WYOMING STATE GEOLOGICAL SURVEY
Lance Cook, State Geologist

Glacial records in the Medicine Bow Mountains and Sierra Madre of southern Wyoming and adjacent Colorado, with a traveler's guide to their sites

by

Brainerd Mears, Jr.

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Front Cover. The steep eastern mountain front of the Snowy Range, Medicine Bow Mountains, Wyoming was the locus of glacial ice at various times in the Quaternary. During glacial maxima, ice probably accumulated to a depth about halfway up the mountain front and flowed both south into the French Creek drainage and east across Libby Flats into Centennial Valley. View is southwest from the gap between Sugarloaf Mountain and Medicine Bow Peak. Photograph by Wayne M. Sutherland, September, 1972.

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University of Wyoming

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Acknowledgements

I thank Richard W. Jones, editor at the Wyoming State Geological Survey, William Adams, Henry Heasler, Cheryl Jaworowski, Edward Kempema, and Wayne Sutherland for their suggestions and assistance in the field. The author also acknowledges the assistance of the following Wyoming State Geological Survey personnel: Jaime R. Bogaard for drafting, manuscript preparation, and layout; Phyllis A. Ranz for drafting; and Fred H. Porter for drafting.

Foreword from a colleague

Brainerd Mears, Jr. is a native of New England where his family was associated with Williams College in Williamstown, Massachusetts. Mears graduated with a B.A. degree in Geology, following which he immediately enlisted in the U.S. Marine Corps. His active military duty included combat in the Pacific Theatre (including Bougainville and Guam) in World War II.

Mears earned a Ph.D. degree from Columbia University after his discharge from military service. He was appointed Assistant Professor of Geology at the University of Wyoming in 1949, became a full Professor in 1963, retired in 1989, and has continued as Professor Emeritus since that time. Mears' area of earth science was geomorphology. His ability to present physical geology by means of block diagrams were a part of his teaching skills.

Mears' recognition of fossil ice wedges in the Laramie Basin and in Wyoming at large was a major scientific discovery. The preservation of the ice wedges demonstrated the climate of the region in late Pleistocene time.

The current paper is a summation of literally years of observing and recording data relative to the "Ice Age" in the Laramie area. The non-geologic public as well as students of geology will now have an excellent account of climatic change in this part of Wyoming.

D. L. Blackstone, Jr.
January, 2001

Dr. Brainerd Mears, Jr. at Hanna Junction during geology field camp in June, 1970. Photograph by Wayne M. Sutherland.

Foreword from a student

In the Spring of 1969, I took my first course from Dr. Brainerd Mears, Jr. Dr. Mears, or "Nip" as his friends call him, taught "Geomorphology, the Queen of the Earth Sciences," a phrase he used to emphasize the overall importance of his chosen field. Nip taught geomorphology and physical geology with dedication and a dry sense of humor which was woven into the fabric of all his lectures; any student who paid attention enjoyed his courses. Nip first was my professor, then my advisor, then my friend.

Nip's field trips covered a wide range of geology in Wyoming, always focusing on geomorphology and geomorphic processes, with special emphasis on glacial and periglacial phenomena. He always had appropriate commentary accompanied by diagrams drawn on a portable chalk board. His ever-present cigar lent a distinctive air to the trips, kept down mosquitos on occasion, and served as a permanent aromatic marker for any book which he might lend from his personal library. Those of us who were lucky enough to have him as a professor owe him much. He truly is the "King of the Earth Sciences."

Wayne M. Sutherland
January, 2001

Foreword from the editor

Like Wayne Sutherland, the first geology course I took was Dr. Mears' physical geology. Not only were his lectures informative and highly organized, Dr. Mears had a unique style that combined hand-drawn three-dimensional graphics on the chalk board (clearly patterned after the master, Dr. S.H. Knight), a penetrating baritone voice, and a wry, tongue-in-cheek wit that had attentive students chuckling to themselves (or sometimes out loud) during the class.

Many students became interested in geology, and a number even went on to become geologists (like I did), as a result of their freshman geology course and subsequent geomorphology courses with Dr. Mears. Nearly every field trip with him was a memorable experience, as he taught his students the importance of keen observation and rigorous scientific method as well as the necessity for field geology. He made his geology students relate the concepts and facts he presented in the classroom to what they could actually see and touch in the field. I still consider Dr. Mears my professor, but more importantly, I now consider him my friend.

The Wyoming State Geological Survey is proud to publish this and what we hope will be several more reports on glaciation and geomorphology of Wyoming. Dr. Mears remains a valued friend of this agency, a great resource for the University of Wyoming, and an inspiration to all that know him.

Richard W. Jones
January, 2001

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Abstract

The Medicine Bow Mountains and the Sierra Madre of southern Wyoming and northern Colorado are excellent, generally accessible areas to view the effects of glaciation in the Rocky Mountains. The mountains contain evidence of two major times of glaciation: a very early episode recorded in the Precambrian bedrock exposed by erosion following the rise of the Rocky Mountains some 60 million years ago, and the well known Pleistocene episode whose effects are prominent in the present landscape.

The evidence for Late Precambrian glaciation is in metamorphosed, poorly sorted conglomerates and sandstones interpreted as tillites, as well as in slaty rocks having pebbles interpreted as dropstones from floating ice.

The Medicine Bow Mountains had extensive Pleistocene glaciers at two major sites. In southern Wyoming, glaciers radiated from the steep flanks of the Snowy Range across the subsummit upland feeding valley glaciers that in places extended onto the adjacent plains. In northern Colorado, extensive valley glaciers developed in the rugged terrain of the Rawah Peaks and created an ice cap on the adjacent subsummit surface to the northeast. Along the steep west flank of the Rawah Peaks valley glaciers reached the adjacent North Park Basin. In the Sierra Madre, which lack high peaks, less extensive glaciers were confined in valleys.

The Pleistocene glacial sequence is recorded by: a) isolated relics of an earliest episode, b) Illinoian-age Bull Lake tills in subdued moraines, c) adjacent Pinedale tills of Wisconsin age in more prominent end moraines, and d) a sequence of progressively less recessional moraines of several later Pinedale episodes. Small Holocene (post-Pleistocene) glaciers developed in cirques along the east side of the Rawah Peaks, but were less prominent along the Snowy Range where massive talus developed, and were absent at the lower elevations of the Sierra Madre.

Introduction

Some of the most scenic and generally accessible areas of Rocky Mountain glaciation are in the Medicine Bow Mountains and the Sierra Madre, which extend southward from Wyoming into Colorado (**Figure 1**). The mountains contain evidence of two major times of glaciation: the well-known Pleistocene, whose effects are prominent in the present landscape, and a far earlier event for which the evidence is preserved in the Precambrian bedrock. This report documents, in relatively non-technical terms, the glaciation and is a guide to the major glaciated areas of the region (**Back cover**).

Travelers on Interstate 80 can take a side trip on Wyoming Route 130 from Laramie to the town of Centennial (**Figure 2**) at the base of the Medicine Bow Mountains. The highway then rises through prominent end moraines along the mountain front and continues along a glaciated canyon to a broad upland bordering the 1000-foot-high white quartzite cliff of the photogenic Snowy Range (**Front cover**). The highway then gradually descends across glaciated terrain to the margin of the Saratoga Valley.

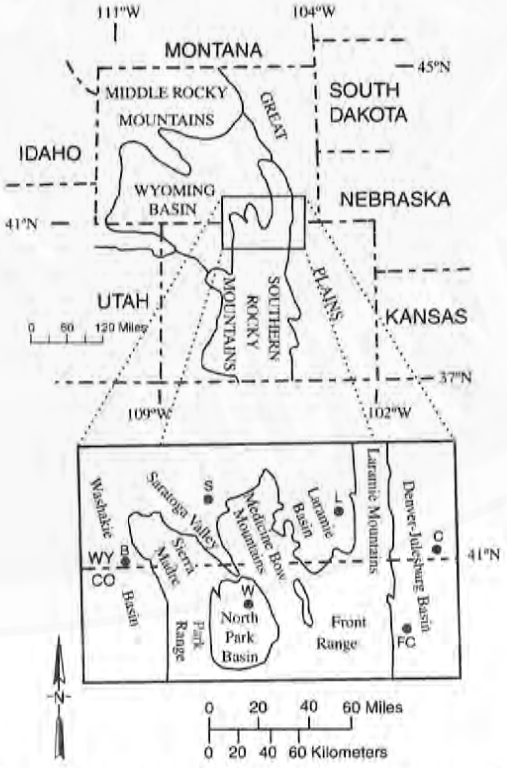

Figure 1. Regional setting of southeastern Wyoming and central northern Colorado, showing geomorphic provinces (top) and major mountains and basins (bottom). B = Baggs, C = Cheyenne, FC = Fort Collins, L = Laramie, S = Saratoga, and W = Walden.

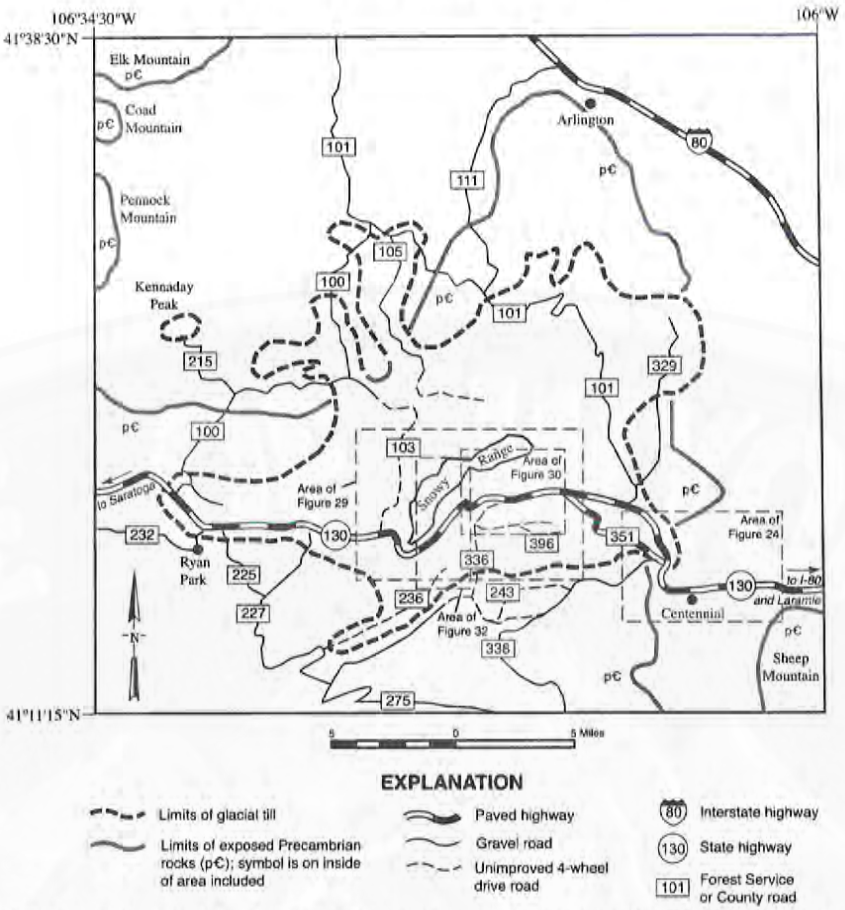

Figure 2. Access to the glaciated region in the northern Medicine Bow Mountains, Wyoming and key to locations of detailed maps.

The glaciated southern part of the Medicine Bow Mountains is accessible from Colorado Route 14, a paved road through scenic Poudre Canyon, and Colorado Route 10 (**Figure 3**), a well-graded gravel road crossing end moraines in the upper Laramie Valley. The area can also be reached via Route 10, south of Woods Landing, 27 miles southwest of Laramie on Wyoming Highway 230. However, trips to the scenic glaciated upland surmounted by cirques along the east side of the Rawah Peaks (**Figure 4**) require hiking with backpacks for overnight camping on long and locally steep trails. On the west side of the peaks several of the end moraines and glaciated valleys are accessible from North Park, Colorado via Colorado Route 125 and then eastward along graded and ungraded dirt roads ending at trails into the cirques.

The glaciated area in the Sierra Madre is crossed by Wyoming Highway 70 (**Figure 5**). North of the paved highway, a 4-wheel-drive road extends along the summit upland where the Bridger Peak lookout tower gives a panoramic view of numerous cirques and glaciated valleys. South of the highway, well-graded dirt roads (adjacent to the glaciated valleys in the Huston Park and Encampment Wilderness areas) extend to Hog Park, where end moraines of glaciers from the high Park Range to the south (**Figure 6**) are partially flooded by a reservoir. Visits to glaciated sites in the southwestern part of the Sierra Madre require hiking from the road to Hahns Peak.

For longer stays to explore the glaciated sites, campgrounds are available on graded gravel or 4-wheel drive roads and hiking trails (although the campgrounds are often crowded on summer weekends and holidays). Excellent maps (see **Appendix A**) which include sites of campgrounds and other cultural features, roads and trails, topography, bedrock, and glacial deposits throughout the Medicine Bow Mountains and Sierra Madre are available from the U.S. Forest Service, U.S. Geological Survey, and the state geological surveys in both Wyoming and Colorado.

Precambrian glaciation

Eliot Blackwelder introduced the concept of Wyoming's Precambrian glaciation in his study of the bedrock in the northern part of the Medicine Bow Mountains. Blackwelder (1926) proposed three episodes of Late Precambrian (Proterozoic) glaciation based on strongly metamorphosed conglomerates and slate-like rocks (phyllites) that he interpreted as "metatillites" and "boulder slates of glacial origin" in a unit which he designated the Headquarters Formation.

George Sylvester, in a detailed study of the Headquarters Formation (1973), evaluated possible non-glacial origins for three layers which might be interpreted as talus deposits at the base of former cliffs, mud flows, or deposits of turbid currents in water. Sylvester concluded that the metamorphosed conglomeratic rock might be lithified glacial till because the pebbles and cobbles (unlike those in stream deposits) were separated by fine-textured material. However, the best evidence for a glacial origin was in the slaty rock (phyllite) which contains some medium to large pebbles at the bottom of streak-like marks indicating dropstones from floating ice (**Figure 7**). A representative site to view these rocks is on the southwestern side of the Snowy Range. It is easily accessible by walking west a short distance from just north of the graded part of Forest Service Road 103.

Several similar sites are mentioned by Karlstrom and Houston (1981) in their comprehensive article on the Precambrian history of southern Wyoming. The sites are interpreted as glacial deposits in a marine environment on a continental platform. This environment was the re-

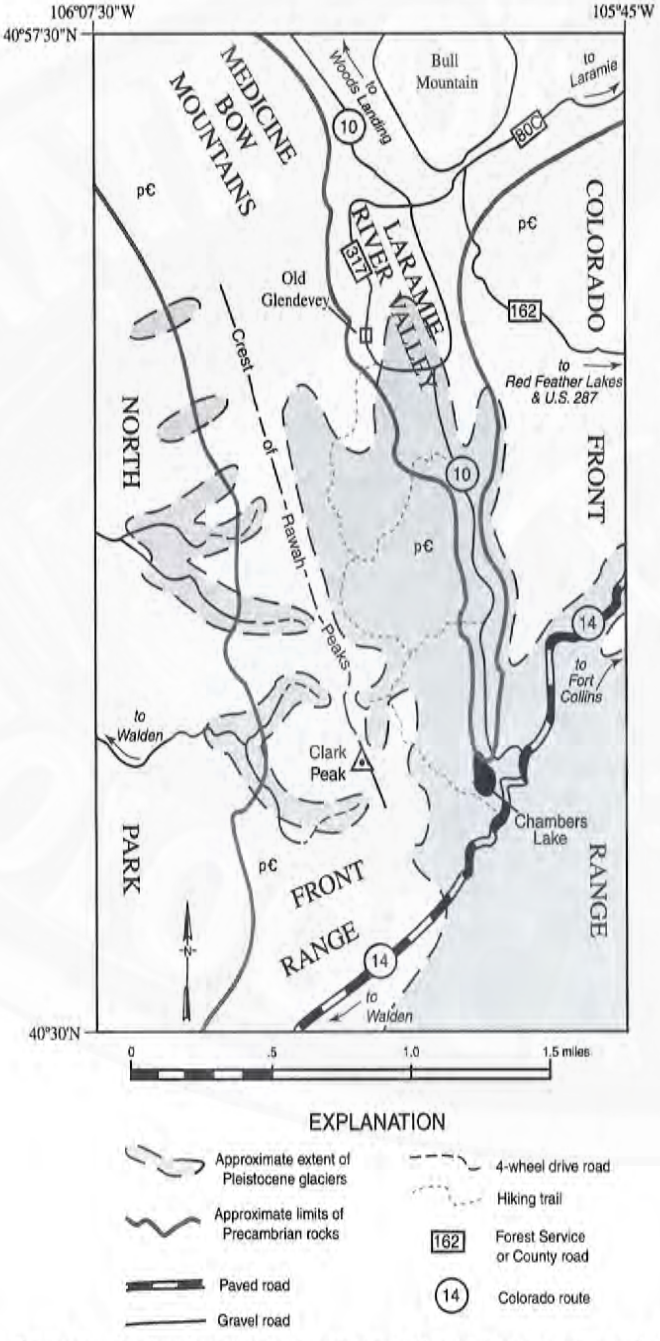

Figure 3. Regional setting and access to the glaciated areas in the southern Medicine Bow Mountains, Colorado.

Figure 4. Rawah Peaks in the Medicine Bow Mountains, Colorado stand above the tree-covered subsummit surface. The peaks are composed of Precambrian granite and granite gneiss. Several well-developed cirques at their base were sources of ice during glacial maxima. View is southwest across Laramie River Valley (foreground) from Colorado Route 10 near Middle Mountain. Photograph by Richard W. Jones, October, 2000.

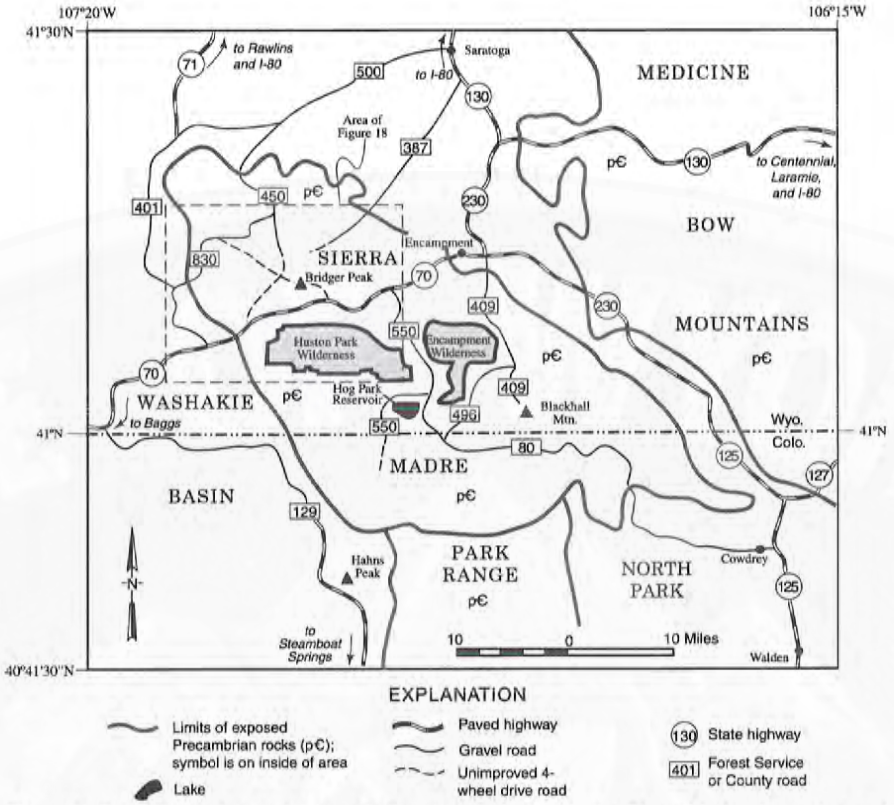

Figure 5. Regional setting and access to the glaciated areas in the Sierra Madre, Wyoming and northern Park Range, Colorado from highways and selected roads.

Figure 6. A portion of the Park Range in northern Colorado. The range extends northward into Wyoming where it becomes the Sierra Madre. These high peaks on the west side of North Park, Colorado are primarily Precambrian granitic and gneissic rocks that have been glaciated. View is west from Colorado Highway 14 southeast of Walden, Colorado. Photograph by Richard W. Jones, October, 2000.

sult of deepening and incursion of an ocean into a rift valley system that cut across early Precambrian (Archean) bedrock of orogenic mountain zones that had developed in the 2.8-billion-year-old Wyoming Archean Province (**Figure 8**). The glacial sediment from a land mass, along with sediments from deltas that developed along the shoreline, were deposited in what Karlstrom and Houston (1981) called a "proto-oceanic gulf." The province was later juxtaposed along major shear zones (the Cheyenne Belt) against metamorphic island-arc materials now exposed in southernmost Wyoming and northern Colorado. Houston (1993) correlated the early Proterozoic glacial units with those in the Huronian Supergroup of Canada and the Marquette Supergroup in northern Michigan.

Figure 7. Precambrian tillites in the Headquarters Formation are composed of pebbles deposited adjacent to dropstones in a fine-grained phyllite matrix. Photograph by Brainerd Mears, Jr.

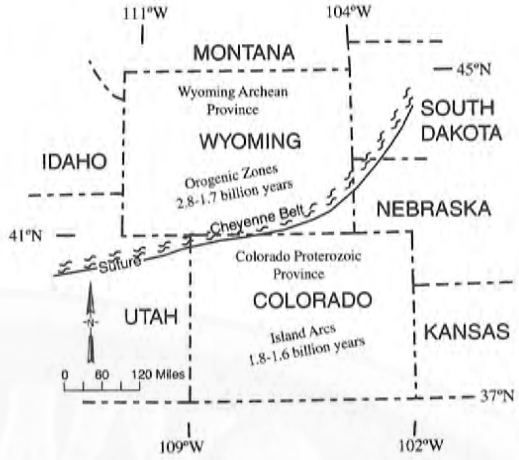

Figure 8. Regional setting of the Precambrian glaciation that followed planation creating a continental platform in Wyoming.

Quaternary glaciation

The Medicine Bow Mountains were glaciated at two localities where their plateau-like upland, from 9000 to 10,500 feet above sea level, is surmounted by alpine ridges. The northern site is adjacent to the metaquartzite mountain front of the Snowy Range where the summit of Medicine Bow Peak is at 12,013 feet. The southern site is adjacent to the gneissic Rawah Peaks (**Figure 9**) reaching 12,151 feet on the summit of Clark Peak. During the major glacial episodes ice radiated from the base of the peaks across the adjacent subdued uplands and fed glaciers extending far down canyons and in places reaching the adjacent plains.

In the Sierra Madre, where the 11,000-foot summit of Bridger Peak is about 1000 feet lower than the peaks in the Medicine Bow Mountains, glaciers were at isolated sites in mountain canyons and along the base of the north end of the mountains.

Cirques, the steep-sided amphitheaters that develop at the head of a glacier, are common in the hard gneissic rocks (**Figure 10**) of the Rawah Peaks and Sierra Madre, but notably absent in the extremely hard quartzites forming the Snowy Range (**Figure 11**).

Beckwith (1941) mentioned a glaciated valley head on Elk Mountain (**Figure 2**), the 11,156-foot-high peak on the north end of the Medicine Bow Mountains; however, that site has only a litter of blocks that fell from the frost-shattered summit

Figure 9. Many of the east-facing cirques in the Rawah Peaks contain glacial lakes (arrow) dammed by moraines from several ice advances during the Neoglaciation. This high peak is south of South Rawah Peak viewed north from atop Clark Peak. Photograph by Wayne M. Sutherland, August, 1999.

Figure 10. Eugene Kiver, who did the major glacial study of the Rawah Peaks, Colorado, is standing on lateral moraine at the Temple Lake type locality (in the Wind River Range) near a cirque lake developed in gneissic rocks. Photograph by Brainerd Mears, Jr., October, 1967.

Figure 11. The steep mountain front of the Snowy Range is composed of metasedimentary quartzite that is tilted nearly vertical and is highly resistant to formation of cirques. The valley east of the mountain front is primarily less resistant schist. Photograph by Wayne M. Sutherland, October, 1969.

Figure 13. Patterned ground west of and below summit of Medicine Bow Peak. Note the white Medicine Peak Quartzite blocks and the steeply dipping quartzite beds on the nearby peak. View to south from Medicine Bow Peak Trail 295. Photograph by Wayne M. Sutherland, October, 1972.

area. The 8000-foot-high windswept upland on the Laramie Mountains east of Laramie (**Figures 1** and **12**) contains ice-wedge casts indicative of Pleistocene permafrost and low snow covers (Mears, 1987), but there is no evidence of glaciation.

Whether the mountains were glaciated or not, the summits above timberline contain evidence of intense past and present frost action (Mears, 1953; Kiver, 1968). Frost action features, which are well displayed along the crest of the Snowy Range, include the jumbles of large angular frost-shattered blocks with sand-blasted surfaces on the massive quartzite bedrock forming the range crest. The somewhat less-hard basalt in an alpine meadow on a cross-cutting basalt dike, displays stone nets (**Figures 13** and **14**) which be-

Figure 12. Ames Monument, located near the old townsite of Sherman, marks the highest point reached by the Transcontinental Railroad. The monument rests on the unglaciated surface atop the Laramie Mountains, which contains no evidence of Pleistocene glaciation. Photograph by Brainerd Mears, Jr., June, 1958.

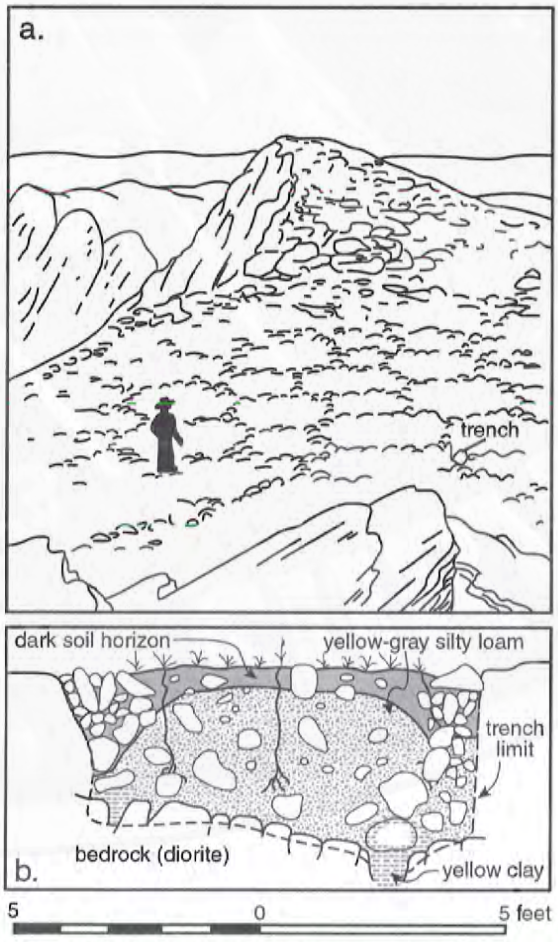

Figure 14. a) Sketched view from the large quartzite blocks on Medicine Bow Peak across the stone nets (polygons) on an igneous dike in the alpine zone, and b) cross section of a trench through a polygon. After Mears (1962).

come elongated and merge into stone stripes on moderate slopes. The nets are attributed to soil sorting in a seasonally frozen zone on permanently frozen Pleistocene ground. Lichens on the uppermost stones indicate that the nets are currently stable and are relics of previously colder episodes.

Today the windswept crest of the Snowy Range (**Figure 15**) develops snow cornices at the top of the 1000-foot-high near-vertical east face, where the occasional clatter of falling blocks indicates currently active strong frost action.

Figure 15. Panorama of Snowy Range mountain front showing major peaks and features. Tree-covered ridge in middle foreground is a parallel ridge of resistant quartzite (Sugarloaf Quartzite) similar to the Medicine Peak Quartzite on skyline. Wide angle photographs taken from Medicine Bow Peak overlook and Miners Cabin trail by Richard W. Jones, October, 2000.

The glacial sequence

The Pleistocene glacial episodes in the Medicine Bow Mountains and Sierra Madre have been correlated with the type localities in the Wind River Range of central Wyoming; however, the records are not identical because the mountain peaks in southern Wyoming and adjacent northern Colorado are about 1700 feet lower. The 13,804-foot summit of Gannett Peak (**Figure 16**) in the Wind River Range (Wyoming's highest mountains) is some 7000 feet above the Wind

Figure 16. Dinwoody Canyon and Gannett Peak with glaciers and Neoglacial moraine (upper center). Photograph by Finis Mitchell.

River Basin to the east and 6500 feet above the Green River Basin to the west.

The type localities (**Figures 17** and **18**) stem from the pioneering work of Eliot Blackwelder (1915) as well as the many subsequent studies by Gerald Richmond which he summarized in 1986. Blackwelder (1915) named the Pinedale glaciation from the town of Pinedale near the prominent end moraines (**Figure 19**) that enclose Fremont Lake, and the preceding Bull Lake glaciation from the more subdued moraines at Bull Lake on the northwestern side of the range (**Figure 20**). He designated the earliest episode as the Buffalo glaciation from scattered deposits of till on ridge and hill tops near Buffalo Fork of the Snake River which flows westward into Jackson Hole. Blackwelder (1915) tentatively dated the Pinedale tills as late Wisconsin, the Bull Lake as early Wisconsin, and the Buffalo as Illinoian based on a glacial sequence he had previously studied in the mid continent.

Gerald Richmond compiled the present scheme from his extensive glacial studies of the Wind River Range (**Figure 17**). He found that Blackwelder's Buffalo sites were actually Bull Lake tills, and selected new type localities for the pre-Illinoian Pleistocene deposits on the plains in the vicinity of the Wind River Range. Richmond designated three pre-Bull Lake glacial episodes: Washakie Point (oldest) and Cedar Ridge for tills and lake beds that preceded major canyon cutting in the mountains, and a Sacagawea Ridge which followed. A cross section of the sequence is well exposed near the top of the 1000-foot-high steep slope developed in Cretaceous and Eocene bedrock along Bull Lake. (Visits to the site, which is on the Wind River Indian Reservation, require permission from the Arapaho and Shoshone tribes, obtained at Fort Washakie).

Recently (1999) Hall and Jaworowski reinterpreted the pre-Bull Lake deposits of Richmond at the Wind River type locality. They rejected a glacial origin for the Washakie Point and Cedar Ridge deposits and accepted only a Sacagawea glaciation. Their concept better fits the glacial sequence in the Medicine Bow Mountains where only one pre-Bull Lake glaciation is indicated.

Relative Time Scales			Glacial Stages Blackwelder (1915)	Moraines and tills Richmond (1986)	Terminology or equivalents used in this paper	Approximate years before present
QUATERNARY PERIOD	Holocene Epoch	Neoglaciation ("Little Ice Age")		Gannett Peak	Gannett Peak	
				Audubon	Audubon	
				Indian Basin	Indian Basin	
				Temple Lake	NR	10,000
	Pleistocene Epoch	Wisconsin Stage	Pinedale	Donald Creek	P5	
				Green River Lakes	P4	
				Third	P3	
			Bull Lake	Pinedale Second	P2	
				First	P1	
						35,000
		Illinoian Stage	Buffalo	Third	NR	
				Bull Lake Second	B2	
				First	B1	
						160,000
		Pre-Illinoian Stage		Sacagawea Ridge	S or	
				Cedar Ridge	Pre-Bull	
				Washakie Point	Lake	
						2,000,000
	TERTIARY PERIOD					

Figure 17. The glacial sequence in the Wind River Range type locality as originally proposed by Blackwelder (1915), subsequently refined by Richmond (1986), and key to abbreviations for glacial episodes used in this paper. NR = Not recognized in the area. Type localities used by Richmond are shown in **Figure 18**.

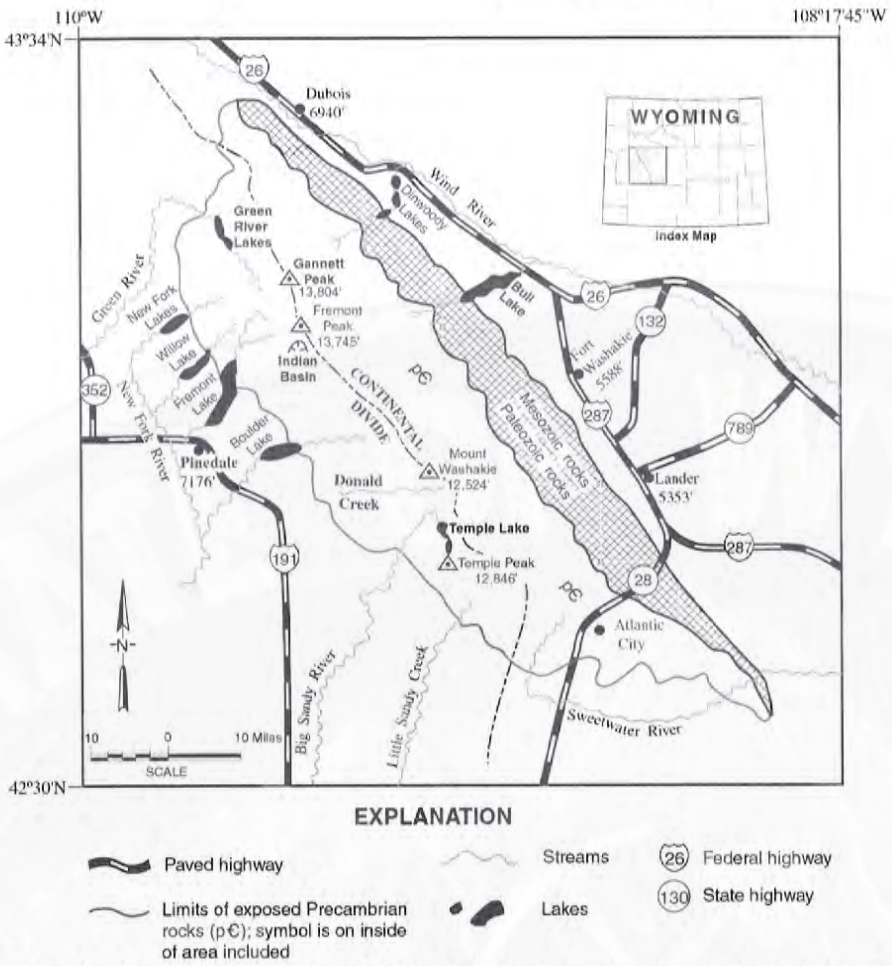

Figure 18. Locations of glacial type localities (bold face), major geologic features, highways, and selected elevations, Wind River Range, Wyoming. See **Figure 17** for approximate glacial sequence and ages.

Figure 19. Air photograph of Boulder Lake east of Pinedale. Like Fremont Lake to the northwest, Boulder Lake also shows Bull Lake (outer) and Pinedale (inner) terminal moraines that served to dam the river valleys, forming the lakes.

Figure 20. Knob and basin topography developed on Pinedale moraine near Dubois in the Wind River Range. Photograph by Brainerd Mears, Jr., October, 1958.

Richmond found three Bull Lake tills forming subdued end moraines bordered by outwash deposits on prominent terraces, and three Pinedale tills with well-preserved end moraines which in places overlap the Bull Lake deposits and extend down to the present floodplain. Pierce and others (1976) determined from the thickness of weathering rinds on obsidian cobbles in Yellowstone Park that Bull Lake glaciation occurred about 140,000 years ago in Illinoian time and the Pinedale from 40,000 to 15,000 years ago in Wisconsin time.

The major retreat of glacial ice in late Wisconsin time was interrupted by some four limited readvances (**Figures 7, 8,** and **16**) of ice in valleys extending into the high upland near the major peaks.

Following a warm interval during latest Pleistocene and much of Holocene time, glaciers in the high country were greatly reduced or disappeared. Small glaciers of a "Little Ice Age" in the highest cirques deposited tills and moraines of several Neoglacial episodes whose type localities in the Wind River Range were named by Richmond. Their sites are in the vicinity of the 13,804-foot Gannett Peak (**Figure 21**) where wasting glaciers can be visited by backpacking on long and often steep trails.

Figure 21. View from Downs Mountain across Grasshopper Glacier to Gannett Glacier (below snow-capped Gannett Peak). Photograph by Finis Mitchell.

Glaciation of the Medicine Bow Mountains, Wyoming

The Pleistocene glacial episodes in the Medicine Bow Mountains accompanied the progressive fluviatile (stream) excavation of the adjacent intermontane basins and associated mountain valleys.

Early Pleistocene upland boulders

In contrast to the Wind River Mountains, where Richmond (1986) proposed three pre-Bull Lake episodes, the Medicine Bow Mountains in Wyoming have evidence of only one episode. This is recorded by conglomerates containing some "king-sized" boulders that are at widely isolated sites on the subsummit upland (**Figure 22**).

West of Centennial the deposits of boulders, some as large as ten feet, were derived from chatter-marked quartzite bedrock along the eastern face of the Snowy Range and transported as much as five miles across the Precambrian rocks of the upland (**Figure 22**). The pre-Illinoian age of these deposits is shown by the wind-polished and pitted surfaces of the boulders that were subsequently broken in places by frost action to expose fresher glassy surfaces.

East and northeast of the Snowy Range, comparable sites of glacially transported upland boulders discovered by Blackstone (1975) overlie the subsummit surface and adjacent strata along Rock Creek Ridge. Northwest of the upland the summit of Kennaday Peak, which is underlain by massive Paleocene conglomerates, is capped by boulders as large as 13 feet. Although Knight (1953) considered all the high-level boulders as part of the Paleocene Hanna Formation, Blackstone pointed out that Hanna boulders are iron-stained roundstones having an average size of 6 feet, whereas the boulders capping Kennaday Peak have dimensions of as much as 13 feet, and are not iron-stained roundstones.

Following the early glaciation, erosion markedly excavated the canyons in crystalline rock, deepened the adjacent basin floors of sedimentary rocks as much as 2000 feet, and isolated the Tertiary deposits and early tills on Kennaday Peak prior to the onset of the late Pleistocene glaciations.

Illinoian and Wisconsin glaciation

During the Bull Lake and Pinedale glaciations, ice caps as much as 500 feet thick along the 1000-foot-high east face of the Snowy Range are indicated by crescentic percussion marks made by transported boulders on the quartzite cliff, striations scratched on diorite dikes, and by isolated boulders on adjacent ridge tops. The ice flowed onto the plateau-like upland and far down canyons, removing older tills and planating a broad area on Precambrian bedrock (**Figure 23**). The extent of the ice is marked by terminal moraines (**Figure 22**): extending far down French Creek, Brush Creek, and Rock Creek canyons; reaching the west side of Centennial Valley; and extending well into Pass Creek Basin. Atwood (1937) designated Wisconsin and pre-Wisconsin

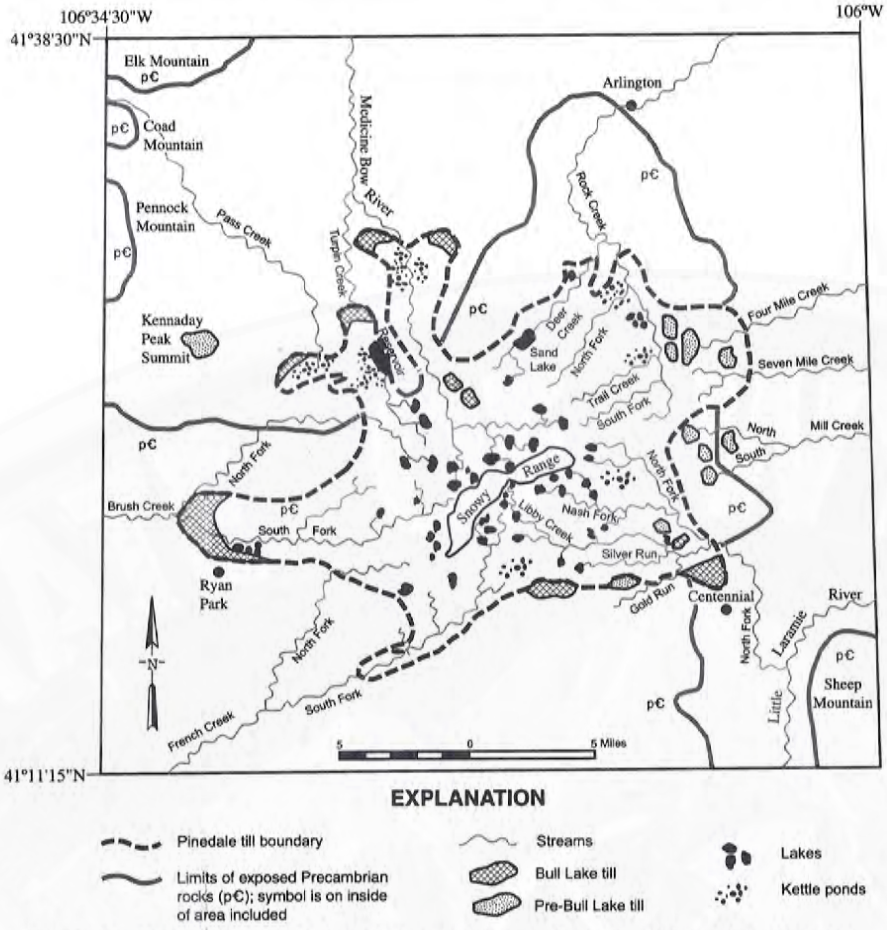

Figure 22. Extent of glacial features in the northern Medicine Bow Mountains, Wyoming.

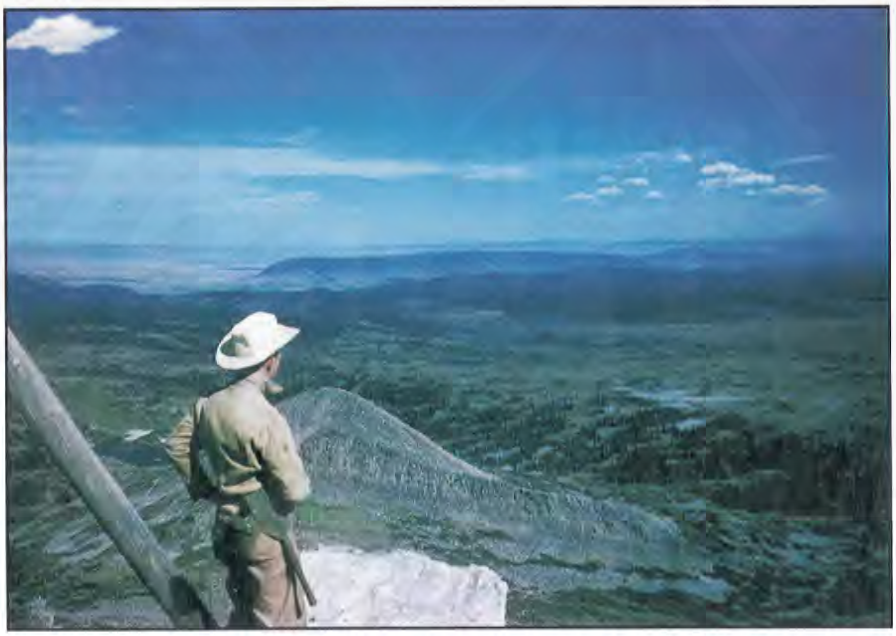

Figure 23. View to east from top of Medicine Bow Peak across Libby Flats (middle distance). Sugarloaf Mountain to right and Lewis Lake to left of Lewis M. Eldred; Laramie Mountains on horizon, Sheep Mountain and Jelm Mountain just below horizon. Photograph by Brainerd Mears, Jr.

episodes in mapping the end moraine throughout the northern Medicine Bow Mountains. Horberg (1951) introduced Blackwelder's terminology of Bull Lake and Pinedale for the moraines near Centennial.

The 100,000-year interval between the Bull Lake and Pinedale glaciations is evident at two sites near Centennial (**Figure 24**). One is inside the broad canyon where Bull Lake till overlies Precambrian bedrock on a mesa-like relic (marked by a 9000-foot elevation symbol) standing some 85 feet above the Pinedale till along the North Fork of the Little Laramie River and 55 feet above the Pinedale till along Libby Creek. The more extensive Bull Lake deposit (**Figure 25**) caps the broad bench to the southeast beyond the mountain front. Highway 130 north of Centennial rises some 200 feet on Cretaceous bedrock (**Figure 26**) above the Pinedale outwash at Centennial. The adjacent Pinedale till is marked by the prominent terminal moraine (P1) that extends from the southeastern side of Libby Creek Canyon, across the bench capped by Bull Lake till, then descends 200 feet to the North Fork where it continues along the southwestern side of Corner Mountain. East of the Pinedale terminal moraine, a water well penetrated 85 feet of glacial outwash on the basin floor of Centennial Valley (Blackstone, personal communication, 1990).

The multiple Pinedale episodes

Following the major Pinedale advance, recession of the ice in the broad canyon west

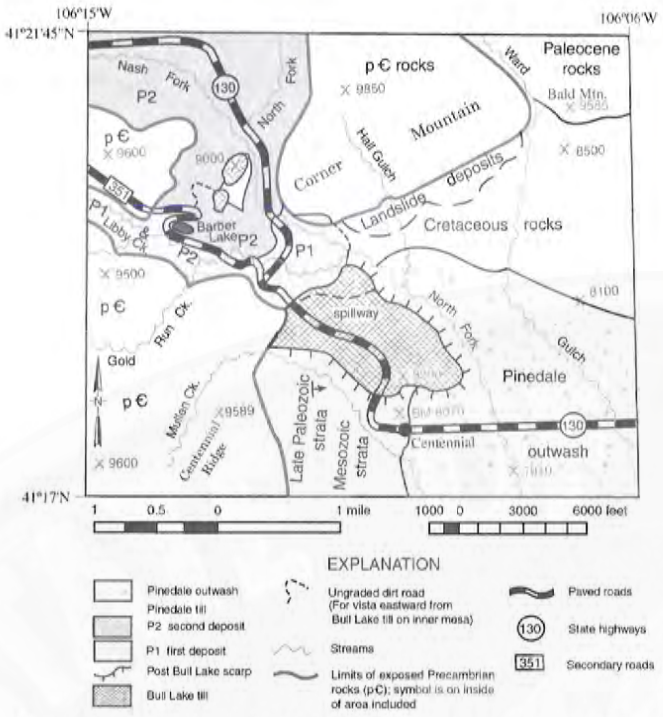

Figure 24. Illinoian and Wisconsin glacial deposits and features in the vicinity of the mountain front near Centennial, Wyoming.

Figure 25. Granitic erratic boulder on Bull Lake moraine near Centennial; Corner Mountain on left skyline, North Fork Little Laramie River in valley to left of boulder.

of Centennial left hummocky till behind. Trapped meltwater created a pond here which is recorded by thin varves (sedimentary layers in a glacial lake) of sand and pebbles washed in during summers, and silts that slowly settled when the pond's surface was frozen. The varves, now exposed in an old gravel pit near Highway 351 (**Figure 27**), are overlain by till of a second advance (P2) that deposited an end moraine half a mile inside the broad canyon mouth. This till contains Barber Lake (**Figure 24**), a large kettle pond attributed to the melting of a stagnant block of ice during the climatic warming near the end of the Pleistocene. The general recession left many small lakes in ice-scoured depressions on the planated upland bedrock (**Figure 28**) and abundant kettle ponds in the hummocky lateral moraines (**Figure 29**). The recession was interrupted by three progressively less extensive glacial resurgences in the high country.

The alpine area

The third Pinedale episode (P3) is marked by a moraine about two miles from the front of the Snowy Range on Precambrian rocks of the broad upland (Libby Flats) and by an end moraine some two and a half miles from the front on Precambrian rocks cut by the steep-sided French Creek Canyon. On the upland near Highway 130, segments of the P3 moraine (**Figure 30**) can be traced two miles eastward from the south side of Black Jack Lake to the vicinity of Forest Service Road 318, beyond which the till has been removed by erosion adjacent to Telephone Creek.

Moraines mapped as Pinedale 4 and 5 (P4 and P5), which are absent on the west side of the

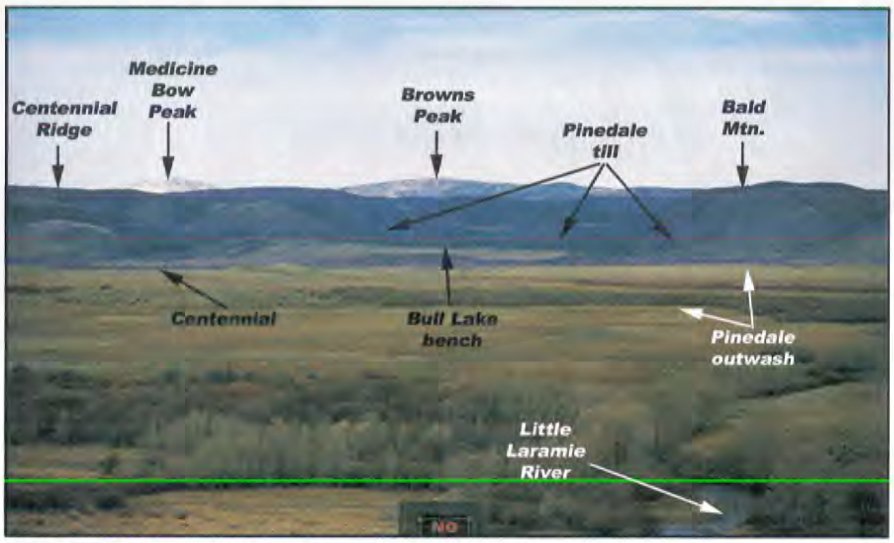

Figure 26. Annotated telephoto view of Centennial (middle left) and the broad bench of Bull Lake till, overlain by Pinedale till above Centennial. View is north from Highway 11 across the Little Laramie River and Centennial Valley. Photograph by Richard W. Jones, October, 2000.

Figure 27. Glacial varves from a meltwater pond near Barber Lake preserve a record of seasonal deposition. Photograph by Wayne M. Sutherland, September, 1972.

Figure 28. View to south across Libby Flats (average elevation about 10,000 feet), a high windswept subsummit surface across which glacial ice flowed. Rawah Peaks in Colorado on skyline. Note that many of the pine trees in the foreground have no branches on their windward side, attesting to the wind's influence. Photograph by Richard W. Jones, October, 2000.

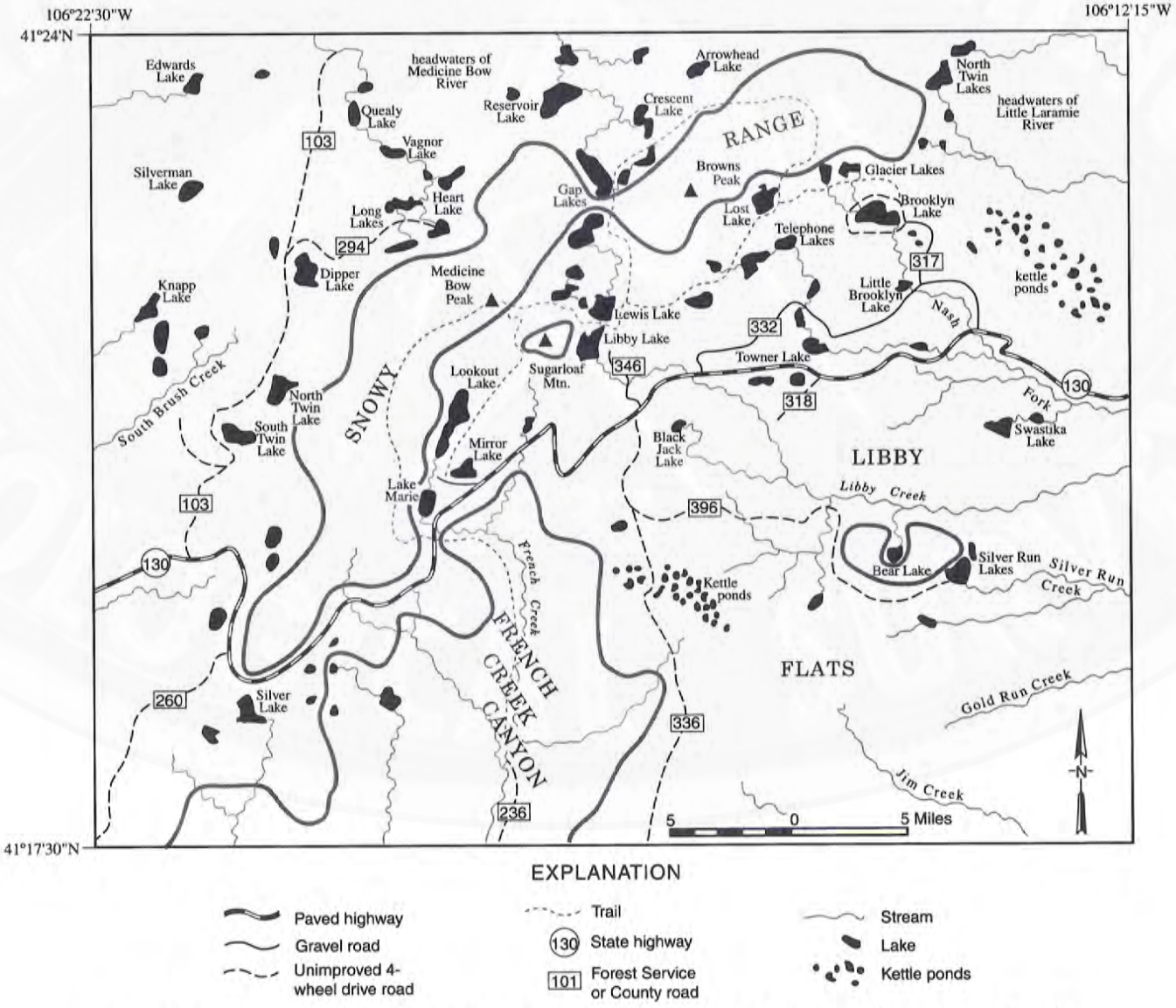

Figure 29. Lakes, ponds, roads, and trails on the glaciated subsummit upland adjacent to the Snowy Range, Wyoming.

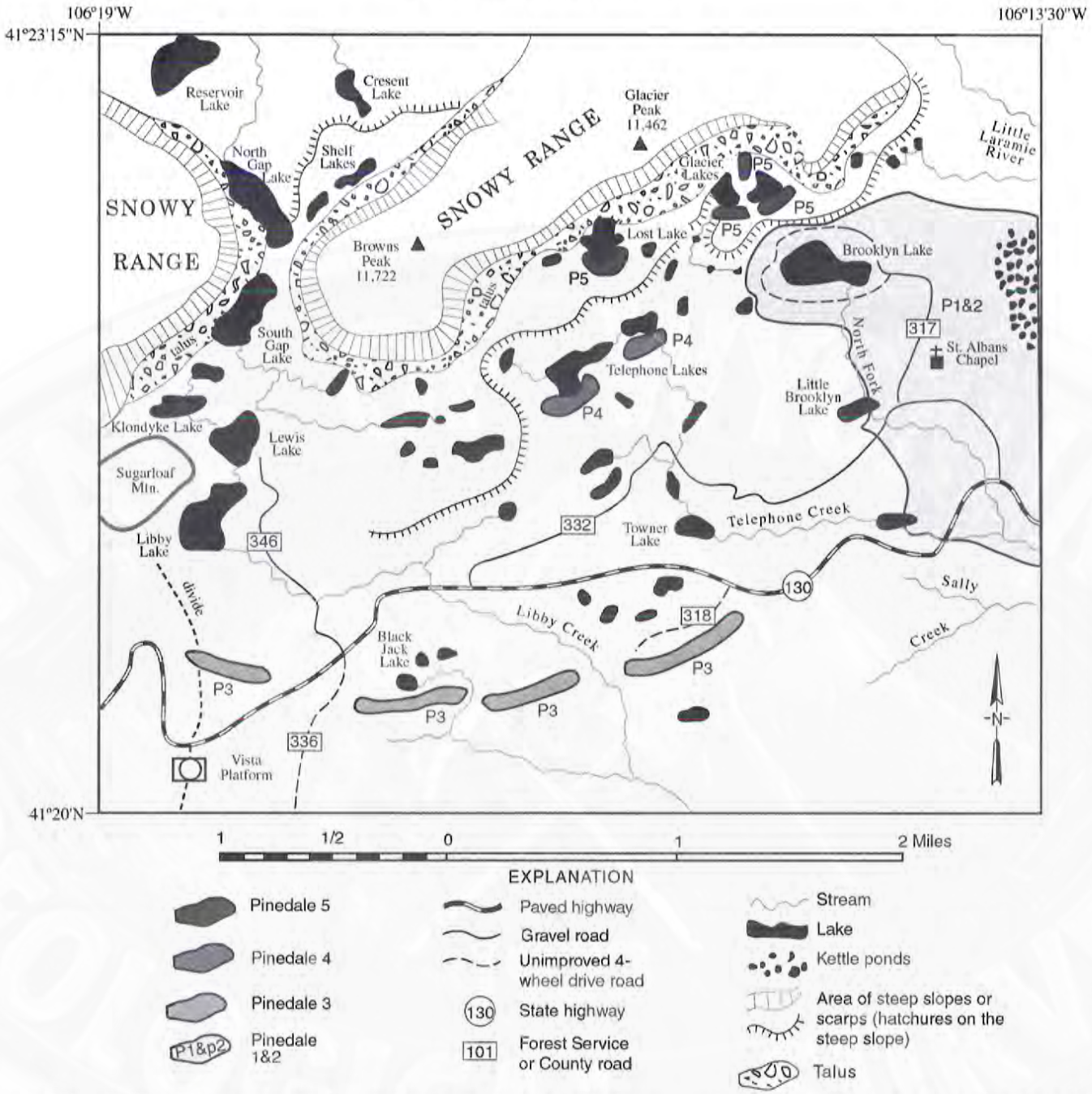

Figure 30. Late Wisconsin moraines (P3, P4, and P5) and other features on the bedrock upland south of the Snowy Range, Wyoming and west of the early Pinedale tills (P1 and P2) along Nash Fork.

Snowy Range (e.g. Saulnier, 1968), are attributed to drift glaciers fed by snow blown by the prevailing strong winds across the mountain crest and down the steep east face of the range[1]. The small glaciers were at two localities separated by a divide extending from the front of the range through Sugarloaf Mountain (**Figure 31**) to the Vista Platform (**Figure 30**).

East of the divide an outer moraine (P4) borders the Telephone Lakes on the subsummit upland. Inner moraines (P5) of the last Pinedale glacial event enclose Lost Lake and the two Glacier Lakes on the gravel-covered bench bordering the active talus along the Snowy Range front.

[1] The downdrafts may have caused the 1955 fatal crash of a misguided propeller-driven airliner into Medicine Bow Peak.

Figure 31. Sugarloaf Mountain (left) and Medicine Bow Peak (right) as viewed from Medicine Bow Peak trailhead at Lewis Lake. Photograph by Richard W. Jones, October, 2000.

West of the divide, ice moving southward between the steep face of the Snowy Range and the spur extending from Sugarloaf Peak flowed two miles down French Creek where it deposited a P3 moraine across the canyon (**Figure 32**). The ensuing recession was interrupted by a minor advance that deposited a broad moraine (P4), mapped by Oviatt (1977) in the scenic area of Lake Marie (**Figure 33**). The last glacial pulse is marked by a small but well defined segment of lateral moraine (P5) on the southeast side of Lookout Lake where it has been partially overlapped by blocks of rock (termed the protalus rampart) that fell from the face of the Snowy Range and overrode late glacial ice.

Along the west side of the lakes the P5 moraine is covered by quartzite blocks as much as

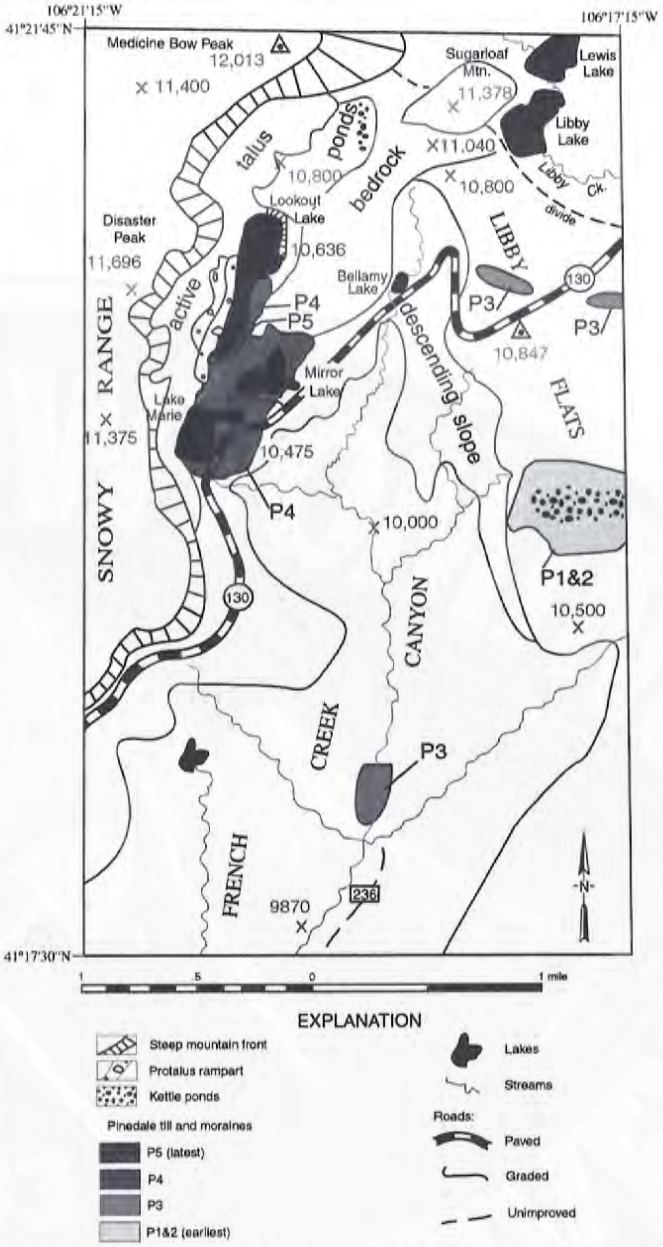

Figure 32. Wisconsin till and moraines, and Holocene protalus along the headwaters of French Creek, east of the Snowy Range, Wyoming.

Figure 33. The northern and eastern edges of Lake Marie are composed of P4 moraines (tree-covered hills in center and right side of photograph). Top of the protalus ramparts described in the text can be seen at the base of the talus slopes below the peak called "Old Main." Photograph by Richard W. Jones, October, 2000.

10 feet on a side that fell from the cliff and skidded on ice or compact snow to form a protalus ridge. Its front can be climbed, avoiding unstable blocks, to the 50-foot-high crest (**Figure 33**) beyond which a prominent hollow formerly occupied by glacial ice extends to an inner rampart bordering the massive talus along the steep face of the range. The ongoing growth of talus is marked by the occasional clatter of large blocks falling down the near-vertical face and periodic rock avalanches on the steep upper talus slopes.

Glaciation of the Medicine Bow Mountains, Colorado

The first report of glaciation in the Medicine Bow Mountains was in 1867 by Clarence King, first director of the U.S. Geological Survey, who described a locality near Clark Peak in Colorado. That site (**Figure 34**) is at the south end of the 14-mile long crest of the glaciated Rawah Peaks, which stand above the extensive subsummit upland. The glacial sequence east of the divide along the peaks has been studied in detail by Kiver (1968, 1972). The sequence west of the divide has not been described. However, preliminary observations suggest that, as in the northern Medicine Bow Mountains, late Wisconsin drift glaciers (P3 and P4) fed by snow blown across the mountain crest only developed east of the summit and were absent at the heads of eight glacial troughs on the west flank of the Rawah Peaks bordering North Park (**Figure 3**) which is drained by the North Platte River.

During the Pleistocene glacial maxima, ice flowing northward from the high Colorado Front Range into the Laramie Valley and the head of the Laramie River (**Figure 3**) was joined by glaciers flowing eastward from the vicinity of the Rawah Peaks.

Early episodes

Tills of pre-Illinoian advances are preserved at three isolated sites on and near North Middle Mountain (**Figure 35**), a mesa-like relic of a former valley floor some 300 to 450 feet above the present stream levels. The oldest deposits, which are on the main valley wall and on North Middle Mountain, include locally derived boulders as much as 10 feet in diameter, as well as cobbles derived from volcanic bedrock in the Front Range. A lower deposit along the south end of North

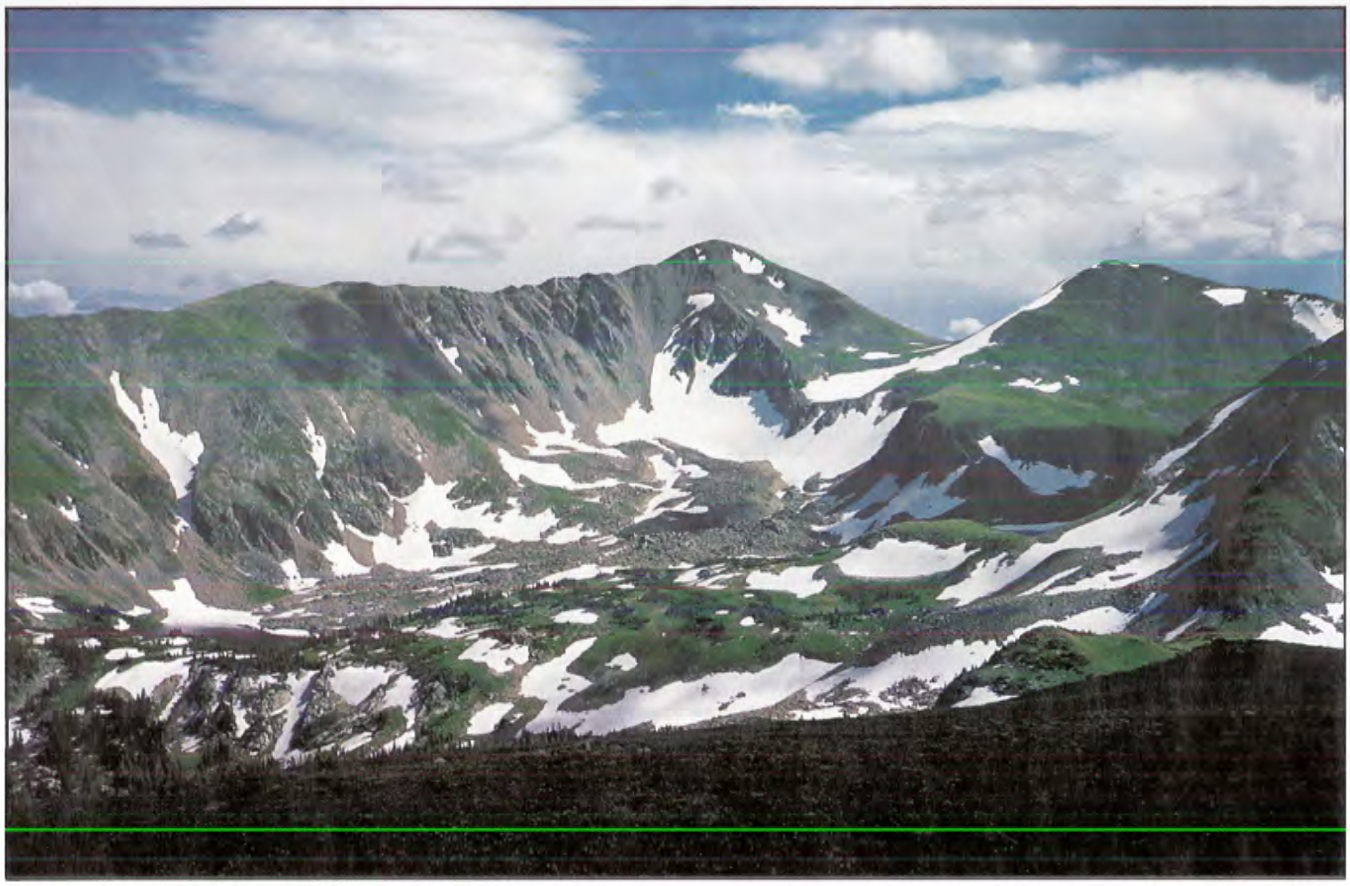

Figure 34. Clark Peak, elevation 12,151 feet, is the highest of the Rawah Peaks and the highest peak in the Medicine Bow Mountains. Three moraines from the Little Ice Age are present between Timber Lake (lower left) and the cirque headwall (which still contains ice) at the base of the snowfield below Clark Peak. Oblique air photograph by Brainerd Mears, Jr., August, 1968.

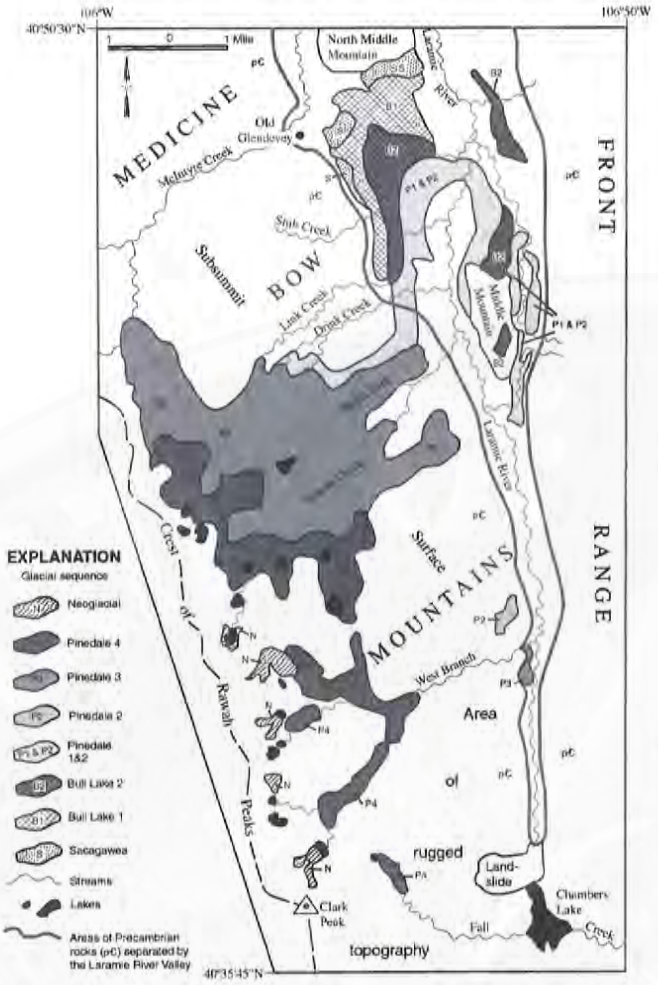

Figure 35. Glaciated areas and the sequence of tills east of the divide along the Rawah Peaks in the Medicine Bow Mountains and upper Laramie Valley of Colorado. Abbreviations include S (pre-Illinoian) Sacagawea; B1 and B2 (Illinoian) Bull Lake; P1, P2, P3, and P4 (Wisconsin) Pinedale; N (Neoglacial) includes Indian Basin, Audubon, and Gannett Peak episodes.

Middle Mountain and a related high terrace on the west side of the valley near old Glendevey has a very subdued topography of rounded ridges and shallow depressions. Kiver (1968) interpreted that deposit as equivalent to Richmond's Sacagawea episode in the Wind River Range.

The Illinoian

Bull Lake tills, whose moraines have been eroded to a moderately subdued topography, are found at three isolated sites bordering the prominent Pinedale terminal and lateral moraines along the valley floor (**Figure 35**). The Bull Lake deposits represent two episodes during which end moraines of the first episode were breached and their outwash eroded to form a terrace prior to the second advance that partially overlapped Middle Mountain and diverted the Laramie River to its present course along the east side of North Middle Mountain. The notable absence of Bull Lake recessional tills is attributable to the major interval of erosion that preceded the onset of Pinedale glaciation whose advancing ice scoured the uplands and valleys.

The Wisconsin

Tills and moraines of four progressively less extensive Pinedale episodes (P1, P2, P3, and P4) were mapped by Kiver (1972) and correlated with the sequence of terraces (**Figure 36**) along the Laramie River. In the rugged topography near Clark Peak (**Figures 34** and **35**) the tills are confined to the deep glacial troughs along the West Branch of the Laramie River. To the north where the subsummit surface is prominent, ice caps extensively planated the upland bedrock and fed valley glaciers along McIntyre and Rawah creeks. During the Pinedale glacial maximum (P1), ice flowing from alpine sources deposited the prominent moraines whose outwash and till are markedly lower than the sites of Bull Lake deposits. The second Pinedale advance (P2), which followed a limited recession, left a directly adjacent inner moraine whose outwash is slightly lower than that of the preceding advance.

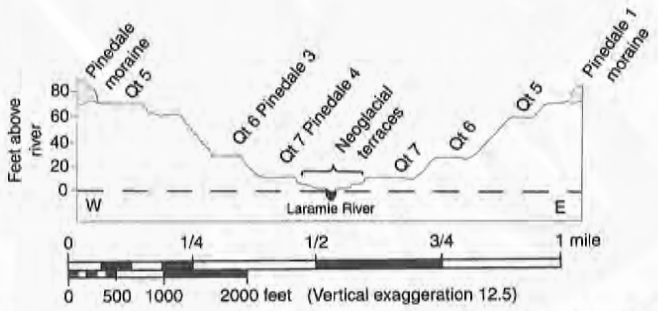

Figure 36. Sequence of Pinedale outwash terraces and their tentative dates, plotted by Kiver (1972) along the upper Laramie River, Colorado, inside the outer Pinedale moraines.

The tills contain distinctive volcanic cobbles derived from remote bedrock to the south in the high Colorado Front Range. The source was cut off by a late Wisconsin landslide that blocked the Laramie River at the south end of Chambers Lake and diverted the headwaters into the Cache la Poudre River (which flows eastward through the

Front Range upland to the Colorado Piedmont in the vicinity of Fort Collins).

The major recession of the Wisconsin ice was interrupted by a third Pinedale episode (P3) marked by a moraine on the floor of the Laramie Valley near the mouth of the West Branch Canyon, and by moraines that border broad ice-scoured areas on the subsummit surface and extend into the canyons of Rawah, Link, and McIntyre creeks. The fourth Pinedale episode (P4) is recorded by tills along the narrow valleys in the rugged terrain at the headwaters of West Branch of the Laramie River (**Figure 35**), and the hummocky tills containing small lakes in the rugged terrain at the head of Rawah Creek.

Following the end of the Pleistocene some 10,000 years ago, the onset of the present epoch known as the Holocene was marked by climatic warming. It reached a maximum about 5000 years ago and eliminated the last Wisconsin glaciers in the Medicine Bow Mountains.

The Little Ice Age (Neoglaciation)

Late Holocene cooling which began about 4000 years ago led to the development of drift glaciers along the east flank of the Rawah Peaks in 14 cirques above 11,000 feet (four timbered cirques at lower elevations have no evidence of post-Wisconsin glaciation). Kiver (1968) found relics of wasting ice above 11,400 feet in four cirques bordered by deposits of three Little Ice Age episodes. Along the head of the broad valley north of Clark Peak (**Figure 37**) he mapped an outer Neoglacial till (Indian Basin) bordered by moraine, an adjacent less extensive till (Audubon) largely overridden by rock glaciers (whose ice was from snow that filtered down into piles of talus blocks), and deposits of a final episode (Gannett Peak) extending from the cirque headwall and partially overlapping the earlier deposits (**Figure 34**). Another site accessible by backpacking is at Rawah Lake Number Four (**Figure 38**) which is ponded by moraines of the first and second Neoglacial episodes (Indian Basin and Audubon) and bordered by till of the third (Gannett Peak) along the steep cirque headwall.

Although Kiver (1968) found no material for radiocarbon dating, the three Neoglacial tills are comparable to the sequence that Richmond subsequently (1986) designated as type localities in the Wind River Range. The sequence includes Indian Basin tills, deposited 3000 or more years before the present (b.p.) or 1000 B.C.; Audubon tills, 2400 to 800 b.p.; and 350 to 130 b.p. Gannett Peak tills, that preceded the ongoing episode of warmer climate.

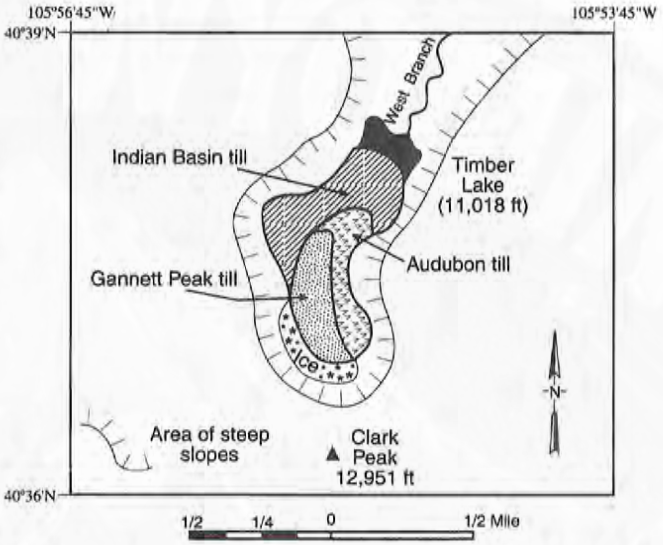

Figure 37. Neoglacial tills and moraines in valley north of Clark Peak, Colorado.

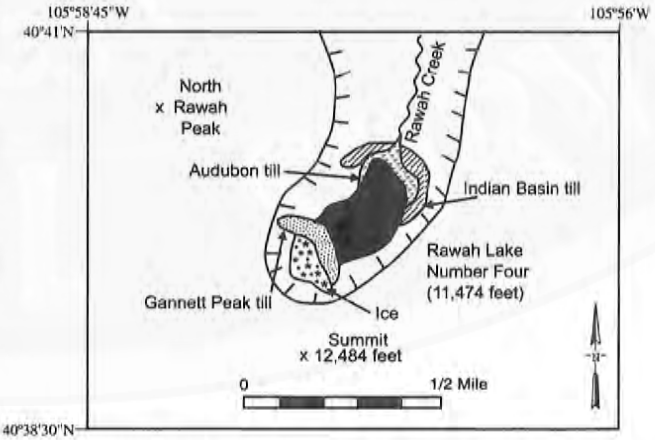

Figure 38. Neoglacial tills and moraines at Rawah Lake Number Four, Colorado.

Glaciation of the Sierra Madre

The lack of previous publications on Pleistocene glaciation of the Sierra Madre may in part reflect their general forest cover. In contrast to the Medicine Bow Mountains where the Snowy Range and Rawah Peaks rise a thousand feet above the subsummit surface, the crest of the Sierra Madre, which extends along the Continental Divide, is an elongate plateau-like upland surmounted by the isolated 11,004-foot summit of the treeless Bridger Peak. This peak stands only about 120 feet above the adjacent upland and is mantled by frost-shattered quartzite blocks.

The unglaciated upland, which has evidence of strong Pleistocene frost action, is bordered by cirques at the heads of some six glaciated valleys. The glaciers were longest in north to east trending valleys bordering the upland, and less extensive where the ice flowed south or west (**Figure 39**). With two exceptions where south facing cirques had short glaciers, headward erosion has created north-facing cirques (**Figure 40**) whose ice was shaded when the daily temperatures were highest in mid-afternoon.

Cow Creek glaciation

In Cow Creek Canyon (**Figure 41**) where two north-facing cirques border the main valley, glacial ice extended some four miles eastward from the subdued cirque at the head of the valley. Detailed mapping, following Price (1973) who recognized the evidence of multiple glaciations, indicates a pre-Illinoian episode marked by a relic of bouldery till on the subsummit upland. The boulders, derived from a distinctive (garnet-schist) bedrock, had been transported eastward across the upland before the major canyon deepening of some 600 feet that preceded the Illinoian and Wisconsin glacial episodes.

Figure 39. Battle Lake as viewed to the southeast from near the Edison historical marker along State Highway 70. The lake occupies a north-facing cirque dammed by Pinedale 4 moraine. Photograph by Richard W. Jones, October, 1988.

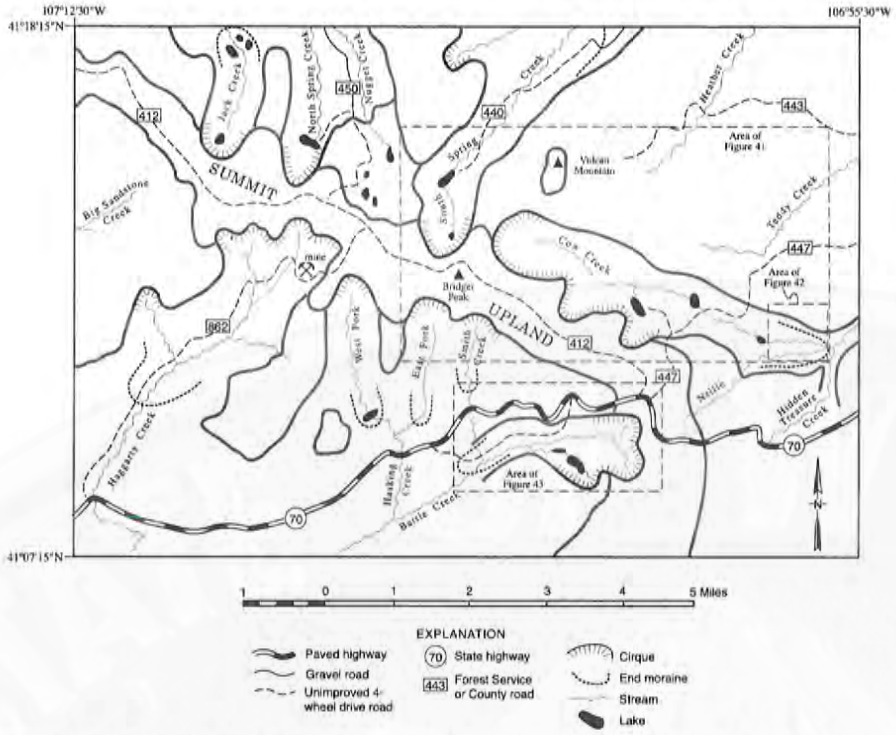

Figure 40. Glaciated sites in the central part of the Sierra Madre, Wyoming and their access from roads.

As in the Medicine Bow Mountains, a moderately subdued relic of Bull Lake moraine is preserved at a slightly higher level than the prominent Pinedale (P1) terminal moraine that occupies the canyon (**Figure 42**). During an initial glacial recession, meltwater reworked some of the adjacent moraine creating a kame terrace, and an esker where deposits washed into a tube in the ice. A resurgence of the Pinedale ice (P2) created a prominent end moraine across the recessional deposits and lateral moraines which are partially overridden by a rock glacier along the north canyon wall (**Figure 42**). The ensuing major glacial recession was interrupted by resurgences marked by a moraine (P3) on the canyon floor (which is now mostly buried by younger deposits) and moraines (P4) in the vicinity of the cirques.

Post-Pleistocene deposits include talus and landslides along the canyon walls, and extensive swamp and pond alluvium inside the moraines on the valley floor.

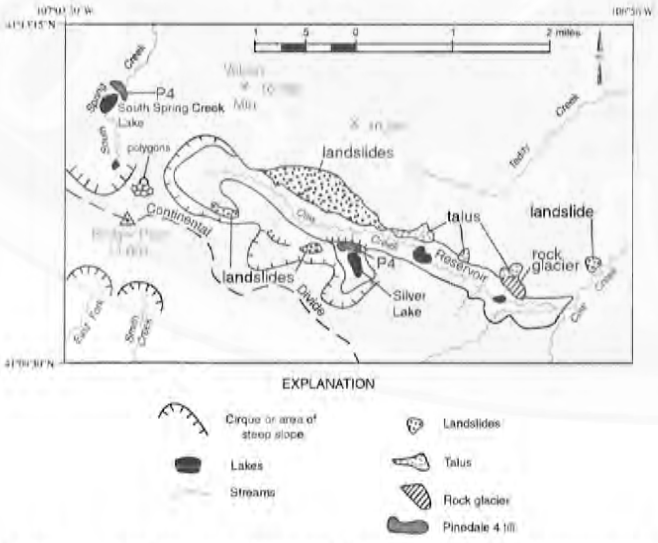

Figure 41. Cirques and associated features along the glaciated segment of Cow Creek Canyon, Wyoming.

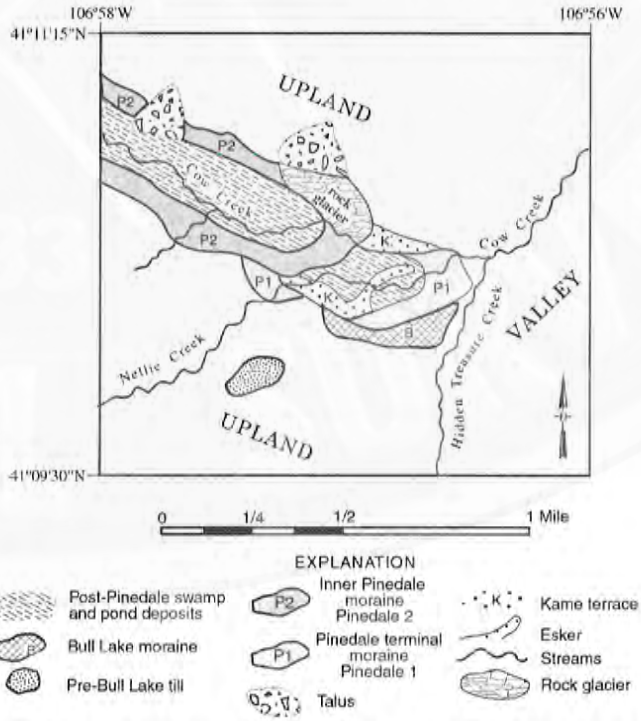

Figure 42. End moraines and related deposits along or near Cow Creek Canyon, Wyoming.

Battle Creek glaciation

In Battle Creek Canyon (**Figure 43**) where the broad cirques face the afternoon sun, the glaciers only extended two miles westward. Bull Lake tills deposited on the Illinoian valley floor were stripped during the advance of Wisconsin ice. The outermost Pinedale till (P1) on the present valley floor is bordered by outwash extending a quarter of a mile westward to the steep narrow where the creek flows through a ridge of Precambrian rock.

The hummocky timber-covered Pinedale moraines, whose deposits are exposed in many abandoned exploration pits for uranium ore, include the outermost till (P1) and two inner tills (P2 and P3) whose boundaries are poorly defined. Tills of the last Pinedale episode (P4) make a well-defined end moraine in the generally unforested north-facing cirque containing Battle Lake (**Figures 39** and **43**). The moraine is bordered by a rock step descending to the earlier tills along the west-trending main valley floor. The orientation of this cirque is attributed to headward erosion which was shaded in the afternoon.

A point of interest on the highway overlooking Battle Lake is a stone marker where Thomas A. Edison (in 1878) decided that the bamboo fibers in his fishing pole could be used as the filament for an electric light.

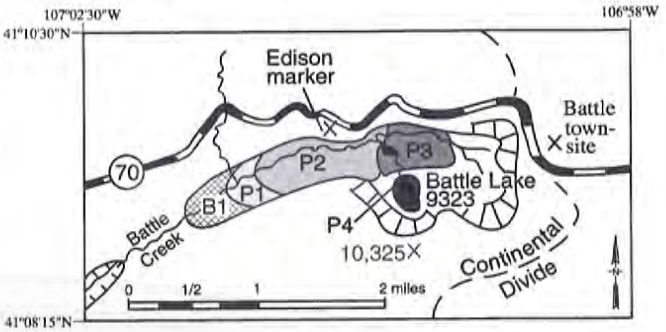

Figure 43. Glacial sequence and cirques at the head of Battle Creek, Wyoming.

The southern Sierra Madre

South of Battle Lake where the upland along the Continental Divide extends through the Huston Park Wilderness, the glaciated terrain has numerous cirques at the head of ice-scoured valleys, in sites which are accessible from hiking trails. In Hog Park, along Forest Service Road 550 (**Figure 5**), the moraines at the south end of the reservoir and adjacent sites were deposited by glaciers flowing northward from the high Park Range in Colorado.

Conclusions about the climate

Although the glaciers indicate much colder conditions when snow that survived summer melting was progressively converted to flowing ice, the best approximation of annual temperatures during the glaciations is provided by distinctive sand and silt-filled wedges exposed by excavations into Pleistocene deposits and the bedrock on the unglaciated basin floors (**Figures 44, 45,** and **46**). The wedges, some 6 feet deep, originated along ice-filled polygons, as much as 30 feet across, during the Pleistocene when the Wyoming basin floors

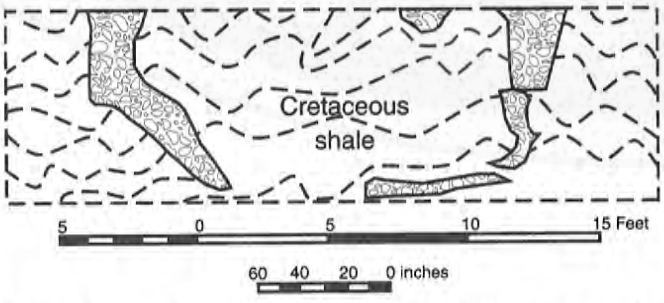

Figure 44. Sketch of sediment-filled casts of former Wisconsin ice wedges, in an excavation to enlarge the Centennial school building.

Figure 45. Ice wedge casts in excavation (now walled off) behind the Centennial School. These casts are developed in Cretaceous shales below Bull Lake moraines to the north. Photograph by Brainerd Mears, Jr., 1999.

Figure 46. Ice-wedge cast at the Rawlins city dump contains a large cobble that fell into the space left when the ice melted. Photograph by Brainerd Mears, Jr., July, 1989.

were underlain by permanently frozen ground of the sort now found in northern Alaskan tundras (Mears, 1987). The present sediment-filled wedges developed when the ice melted and was replaced by infalling wind-blown silt and sand.

Based on studies of 85 wedge sites throughout Wyoming (Mears, 1987), the state's mean annual temperatures were some 25°F (14°C) colder than the present during the major glacial episodes.

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Appendix A.
Maps and other sources

The U.S. Forest Service (located at the junction of Wyoming Highways 130 and 230 in west Laramie) sells an excellent large map published in 1998, folded to pocket size, that shows campgrounds as well as roads and trails in the Medicine Bow-Routt National Forest, including the Sierra Madre and the Laramie Mountains.

The Wyoming State Geological Survey (located on the University of Wyoming campus in Laramie) has free Wyoming highway maps, sells U.S. Geological Survey topographic and other maps, and has numerous maps and publications on geology and mineral resources of the areas described in this report. A free publications list is available.

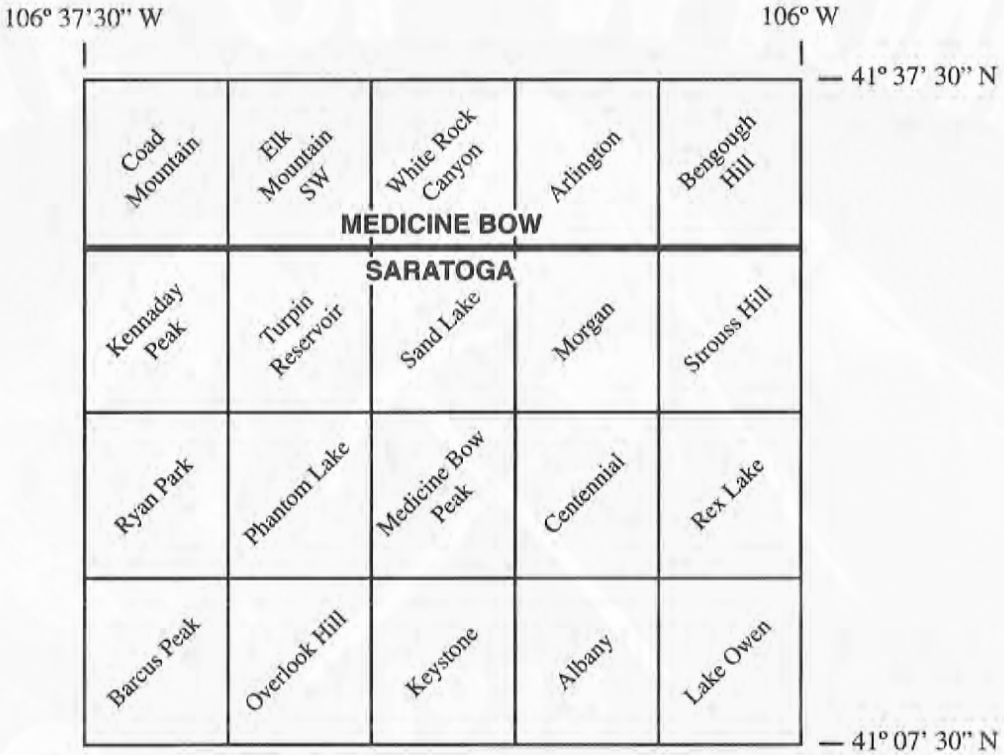

Figure A-1. Index to 1:24,000- and 1:100,000-scale topographic maps for the glaciated and directly adjacent sites of the Medicine Bow Mountains, Wyoming. The 1:100,000-scale metric map names and areas are shown in bold.

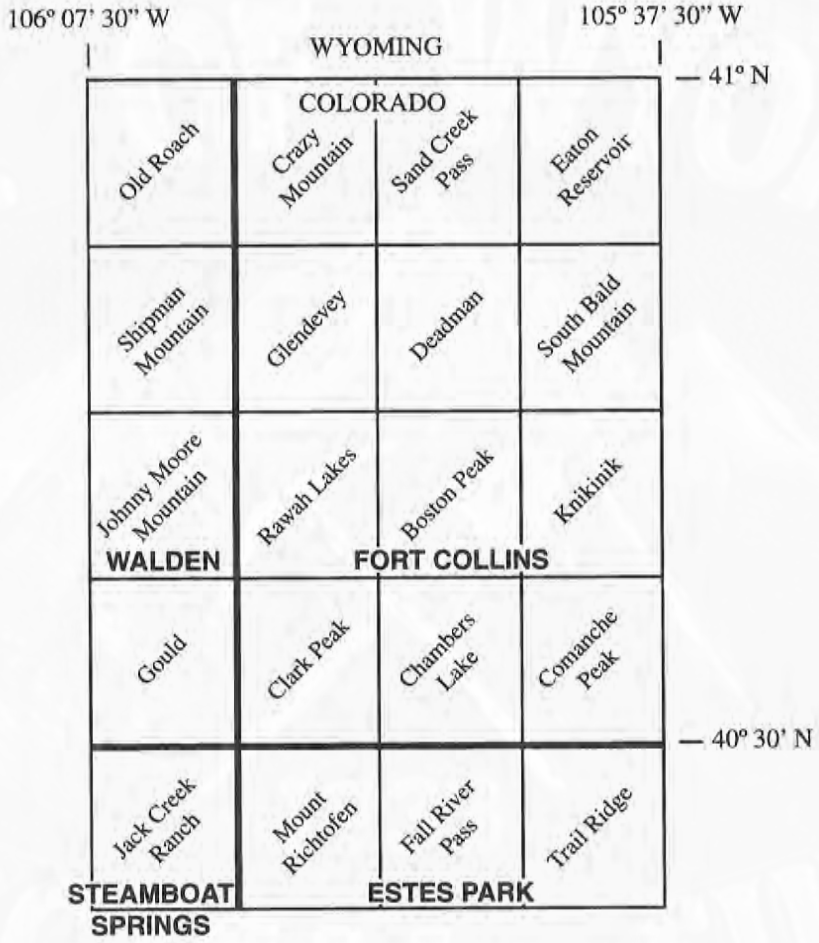

Figure A-2. Index to 1:24,000- and 1:100,000-scale topographic maps for the glaciated and directly adjacent sites of the southern Medicine Bow Mountains, Colorado. The 1:100,000-scale metric map names and areas are shown in bold.

Figure A-3. Index to 1:24,000- and 1:100,000-scale topographic maps for the glaciated and directly adjacent sites of the Sierra Madre, Wyoming and adjacent Colorado. The 1:100,000-scale metric map names and areas are shown in bold.

STATE OF WYOMING
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