

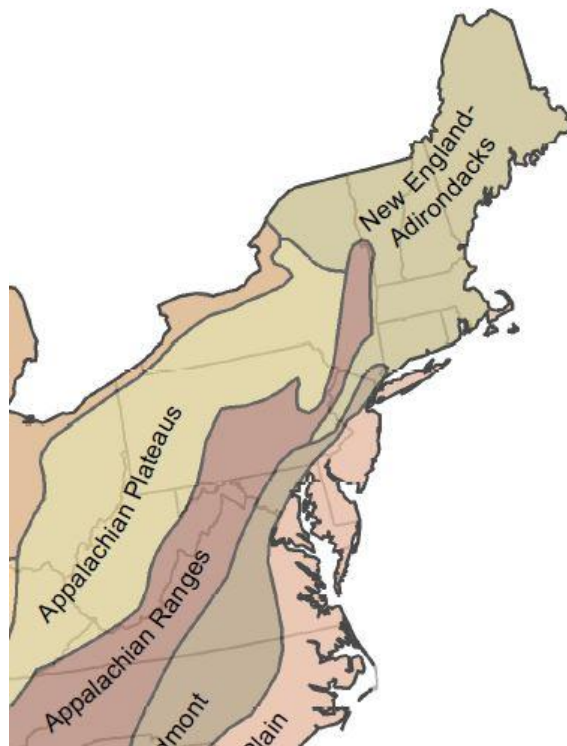
Spectacular geology of the northeast: high-priority sites for evaluation as National Natural Landmarks in the Appalachian Ranges and Plateaus, Adirondacks, and New England

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New England and Adirondacks province

Summary

In the New England and Adirondacks biophysiographic province, we identify 12 continentally significant and/or world-class sites deserving full evaluation for National Natural Landmark (NNL) designation. These are (in alphabetical order) the 1840 Oxbow (MA), the Brandon Lignite (VT), Cobscook Bay (ME), the Cutler – Quoddy Head coast (ME), the Franklin Ore Body (NJ), Glacial Lake Hitchcock (NE), High Peaks (NY), Merrymeeting Bay (ME), the Ossipee Mountains (NH), the Presque Isle Silurian Fossil Localities (ME), Traveler Mountain (ME), and the Trout Brook Plant Fossils (ME) (Table 1). All but the 1840 Oxbow and High Peaks would also fill theme gaps in the NNL catalog. Our analysis finds that many spectacular sites have gone unrecognized in this geologically rich province, and coverage of earth history themes is virtually absent among established NNL sites here. We recommend that in addition to focus on underrepresented themes, great geology be recognized broadly.

Table 1: Remarkable geologic pNNL sites in New England-Adirondacks

Site	State	Primary Theme	Theme Gap	Additional value	Ownership
1840 Oxbow	MA	8b,c	N	Historic, Educational, Scientific	Multiple
Brandon Lignite	VT	19b	Y	Scientific	Private
Cobscook Bay	ME	10a	Y	Scenic	Multiple
Cutler-Quoddy Head Coast	ME	10a	Y	Scenic	Multiple
Franklin Ore Body	NJ	13	Y	Scientific, Historic, Cultural	Local
Glacial Lake Hitchcock	NE	19d	Y	Scientific	Multiple
High Peaks	NY	3	N	Wonderous	Public
Merrymeeting Bay	ME	8/10	Y	Ecological	Multiple
Ossipee Mountains	NH	4b	Y	Scientific, Ecological	Multiple
Presque Isle Fossil Localities	ME	15a	Y	Scientific	Multiple
Traveler Mountain	ME	4a	Y	Scientific, Wonderous, Ecolog.	Public
Trout Brook Plant Fossils	ME	15b	Y	Scientific	Public

Discussion of findings

North America provides a model for continental accretion with the oldest crustal pieces (terranes) in the middle and younger material accumulating along the margins. Geology of the New England and Adirondacks biophysiographic province illustrates nicely. From west to east, the crystalline rocks of the Adirondacks (and underlying the younger sedimentary deposits across upstate New York State generally) are one-billion-plus years old. In the early Paleozoic (Cambrian and Ordovician Periods), collision of the Bronson Hills volcanic island arc (and associated marine sediments) with North America caused the Taconic Orogeny, and corresponding units are found through western New England today. To the east, through central Massachusetts, New Hampshire, and Maine, a second group of volcanic island arcs, Ganderia, and associated metamorphosed marine sediments, are found. The high grades of metamorphism in some of these rocks indicate that the associated Acadian mountains of the middle Paleozoic (Silurian and Devonian) would have been as high as the modern Alps. A Neoproterozoic terrane, Avalonia (730-570 million years old), characterizes eastern Massachusetts, eastern Connecticut, and Rhode Island. Early-middle Paleozoic (mostly Ordovician) ages of igneous rocks in eastern Massachusetts indicate that it had already joined the Gander Terrane by the time Gander collided with the eastern margin of North America (Domeier, 2016).

Following the tectonic events that brought the pieces of New England into place, there were three important processes that shape the landscape as we appreciate it today. During the Mesozoic, volcanic

activity is associated with the opening of the Atlantic Ocean. Near the Triassic-Jurassic boundary, a rift basin began to open, forming the Hartford Basin of central Connecticut and the Pioneer Valley of Massachusetts. During the Late Jurassic and Early Cretaceous, large volcanoes formed in the White Mountains of New Hampshire. During the Cenozoic, it seems that the landscape experienced widespread uplift, which could explain why this tectonically old surface is so varied. Uplift is difficult to investigate, but it may be related to deep-earth processes now being revealed in this region (*e.g.* Levin et al., 2017). The third major process is continental-scale glacial activity during the Pleistocene, which had the effect of reworking materials at the surface. Ice would have been miles thick, depressing the crust, scraping the bedrock clean in many places, collecting sediments, and re-depositing these sediments upon melting. Glacial deposits constitute the surficial geology of this province, provide an interface with the earth to support rich habitats through their associated water resources, and become so thick in places that they extend the coastal plain northward through Long Island and southeastern Massachusetts.

Regarding geological (Groups I and II) natural history themes, then, the New England and Adirondacks biophysiographic province is characterized chiefly by Mountains systems (Theme 3), Sculpture of the land (Theme 6), River systems and lakes (Theme 8), Works of glaciers (Theme 9), Seashores, lakeshores, and islands (Theme 10), the Precambrian era (Theme 13), Cambrian – Early Silurian periods (Theme 14), Late Silurian – Devonian periods (Theme 15), Triassic – Cretaceous periods (Theme 17), and Oligocene – Recent epochs (Theme 19) (Siccama et al., 1982). Established NNL sites capture Mountain systems (5 sites), Sculpture of the land (4 sites), River systems and lakes (4 sites), and Works of glaciers (11 sites). Although various lake and pond environments are well represented in the NNL canon for this province (17 sites) under ecological theme designation, and estuary (2 sites) and marine (1 site) environment are included, no established sites apparently address Seashores, lakeshores, and islands (Theme 10) explicitly. Earth history themes are poorly recognized generally. Two established NNL sites, Chazyan Coral Reef (VT) and Camel's Hump (VT), address Cambrian-Silurian periods (Theme 14); two NNL sites, Dinosaur Trackways (CT) and the Riker Hill Fossil Site (NJ), exemplify Triassic – Cretaceous periods (Theme 17). As observed by Trocki (2011), to the extent that they illustrate earth history, then, nearly every potential site would apparently fill theme gaps in the New England-Adirondacks province. Most of this province's geology is Precambrian, Paleozoic, and Quaternary. Significance of earth history themes at the sites is unclear, however, and the site description must be interpreted by a geologist familiar with the region to determine whether associated earth history themes are indeed exemplary at a national level, or merely provide details into regional history.

A previous gap analysis (Trocki, 2011) focused on Seashores, lakeshores, and islands (Theme 10), and recommended earth history themes be investigated more thoroughly. However, these theme gaps are so large that they do not effectively point to exemplary geology. Instead of strictly a theme gap analysis then, we first recognize spectacular geology in exemplary or superlative sites from the entire potential NNL site inventory, and include sites that are known within the geologic community to be remarkable. We then compare these by type. This approach allows us to work with a list of worthy geologic sites, compare by type to find the most outstanding, then include whether these would additionally address under-recognized geologic themes. From this perspective, in addition to coastal sites (Theme 10), potential NNL sites in the province naturally group into quarries and mines, fossil localities (various Group II themes), physiographic features (mostly Theme 3), glacial features and Quaternary history (Theme 9 and/or 19), caves and springs (Theme 12), volcanic features (Theme 4), fluvial features (Theme 8), and structural and stratigraphic features (various Group II themes). Sites recommended for full evaluation as National Natural Landmarks are listed in bold and discussed in context below.

Coastal sites

Seashores, lakeshores, and islands (Theme 10) are apparently unrecognized (0 sites by the 1990 NPS guide) among NNL sites in the New England-Adirondacks province, despite a scenic and diverse coast here, where 23 potential sites appear in the Siccama et al. (1982) inventory. It is unclear whether this theme is indeed unrepresented in this province, or whether designation as exemplary Seashores,

lakeshores, islands (Theme 10) site has not been consistently and clearly applied. Spicer (1987) lists 5 such NNL sites in this province and refers to a process-based and a theme-based characterization scheme, suggesting that there is room for interpretation when tallying sites in the theme-based categorization. Notably, Acadia National Park is an exemplary seashore and islands (and many other geological themes) site, and the Boston Harbor Islands National Recreation Area may address seashore and islands themes, too.

Of the 23 sites in the Siccama et al. (1982) inventory we identify a number of sites that exemplify various coastal environments within the biophysiographic province, each with its own special characteristics in Table 2. The high-amplitude tides along Maine's rocky eastern coast, approaching the Bay of Fundy are a geologic marvel, such that **Cobscook Bay** and the **Cutler – Quoddy Head** coast most deserve recognition. Moreover, these rocky coastal sites of northern New England are unlike the coastal plain province to the south, characterized instead by sandy beach and marsh environments generally, and poor bedrock exposure. Middle Paleozoic volcanics along coastal Maine are spectacular features of the New England province and deserve recognition, but whereas these sites (e.g. at Marginal Way, Acadia, Libby Islands) are included primarily for their coastal processes and environments, their volcanic features may be only secondary themes at these sites. Marginal Way and Quinnipiac River Estuary Marshes deserve mention for underappreciated and highly accessible Devonian volcanic rocks at Marginal Way, and the excellent Quaternary stratigraphy and fossils that add value to the Quinnipiac River Estuary Marshes site. Unfortunately, both sites' coastal features and volcanic or Quaternary aspects are more spectacular at other sites within the biophysiographic province. Within the New England province, Trocki (2011) supports recognition of **Cobscook Bay** as an NNL site, but also identifies Pleasant River Estuary (ME), and **Merrymeeting Bay (ME)** as good candidates for full evaluation. We agree that for their unique ecological conditions, these sites are remarkable. **Merrymeeting Bay**, the largest of its kind along the New England Coast, exemplifies an unusual freshwater tidal system that illustrates both coastal and fluvial characteristics. Coastal sites in Connecticut and Rhode Island reflect a transition from the sediment-dominated coastal environments of the Atlantic coastal plain province toward northern New England's rocky coast.

Table 2: notable Seashore, lakeshore, and islands potential NNL sites

Site Name	St.	Description
Acadia	ME	Spectacular rocky coast, volcanics, glacial features (National Park)
Cobscook Bay	ME	Highest-amplitude tides in contiguous US, reversing falls
Cutler-Quoddy Head	ME	Exemplary rocky coast, high-amplitude tide, easternmost US point
Griswold Point	CT	Exemplary bay-mouth bar
Libby Islands	ME	Exemplary coastal volcanics
Marginal Way	ME	Uniquely accessible coastal volcanics
Merrymeeting Bay	ME	Largest freshwater tidal bay north of the Chesapeake
Newport Cliff Walk	RI	Coastal access to upper Paleozoic Narragansett Basin sediments
Pattagansett Salt Marsh	CT	Exemplary salt marsh
Pleasant River Estuary	ME	Especially healthy estuary with salt marshes, Devonian exposures
Quinnipiac R. Marshes	CT	Exemplary estuary with great Quaternary stratigraphy and fossils
Sheepscot R. Estuary	ME	Exemplary healthy drowned river estuary with marshes
Small Point Beach	ME	Northern sandy beach with salt marsh

Quarries and mines

Although its heyday has now past, mineral extraction in the New England and Adirondacks province clearly has a long and rich history as illustrated by the number of superlative potential NNL sites. Quarries and mines might be more appropriately recognized as National Historic Landmarks rather than National Natural Landmarks, with the exception of the **Franklin Ore Body**, from which a number of

unique phosphate minerals are described, and which has received attention as a potential UNESCO World Heritage site. Unfortunately, even this mineralogical wonder does not fit neatly into NNL theme categorization, except perhaps for its record of Precambrian history (Theme 13). Recent investigations interpret the feature as a deep-sea hydrothermal deposit in an unusual tectonic setting. And such an unusual mineral assemblage may be more of an oddity or curiosity than a broader representation of the Precambrian Era. Whether as historic or natural landmarks, the region clearly hosts a number of world-class features (Table 3).

Table 3: mine and quarry potential NNL sites

Site Name	St.	Description
Barre Granite Quarries	VT	World's largest granite quarry
Belvidere Mine	VT	Largest mine in New England
Franklin Ore Body	NJ	World-class zinc deposit, unique phosphatic minerals
Gore Mt. Garnet Mine	NY	World's largest garnet mine, very long operating history
Iron Mine Hill	RI	Unique iron ore (cumberlandite) deposit
Lantern Hill	CT	One of the world's largest quartz masses
Mount Mica	ME	Exemplary pegmatite mine still yields spectacular gems and minerals
Old Newgate Prison Mine	CT	The region's oldest copper mine, important historical value
Ruggles Mine	NH	Old, famous pegmatite mine (now exhausted)
Vermont Marble Co. Quar.	VT	World's largest quarry
Vermont Slate Valley	VT	Slate used extensively throughout northeast for roofing, flooring
Westerly Granite Quarries	RI	Fine-grained granite world-renowned for homogeneity

Fossil localities

Although the New England – Adirondack region is better known for its crystalline bedrock than its sedimentary basins and fossils, a number of superlative fossil localities stand out (Table 4). Like Chazyan Coral Reef NNL (VT; established 2008), Middle Paleozoic Era (Theme 15) fossil localities, **Presque Isle Fossil Localities**, or **Trout Brook Plant Fossils** are both world-class in quality and would exemplify earth history representative of the New England-Adirondacks province. Moreover, the fossils at these localities capture pivotal moments of life evolution in stunning detail. Although New England's Tertiary history was perhaps not as central as other intervals of geologic time, the Neogene **Brandon Lignite** (Theme 19) is nonetheless geographically unique, extensively studied, and deserves recognition for excellent preservation of life during a period of earth history that contains few records from this part of the world. These three localities beautifully capture moments in time rather than provide grand overviews of long intervals of earth history.

Table 4: potential NNL fossil locality sites

Site Name	St.	Description
Brandon Lignite	VT	Only Tertiary plant fossils in eastern North America
N. Guilford Fish Fossils	CT	Particularly abundant Mesozoic (Jurassic) fish fossils
Presque Isle Fossils	ME	World-class Silurian fossil locality
Thomaston Fossils	ME	Brachiopod fossils in high-grade metamorphics, exceedingly rare
Trout Br. Plant Fossils	ME	Major stand of early plants with insect and fish fossils

Physiographic features (including mountains)

Outstanding physiographic features exemplify provinces or boundaries between provinces or regions. (Table 5). Although mountain systems (Theme 3) are well represented in this province (5 established NNL sites), the process that creates the Adirondack Mountains is of global significance. To the extent that **High Peaks** illustrates active uplift of the Adirondacks—possibly due to suspected mantle

activity (Levin et al., 2017)—it should be recognized as an NNL site for the way these mountains are forming. There is no theme category for deep-earth processes, however, and the ancient mountain building history that these Precambrian anorthosite (composed almost exclusively of plagioclase) rocks record is somewhat cryptic. Nonetheless this sort of basement uplift due to mantle activity is no doubt a geologic wonder on a world-class scale. The other sites are clearly regionally significant, but do not appear to stand out on a national scale.

Table 5: Physiographic potential NNL sites

Site Name	St.	Description
Bristol Cliffs and Talus	VT	Physical eastern edge of Champlain Valley
High Peaks	NY	Exemplifies Adirondack uplift, a potential modern mantle plume
Mount Penn	PA	Intersection of major biophysiographic provinces
Mount Toby	MA	Only sandstone mountain represented in the region
Storm King, Highlands	NY	Famous northern gateway to Hudson River Gorge

Glacial features and Quaternary history

Works of Glaciers (Theme 9) is already the best represented geologic theme among NNL sites in this province (11 NNL sites), and remarkable sites appear in the Siccama et al. (1982) inventory (Table 6). Perhaps Belgrade Esker System and Miller Brook were overlooked or simply not feasible to establish as NNL sites. The only reason we do not recommend these for full evaluation is that Works of glaciers are already well represented in this province. On the other hand, Quaternary history (Theme 19) is arguably the most under-recognized theme in the New England-Adirondack province considering its ubiquitous influence here. Some sixty sites described in the Siccama et al. (1982) potential NNL inventory (nearly half) highlight the prominence of this theme. In contrast, there are no (0) established Oligocene-Recent NNL sites in this province, and in the National Park System only Acadia National Park addresses this theme here. We list three of the most exemplary and insightful in Table 6. **Glacial Lake Hitchcock**, a large, elongate glacial lake in New England's Connecticut River Valley, would fill that gap superbly. The long, annually resolved deglaciation history that it preserves is unique in the northeast and perhaps North America. For a hundred years it has provided the master chronology for this critical period of time in the northeast (Antevs, 1922; Ridge, 2004). Budd Lake and the Quinnipiac River Estuary Marshes would also be valuable additions to the NNL program for their Quaternary stratigraphy and microfossil assemblages, though these are of lower priority as compared to Hitchcock. Although many remarkable features in this province indeed represent Quaternary processes of glaciations and deglaciation, the extent to which they provide unique insight into this pivotal interval of geologic time is very limited in nearly all cases. That is, these features typically record violent or grand processes, accounting for the prevalence of Theme 9 sites, but lack sufficient detail or context to provide meaningful insight into the larger climatic and physiographic interplay that characterized Quaternary earth history (Theme 19).

Table 6: Glacial and Quaternary potential NNL sites

Site Name	St.	Description
Belgrade Esker System	ME	Best esker system in Maine, perhaps the East
Budd Lake	NJ	Oldest continuous Pleistocene record in the northeast
Glacial Lake Hitchcock	NE	Unique 4000+-year recording of deglaciation at annual resolution
Miller Brook	VT	Some of the country's best glacial features
Quinnipiac R.Marshes	CT	Estuary environment preserves excellent Quaternary deposits, fossils

Caves, springs, and karstic features

A surprising number of superlatives regarding caves, springs, and karstic features (Theme 12) appear in this province's inventory study (Table 7). We find, however, that these are poorly developed and caution that superlatives here are with respect to the province and doubt that any would meet national

significance criteria. These types of features in the Appalachian Ranges and Plateaus provinces are far more impressive.

Table 7: cave, spring, and karst sites

Site Name	St.	Description
Dorset Mountain Spring	VT	Largest spring in New England
Natural Bridge	MA	Regionally unique bridge
Pettibone Falls Cave	MA	Best cave in New England
Pottersville Bridge/Caves	NY	Largest caves in the Adirondacks
Sweets Boiling Spring	RI	Region's only boiling spring

Volcanic features

Although the modern New England and Adirondacks province lacks volcanic activity, an impressive record of these processes is spectacularly preserved in its rocks (Table 8). Only one established NNL site, Great Falls of Patterson-Garrett Mountain (NJ), recognizes this aspect of the province. Maine hosts a Coastal Volcanic Belt of largely undeformed Paleozoic supervolcanoes, as is recognized at Acadia National Park. The Traveler Rhyolite (**Traveler Mountain**) and its supporting Katahdin Batholith of Maine's Central Volcanic Belt are larger than any of these coastal complexes (Theme 4). The volume of Traveler Rhyolite indicates that this was one of the largest silicic caldera eruptions in the rock record (Rankin and Hon, 1987; Seaman et al., 2014), representing arguably the most spectacular geologic feature in the entire New England province. Mesozoic volcanism produced the **Ossipee Mountains** (primarily Theme 4) as a world-class example of a great undeformed ring dike. It has a very clear geomorphic expression and excellent exposure.

Table 8: volcanic potential NNL sites

Site Name	St.	Description
Libby Islands	ME	Exemplary coastal volcanics
Marginal Way	NY	Uniquely accessible coastal volcanics
Ossipee Mountains	NH	Great, undeformed, well-exposed world-class ring dike
Traveler Mountain	ME	One of the largest volcanic eruptions in the rock record

Fluvial sites

With four established NNL sites in this humid province, fluvial (river) features are already well represented. Nonetheless, a number of sites deserve mention (Table 9), primarily addressing Theme 8. Although now dissected by a highway, exclusion of the archetypal **1840 Oxbow** from the NNL registry is nonetheless a major omission. The cutoff is reported to have formed while Edward Hitchcock and his students observed from the Holyoke Range, where Thomas Cole had painted the iconic Hockanum Bend only a few years before. The West Branch of the Penobscot may deserve recognition as a Wild and Scenic River, National Recreation Area, etc.

Table 9: fluvial potential NNL sites

Site Name	St.	Description
1840 Oxbow	MA	Type physiographic location for abandoned meander channel in river
Bashbish Falls	MA	Highest falls in the Taconic Region
Kennebec River Gorge	ME	Largest gorge in the region
West Br. Penobscot R.	ME	Best whitewater in New England, excellent geology, scenery

Structural and stratigraphic features

Finally, some sites stand out for the conceptual understanding of this region's geology that they provide (Table 10). Although these features may be exemplary or especially insightful to a geologist, the ideas that they represent are difficult to appreciate from their physical manifestations and would likely resonate much more strongly within the scientific community than for the public. Indeed, the unconformities are defined by absence, for example. In terms of themes, these features would best fit into the various time intervals to which they belong (themes 13, 14, 15, and 17). None appear to be high priorities for NNL evaluation at this time.

Table 10: structural and stratigraphic potential NNL sites

Site Name	St.	Description
Great Unconformity	CT	Especially long unconformity (gap in rock record)
Lone Point Rock	VT	Exemplary thrust fault suggests motion
Schunnemunk Mountain	NY	Provides critical insight into Appalachians' sedimentary history
Whitaker Falls Unconform.	NY	Especially long unconformity (gap in rock record)

Appalachian Ranges province

Summary

In the Appalachian Ranges province we recommend 12 sites for full evaluation for National Natural Landmark designation. These are: (in alphabetical order): Beemerville Carbonatite (NJ), Blue Mountain (PA), Dolls Gap (WV), Kline Gap (WV), Lost River Sinks (WV), Manassas Gap (VA), Nippono Spring (PA), North Fork Mountain and North Fork Gap (WV), Omega Cave System (VA), Red Mountain Roadcut, Seven Bends of the Shenandoah (VA), and Thorn Hill (TN) (Table 11). Among established NNLs, well-developed caves of this province are appropriately recognized (10 established sites), while similarly impressive springs (Theme 12e) receive less attention. Considering that caveat, all but Omega Cave System would also address major natural history theme gaps within this region, while Lost River Sinks and Nippono Spring would fill subtheme gaps.

Table 11: Remarkable geologic pNNL sites of the Appalachian Ranges

Site	State	Primary Theme	Theme Gap	Additional value	Ownership
Beemerville Carbonatite	NJ	4b	Y	Ecological, Scientific	State/Priv.
Blue Mountain	PA	3a	Y	Ecol., Multiple NNLs, Scenic	Multiple
Dolls Gap	WV	6b	Y	Historical	Private
Kline Gap	WV	6b	Y	Scientific, Historic	Private
Lost River Sinks	WV	12a,f	Y	Ecological, Recreational	Priv./Pub.
Manassas Gap	VA	6b	Y	Scientific	Priv./State
Nippono Spring	PA	12e	Y	Wonderous	Private
North Fork Mtn, Gap	WV	3a,6b	Y	Ecological, Multiple features	Priv./Pub.
Omega Cave System	VA	12a	N	Wonderous, Ecological	Private
Red Mountain Roadcut	AL	14,15,16	Y	Scientific	State
Seven Bends of Shenandoah	VA	6b	Y	Scenic, Multiple features	Private
Thorn Hill	TN	14,15,16	Y	Scientific	State

Discussion of findings

In this province, large-scale structural deformation features in sedimentary units are unparalleled, as a neatly folded thick Paleozoic sedimentary section records displacement over great distances during multiple episodes of mountain building, particularly the Late Paleozoic Alleghanian Orogeny (e.g. Shultz, 1999). Mountain building here was achieved by long lateral displacement of this sedimentary cover over crystalline bedrock, as opposed to deep burial and intense metamorphism as in New England. Because of this, physiographic transitions from one area of the province to the next are clearly apparent in the landscape, and lower grades of metamorphism more reliably preserve evolutionary history through fossils. Water predominates as a land sculpting agent, cutting gorges, dissecting ridges at ancient wind and water gaps, flowing through the subsurface in karstic terrain and caves to emerge as springs, and cascading over resistant bedrock units. These resistant rocks—conglomerates, quartzites, even limestones—form a number of pedestal features. In addition to these erosional curiosities, along the region's ridges a remarkable number of periglacial features are found.

As characterized by the potential NNL inventory study of Clark (1985), dominant physiographic natural history themes of the province are Mountain systems (Theme 3), Sculpture of the land (Theme 6), River systems and lakes (Theme 8), Works of glaciers (Theme 9), Caves and springs (Theme 12), Cambrian-Early Silurian periods (Theme 14), and Oligocene-Recent (Theme 19) stand out as temporal natural history themes. Of all these themes, only Caves and springs is already well represented (10 established NNL sites). Works of glaciers and Mountain systems are distant seconds, each with two established sites. As opposed to the New England-Adirondacks and Appalachian Plateaus provinces,

where the Middle Paleozoic Acadian Orogeny was pivotal, effects of this tectonic episode were limited here, so potential sites that address Late Silurian-Devonian periods (Theme 15) are fewer. In contrast, the Late Paleozoic Alleghanian Orogeny (Theme 16) impacted this area dramatically, and deserves recognition, despite a dearth of identified potential NNL sites that would exemplify this interval's effects. As with the New England-Adirondacks province, we first look for spectacular geology across the entire province, then consider whether the themes are already represented by existing NNL sites and where they occur. Sites recommended for full evaluation appear in bold in the following discussion.

Physiographic terrain

Given the name of this province, having only two established NNL sites addressing the Mountain systems natural history theme (Theme 3)—Hawk Mountain Sanctuary (PA) and Ice Mountain (WV)—this is an obvious gap that should be filled, and **Blue Mountain**, Beartown North, and Dugger Mountain would address it (Table 12). Blue Mountain, a broad, elongate ridge that extends into New Jersey as Kittatinny Mountain across the Delaware Water Gap, exemplifies the great frontal ridge of the Valley and Ridge province ([https://en.wikipedia.org/wiki/Blue_Mountain_\(Pennsylvania\)](https://en.wikipedia.org/wiki/Blue_Mountain_(Pennsylvania))). A number of wind gaps and other features are described as potential NNL sites along this encompassing feature (Clark, 1985).

Table 12: physiographic sites

Site Name	St.	Description
Blue Mountain	PA	Exemplary ridge with numerous potential NNL sites
Beartown North	VA	Highest mountain in Ridge and Valley province
Dugger Mountain	AL	Exemplifies transition from Blue Ridge to Ridge and Valley

Structures

The large-scale structural geologic features of the Valley and Ridge section of the Appalachian Ranges province are clearly developed and well preserved such that these features provide world-class examples of folded sedimentary rock packages. These structural features are somewhat difficult to appreciate, however, and do not fit clearly into established natural history theme categories. Nonetheless, **North Fork Mountain** illustrates an anticline beautifully to form an impressive and scenic mountain, and is similarly recommended as a top priority for evaluation by Lookingbill and Englehardt (2011) (Table 13). As a structural feature, Burkes Garden deserves mention for its compelling geometric symmetry as a breached dome, manifesting neatly as a high-altitude valley (Sculpture of the land). The **Beemersville Carbonatite**, although part of a volcanic complex, is somewhat difficult to recognize through the national history theme characterization, too. This is an intrusive structure with unusual minerals and spectacular specimens that provide insight into ancient tectonic processes in this complex area. Previous theme gap analysis (Lookingbill and Engelhardt, 2011) identified this site as being of second-tier priority for evaluation.

Table 13: structural potential NNL sites

Site Name	St.	Description
Beemersville Carbonatite	NJ	Most significant intrusive complex in province, many rare minerals
Joyce Kilmer, Paddy Mtn.	PA	Best breached plunging anticline in province, features axial stream
Burkes Garden	VA	Best breached dome in the Valley and Ridge province
Massanutten Peak	VA	Best synclinal nose in the Valley of Virginia
North Fork Mountain	WV	World-class breached anticlinorium with debris slides

Stratigraphy and fossils

Despite its predominance as a theme of this province, Paleozoic natural history (themes 14, 15, and 16) is not explicitly recognized among National Natural Landmark sites within the Appalachian

Ranges province. The five sites below would all address this largest thematic gap (Table 14). Highest priority among these would be the extensively studied section at **Thorn Hill**, which provides a master stratigraphy of the Paleozoic to cover the entire evolution of the Appalachian Mountains. In Tennessee, the site lies in the southeast region, and exposure is achieved by a roadcut. A roadcut at **Red Mountain** reveals a similarly impressive stratigraphy in the southeast.

Table 14: potential NNL sites to illustrate earth history

Site Name	St.	Description
Red Mt. Expressway	AL	Roadcut exposes 170-m.y. Paleozoic stratigraphic section
Egg Hill	PA	Provides critical understanding of Ridge and Valley province
Saint Clair Fern Fossils	PA	World-class fern fossils preserved in dramatic contrast to host rock
Swatara Gap, Fossil Site	PA	Prime fossil-collecting site
Thorn Hill	TN	Master Paleozoic section for province, extensively studied

Caves

Despite good representation within the NNL system in this region (10 established NNL sites), some spectacular features are nonetheless unrecognized. **Omega Cave System**, discovered in the 1990s (not included in the Clark (1985) inventory), is now regarded as the longest and deepest cave system in the eastern US, and Ellison's Cave (also included in Appalachian Plateau inventory) is the second deepest (Table 14). Both are highly dangerous, publicity should be discouraged, and only the most experienced expert cavers should be allowed access, but these features clearly deserve recognition. Warm River Cave may warrant a closer look, too, for its unique geothermal properties. Hot water phenomena (Theme 5) may be at play here, rare in the province, and the eastern US more broadly. Finally, Cumberland Bone Cave was identified as a second-tier priority for evaluation in previous analysis (Lookingbill and Engelhardt, 2011).

Table 15: cave sites

Site Name	St.	Description
Ellison's Cave	GA	Very deep cave, contains deepest pits in US
Cumberland Cave	MD	Contains rare Illinoian fossils
Morrill Cave	TN	Largest cave in eastern Tennessee
Omega Cave System	VA	Longest and deepest cave in eastern US
Skyline Caverns	VA	World-class cave flower locality
Warm River Cave	VA	Only thermal cave system in eastern US

Springs

Despite good representation of Caves and springs (Theme 12) in this province (10 sites), few of these NNL sites explicitly recognize springs (Theme 12e). **Nippono Springs**, Pennsylvania's largest, emerges from a limestone unit forming the floor of a breached anticline as Antes Creek (Table 16). **Lost River Sinks** is somewhat similar in that flow through a limestone unit is structurally controlled, except that here the underground flowpath can be neatly traced to a nearby swallet above, such that the transition from surface flow to groundwater flow and back again can be easily appreciated in a popular recreation area.

Table 16: remarkable springs

Site Name	St.	Description
Arch Spring	PA	Best arch spring in the Ap. Ranges province
Nippono Spring	PA	Largest spring in Pennsylvania yields 18,000 gallons per minute

Seven, Ruhl Spring	PA	Second largest spring in Pennsylvania
Lost River Sinks	WV	Exemplary swallet and re-emergence through stratigraphy

Wind gaps

Wind gaps are abandoned stream valleys where stream capture has left the valley dry, thereby representing superposition of drainage systems (Theme 6b). That is, headward erosion might have caused the bank of a high-altitude stream to fail, rerouting that stream, or the landscape may have tipped due to tectonic activity. Wind gaps are common in an ancient landscape where tectonic uplift has been imposed on an existing drainage network, and therefore characteristic of the Appalachian Ranges. These curious geomorphic features address Sculpture of the land (Theme 6) better than River systems and lakes (Theme 8), and should be recognized, as Theme 6 is only addressed at present by one NNL in the province, Susquehanna Water Gaps (PA). **Manassas Gap** would recognize the important process of stream capture, whereas **Dolls Gap** on Saddle Mountain is the more scenic representative of the wind gap as a characteristic feature of this province (Table 17). **Blue Mountain** (see physiographic terrain discussion) also hosts a number of exemplary wind gaps (Clark, 1985). Inclusion of a wind gap in this province should be a high priority for the NNL program.

Table 17: wind gaps

Site Name	St.	Description
Wind Gap	PA	Best wind gap in Pennsylvania with eponymous town
Manassas Gap	VA	Best-known example of stream capture in the United States
Saddle Mtn. (Dolls Gap)	WV	Best wind gap in Appalachian Ranges province

Water gaps

After this province's caves and springs, its water gaps are the most spectacular and special geologic features (Table 18). These illustrate stunning examples of how superposition of modern rivers (Theme 8) can shape the landscape (Theme 6b) in spectacular ways. Delaware Water Gap is the most impressive, and enjoys status as a National Recreation Area. Next are water gaps along the Susquehanna, and some of these are recognized as an NNL site, Susquehanna Water Gaps (PA). Considering recognition of these, Penns View and Penns Creek Gorge (on the Susquehanna) would be somewhat redundant despite their scenic value. The Lehigh Gap might be third. We recommend **Kline Gap** be recognized for its historic illustration of the Potomac Basin's ancient drainage superimposed on the landscape.

Table 18: water gaps

Site Name	State	Description
The Narrows	MD	Best example of a transverse water gap in Maryland
Delaware Water Gap	PA/NJ	Most spectacular water gap in Ap. Ranges province
Lehigh Gap, Devils Pulpit	PA	Exemplary water gap
Penns View, Cr. Gorge	PA	Most scenic and lengthy series of water gaps in province
Hook and Gooseneck	PA	Curved water gap through most representative Ridge and Valley
Blue Hole of Passage Creek	VA	Best entrenched curved water gap in Virginia Ridge and Valley
Rainbow Gap, Iron Gate G.	VA	Famous iron gate arch/gorge exposes Paleozoic stratigraphy
Kline Gap	WV	Best of classic trio illustrating Potomac River superposition

Gorges, falls, incision

Aside from the water gaps, a number of potential NNL sites would address the River systems and lakes (Theme 8) natural history theme in addition to Sculpture of the land (Table 19). Bushkill Falls, a superlative of Pennsylvania, though recognized as of second-tier priority for evaluation (Lookingbill and

Engelhardt, 2011), is already popular as a major attraction within Delaware Water Gap National Recreation Area. Perhaps more interesting geologically within this category are the **Seven Bends of the Shenandoah**, which provide an extreme example of this geomorphic feature with beautiful symmetry.

Table 19: additional fluvial features

Site Name	St.	Description
Bushkill Falls	PA	Largest waterfall in Pennsylvania (within Delaware Water Gap)
Dingmans, Silverthread	PA	Highest waterfall in Pennsylvania
Lehigh Gorge, Okono	PA	Deep gorges along wild and scenic Lehigh River
Raymondskill Falls	PA	Second highest falls in Pennsylvania (within Delaware Water Gap)
Winona Falls	PA	Most scenic falls in Pennsylvania
Seven Bends Shenandoah	VA	World-class, symmetrical meanders
Smoke Hole	WV	Best sculpture through Devonian and Silurian in Ridge and Valley

Periglacial features

Although much of this province lies south of the Wisconsin (most recent) glacial limit, a number of periglacial features are described from the higher altitudes of the province (Table 20). Ice Mountain, a classically described glaciare, like the boulder field at Hickory Run (established NNL in Appalachian Plateaus province), are special features that deserve recognition. We understand that both of these sites have been established as NNL sites since the inventory study of Clark (1995) and the publication of the national registry of NNL sites (1990), and note that Ice Mountain was recommended as a top-priority site for evaluation (Lookingbill and Engelhardt, 2011). Although not officially recognized as a Work of glaciers, this would complement two others in the province (Susquehanna River Gaps (PA) and Sunfish Pond (NJ)), in representing works of glaciers (Theme 9). Consistent with the idea that Works of glaciers are not a major theme of this province, those listed below are regionally significant, though perhaps not nationally significant.

Table 20: periglacial features

Site Name	St.	Description
Big Flat	PA	Best periglacial environments in the province
Devils Racecourse	PA	Best regional valley-axis Weaverton sandstone boulder field
Totts Gap	PA	Best patterned ground south of glacial limit
Treaster Kettle	PA	Most famous of well-known central Pennsylvania kettles
Mountain Lake, Butt Mtn.	VA	Largest unspoiled lake south of glacial limit, great surficial geology

Natural sculptures

A number of superlative pedestal rocks and small-scale sculptures appear in the Clark (1985) inventory of potential NNL sites (Table 21). These are regional landmarks, but not necessarily of national relevance. Natural Bridge is probably the most geologically remarkable of these, and designated a National Historic Landmark. As a geologic feature, it certainly merits regional recognition, though this type of arch or bridge is relatively common on a national level. Also, White Rocks was previously recommended for evaluation (second-tier) for its Cambrian quartzite (Lookingbill and Engelhardt, 2011).

Table 21: natural sculptures

Site Name	St.	Description
Chimney Rocks	PA	Best-developed limestone pedestal rocks in the Ap. Ranges province
Chinese Wall	PA	Best Pennsylvanian pedestal rocks in Ap. Ranges province
White Rocks	PA	Great metaquartzite pinnacles of Cambrian Antietam Formation

Natural Bridge	VA	215'-high world-class natural bridge (National Historic Landmark)
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Appalachian Plateaus province

Summary

In the Appalachian Plateaus province we recommend 12 sites for evaluation as National Natural Landmarks. These are (in alphabetical order) Allegany State Park (NY), Breaks Interstate Park (VA), Cayuga Lake (NY), Cloudland Canyon Park (GA), Ellison's Cave (GA), John Boyd Thacher Park (NY), Letchworth Gorge State Park (NY), Montlake/Walden Ridge (TN), Red Hill (PA), Teays Valley (WV-OH), Tug Hill (NY), and Watkins Glen State Park (NY) (Table 22). Allegany State Park, and Tug Hill would address clear thematic gaps in Plains, Plateaus and Mesas (Theme 1), and Cuestas and Hogbacks (Theme 2); Thacher Park and Red Hill address a gap in earth history, specifically Late Silurian and Devonian periods (Theme 15). The others would not fill obvious thematic gaps, but are at least as exemplary as their established NNL contemporaries. Although sculpture of the land (Theme 6) is already well represented in this province, the spectacular gorges selected here—Breaks Interstate Park, Cloudland Canyon, Letchworth Gorge, Teays Valley, and Watkins Glen—are at least as significant and exemplary as their established NNL contemporaries that would illustrate superposition of drainage systems (Theme 6b), Fall Brook Gorge (NY), Pine Creek Gorge (PA), and Piney Falls (TN). Similarly, Ellison's Cave is exemplary in the east for the superlative depth of its pits, despite a number of established solution cave NNLs (Theme 12a). Finally, the lakes (Theme 8c), Cayuga Lake and Montlake are truly significant or unique in their formation, and are arguably more exemplary in this thematic category than their established NNL contemporaries in Lake Lacawac (PA) and Round Lake (NY).

Table 22: Remarkable geologic pNNL sites in the Appalachian Plateaus

Site	State	Primary Theme	Theme Gap	Additional value	Ownership
Allegany State Park	NY	1b	Y	Scenic, Ecol. Multiple feat.	State
Breaks Interstate Park	VA	6b	N	Scen., Rec., Ecol., Multi.	State
Cayuga Lake	NY	9b,8c	N	Scen., Rec., Wonderous	Multiple
Cloudland Canyon Park	GA	6b	N	Scenic, Historic, Ecological	State
Ellison's Cave	GA	12a	N	Scientific, Wonderous	Private
John Boyd Thacher Park	NY	15a,b	Y	Sci., Hist., Scenic, Ecol.	State
Letchworth Gorge SP	NY	6b	N	Scenic, Recreational	State
Montlake/Walden Ridge	TN	8c	N	Scenic, Scientific, Rec.	Private
Red Hill	PA	15b	Y	Scientific	State
Teays Valley	WV/OH	6b	N	Scientific	Multiple
Tug Hill	NY	2a	Y	Scenic, Ecological	Priv./State
Watkins Glen State Park	NY	6b	N	Scen., Educ., Sci., Rec.	State

Discussion of findings

The Appalachian Plateaus province is a broad upland on the northwest side of the Appalachian Valley and Ridge province. Here generally flat-lying and minimally disturbed Paleozoic sediments record the region's episodes of mountain building in the Allegheny and Cumberland Plateaus. Fossil preservation is good, especially in Upper Paleozoic coals. Due to uplift of this landscape during the Cenozoic Era and rerouting following the last glaciation, rivers carve deep gorges into the sedimentary rocks where these units are less resistant, and form spectacular waterfalls where more resistant beds meet less resistant ones. Development of caves and karstic terrain is excellent in limestones. As in the Appalachian Ranges, episodes of uplift have tilted the landscape, and relatively recent glacial rebound preserves previous drainage patterns in the Allegheny Plateau, which was glaciated in its northern portion.

In the Appalachian Plateau, Sculpture of the land (Theme 6), River systems and lakes (Theme 8), and Works of glaciers (Theme 9) dominate natural history themes as measured by the inventory study of Baer et al. (1982). The Paleozoic, specifically the Middle and Late Paleozoic (Theme 15 and Theme 16) for orogenic episodes, should not be overlooked here, even if in the inventory these themes do not appear as commonly as some of the more recognizable physiographic themes. Plains, plateaus and mesas (Theme 1), Mountain systems (Theme 3), and Caves and springs (Theme 12) are also numerous. Among established NNL sites in this province, Sculpture of the land, River systems and lakes, Works of glaciers, and Oligocene –Recent periods (Theme 19) are well represented. Indeed, of the three provinces within the scope of this natural history theme gap analysis, the Appalachian Plateau recognizes the broadest diversity of geologic themes among established NNL sites, such that consideration of this aspect is a more useful tool to identify gaps in exemplary geology. Theme gaps occur at Middle and Late Paleozoic earth history, Plateaus, plains and mesas, and Mountain systems, so we give these more attention, discussing all sites confidently identified as nationally significant. However, whereas many of the established NNL sites appear to primarily capture ecological features, there should be room for spectacular geology within the province, too. Sites recommended for full evaluation appear in bold in the following discussion.

Physiographic features

Plateaus, plains and mesas (Theme 1) and Mountain systems (Theme 3) are the dominant physiographic features of the province, and are underrepresented among established NNL sites. No presently established NNL sites recognize these themes in this province. We have selected a number of sites that exemplify major physiographic features of the province as plateaus, cuestras (Theme 2), and mountains (Table 23) and deserve consideration as National Natural Landmarks. **Allegheny State Park** exemplifies the dissected Allegheny Plateau and ranks favorably (Tier 2) in the Lookingbill and Engelhardt (2011) gap analysis. Similarly, the Sewanee/Montecagle area exemplifies the dissected Cumberland Plateau, whereas The Knobs represent a part of this plateau so completely dissected that it has become an isolated erosional remnant, thereby illustrating a model for mountain formation in addition to representing a piece of the plateau. **Tug Hill** (plateau) is a unique portion of the Appalachian Plateaus province that illustrates a snowy, transitional environment between the Allegheny Plateau and the Adirondacks. Lookingbill and Engelhardt (2011) similarly identify this as having good potential as an NNL (third tier). Its eastern face is characterized by a cuesta (Theme 2), where Bear et al. (1982) suggest Whetstone State Park and Gomer Hill (NY) represent the feature. **Breaks Interstate Park** beautifully captures the Cumberland Mountains and features an impressive gorge carved by the wild Big Sandy River into a rugged forested landscape. It was prioritized (third-tier) in the previous theme gap analysis (Lookingbill and Engelhardt, 2011). Although Alleghany Front at Bear Rocks is much like the Tug Hill plateau in remarkable form and ecology—identified as top priority for NNL designation by Lookingbill and Engelhardt (2011) and more recently (2016) fully evaluated—from a physiographic perspective we favor the Tug Hill plateau for its larger scale and extensive escarpment/cuesta.

Table 23: physiographic sites

Site Name	St.	Description
Tug Hill	NY	Major portion of physiographic province with unique climate
Allegheny Front/Bear Rocks	WV	Scenic, ecologically rare environment on eastern plateau escarpment
Allegheny State Park	NY	Exemplifies the dissected Allegheny Plateau
Breaks Interstate Park	VA	Illustrative of the Cumberland Mountains
The Knobs	KY	Exemplary erosional remnants of the Cumberland Plateau
Sewanee/Montecagle Area	TN	Scenic area exemplifies the dissected Cumberland Plateau

Stratigraphy

The Appalachian plateaus are composed of undeformed Middle and Late Paleozoic (Themes 15 and 16) sedimentary rocks, providing some excellent records of the ancient environments surrounding the

Appalachian Mountains (Table 24). Through a cuesta, the Helderberg Escarpment, **John Boyd Thacher Park** reveals a master Middle Paleozoic stratigraphic section that historically provided the key to unlocking the geology of the Appalachian region. This site is presently under evaluation for NNL designation (Venti et al., in review). **Red Hill** is a world-class fossil locality that provides detailed insight into early tetrapod evolution in a forested environment of the Late Devonian (Cloutier and Lelièvre, 1998). There are no doubt other excellent Late Paleozoic (Theme 16) fossil localities within the Appalachian Plateaus, as abundant coal beds within the province preserve ancient humid forests. We would encourage the NNL program to consider these despite a history of industrial use. Indeed the Pennsylvanian Period is so named for extensive Late Paleozoic deposits in that state.

Table 24: stratigraphic sites

Site Name	St.	Description
John Boyd Thacher Park	NY	Master Middle Paleozoic section key to understanding Eastern US
Red Hill	PA	World-class Late Devonian site with early tetrapods, forest fossils

River systems and lakes

On the plateau, rivers cut gorges through less resistant Paleozoic sedimentary rocks to provide some of the most spectacular physiographic features in this province. The Gauley River Gorge captures some of the best whitewater in the eastern US and clearly deserves recognition. In 1988 it was established as a National Recreation Area, not long after the Baer et al. (1982) inventory study. Similarly impressive in scale, New River Gorge is a National River. Although River systems and lakes is among the better-represented natural history themes (4 established NNL sites), the primary features at some of these sites are ecologic rather than geologic, leaving many of the province's remarkable gorges and lakes unrecognized (Table 25). **Letchworth Gorge** is the largest such feature in the Eastern US. Here the Genesee River has carved deeply (up to 600') through some 15 miles of sandstones and shale since the last glaciation and falls dramatically in three places. It appears on Lookingbill and Englehardt's (2011) second tier for evaluation. Like Letchworth, **Watkins Glen** was cut after the last glaciations, but into a narrower gorge. Watkins' gorge and falls developed at a smaller scale, but offers the visitor a more intimate experience with the spectacular geology than Letchworth. **Cloudland Canyon State Park** cuts another gorge through the plateau at stunning scale in addition to its falls, but in the Cumberland Plateau versus the Allegheny. The Finger Lakes are outstanding large-scale glacial features that are obvious candidates for National Natural Landmark status, though multiplicity of ownership would seem to inhibit designation. **Cayuga Lake** is the largest and most exemplary, but even the smaller lakes of this region are impressive in size.

Table 25: River system and lake sites

Site Name	St.	Description
Cayuga Lake	NY	Exemplifies Finger Lakes, very large glacial lake features
Letchworth Gorge	NY	Very long and deep gorge, referred to as Grand Canyon of the East
Kaaterskill Falls	NY	Scenic highest falls in New York State (260 feet)
Watkins Glen	NY	Best postglacial gorge/glen in its region
Gauley River Gorge	WV	Top-tier whitewater in the eastern US
Cloudland Canyon Park	GA	Most spectacular gorge in the Cumberland Plateau

Caves and karstic features

Caves and springs are appropriately among the best recognized features in the Appalachian Plateaus province (4 established NNL sites). Other superlatives appear in the potential NNL site inventory of Baer et al. (1982) (Table 26). **Ellison's Cave** (included in Baer et al. (1982)) should be included too if this is feasible. It is the second deepest in the eastern U.S., has the deepest unobstructed pit in the

continental U.S. (Fantastic Pit), and is the deepest cave in the province. McFail's and Howe's Karst Area is the best-developed system of this type in the northeast, but do not merit any superlatives across the province. **Montlake** is an unusually large sinkhole lake that is not well understood. This type of rare feature illustrates the only way that natural lakes form in large portions of the Appalachian plateaus and ranges provinces and thus deserves recognition.

Table 26: caves and karst

Site Name	St.	Description
McFail's/Howe's Karst	NY	Largest cave in the northeast
Ellison's Cave	GA	Deep cave with some of the deepest pits in the eastern US
Fern Cave/Surprise Pit	AL	One of the deepest freefall pits in eastern US
Montlake/Walden Ridge	TN	Unique, large sinkhole lake

Sculpture and structure of land and rocks

These curiosities are worth mentioning but do not group into a single natural history theme category (Table 27). **Teays Valley** (Sculpture of the land, River systems and lakes), as a great abandoned pre-glacial drainage, is perhaps most compelling here.

Table 27: sculpture and structural features

Site Name	St.	Description
Rock City at Olean	NY	Largest exposure of quartz conglomerate, exaggerated joints
Teays Valley	WV/OH	Best abandoned river valley in the province
Natural Bridge	AL	Most beautiful natural bridge in province for symmetry
Big "A" mountain	VA	Exemplifies the Cumberland overthrust block
Sequatchie Valley	TN	Exceptional anticlinal valley

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