In the Yellowstone with Princeton.¹

By Prof. O. T. JONES, University of Manchester.

IN the issue of NATURE of Nov. 5, 1927, Mr. E. B. Bailey gave a brief account of the 'Summer School of Geology and Natural Resources', which has been organised by Prof. R. M. Field, of the University of Princeton, N.J. I was privileged last summer to be the guest of the Summer School in a tour through some of the characteristic regions of the United States, my fellow guests being Mr. W. J. Johnston, of the Canadian Geological Survey, and Prof. W. A. Parks, of Toronto.

FIG. 1.—Section of lower part of sediments near Red Rock. Photograph by Prof. O. T. Jones.

We started from Princeton on June 21, and returned on Aug. 2, and in the course of the tour we visited the Yellowstone National Park.

Within its area of 3344 square miles, this Park numbers many remarkable features, and among them the great canyon which has been carved by the Yellowstone River on its way to join the Missouri is one of the most interesting. After leaving Yellowstone Lake the river winds through a flat-floored valley before plunging in succession over the Upper Fall (108 ft.) and the Lower Fall (309 ft.), where the canyon commences. About 20 miles lower down, the Yellowstone is joined by the Lamar, an important tributary flowing in a wide, flat-floored valley.

In the course of the 1926 excursion, Prof. Field observed from near Artist's Point some sediments in the opposite wall of the canyon about half a mile

below the Great Fall, and with a kinematograph camera and telephoto lens obtained a clear record of these deposits. In August 1928 we visited the locality and examined the sections in detail. Our examination led to the discoveries in regard to the remarkable history of the canyon which are briefly summarised below.²

The sediments which Prof. Field had previously observed lie in a narrow 'in and out' channel which passes behind a prominent pinnacle on the canyon wall known as the Red Rock, and consist of more than 187 feet of alternations of blue muddy silt, yellow sand, and conglomerate, the coarser deposits having a calcareous or tufaceous cement (Fig. 1). The base of the channel lies about half-way down the canyon wall, which at this point is about 800 feet high. Dr. Elwyn Perry and other members of the Summer School observed also a small thickness of sediments within 50 ft. of the bottom of the canyon and within about 100 yards from the foot of the Great Fall, and one of us noticed on the west side of the canyon, where it is drenched by the spray of the fall, a patch of blue stratified material which appeared to be similar to the silt near the Red Rock. On our return to the east we discovered that this exposure had been visited nearly sixty years ago by Dr. A. C. Peale, during the preliminary survey of the Park by F. V. Hayden and his assistants. Dr. Peale described this material as a blue mud, and there is little doubt that this and the sediments low down on the opposite side of the canyon are relics of the same series as that more fully preserved near the Red Rock. We found, too, that the east wall of the canyon, between the Upper and the Lower Fall, is composed in large part of cross-bedded sands capped by a tough conglomerate with tufaceous cement.

According to the prevalent opinion, the canyon was eroded in postglacial times, and it has been regarded as evidence of the enormous amount of denudation that has taken place since the Glacial Epoch. Colour was lent to this view by the distribution of the terraces which surround the Yellowstone Lake and extend down into the Hayden Valley towards the Yellowstone Falls. These terraces are composed in part of resorted glacial deposits which occur around the Yellowstone Lake and in the Hayden Valley, and are therefore clearly of postglacial date. It appears also that the conglomerate between the Upper and Lower Falls has been interpreted as an extension of these terrace deposits, and it was so regarded by E. De Martonne, who figured the section in the *Annales de Géographie* (vol. 22, 1913, Pl. II. B, facing p. 136). This was also the interpretation adopted by Mr. W. H. Holmes in his report on the geology of the Park attached to Hayden's 12th Annual Report on the Territories, 1878. As this conglomerate occurs on both sides of the present canyon, it was argued that the canyon must be of later date than the Yellowstone Lake terraces, and therefore postglacial. Our examination disclosed, however, that a pre-existing canyon had been at some period filled to the brim with sediments, and the relation of these to the glacial deposits seemed to indicate that not only the erosion of the canyon but also its subsequent filling had taken place before the advent of the glacial period, and that the canyon was a much older feature than had been previously supposed.

The fine muddy silts which form a considerable proportion of the sedimentary succession in the canyon recall lake deposits, and the occurrence of several

¹ Based on a lecture entitled "The History of the Yellowstone Cañon (Yellowstone National Park), U.S.A.", delivered before the Geological Society of London on Jan. 9.

² A more detailed account appears in the *Amer. Jour. of Science*, March 1929.

layers of silt following immediately upon conglomerate inevitably suggests the establishment of lakes in the canyon at successively higher levels, and their subsequent filling with deposits, beginning with fine sediments and ending up with coarse sands and gravels. Such lakes could only come into existence if the canyon

Pleistocene	Glacial drifts, etc.
	Basalt.
	Rhyolite.
	Basalt.
Neocene	Canyon Conglomerate.
	Basalt.
	Andesitic flows and breccias
	Trachytic rhyolites.
	Basic breccias.
Eocene	Acid breccias.
	Pinyon Conglomerate
Unconformity.	
Cretaceous	Laramie formation

FIG. 2.—Section near Tower Falls showing two basalts with intervening conglomerate resting on andesitic breccias. Photograph by Dr. M. B. Hodge.

had been dammed below this point subsequent to its erosion. What then was the agent which impounded these lakes in the canyon? The study of the geological maps in the United States Folio (1896) suggested the possibility that great flows of lava had entered the Yellowstone Valley from the north from the direction of Gardiner, and had flowed against the direction of the drainage into the Lamar Valley and the canyon. On the geological map of the Canyon and Gallatin Sheets several small masses of basalt and trachytic rhyolites have been mapped, the relation of which to the flanks of the valley suggests that they are relics of flows which must originally have been of wide extent and filled the lower Yellowstone Valley to a depth of more than 1500 ft.

The suggestion that arises naturally from the study of the geological map is, however, contrary to the interpretation of certain of these flows which is embodied in the description of the Folio which was published in 1896. The summary in the Folio of the geological and volcanic history of the region is due to Arnold Hague. The igneous rocks were described by Iddings in Monograph 32, Part II, and in this monograph reference is made to the account of the physiography of the Park by Hague in Monograph 32, Part I. It appears, however, that this part of the monograph has never been published, and we are dependent upon the brief summary of the geology of the Park which accompanies the folio.

Hague's view of the volcanic history of the Park is embodied in the following table:

must have occurred at a still later period. As this interpretation of the relation of the basalts, canyon conglomerate, and trachytic rhyolite to the main

FIG. 3.—Drawing of section near Tower Falls by W. H. Holmes. From Hayden's 12th Annual Report of the Territories, 1878.

rhyolite seemed to be at variance with the distribution of these rocks as shown on the geological map, Prof. Field and I decided to investigate this problem further.

In various places on the route between Gardiner and Camp Roosevelt, which lies near the junction of the Yellowstone and Lamar Valleys, there are masses of

basalt and trachytic rhyolite which are obviously perched on narrow shelves on the valley sides and their situation is such that these lavas must have been poured out on to the floor of a pre-existing valley.

The most convincing evidence of the relation of the basalts to other rocks in the canyon is, however,

FIG. 4.—Section in canyon below Tower Falls showing upper basalt and upper part of conglomerate resting on andesitic breccias. Photograph by Prof. O. T. Jones.

obtained near the Tower Falls south of Camp Roosevelt, where Tower Creek drops into the Yellowstone. Above Tower Falls the 'canyon' is a fairly wide valley with terraced slopes. Near Tower Falls the river swerves to the west and enters a very narrow canyon with almost precipitous walls of andesitic breccia which has been eroded into a striking series of pinnacles or 'needles'. This is the 'second canyon' of earlier observers, and is probably of postglacial origin. Its rim is formed by a sheet of basalt with remarkably regular columnar jointing; this sheet is easily accessible on the road on the west side, where it rests on a conglomerate. On the east side the basalt overlies a conglomerate about 100 feet thick, underneath which is another band of columnar basalt (Fig. 2). This striking section is among those drawn by W. H. Holmes, and a comparison of recent photographs with the sketch made more than fifty years ago demonstrates the remarkable accuracy of that artist (Fig. 3).

If the east side of the second canyon be examined for about a mile below Tower Falls the upper basalt can be traced as a continuous band, but the lower basalt is only present at the north end and the south end, and is not visible in the intervening space, where also the conglomerate is reduced to about one-quarter of its thickness (Fig. 4). This behaviour of the lower basalt and the conglomerate as seen from the west side of the canyon is due to the fact that the lower basalt and the lower part of the conglomerate

pass behind a screen of the andesitic breccias which form the lower wall of the canyon. In other words, the basalt and conglomerate series occupy an old valley, and the existing canyon has been eroded on the flank of that valley through the basalts and conglomerate into the underlying andesitic breccia. On

the roadside south of Tower Falls the flank of the old valley stands at a still higher level, so that only a few feet of conglomerate separate the upper basalt from the andesitic breccias; ultimately it cuts out from below the upper part of the conglomerate, and the upper basalt then comes to rest on the andesitic breccias that formed the flank of the old valley. There is here convincing evidence that the basalts and conglomerate have filled in a valley which formerly continued in the line of the wide part of the canyon above Tower Falls.

In the same line about two miles farther north stands the striking feature known as Junction Butte. The capping of the butte is basalt, while the lower part of it is composed of trachytic rhyolite. Both here and in other places farther down the canyon, the relation of the basalts to the trachytic rhyolites appears to indicate that these two rocks belong to the same general period of eruption. A narrow outcrop of trachytic rhyolite is in fact represented on the geological map directly on the course

of the buried canyon more than a mile south of Junction Butte.

Holmes has also given a drawing of a sheet of basalt lying on conglomerate about half-way down the wall of the canyon, four miles above Tower Falls. Again, basalt overlying in places the canyon conglomerate is

FIG. 5.—Longitudinal profiles of Yellowstone and its principal tributaries, showing also the lava flow relics in relation to the profiles. The black masses labelled B are basalts; the areas marked T are trachytes; C indicates the canyon conglomerate near Tower Falls; and S the sediments near the Yellowstone Falls.

mapped on the floor of the wide Lamar Valley for a distance of 20 miles above Junction Butte.

There is no doubt, therefore, that lava flows entered the Lamar Valley and penetrated for several miles into the canyon, and that near Tower Falls this filling of the older canyon is by a fortunate circumstance still preserved, and it confirms the suggestion made above that the damming of the canyon may have been due to lava flows.

If we inquire further into the distribution of the basalt relics that now lie in the flanks of the lower Yellowstone canyon—the 'third canyon' of previous

authors—we find that they rise in places to a level of between 7800 ft. and 8000 ft., whereas the highest level attained by the sediments near the Yellowstone Falls is a little above 7800 ft. The lava surface stood, therefore, at a height sufficient to cause the filling of the upper end of the canyon to its very brim.

We turn now to a consideration of the longitudinal profile of the Yellowstone River and its principal tributaries. The Lamar Valley profile shows clearly three cycles of erosion—the earliest cycle is only represented by a portion near the head of the valley, the second cycle extends down to within about five miles of Junction Butte, where the valley of the third cycle begins. In the Yellowstone there are three or perhaps even four cycles represented (Fig. 5).

There is some doubt whether the part of the valley above the falls or the portion between the two falls should be assigned to the first cycle, but it is immaterial in this connexion. The main canyon belongs clearly to the second cycle and the third canyon to the third cycle, the second canyon being probably due to a later and postglacial cycle. The greater part of Tower Creek pertains to the second cycle, and at present hangs conspicuously above the second canyon. The profile of Broad Creek, which enters higher up the main canyon on the east side, is related as to its middle portion to the first cycle and as to its lower portion to the second cycle. Evidences of these cycles can also be traced in the transverse profiles of the various canyons. If now we project on to these profiles the outcrops of the basalt and trachytic rhyolite relics, we find that these descend at their lower ends to within about 100 feet of the river level in the third canyon and at their upper ends attain increasingly greater heights downstream.

It follows that these lava flows entered the canyon when the third cycle of erosion was far advanced.

Since the main canyon which pertains to the second cycle was eroded through the rhyolitic rocks it is obvious that a great interval of time separates the eruption of the rhyolites and that of the valley basalts which occupied the valleys of the third cycle. These considerations render it unthinkable that the basalts and conglomerates near Tower Falls were in existence prior to the eruption of the rhyolites. Moreover, there is reason to believe that the surface of the rhyolites had been reduced by prolonged erosion to a peneplain before the initiation of the first cycle of erosion. The canyon cycle of erosion thus commenced a very long time after the eruption of the rhyolites, and as a result, it is assumed, of successive uplifts, rejuvenation brought about the erosion of the main canyon and later of the third canyon. While the latter cycle was far advanced, eruptions of basalt and trachytic rhyolites dammed the canyon, and near the falls it was filled to the brim with sediments. Erosion was thus arrested and the canyon became a fossil canyon.

Since the lava eruptions of the Upper Pliocene the greater part of the lava dam has been removed, leaving only relics here and there as witnesses to the former extent of the lava floods. The erosion of the dam allowed of the removal of the sediments and the resurrection of the canyon. The original canyon is therefore an extremely ancient feature, dating probably from the Middle or Lower Pliocene.

In conclusion, it gives me great pleasure to put on record the remarkable accuracy of Mr. Holmes's observations and his deductions made during the short period when he was examining the geology and physical features of the Park more than fifty years ago.

Mineral Industry of New South Wales.

THE Department of Mines of New South Wales has issued a very useful volume entitled "The Mineral Industry of New South Wales", written by E. C. Andrews and the staff of the Geological Survey, and edited by F. S. Mance, Under Secretary for Mines, who contributes two introductory sections. Such a work was long overdue; in 1901 a similar work, entitled "The Mineral Resources of New South Wales", was produced by Mr. Edward F. Pittman, at that time Government Geologist of New South Wales. This book contained a mass of useful information, and was in such demand that it has been out of print for many years. When Mr. Pittman's book was written, the most important mineral products of New South Wales were gold, copper, and tin, whereas to-day lead, zinc, and coal are of far greater importance.

The general trend of mineral production in the State has been markedly upwards, and the value of these productions has risen tremendously. The total value of the metals and minerals produced in the State of New South Wales to the end of 1927 is given as close upon 445 million pounds sterling, out of which the decade 1918–1927 has contributed no less than 155½ million pounds sterling, and there is every evidence that the upward trend is likely to continue.

The present work covers satisfactorily the whole field of mineral production; it commences with a few brief sections of a general character, followed by a description of the occurrences of metals and metallic ores, ranged in alphabetical order; the only serious exception to this statement may be found in the fact that the four metals, silver, lead, zinc, and cadmium, are all lumped together mainly for the reason that the ores of these metals are generally found intimately associated. Of course by far the most important deposit of these minerals in the State of New South Wales is in the Great Broken Hill deposit, one of the most important in the world, not only on account of its magnitude, but also because the intimate admixture of ores occurring there has stimulated the ingenuity of inventors to devise processes which have since been applied successfully to deposits in all parts of the world.

The third part of the book consists of a description of the occurrences of non-metallic minerals, also arranged in alphabetical order. The term 'non-metallic' minerals is used in its ordinary acceptance, compounds of the elements which the chemist would speak of as metals of the alkalis, and the alkaline earths being, in accordance with ordinary everyday usage, spoken of as non-metallic substances. The work is a very complete one, and will no doubt satisfactorily fulfil its object of presenting to the reader a brief but accurate and authoritative description of the mineral wealth of New South Wales.

University and Educational Intelligence.

CAMBRIDGE.—The Director of the Observatory has, with the consent of the Vice-Chancellor, reappointed Dr. W. M. Smart, of Trinity, as chief assistant at the Observatory for five years.

The Sudbury Hardyman Prize at Emmanuel College, offered to a graduate of less than M.A. standing, has been awarded to A. H. Wilson for a dissertation on "Quantum Mechanics". Special dissertation prizes have been awarded to C. B. Allsopp (physical chemistry) and J. G. A. Griffiths (chemistry).

SIXTY-NINE 'land-grant' colleges and universities have been established in the United States under a series of Acts, beginning in the year 1862, for the granting of land for financing education in agriculture