigation will be furnished in terse summaries to the engineer. It will be his duty, with these data before him, to determine the location and plan of water-supply stations and the type of mechanical equipment. He will also direct the execution of the project. This division of duties and responsibilities between the military geologist and the engineer was the plan followed by both the British and German armies.

In time of war provision for water must be made (1) to supply camps, cantonments, hospitals, railways, shops, etc., in rear and mobilization areas, (2) to supply the mobile armies in the theater of operations. The task of providing water for the rear areas will be the simpler of the two, because usually the information available about the water resources of the rear areas is better and if information is lacking local surveys, such as can not be made at the front, are possible. On the other hand, the largest local demands and therefore the largest water-supply units will be in the rear areas where there are the greatest permanent concentrations of personnel as well as of war industries and means of transportation. In the areas of mobilization and supply there will be time, which is often lacking at the front, to develop underground water, if it is present, by drilling. Similar conditions prevail along the line of communication, but the development of water supply becomes more difficult as the front is approached.

One of the first steps to be taken in time of war or when war is threatened is to call into the service a sufficient number of geologists to de-

[49] Notice descriptive et statistique, Ministère de la Guerre, Commission du Service géographique de l'Armée.

termine the water resources in the mobilization and rear areas, for these resources must be determined before sites are selected for camps, hospitals, depots, etc. Much of this work can be done in times of peace, but supplementary local examinations and surveys will always be necessary.

Knowledge of the water resources of the theater of operations will also be based on information collected during times of peace, but supplementary investigations will always be necessary, including compilations, as well as field examinations, in so far as the military situation permits. This task should receive immediate attention at time of war or when war is threatened.

The first important task will be the preparation of maps and reports showing the general distribution of water resources in the entire theater of operations and including a general classification of the area in accordance with sources, quantity, and quality of water. The purpose of such maps and reports will be strategic, for water supply is one of the important factors to be considered in the general plan of a campaign. These maps and reports will contain also a statement of the equipment needed to develop the water supply in different parts of the theater of operations. This statement will be prepared by the water-supply officers from the information furnished by the geologist. Its purpose is to serve as a guide in providing the mechanical equipment needed to develop a water supply.

Detailed water-supply maps accompanied by brief descriptive texts are necessary for the use of armies in the field. These maps and reports will present every detail of developed and potential sources of water, including springs, wells, reservoirs, tanks, cisterns, stream volumes, lakes, ponds, and available underground water. Information showing the quantities of water available is of the utmost importance, and the quality of the water must also be reported. Seasonal variations of stream flow must likewise be considered. The preparation of such maps and reports is a proper function of the geologic corps, which will, however, cooperate with the water-supply and sanitary officers.

The water-resource maps and reports must be ready before troop movements are begun. As new and more detailed information will be collected during an advance, the reports on water resources will receive constant revision which will involve new additions and supplements. A necessary extension of this work will include the collection and coordination of information about the water resources of areas within the enemy lines. The collection of this information will form a part of the peace-time preparation, but no matter how exhaustively it may be done in advance, the information will always require revision in time of war. The determination, as far as may be, of the water resources within the enemy lines also lies essentially within the field of the geologist. It can not be too strongly emphasized that though the development of a water supply is a function of the water-supply engineer, the available water resources can best be determined by the geologist.

TRANSPORTATION.

Geologic facts and their interpretation clearly deserve recognition in problems of road, railroad, canal, reservoir, and wharf construction.[50] The application of geology in this field relates to depth and physical character of bedrock, stability of slopes, and character of river crossings, as well as to sources of road metal and railroad ballast. In this, as in other branches of geology applied to engineering, profound knowledge of the science is not always needed, and in many problems the experienced engineer will himself be able to determine the necessary facts correctly and make accurate deductions. If properly trained, he will also know when the problem is beyond his experience, so that he should seek the assistance of the professional geologist. So far as I know, little use was made of geologists on engineering problems relating to transportation on the western front. The Germans, however, have so long recognized the need of advance geologic knowledge in building railroads, canals, etc., that it is not likely that they ignored this need in time of war. Much space is given to this subject in the German manual of military geology. The average American railroad engineer, however, has not yet learned the use of geology in his own field.

In the British and American armies geologists were called upon for information on the

[50] Some applications of geology to engineering are presented in the following publications:

MacDonald, D. F., Some engineering problems of the Panama Canal in their relation to geology and topography: Bur. Mines Bull. 86, 1915.

Atwood, W. W., Relation of landslides and glacial deposits to reservoir sites in the San Juan Mountains, Colo.: U. S. Geol. Survey Bull. 685, 1918.

distribution of road metal; the French appear to have relied on their engineers for this service. As the French engineers were operating in their own country, they had far more local knowledge than their allies had. No general reports on the road metals of France have been issued, and under war conditions it was not always possible for the British and American officers to find the individuals who had the local information.

Special road and quarry services were organized in the American Expeditionary Force, and these did not call upon the geologist for much information. Time and effort would undoubtedly have been saved had more use been made of geologic facts in this field. However, when advances were planned it was found that the geologists were the best sources of information about the distribution of road metal and railroad ballast within the enemy lines. This information was in part embodied in the geologic engineering maps which have been described and in part presented on special maps. The special maps showed the surface distribution of all hard rocks that might be used for road metal and also the gravel deposits. The location of all quarries and gravel pits was also shown. Eight maps showing the distribution of road metal were prepared by the geologists of the American Expeditionary Force.

Military preparation should include the preparation of general small-scale maps on which the distribution of all rocks that may be used for road ballast is indicated, with a classification of their relative value for this purpose. All quarries and gravel pits should be shown on such maps, with an indication by symbol of their relative importance. Large, well-equipped quarries should be distinguished from those whose product is used only locally. Special large-scale maps showing road metal should be issued for important areas in the theater of operations. These would be prepared after the plan of campaign had been determined.

CONSTRUCTION.

What has been said about the application of geology to the building of roads, railways, and canals applies equally to other forms of engineering construction. In this field the determination of the character of foundation and stability of slopes, as well as sources of raw materials, involves some use of geologic facts. Here again many of the problems are so simple as not to require the advice of a professional geologist. Yet there is always danger that the engineer who is ignorant of geology will make blunders that could easily have been avoided. Such errors are even more costly in war than in peace. All engineering works constructed during war are built in a hurry, and often the advice of the geologist can save time by forecasting the physical conditions.

The only service to construction rendered by the geologists of the American Expeditionary Force was in locating sources of aggregate for making concrete. There was during the war a hurried call for the building of a plant near the front to make reinforced-concrete blocks (shell bursters) used for dugout protection. (See fig. 9.) The geologic problem was very simple, for it was evident that the gravels from the hard rocks of the Vosges Mountains were the only possible source of suitable material. Knowledge of the bedrock geology and of the physiographic history, together with limitations on locations placed by the military situation, narrowed the choice of location to a small area. A brief field examination settled the problem and showed that the situation permitted only two possible locations, and the transportation conditions practically limited the selection to one, and in two days the matter was settled. This was a very good example of the value in an emergency of definite geologic information about the field of operations.

The British geologists performed valuable service in bringing definite proof that the concrete of the German "pill boxes" (surface shelters) was being made of gravels from the Rhine. It was established by the British Foreign Office that this gravel was being brought to Belgium by canals through Holland. A protest to the Dutch Government, with this proof as to source of material, ended this military traffic through a neutral country.

MINERAL RESOURCES.

War investigation of mineral resources will fall into three classes—(1) that in the home country to meet military needs; (2) that in the theater of operations for use of the army in the field; (3) that in the country of the enemy as a guide in broad strategy or in minor attacks. The first of these is plainly a civil function and needs no further mention here. Investigations of mineral resources within the theater of operations, such as investigations of road metal, concrete material, and water, have already been referred to and included all those of this type performed by the Allies. In some regions military geologists would be called upon to investigate mineral fuels in the theater of operations for use of the field armies. The Germans made elaborate investigation of the mineral resources of the occupied territory. They paid special attention to deposits of phosphate, coal, and iron, doing a large amount of drilling and open-cut work. There were probably as many geologists engaged in these investigations as were employed on military problems. This was not specifically war work, however, for its purpose was to obtain commercial information that could not be acquired during peace. It was, no doubt, the intention of the German Government to evaluate the resources of the conquered territory as a guide in delineating its proposed expanded frontier after it had won the war.

The mineral reserves of the enemy and their distribution are evidently important factors in military strategy. Some work on this problem was done by the geologists of the American Expeditionary Force, and a large number of French geologists were employed during the war on a similar mission. Under ordinary war conditions work of this kind would not fall to geologists of the field armies, as it can better be performed at the rear, where access to good libraries is to be had. A more purely tactical problem in which the geologists of the American Expeditionary Force gave some help is the designation of important localities of the enemy mineral industry for bombing raids or even shelling.

MISCELLANEOUS APPLICATIONS.

There are many other fields in which geologic knowledge can be of service during war. The location of camps, cantonments, hospitals, aviation fields, and munition and engineer dumps must evidently take into account drainage and character of soil and subsoil, as well as water supply. The geologic facts relating to these subjects are usually simple but were often ignored by the armies of the western front. It is most likely that the French engineers made use of geologic maps in choosing sites. It is known also that in the British service no important locations were made without a report by a geologist, at least on the water supply. In the American Expeditionary Force the practice of calling on geologists for information before the establishment of hospitals, aviation fields, etc., was not very general, and as a consequence some needless blunders were made.

It fell to the geologists of the British and German armies to help determine the areas of possible artificial inundation. This phase of warfare formed an important part of defensive and offensive operations at certain localities in northwestern France and Belgium. Both American and British geologists were called to locate sources of filter sand.

In the German military geologic manual considerable attention is devoted to the influence of geology on earth telegraphy and listening-in devices, for it was found that certain underground conditions favored the transmission of electric currents. The determining factor appears to be the distribution of water-bearing strata, and the best transmission was obtained where such a bed was included between two impervious formations. These conclusions regarding geologic influences on earth electric transmission seem to have been overlooked by the German Signal Corps. A manual[51] dealing with this subject published as late as the end of 1917 makes no mention of the use of geology in this field. In reference to this subject it says: "The range of the power buzzer depends on the nature of the ground between the stations. * * * Power-buzzer communications must not therefore be selected from the map, but their suitability must be ascertained by experiment." This statement is all the more remarkable because when it was printed many German military geologic maps had already been issued, and on all of these the relative conductivity of each formation was noted in the explanation. It indicates that the work of the German military geologist was by no means completely coordinated with that of other branches of the service. It brings additional proof that the application of geology

[51] Manual of position warfare for all armies, part 9, The Signal Service and its employment, paragraph 15, Berlin, issued by the Chief of the General Staff of the Field Army, Dec. 15, 1917.

to military problems developed only during this war was so new a field that its full usefulness had by no means been reached when hostilities ceased.

CONCLUSIONS.

The many applications of geology to war have been set forth above. It has been shown that nearly all the great powers recognized the usefulness of the science before the end of the war by organizing geologic staffs. Furthermore, many instances have been cited from the experience of the war where the direct military value of geologic knowledge was proved beyond question. Modern scientific warfare evidently compels an army to seek every possible advantage by making full use of all sources of information about the physical conditions within the theater of operations. Of two opposing armies the one having the better knowledge of the terrain will have an advantage and at times a decisive advantage. A complete knowledge of the terrain is, however, possible only by the use of geology.

All this brings proof that geologic knowledge must be considered a part of the preparation for war. Geologic preparation for war may be classed under three headings:

1. The general principles of geology and their application to war must be made a part of military education.

2. Peace-time preparation should include the collection and coordination of geologic data relating to all possible theaters of operations.

3. A staff of geologic engineer reserve officers should be organized. This should be made up of experienced professional geologists who should receive the special peace-time training necessary to develop them to their full usefulness when called into active service.