Digitized by the Internet Archive
in 2010 with funding from
Boston Public Library

7572.55
Please do not destroy or throw away this publication. If you have no further use for it write to the Geological Survey at Washington and ask for a frank to return it

---

DEPARTMENT OF THE INTERIOR

Hubert Work, Secretary

U. S. GEOLOGICAL SURVEY

George Otis Smith, Director

Bulletin 760-D

PEDESTAL ROCKS IN STREAM CHANNELS

BY

KIRK BRYAN

Contributions to the geography of the United States, 1923-1924

(Pages 123-128)

Published April, 1925

WASHINGTON
GOVERNMENT PRINTING OFFICE

1925

II

PEDESTAL ROCKS IN STREAM CHANNELS.

By KIRK BRYAN.

INTRODUCTION.

Isolated masses of rock, especially those of unusual shapes, excite much interest and are commonly regarded with some little awe—a relic, perhaps, of those feelings and impulses which caused the erection of the great stones of the Druid monuments. The fanciful or mythical names that are almost spontaneously applied to such rocks testify to this popular interest, but the origin of these masses has received only scant notice by scientific men. This attitude is no doubt justifiable on the ground that there are more important matters for study. However, the type of isolated rock consisting of a larger mass above supported on a more slender pedestal has been used as a criterion in the study of larger problems. Such pedestal rocks have been cited as a measure of weathering since glaciation¹ and also as proof that an area was not covered by continental ice.² That pedestal rocks may be formed by the sand-blast action of winds seems probable, but that such rocks in arid regions are necessarily proof of wind scour has been denied in a previous publication,³ in which a fairly complete list of papers on the affirmative of this question may be found.

The object of this paper is to call attention to some examples of pedestal rocks of well-developed form that stand in stream channels and are produced by a process which bears no causal relation to wind erosion, yet that, if found in some other environment, might easily be confused with pedestal rocks resulting from wind scour.

Two of the examples cited have not been seen by me. One is described from a photograph and notes by Willard D. Johnson, whose untimely death cut short the career of a keen observer much interested in the minutiae of erosive processes. The other was called to my attention by my friend and colleague, H. T. Stearns, who has allowed me to use his photograph and notes. William Donahue, of Spokane, furnished the photograph of the Devils Top.

---

¹ Hughes, T. M., On some perched blocks and associated phenomena: *Geol. Soc. London Quart. Jour.*, vol. 43, pp. 522–539, 1886.

² Alden, W. C., The Quaternary geology of southeastern Wisconsin: *U. S. Geol. Survey Prof. Paper* 106, p. 41, pl. 16, A, 1918.

³ Bryan, Kirk, Pedestal rocks in the arid Southwest: *U. S. Geol. Survey Bull.* 760, pp. 1–11, 1923 (*Bull.* 760–A).

DEVILS TOP AND SIMILAR ROCKS NEAR SPOKANE,
WASH.

Spokane, Wash., lies at the eastern margin of the Columbia Plateau, which terminates here in black cliffs and crags of basalt that front on the broad valleys of Spokane and Little Spokane rivers. In these valleys stand outlying portions of the plateau bounded by similar cliffs. Spokane River within the city plunges over ledges of basalt in Spokane Falls and about 7 miles below the city enters the long canyon that forms the northeastern boundary of the Columbia Plateau. The basalt flows that form the top of the plateau, known as the "rim rock" flows, have an altitude of about 2,400 feet. The flows that crop out in the bed of Spokane River and in the immediately adjacent cliffs are a younger series that attain an altitude only slightly above 2,100 feet. They lie within ancient valleys eroded in the plateau. These valley flows, though younger than the flows of the plateau, are thought to belong to the same general period of volcanism, in Tertiary time.⁴ The lavas of this series, at least in the immediate vicinity of Spokane, do not have the columnar jointing normal to basalts but are divided into great blocks by widely spaced joints. In consequence they yield on erosion large masses, many of which have peculiarly striking forms. Some of the most interesting of these masses are to be found in the canyon traversed by the lower course of Deep Creek, a stream that rises on the plateau and flows northeastward about 15 miles to Spokane River, which it enters 8 miles below Spokane. The stream plunges over the "rim rock" basalt and has cut a deep and narrow gorge in the younger basalt flows, which form a shelf along Spokane River. The lower part of the canyon is at one place only about 50 feet wide, and here is the Devils Top, one of a number of blocks that have fallen from the cliffs above. As shown in Plate XXXI, *A*, this block tapers from a rounded top to a narrow base. The rock would fall but for the fact that it rests against the side wall. It is nearly circular in plan and about 30 feet in greatest diameter. It is about 28 feet high and the tapering base is about 3 feet in diameter where it rests on the bedrock of the stream channel.

The rounded form of the upper part of the Devils Top is a characteristic weathering form of the basalt of this locality, and similar rounded domes cap the cliffs from which this block has undoubtedly fallen. The minutely and irregularly fractured surface is also characteristic and may be ascribed with some assurance to frost action. Only in shape does the rock differ from adjacent blocks.

⁴ Pardee, J. T., and Bryan, Kirk, *Geology of the Latah formation in relation to the lavas of the Columbia Plateau near Spokane, Wash.*: U. S. Geol. Survey Prof. Paper 140-A (in press).

The undercut sides seem, however, to be due to the erosive work of the stream. Deep Creek has strong freshets each spring, and during these freshets the velocity of the water around the rock must be high, because of the reduction in the width of the channel. The driftwood on the top of the rock, plainly visible in Plate XXXI, *A*, shows that the rock is at times overtopped by the stream, but the action of the stream is more prolonged and effective on the lower part of the rock. Here the force of the moving water, with its contained débris, removes the small blocks already loosened by frost, and perhaps the freezing of the water in winter facilitates such loosening. That direct scour does not seem to take much of a part in this process is shown by the lack of polished surfaces.

Undercutting by streams is hardly a common phenomenon in this region, and there are cliffs and individual rocks along Spokane River and elsewhere in the region that are not notched. On the left bank of Columbia River below China Bar, however, there are a group of rocks of which some are loose blocks and others are portions of a lava flow isolated by weathering along widely spaced joints. The lava is part of the great series underlying the Columbia Plateau but resembles in its lack of columnar joints and method of weathering the flows on Deep Creek, which are doubtless somewhat younger. Some of these blocks have vertical walls, and others are notched near low-water level. The rock shown in Plate XXXI, *B*, approaches the form of a pedestal rock. The minutely and irregularly fractured surfaces of the block indicates weathering by mechanical forces, but examination of the interior of these fractured pieces shows that there has also been some chemical action. Apparently the effect of the river water is to speed up mechanical erosion and remove partly weathered fragments. Doubtless the undercutting would be more marked if the river held a nearly constant level, so that its action affected only a small zone. But Columbia River is subject to a prolonged annual rise of 30 to 40 feet. The maximum estimated discharge of the river at Wenatchee and Vernita, the nearest stations downstream, was 710,000 second-feet, on June 7, 1894, and the minimum discharge 23,900 second-feet, on January 31, 1917.⁵ During such floods the water doubtless has the same effect on all parts of the rock. In the rise and fall also the surface of the water occupies every position on the rock. Not only do these conditions tend to diminish the relative intensity of the notching action, but it is obvious that on a river subject to such floods pedestal rocks with slender pedestals would be snapped off, and there is thus a limit to the development of such forms.

⁵ Parker, G. L., and Lee, Lasley, Summary of hydrometric data in Washington, 1878-1919: U. S. Geol. Survey Water-Supply Paper 492, p. 118, 1923.

ROCK IN OWENS RIVER, CALIF.

The photograph reproduced in Plate XXXII, A, was taken by Willard D. Johnson in the canyon of Owens River, Inyo County, Calif. According to his notes the locality is "just above the junction of Burcham Canyon and 'The Bridge'"; the rock is rhyolite of the "exfoliating type" found thereabouts and contrasting with a neighboring type which yields to weathering largely by solution. Johnson records also that the boulder is said to have developed the neck or pedestal in the 20 years that it had been under observation by ranchmen in the neighborhood.

At this point Owens River runs in a deep canyon and, as indicated in Plate XXXII, A, is swift and turbulent. However, as shown by the records of the United States Geological Survey gaging station near Round Valley, just above the junction of Rock Creek, at the lower end of the canyon, the flow of the stream is relatively steady. The yearly mean discharge has ranged from 181 to 380 second-feet. The maximum recorded discharge of 1,190 second-feet occurred in June, 1907, and the minimum of 100 second-feet in February, 1919. Evidently the ordinary flow, fluctuating over a narrow range, has eroded the neck of the rock, and the flood flows are not severe enough to break it off.

The region has an arid climate and might even be called a desert. The river in the canyon descends from an altitude of 6,700 feet to 4,400 feet, and the climatic conditions are similar to those at the nearest towns, Bishop and Laws, which have an altitude of about 4,100 feet. The 16-year rainfall record at Bishop, as compiled by Lee,⁶ shows an annual mean of 5.61 inches, and the 14-year record at Laws, 4.40 inches. Even if allowance is made for an increased rainfall in the locality of the pedestal rock on account of its greater altitude, it may still be considered in an arid region.

Though the statement of the local ranchers recorded by Johnson that the shape of the rock was developed in 20 years can hardly be true, it is evident from the photograph that stream abrasion operating against the surface of a rock already divided into small flakes by exfoliation has produced the notch that forms the neck. The neck is excentric, and the greater overhang on the upstream side may be due to greater wear on that side. The rock appears also to have been slightly polished by the water and its contained suspended matter.

---

⁶ Lee, C. H., An intensive study of the water resources of a part of Owens Valley, Calif.: U. S. Geol. Survey Water-Supply Paper 294, p. 91, 1912.

A. DEVILS TOP, DEEP CREEK CANYON, 8 MILES NORTHWEST OF SPOKANE, WASH.

B. INCIPIENT PEDESTAL ROCK, COLUMBIA RIVER BELOW CHINA BAR, 9 MILES DOWNSTREAM FROM JUNCTION OF SPOKANE RIVER, WASH.

A. PEDESTAL ROCK IN OWENS RIVER, INYO COUNTY, CALIF.

B. PEDESTAL ROCK IN GIBBON RIVER AT CHOCOLATE CASCADE, YELLOWSTONE PARK, WYO.

ROCK IN YELLOWSTONE NATIONAL PARK.

The pedestal rock illustrated in Plate XXXII, *B*, is one of the features of Chocolate Cascade, a small rapid in Gibbon River 3 miles southwest of the well-known Norris Basin, in Yellowstone National Park. According to H. T. Stearns, who visited the locality in 1923, the rock is composed of rhyolite. As is evident from the photograph, it is a remnant of a ledge, and the notched rock, or incipient pedestal rock, on the right, once belonged to the same ledge. Doubtless at one time there was at this place a considerable fall. The stream has eroded the ledge in such a way as to leave remnants which, though obstructing the flow, were strong enough to resist being carried entirely away.

Gibbon River at the United States Geological Survey gaging station 4 miles above its mouth has a drainage basin of only 117 square miles and a minimum recorded discharge of 62 second-feet. No gagings have been made at high water, but the maximum discharge is probably not much over four times this amount. The incomplete record indicates that the stream has a relatively steady flow, such as might be expected of a stream rising in well-wooded mountains and having a number of meadows and swamps along its course.

On account of prevailing low temperatures the climate of the area is relatively humid, although the mean annual precipitation shown by a 32-year record at the Weather Bureau station at Yellowstone is only 18.70 inches. Much of this precipitation falls as snow, and the result is that the vegetation and most of the erosional features of the area are those of a humid country.

CONCLUSIONS.

The rocks described in the foregoing paragraphs are, so far as form alone is concerned, typical "mushroom" or pedestal rocks. They are composed of material of almost equal hardness from base to top and have attained their form as the result of differential scour rather than differential weathering. Thus they differ in composition and origin from the pedestal rocks described in a previous publication.⁷

Save for the fact that these rocks occur in stream beds, they might be mistaken for rocks formed by wind scour. It is also entirely possible that rocks in arid regions formed by stream scour may have been mistaken for rocks formed by wind scour. Such confusion is the more likely in that the areas in which the examples cited in this paper occur have no great similarity in climate. Eastern Washington, in which the Devils Top and the rock in Columbia River were formed, has a subhumid or semiarid climate, typified by that of

---

⁷ Bryan, Kirk, op. cit.

Spokane, which has a mean annual precipitation of 18.85 inches and a cold winter. The Owens River canyon lies in a warm arid region with an annual rainfall of only a little more than 5 inches. Yellowstone Park, on the other hand, has a cold humid climate. The character of the stream flow and the original form, position, and physical characteristics of the rocks are probably more influential than climate in producing these remarkable forms.

NOTE.—The rock in Gibbon River, Yellowstone Park, has also been described by E. A. Martel, who visited the locality with the International Congress of Geographers in 1912. His note, illustrated with three excellent photographs, was published in the *Comptes Rendus des Séances de l'Académie des Sciences de Paris*, vol. 159, pp. 87-89, 1914. Martel has also described a large number of pedestal rocks in other localities, which he attributes to the action of both surface and underground streams.

INDEX

A	Page	D	Page
Alden, William C., The physical features of central Massachusetts.....	13-105	Dana diorite, plate showing.....	17
Analyses of waters from Pecos Valley, N. Mex.....	120	Débris, falling of, into caverns.....	117-119
Arizona, southern, pedestal rocks in.....	7-10	Devils Top, in Deep Creek, Wash., description of.....	124-125
"Auburn River," Mass., course of, in Tertiary time.....	22-23, 27	plate showing.....	126
		Drift, glacial, nature of.....	29-31
		Drip furrow below pedestal rock, plate showing.....	4
B		Drumlins in central Massachusetts.....	40-43
Barre Falls, Mass., plate showing.....	105	plate showing.....	38
Blackstone Valley, Mass., Tertiary streams in.....	22, 27	E	
Blocks with vertical bedding planes, erosion of.....	5	Emerson, B. K., cited.....	27-28, 29, 89-90, 91-92
Bottomset beds of sand plain near Clinton, Mass., plate showing.....	70	Esker, plate showing.....	38
Boulders, glacial, in central Massachusetts..	58-59	Eskers in central Massachusetts.....	50-54
glacial, in central Massachusetts, plates showing.....	58	origin of.....	54
of erosion, plate showing.....	4	F	
perched, plate showing.....	58	Flood plain, plate showing.....	58
Brimfield, Mass., glacial lake near.....	77-78	"Flowstone," definition of.....	110
Brookfield, Mass., glacial lake at.....	78-79	Foreset beds of sand plain near Clinton, Mass., plate showing.....	70
Bryan, Kirk, Pedestal rocks in stream channels.....	123-128	G	
Pedestal rocks in the arid Southwest.....	1-11	Glaciation, effects of, on rock at Clinton, Mass., plate showing.....	31
C		effects of, on rock in Greenland, plate showing.....	30
Calhoun, F. H., cited.....	36-37	stages of.....	32-33
Carlsbad Cavern, N. Mex., characteristic scene in, plate showing.....	112	Gregory, H. E., cited.....	1
description of.....	109-113	Gypsum, sink holes dissolved in.....	114-116
entrance to, plate showing.....	112	I	
Hattin's Dome and the Temple of the Sun in, plate showing.....	112	Ice, glacial, thickness of.....	36-37
partition of onyx in, plate showing.....	112	K	
pillars of onyx in, plate showing.....	112	Kame terraces in central Massachusetts.....	49-50
spring deposits in, plate showing.....	112	origin of.....	47-49
stalactites in, plate showing.....	112	Kettleholes, origin of.....	68-69
stalagmites and column in, plate showing.....	112	plate showing.....	70
Twin Domes in, plate showing.....	112	L	
Yeitso's Pillar in, plate showing.....	112	Lacustrine clay, deposit of, in central Massachusetts.....	37-38
Cavernous condition in rocks, possible depth of.....	113	Lake Assabet, glacial, Mass., history of.....	74-75
Caverns in rocks, drainage through.....	116-117	Lake Nashua, glacial, Mass., Ayer stage of..	72-73
Clay, laminated and crumpled, plates showing.....	38, 71	glacial, Mass., Boylston stage of.....	61-65
Clinton, Mass., glacial deposits near.....	65-72	Clinton stage of.....	65-72
Columbia River, Wash., incipient pedestal rock on, plate showing.....	126	map illustrating relations of ice front to.....	70
weathered rocks on.....	125	Quinapoxet stage of.....	60-61
Connecticut Valley, glacial lakes in, history of.....	89-92	Lake Quaboag, glacial, Mass., history of....	79-81
glacial lobe in, history of.....	87-89	Lakes, glacial, origin of.....	59-60
Crosby, W. O., cited.....	24, 66, 68-69	Lancaster, Mass., glacial deposits near.....	73
		Lee, Willis T., Erosion by solution and fill.	107-121

	Page		Page
Lees Ferry, Ariz., erosion of rock cliffs at.....	2-3	Potholes in bed of Blackstone River, Mass., plate showing.....	104
pedestal rocks at, erosion of the pedestal.....	5-6	Prospect Hill, near North Charlton, Mass., plate showing.....	38
run-off and drip of rain water from.....	3-4	Q	
Limestone breccia, origin and volume of.....	113-114	Quaternary deposits, three classes of.....	29
Livingston ranch, N. Mex., wells in soluble rocks on.....	115	Quinsigamond quadrangle, Mass., diagram showing retreat of glacier in. In pocket map showing Quaternary geology of. In pocket	
Lower Blase Dale Glacier, Greenland, plate showing end of.....	30	Quinsigamond Valley, Mass., Tertiary streams in.....	21, 27
M		R	
Massachusetts, central, dissected plateau of plate showing.....	16	Reservoirs on soluble rocks, leaks in.....	118-119
central, early Tertiary streams and valleys in.....	18-23	Russell, G. H., cited.....	116-117
extent of the area.....	13-14	S	
ground and terminal moraines in.....	39-47	Salt, cavities dissolved in.....	114-116
later Tertiary stream adjustments in.....	23-27	Sand, cross-bedded, overlying laminated clay, plate showing.....	71
pre-Wisconsin deposits in.....	37-39	Shinarump conglomerate, block of, with vertical bedding planes, plate showing.....	4
recent epoch in.....	104-105	Sink holes, east of Carlsbad, N. Mex., plate showing.....	112
relations of the topography to the rock formations in.....	27-29	produced by solution of salt and gypsum.....	114-116
summary of glacial history of.....	92-104	Southbridge, Mass., glacial lake near.....	76
map of, showing distribution of drumlins.....	33	Spokane, Wash., basalt flows near.....	124
Moenkopi formation, hillock of, covered with gravel from Shinarump con- glomerate, plate showing.....	4	Stains on under side of boulder, plate showing.....	4
Monadnocks, examples of.....	15	Stream channels, glacial, in central Massa- chusetts.....	55-56
Monson, Mass., glacial lake at.....	79-81	Stream terraces, glacial, locations of.....	56-57
Moraine, ground, in central Massachusetts.....	39-43	glacial, origin of.....	57-58
Moraines, terminal, in central Massachusetts.....	43-47	plate showing.....	58
N		Striae, glacial, directions of.....	34-36
Nashua Valley, Mass., adjustments of drain- age in.....	23-27	Swift River, Mass., glacial history of.....	82-84
Tertiary streams in.....	19-21	T	
New Mexico, central, pedestal rocks in.....	10-11	Till, glacial, plate showing hill of.....	17
O		Travertine, deposition of, in Pecos Valley.....	114
Owens River, Calif., pedestal rock in.....	126	in Last Chance Canyon, N. Mex., plate showing.....	112
pedestal rock in, plate showing.....	127	V	
P		Vermillion Cliffs, Ariz., plate showing.....	4
Palmer, Mass., glacial lake at.....	79-81	W	
Pecos River at Red Bluff dam site, N. Mex., plate showing.....	112	Wachusett Mountain, Mass., plate showing.....	16
Pecos Valley, N. Mex., analyses of waters from.....	120	Ware quadrangle, Mass., diagram showing re- treat of glacier in.....	In pocket
location of.....	107-108	glacial lakes and streams of.....	75-92
rocks of.....	108	map showing Quaternary geology of	In pocket
soluble material in.....	109	Ware River, Mass., glacial history of.....	81-82
Pedestal rock, incipient, showing exfoliation, plate showing.....	4	Warren, Mass., glacial lake near.....	78
Pedestal rocks, in arid regions, forms and origin of.....	1-11	Water, kinds of, in the Pecos Valley, N. Mex.....	119-121
in streams, descriptions of.....	123-128	Wind-blown sand, erosion by.....	6-7
plates showing.....	4	Woolen mill, Gilbertville, Mass., plate show- ing.....	105
Pelham, Mass., glacial lake near.....	84-85	Y	
Peneplain, Cretaceous, of central Massachu- setts, development and dissection of.....	15-18	Yellowstone National Park, pedestal rock in.....	127
Playa, plate showing.....	112	pedestal rock in, plate showing.....	127

DEPARTMENT OF THE INTERIOR
Hubert Work, Secretary

U. S. GEOLOGICAL SURVEY
George Otis Smith, Director

Bulletin 760

CONTRIBUTIONS TO THE GEOGRAPHY
OF THE UNITED STATES
1923-1924

MARIUS R. CAMPBELL
GEOLOGIST IN CHARGE

WASHINGTON
GOVERNMENT PRINTING OFFICE
1925

CONTENTS

[The letters in parentheses preceding the titles are those used to designate the chapters for advance publication]

	Page
(A) Pedestal rocks in the arid Southwest, by Kirk Bryan (published Dec. 15, 1923)-----	1
(B) The physical features of central Massachusetts, by W. C. Alden (published Dec. 16, 1924)-----	13
(C) Erosion by solution and fill, by W. T. Lee (published April, 1925)----	107
(D) Pedestal rocks in stream channels, by Kirk Bryan (published April, 1925)-----	123
Index-----	129

ILLUSTRATIONS

	Page
PLATE I. A, Vermilion and Shinarump cliffs from Lees Ferry, Ariz.; B, Pedestal rock-----	4
II. A, Pedestal rock; B, Block of conglomerate with vertical bedding planes-----	4
III. A, Conical hillock of Moenkopi formation near Lees Ferry, Ariz.; B, Incipient pedestal rock showing exfoliation-----	4
IV. A, Drip furrow below pedestal rock; B, Stains on under side of boulder-----	4
V. A, Pedestal rock of granite; B, Pedestal rocks and boulders of erosion-----	4
VI. Map showing Quaternary geology of the Ware and Quinsigamond quadrangles, Mass-----	In pocket.
VII. Diagram showing stage of retreat of the glacial margin in the Ware and Quinsigamond quadrangles, Mass-----	In pocket.
VIII. A, Dissected plateau of central Massachusetts; B, Wachusett Mountain, a monadnock rising above the plateau of central Massachusetts-----	16
IX. A, Glacial till, a hill of unsorted glacial drift north of Clinton, Mass.; B, Dana diorite ("ribbon gneiss") 1 mile southeast of Gibbs Crossing, Ware, Mass-----	17
X. A, End of Lower Blase Dale Glacier, Disco Island, Greenland; B, Glaciated rock surface near Lower Blase Dale Glacier, Disco Island, Greenland-----	30
XI. Glaciated rock ledge at Clinton, Mass-----	31
XII. A, Crumpled laminated clay, possibly interglacial; B, Esker south of Clinton, Mass-----	38
XIII. Map of Massachusetts showing distribution of drumlins-----	38
XIV. A, Prospect Hill, a drumlin near North Charlton, Mass.; B, Drumlin northeast of Gleasondale, Mass-----	38
XV. Flood plain and stream terrace-----	58
XVI. A, Walls of glacial boulders inclosing farm lands near Dana, Mass.; B, Glacial boulders near Princeton Center, Mass--	58
XVII. A, Glacial boulder north of Gilbertville, Mass.; B, Perched boulders 3 miles northwest of Barre, Mass-----	58
XVIII. Map illustrating the relations of the ice front to glacial Lake Nashua at the Clinton stage-----	70
XIX. A, Kettle holes in sand and gravel south of Clinton, Mass.; B, Foreset and bottomset beds of sand plain 3 miles southwest of Clinton, Mass-----	70

	Page
PLATE XX. A, Cross-bedded sand overlying laminated clay, Still River Station, Mass.; B, Laminated and crumpled lacustrine clay, Still River Station, Mass.....	71
XXI. A, B, Potholes in bed of Blackstone River, Mass.....	104
XXII. A, Barre Falls, Mass.; B, Woolen mill, Gilbertville, Mass.....	105
XXIII. A, Yeitso's Pillar, Carlsbad Cavern, N. Mex.; B, A partition of onyx.....	112
XXIV. A, Stalactites; B, Hattin's Dome and the Temple of the Sun, Carlsbad Cavern, N. Mex.....	112
XXV. A, Stalagmites and column; B, Spring deposits.....	112
XXVI. A, Pillars of onyx; B, Twin Domes, Carlsbad Cavern, N. Mex.....	112
XXVII. A, Coralline stalagmites; B, A characteristic scene in Carlsbad Cavern, N. Mex.....	112
XXVIII. Sink holes east of Carlsbad, N. Mex.....	112
XXIX. A, Pecos River at Red Bluff dam site, N. Mex.; B, A playa.....	112
XXX. A, Entrance to Carlsbad Cavern, N. Mex.; B, Travertine in Last Chance Canyon, N. Mex.....	112
XXXI. A, Devils Top, Deep Creek canyon, 8 miles northwest of Spokane, Wash.; B, Incipient pedestal rock, Columbia River below China Bar, 9 miles downstream from junction of Spokane River, Wash.....	126
XXXII. A, Pedestal rock in Owens River, Inyo County, Calif.; B, Pedestal rock in Gibbon River at Chocolate Cascade, Yellowstone Park, Wyo.....	127
FIGURE 1. Map showing location of the Ware and Quinsigamond quadrangles, Mass.....	13
2. Map of central Massachusetts showing altitudes above sea level.....	17
3. Diagram illustrating stream changes in central Massachusetts.....	20
4. Map of parts of New England, New York, and New Jersey, showing extent, directions of movement, and terminal moraines of the last great ice sheet.....	31
5. Map showing area covered by the great ice sheets in North America at their maximum extension and the centers of ice accumulation.....	32
6. Diagram showing probable origin of many kettle holes.....	45
7. Diagram illustrating formation of kame terraces.....	48
8. Diagram illustrating the relations of a branching sinuous gravel ridge, or esker, near Westboro, Mass., to drumlins, a stream valley, and a glacial terminal moraine.....	51
9. Diagram illustrating relations of the receding front of a melting glacial globe and a later terminal moraine and outwash terrace to an earlier moraine and earlier terrace.....	57
10. Diagrams illustrating relations of the receding front of a glacial lobe in Nashua River valley to glacial Lake Nashua and the pitted terraces, or delta sand plains.....	63
11. Diagram illustrating relations of the ice front to glacial Lake Nashua near the end of the Boylston stage.....	64
12. Map of Eddy County, N. Mex.....	107
13. Sketch section through Carlsbad, N. Mex.....	109
14. Map and profiles of Carlsbad Cavern National Monument, N. Mex.....	111
15. Sketch section of cavernous rocks.....	118
16. Sketch section illustrating the filling of caverns.....	119

BOSTON PUBLIC LIBRARY

3 9999 06625 092 7

1927