THE GEOLOGICAL SURVEY OF WYOMING
Gary B. Glass, State Geologist

LATE PLEISTOCENE PERIGLACIAL WEDGE SITES IN WYOMING:

an illustrated compendium

by
Brainerd Mears, Jr.

Memoir No. 3
1987

Laramie, Wyoming

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Front Cover: Polygons delineated by periglacial sand-wedge relics penetrating Cretaceous shale. This dramatic evidence of Pleistocene permafrost in Wyoming was exposed during construction of U.S. Interstate Highway 80 at Walcott Junction, about 15 miles (24 kilometers) east of Rawlins, Wyoming, (site CB 3, p. 54).

Back Cover: Ice-wedge casts cutting Pleistocene gravel in an excavation wall of the Rawlins sanitary landfill (site R 1, p. 56). (Top) Cross sectional diagram, along 100 feet (31 meters) of the excavation, showing six wedge casts; (lower left) photograph of a single wedge; (lower right) diagram of the wedge in photograph.

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by
Brainerd Mears, Jr.[1]

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Numerous photographs and diagrams appear with site descriptions and are not listed separately here.

*Now we crossed the North Platte River and ran on towards Rawlins in May, over the road were veils of blowing snow. This was Wyoming, not some nice mild place like Baffin Island -- Wyoming, a landlocked Spitsbergen...**

(John McPhee, 1986, *Rising from the Plains*, p. 6)

*McPhee exaggerates. Wyoming has an excellent climate. It does get cold in winter and the wind blows, but our summers are delightful. At Laramie, 7,200 feet above sea level, the University of Wyoming advertises *the coolest summer school in the Nation*. In the Pleistocene however, conditions were probably more rigorous.

Abstract

Late Pleistocene permafrost in Wyoming's high intermontane basins is documented at 85 sites containing hundreds of ice-wedge casts and sand-wedge relics. The wedges penetrate as much as six feet (2 meters) or more into host materials and delineate polygons ranging from about six feet to 30 feet (2 to 10 meters) in diameter. The host materials include various Mesozoic and Tertiary bedrocks, as well as Pleistocene alluvium and colluvium. In one unique case, wedges penetrate a highly weathered Precambrian schist and in another they penetrate eolian sands. Deformation of host materials against wedge margins, either bent up or sagged down, is evident where suitable markers such as laminae or pebbles are present, but is not discernible in fine-grained homogeneous materials.

The wedge fills are derived from a mantle, commonly displaying moderate soil development, that covers the Pleistocene surfaces. Thin vertical veins characterize internal fabrics of sand-wedge relics. Ice-wedge casts contain sagged laminae and large pebbles at some sites. Particle-size analyses show that wedge fills are dominantly poorly to extremely poorly sorted silty sands with some clay content and occasional gravels. Binocular-optical and scanning-electron microscopic examination of material in the medium- to fine-grained quartz sand fractions discloses appreciable quantities of well-rounded quartz grains of probable eolian origin, as well as conchoidally fractured grains and chips attributed to periglacial processes.

The wedge-forming episodes were originally dated as Pinedale and possibly Bull Lake (Mears, 1981) based on the geomorphic sites, the nature of associated Quaternary deposits, and pedologic development of soils across the wedge-filling mantles. In the Laramie basin, where the greatest number of wedges have been studied, they are notably absent in Holocene deposits but are present across low hills and the surfaces and flanking slopes of a series of alluvium-capped benches and terraces ranging from early Pleistocene to late Wisconsin in age. Radiocarbon-datable material is rarely preserved in the oxidizing brown-soil environments of the wedges. However, a late Wisconsin time of wedge development is bracketed by: (1) a radiocarbon age determination of about 25,000 years for host materials cut by wedges, at one perennially wet site, and (2) a radiocarbon-dated 6,000-year-old archaeological site in deposits that unconformably overlie a well-developed paleosol on wedge-filling materials.

The Wyoming wedges indicate that the environment was windswept (confirmed by abundant deflational landforms) and arid; deeper snow covers than the present would have insulated the ground from the penetrating cold snaps that create periglacial wedges. Mean annual temperatures were at least 25°F (14°C) colder than the present, based on calculation of the difference between the present temperature at the warmest weather station near Wyoming wedge sites and the 21°F (-6°C) temperature required for active wedge development in the present-day Alaskan permafrost environment.

Introduction

Eighty-five sites exhibiting hundreds of nonsorted polygons delineated by narrow to moderately flared wedges have been found in the intermontane and piedmont plains of Wyoming (Figure 1). The wedges, interpreted as periglacial ice-wedge casts and sand-wedge relics, are probably of equal abundance throughout Wyoming's basin floors; their apparent concentration in the Laramie Basin reflects the region of my most concentrated investigation.

In the former periglacial zones of the central and eastern United States, Canada, and northern Europe, many wedge-polygons have been discovered from aerial photographs (for example: Johnson, 1982; Walters, 1978; Svensson, 1984). In Wyoming, however, the polygons are commonly blanketed by wedge-filling mantles and younger Quaternary deposits. Natural deflation or surficial bulldozing at construction projects has occasionally exposed the polygonal patterns. However, most discoveries have been of wedges exposed in vertical faces of gravel pits and quarries, pipeline trenches, sanitary landfills (dumps), and building-foundation excavations, as well as a few natural cuts. Such excavations are ephemeral, soon obscured by slopewash and backfill; thus many of the sites are no longer observable. An earlier report (Mears, 1981) described six selected sites (from the 25 then known); evaluated alternate hypotheses for the origin of the wedges; and presented a general paleoclimatic, floral, and faunal interpretation of the late Pleistocene environment. The present work records all currently known wedge sites, and presents an updated discussion of their nature, geomorphic distribution (with emphasis on the Laramie Basin), age, and paleoclimatic significance.

The regional setting

Today, small glaciers (about 30 in the Wind River Mountains alone) exist among Wyoming's high peaks. The highest, Gannett Peak, reaches 13,804 feet (4,207 meters) above sea level[1]. The alpine zones, commencing at about 10,500 ft (3,200 m), contain active and inactive periglacial features, such as rock glaciers, solifluction terraces and lobes, stone stripes, and the stone nets or polygons that involve soil sorting to produce their outlines of cobbles.

Nonsorted polygons, those delineated by ice and sand wedges or their relics, have not been observed in the alpine zones, where the winter snow depths and total annual precipitation greatly exceed those of the intermontane basin floors. Patches of permafrost (permanently frozen ground) have been reported at six localities in Wyoming alpine zones (summarized in Mears, 1981). The relatively few reports of permafrost probably reflect the scarcity of excavations in the alpine zones as well as the prevalence of deep snow packs that insulate the underlying ground from sub-zero (°F) temperatures that follow invading arctic cold fronts.

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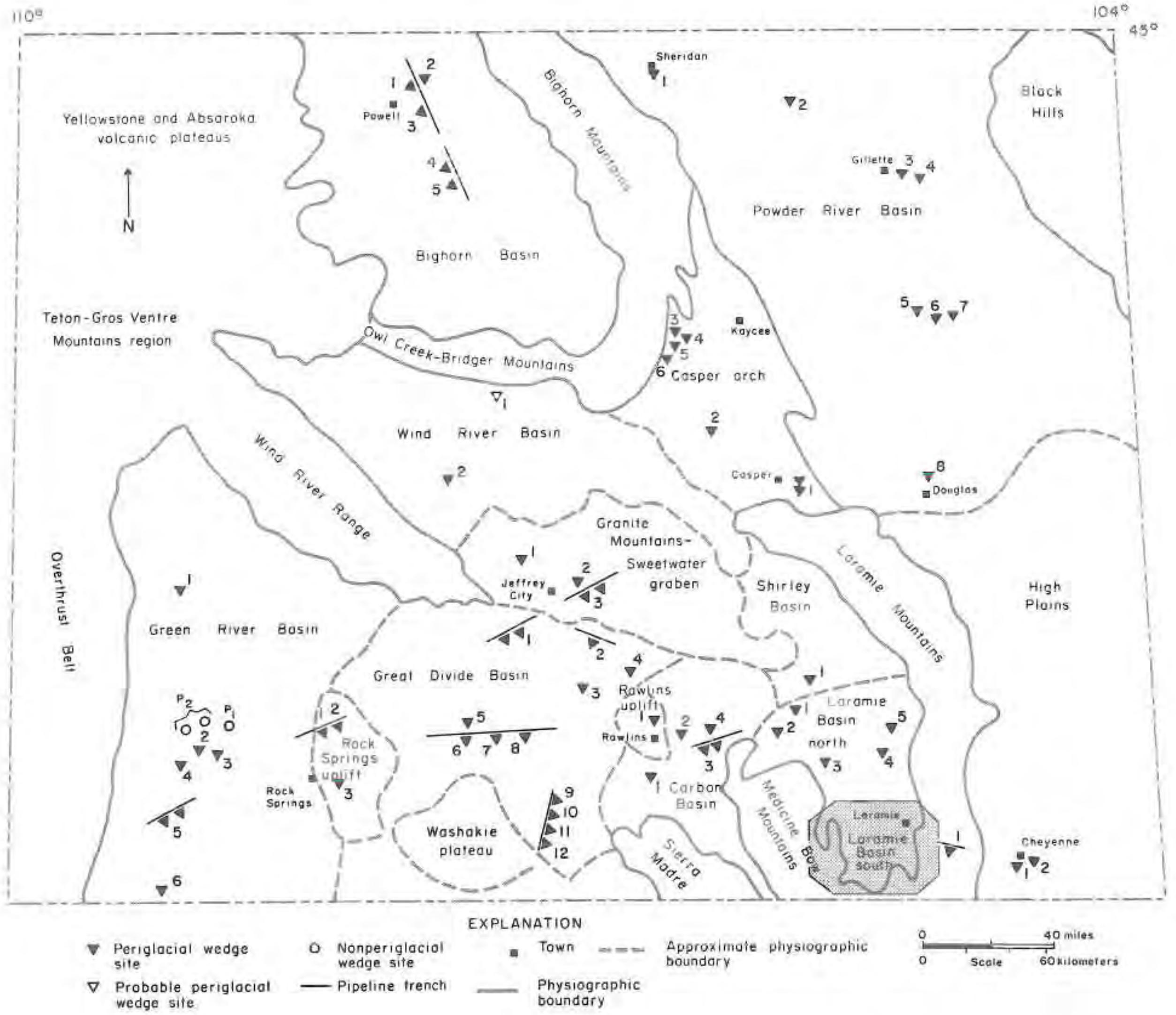
[1]All subsequent elevations in this report will be given in feet (ft) above mean sea level with equivalent meters (m) in parentheses. Other measurements will also be provided in English units with the metric following in parentheses. Other unit abbreviations used in this publication are: mi=mile, in=inch, km=kilomter, cm=centimeter, °F=degrees Fahrenheit, °C=degrees Celsius.



Laramie Basin south

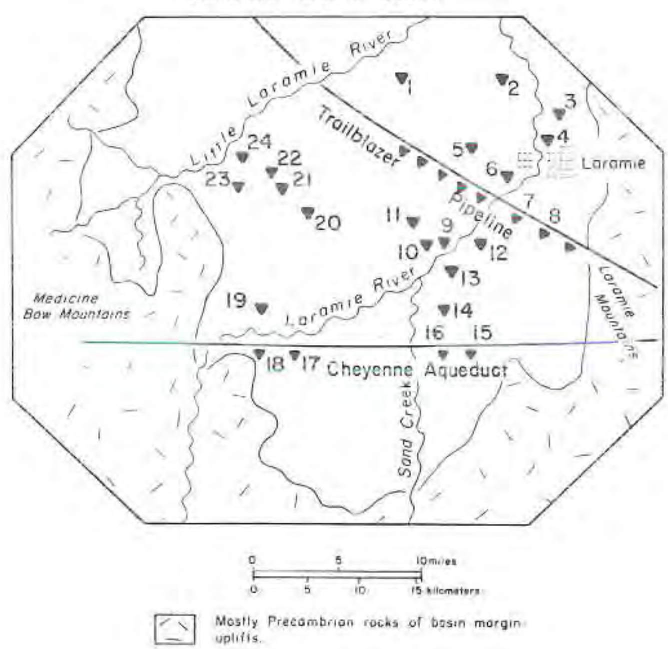


Figure 1. Wyoming periglacial wedge localities. Upper map shows all localities described in this report except those in Laramie Basin south, which are located on the map in the lower right corner.

The mountains largely encircle the broad high-floored basins (**Figure 1**). On calm winter nights when arctic masses prevail, very cold conditions develop on the basin floors, where the normal temperature inversion is strengthened by air draining down from the mountains.

During the late Pleistocene, mountain glaciers in places extended several miles beyond canyon mouths onto the basin floors, whose unglaciated expanses now preserve the abundant features interpreted as ice-wedge casts and sand-wedge relics (**Figure 2**). The basins were arid and windswept, like the present. Low precipitation resulted from the setting in the precipitation shadow of the Rocky Mountain Cordillera. If the basin floors had been blanketed by

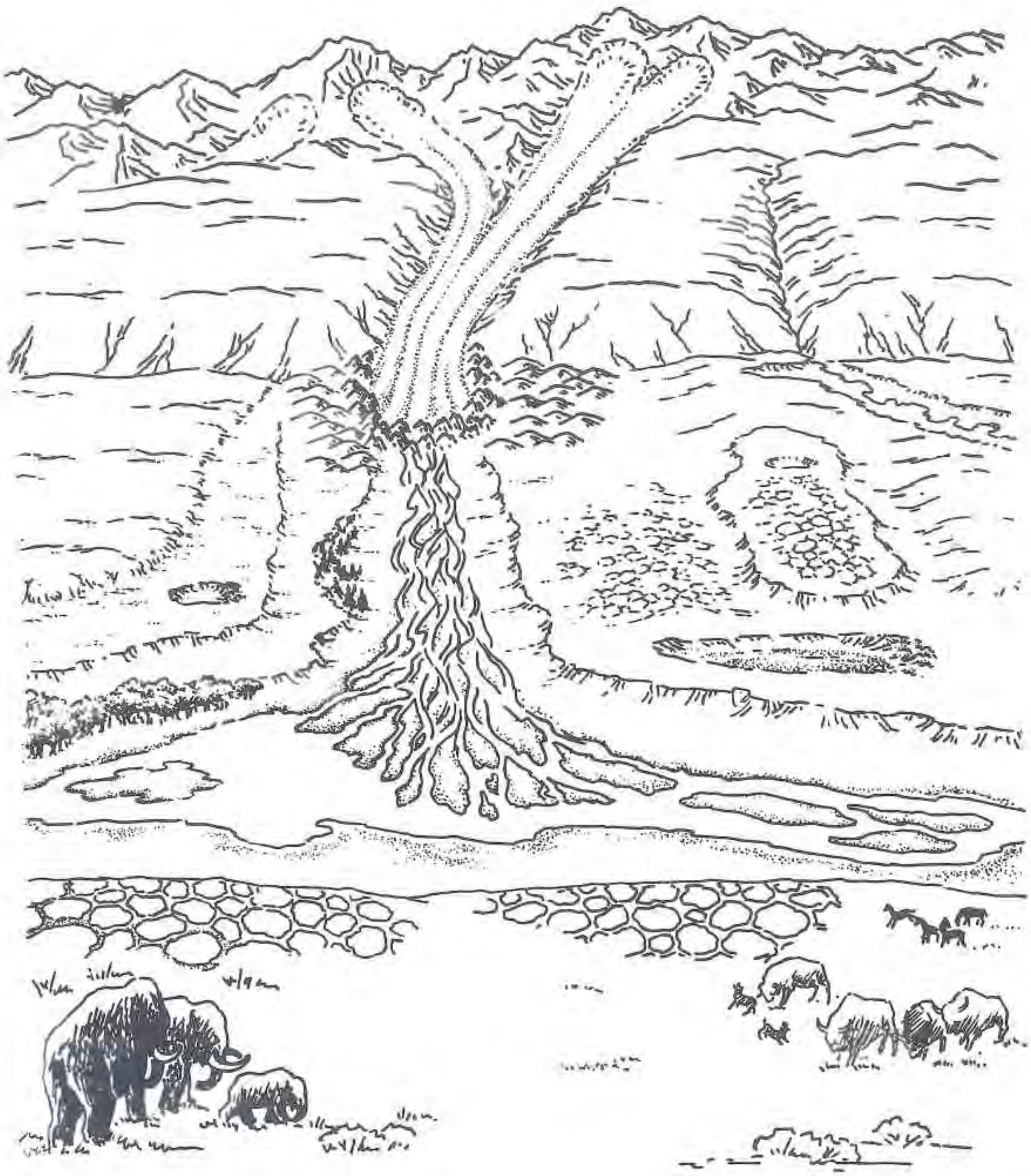


Figure 2. Interpretation of the Wyoming glacial/periglacial landscape during late Pinedale time, showing periglacial polygons forming in foreground and center right. (Drawing by Anne C. Mears.)

deep winter snow, it would have insulated the ground during strong cold snaps and inhibited the thermal cracking of permafrost that produces ice- and sand-wedge polygons.

Strong winds, rivaling or probably exceeding those of the present, are indicated by abundant eolian features. These include: ventifacts on wind-stripped benches and other topographic surfaces; wind-abraded and polished surfaces on some crystalline bedrock faces; abundant deflation hollows, ranging in size from Big Hollow, which is nine by three mi (15 by 3 km) wide and 150 ft (46 m) deep, in the Laramie Basin to countless smaller ones. Other Pleistocene eolian indicators are sand-wedge relics; and probably clay and sand dunes, which were largely reworked during Holocene time.

The floras and faunas of the basins, more fully discussed in Mears (1981), may have been those of a steppe tundra. Generally treeless, nonacidic soil-forming conditions are indicated by the pedologic evidence of increasingly stronger secondary carbonate development in buried and relic soils on successively higher and older topographic surfaces within the basins. Except for the presence of permafrost, the vegetation may have been rather like that of the present, dominantly grass and shrubs. The shrub-grassland concept fits the vertebrate fossil record reported by Walker (in press) of large grazing animals, such as mammoth, large bison, and horses that would have required more fodder than is available on existing acidic arctic tundras.

Wedge description

Locations

The wedges occupy Pleistocene terraces, benches, slopes, and hilltops that stand above Holocene stream terraces and the present floodplains. The observed wedge sites range in elevation from about 3,880 ft (1,183 m) at a location near Arvada, in the Powder River Basin of northern Wyoming (site PR 2, p. 40) to about 8,400 ft (2,500 m) in the southernmost part of the Green River Basin, adjacent to the Uinta Mountains (site GR 6, p. 72). The only wedge locality so far encountered in the mountains (site LM 1, p. 37) is on the windswept, plateau-like Sherman surface of the Laramie Mountains, at an elevation of 8,120 ft (2,475 m), where winter snow accumulations are far less than in alpine zones of the higher mountains.

Sizes and shapes

The wedges form polygons ranging from about six ft (2 m) to 30 ft (10 m) in diameter and penetrate downward to various depths, commonly as much as six feet (2 m) or more in the larger polygons. The shapes of the wedges exposed along vertical excavations reflect the geometry of a vertical slice through the polygons. True widths of the wedges are displayed where the slice is at right angles to the long axis of the wedge fills; oblique slices produce deceptively broad apparent widths.

Host materials

The Quaternary host materials include alluvial, colluvial, and eolian deposits. The varied bedrock hosts include Tertiary claystone, siltstone, and weakly consolidated sandstone; Cretaceous marine shale and thinly bedded shaley sandstone; Jurassic mudstone; and Permo-Triassic red sandstone and siltstone. In bedrock host materials, a moderately weathered upper zone extends downward to about the depth of the deepest wedge penetration. Precambrian crystalline rocks do not contain wedges except for the one unique site in the Laramie Mountains (site LM 1), where an extremely weathered mafic schist was cut by wedges.

Deformation of host materials abutting the wedges is discernible where layering or oriented clasts provide suitable markers. Commonly, the hosts are warped upward against wedge margins, and in some cases they are bent downward. The deformation is not discernible in homogeneous fine-grained host materials.

Wedge fills

The wedge fills are dominantly silty sands containing some small clasts derived from the adjacent host rocks or pebbles from the overlying Quaternary mantles. Internal fabrics, which may not be evident in the more homogeneous silty sands, are shown by vertically oriented chips derived from adjacent shaley bedrock or pebbles from overlying deposits and by thin vertical veins of fill materials in some cases. A few wedge fills exhibit concave-downward laminations, and some contain large pebbles or small cobbles. Soils across the wedge-filling surface mantles characteristically have moderate development with argillic B horizons and 10 YR hues (Munsell soil-color chart).

Dating the wedge-forming episodes

Most wedges are considered late Pinedale in age although some are possibly Bull Lake (**Table 1**). Field evidence providing relative dating of the wedge episodes as late Pleistocene includes their restriction to pre-Holocene topographic surfaces, their stratigraphic position beneath younger surficial deposits, and a degree of soil development on the wedge-filling mantles (personal communications, Richard G. Reider and Larry C. Munn, 1985) that is characteristic of late Pleistocene or early Holocene soil profiles.

Radiometric age determinations for the wedge localities are few; nonetheless they do fit and bracket the initial dating of wedge episodes that was based on relative criteria. Pockets of tephra at two localities in the Laramie Basin (sites LBs 5, p. 20; and LBs 9, p. 23) date host alluvial gravels as 1.2 million years old (personal communication, R. Wilcox, 1974) and 700,000 years (Izett and Naeser, 1976). However, deposition of both the gravels long preceded the wedge-forming episodes. The gravels cap benches that record topographic reversals accompanying the continuous deepening of the basin floor prior to creation of the wedges, which cut bedrock in the flanks as well as top surfaces of the benches (**Figure 3**).

No reliable carbon-datable materials (charcoal or wood) have been found in the wedge fills. However, Spackman and Munn (1984) obtained carbon dates on soil carbonates from wedges in the Laramie Basin (site LBs 2, p. 18). Using the soil carbonate dates supplemented by

Table 1. Simplified glacial/interglacial terminology for the part of the Quaternary period that is relevant to this report.[1]

EPOCH	MID-CONTINENT U.S.A. TERMINOLOGY	ROCKY MOUNTAIN TERMINOLOGY	TENTATIVE DATES IN YEARS AGO
Holocene	Post-Pleistocene	Neoglacial	4,000 to present
		Altithermal maxima	6,000 to 8,000
10,000 years before present			
Pleistocene	Wisconsin (glacial)	Pinedale glaciations	15,000 to 70,000 (several major pulses)
	Sagamon (interglacial)	Interglacial	122,000 to 132,000
	Illinoian (glacial)	Bull Lake glaciation(s)	140,000 to 150,000 (possibly several pulses)
	Pre-Illinoian episodes	Pre-Bull Lake episodes	To beginning of Pleistocene
	(Not considered here)		
1,600,000 years before present			

[1] Selected Pleistocene dates from K.L. Pierce (*in* Porter and others, 1983) and Richmond and Fullerton (1986), who give comprehensive discussions of Pleistocene dating and terminology.

estimates of the time required for the carbonate development, they calculated the time of the wedge formation as between 18,000 and 26,000 years ago, in late Wisconsin time.

Host gravels yielded no datable bone or shell materials. Charcoal and other reliable materials for carbon dating are rarely preserved in the oxidizing brown-soil environments of the Pleistocene deposits on terraces, benches, and hill slopes that contain wedges. However, at one perennially wet site with a high water table, where alluvial gravels were trenched for a gas pipeline in the northern part of the Great Divide Basin along the south flank of the Granite Mountains, gravels cut by a wedge did preserve an organic layer that was radiocarbon dated as about 25,000 years old (Nissen, 1985) (site GD 1, p. 59). At this site, a late Pinedale age for the wedge-forming episode is indicated.

The pre-Holocene age for wedge development has been confirmed by relations at three carbon-dated archaeological sites in the southern part of the Great Divide Basin (GD 5, p. 61; GD 10, p. 65; and GD 12, p. 66). In these sites, the wedge-filling materials had distinct paleosols that were unconformably overlain by younger deposits containing cultural horizons as old as 6,600 years (Altithermal time), based on absolute age determinations of charcoal and the associated artifact types. Assuming a reasonable interval for development of the paleosols, the active wedge-forming episodes were at least late Wisconsin (Pinedale) in age.

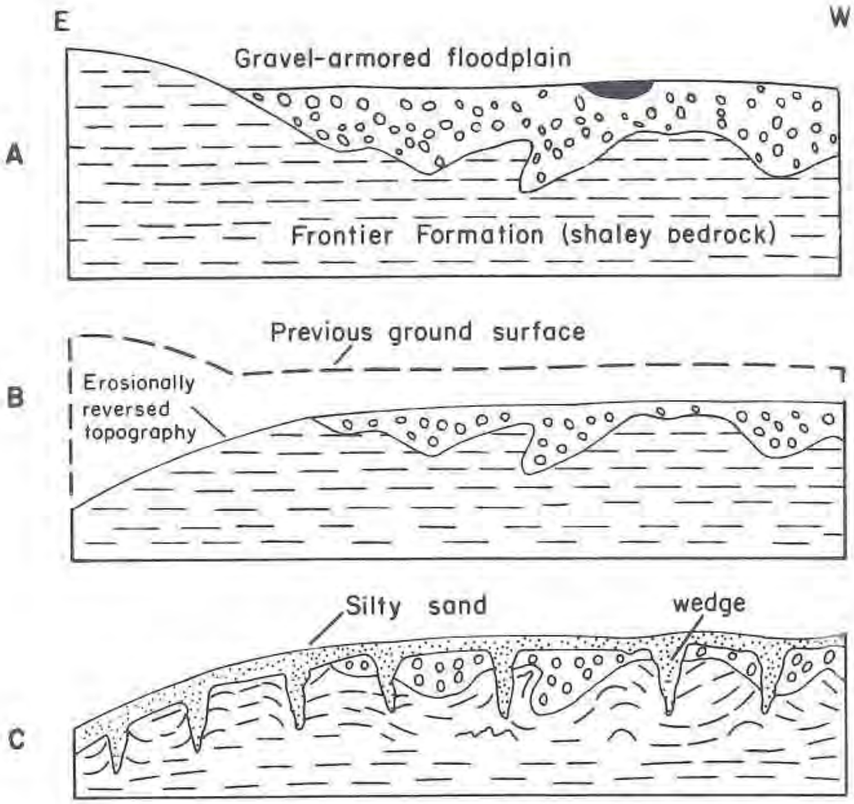


Figure 3. Typical sequence of Quaternary events characterizing periglacial wedge sites in Wyoming basin floors, based on observations at site LBs 13 (p. 25), southwest of Laramie: (A) development of gravel-armored floodplain; (B) topographic reversal accompanying basin floor deepening; (C) late Pleistocene development of periglacial polygons filled with silty sand.

The periglacial interpretation

Field observations

The forms and sizes of the Wyoming wedge relics and associated polygons are within the limits for active ice- and sand-wedge polygons in present-day arctic environments. Péwé (1975) stated that ice-filled polygons in Alaska range from ten to 100 ft (3 to 30 m) or more in diameter; that wedges range from narrow to well flared; and that they extend from three to 33 ft (1 to 10 m) into the ground.

The development of active ice and sand wedges results from repeated cold-thermal cracking of permanently frozen ground. The individual cracks are narrow, about 0.2 to 0.3 in (0.5 to 1 cm) wide (Black, 1976). Where the initial cracks penetrate permafrost, they create planes of weakness that localize the subsequent repeated cracking responsible for the growth of ice and sand wedges.

Ice wedges develop in relatively wet environments, where ice fills the repeated cracks and produces the growing masses of the sort now found in Alaska (**Figure 4**). Their casts form when the ice wedges eventually thaw and leave gaps that become filled with clastic materials. In some cases, the materials sag into the gaps and produce downwarped laminae of the sort found at site LBs 10 in the Laramie Basin. Some casts contain small cobbles or large pebbles that are too large to have fallen into the original narrow thermal cracks (as at site R 1 in the Rawlins sanitary landfill, p. 56).

Figure 4. Active ice-wedge polygons exposed in an Alaskan excavation. (Photograph courtesy of U.S. Geological Survey, Alaskan miscellaneous photo 12.)

Sand wedges develop in relatively drier situations where the narrow thermal cracks are immediately filled with eolian sediments to produce a vertical fabric of the sort found at site LBs 20 in the Laramie Basin (p. 31). However some sand-filled wedges are probably ice-wedge casts. For example, at the Rawlins site, wedge fills contain big pebbles and cobbles too large to have fallen down narrow thermal cracks, but they are devoid of any observable fabric in their sandy components. Some other wedges that lack discernible fabrics or other clues to their origin may be composite forms, where ice and clastic fillings alternated before the ground thawed.

The deformation of host materials abutting the wedges is similar to that observed against active ice wedges in existing permafrost regions of Alaska, Canada, and Siberia. This phenomenon -- attributed to pressure effects when the permanently frozen ground expands upon warming (Péwé, 1975) -- commonly bends the host materials upward or, less commonly, downward. Some of the downward bending of host gravels and dark shales along Wyoming wedge margins is attributed to sagging of these host materials when the ice wedges melted and the permanently frozen ground thawed. This mechanism was proposed by Péwé (*in* Péwé and others, 1969) from his study of ice-wedge casts at Donnelly Dome in Alaska. Moreover, the variety of host materials cut by the Wyoming wedges precludes desiccation as an alternative mechanism. Desiccation cracking is not observable as a present-day process in Wyoming bedrock outcrops or in Quaternary gravel deposits that are common hosts for many of the wedge relics.

Supplementing the previous interpretations based on field observations, a compelling argument for the periglacial origin of the wedges is their apparent absence in lower and warmer regions south of Wyoming. For example, no comparable wedges have been reported in the Colorado piedmont where, at Fort Collins about 50 mi (100 km) south of Laramie, the mean annual air temperature is 7.3°F (4.0°C) warmer than the 40.7°F (4.8°C) recorded for Laramie. If the wedges in the Laramie Basin were a desiccation phenomenon, they should be equally or more abundant in the 2,000-ft (610 m) lower and warmer regions, where the exposed bedrocks and Quaternary deposits, as well as the basin-floor topographies, are very comparable to those in Wyoming.

Laboratory studies of wedge fills

Preliminary particle-size analyses for six selected sites by Mears (1981) and for 14 other sites by Nissen (1985) demonstrate that Wyoming wedge fills are poorly to extremely poorly sorted, dominantly silty sands, with some clay- and pebble-sized components (**Figure 5A**). Wedge fills tend to have fine-skewed particle distributions and reflect local source materials. Dune sands, collected for comparison of particle sizes, were clearly better sorted than wedge-fill deposits (**Figure 5B**). Nissen noted that Korotaj and others (1982) reported poor sorting for sand-wedge relics in Poland and that Black (1969) reported local derivation and poor sorting of fills, which he considers partially eolian, for ice-wedge casts in Wisconsin.

Using a binocular optical microscope and a scanning electron microscope (SEM), Nissen (1985) determined that Wyoming periglacial wedge fills contain appreciable quantities of well-rounded, spherical quartz grains (**Figure 6A**) that are very similar to eolian grains (**Figure 6B**) in the sample collected from stabilized dunes in the Sand Hills of Nebraska, about 145 mi (230 km) east of known Wyoming wedge sites.

Unlike the Nebraska dune sands, however, the Wyoming wedge fills also contain abundant conchoidally fractured grains in the medium- and fine-grained sand fractions (**Figure 7**). Such clasts are notably absent in samples from the stabilized dunes in Nebraska and from deposits in the currently active parts of the Killpecker and Ferris dune fields of the Great Divide Basin in central Wyoming. Comparable conchoidally fractured clasts have been interpreted as products of glacial grinding by Krinsley and Doornkamp (1973); however, the fractured clasts in Wyoming periglacial wedge fills are found as far as 120 mi (190 km) from any possible glacial sources. Moreover, Nissen noted that several workers (for example Kowalkowski and Brogowski, 1983) reported conchoidally fractured, sharp-edged quartz particles in tunda soils, and that Konishchev (1978) reported that quartz is the least mechanically stable of the common rock-forming minerals under cryogenic conditions of strong frost action. Thus Nissen suggested that the conchoidally fractured grains in Wyoming wedge fills result from periglacial frost action.

Wedge distribution in the Laramie Basin

The Quaternary features of the Laramie Basin (Montagne, 1953; Mears, in press), where the greatest number of ice-wedge casts and sand-wedge relics have been studied, provide a working model for the general distribution of periglacial wedges across the characteristic landforms throughout Wyoming's broad intermontane basin floors. Since late Tertiary time, progressive fluviatile and eolian excavation of Mesozoic and Tertiary bedrock in the Laramie Basin has produced a sequence of seven prominent surfaces (**Figure 8**). They include: (1) Table Mountain surface, (2) Eagle Rocks surface, (3) Airport bench,

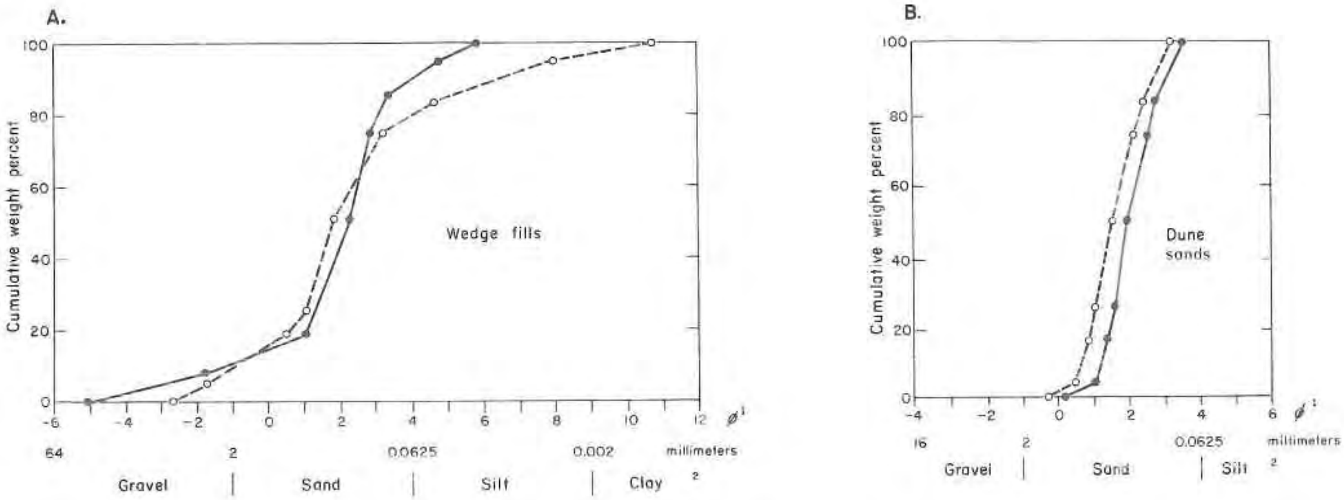


Figure 5. Representative particle-size distributions in periglacial wedge fills are poorly to very poorly sorted in contrast to dune sands. **(A)** Solid line represents sediment in an ice-wedge cast that penetrates Quaternary host material of sandy alluvial gravel at site R 1 (p. 56). Dashed line represents the sediment in a sand-wedge relic penetrating host material of dark shale in the Cretaceous Frontier Formation at site LBs 13 (p. 25). **(B)** Solid line represents sand from a stabilized dune in the western Sand Hills of Nebraska. Dashed line represents sand of a currently active dune in the Ferris dune field at the eastern end of the Great Divide Basin in Wyoming. (From Nissen, 1985.) [1] Logarithmic scale (Krumbein, 1934). [2] German scale (after Atterberg, *in* Blatt and others, 1972, p. 45-46.

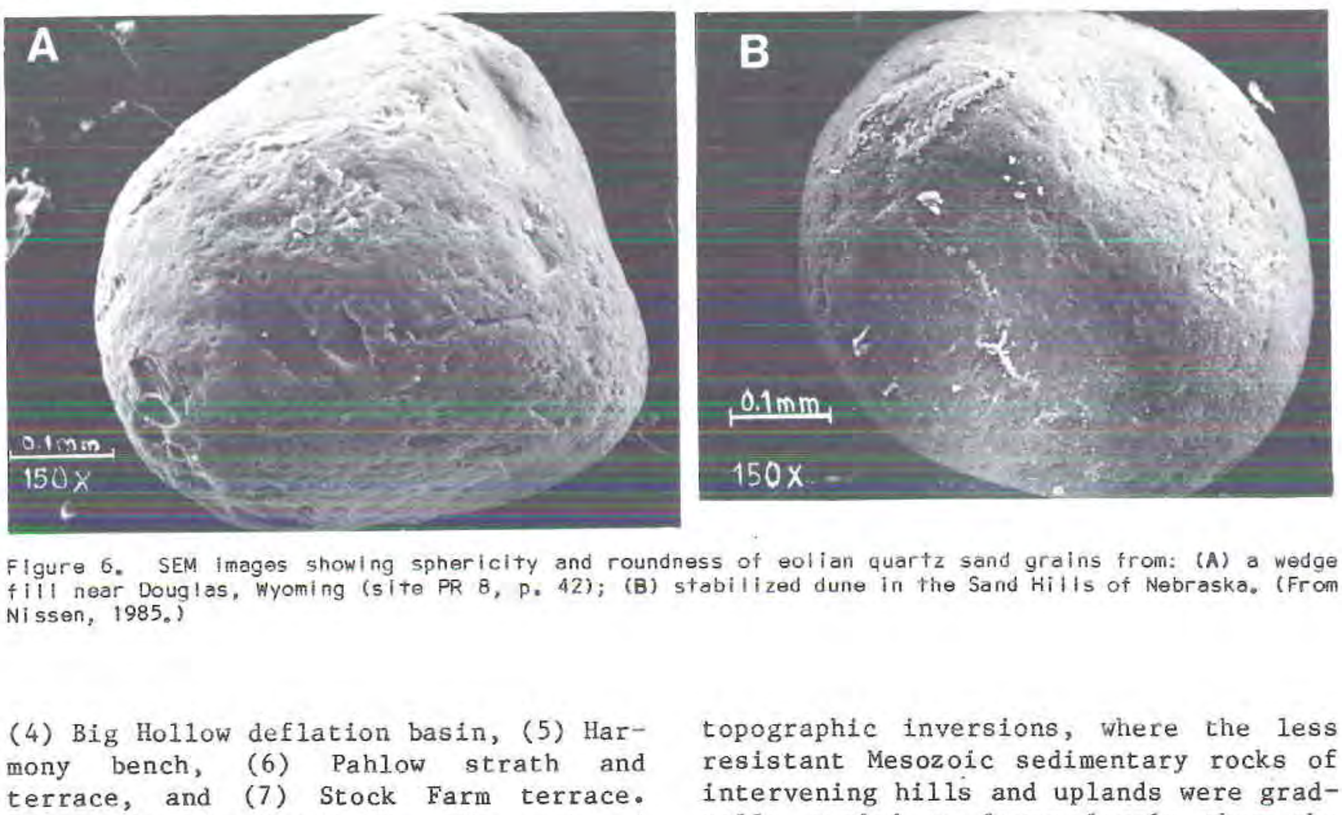


Figure 6. SEM images showing sphericity and roundness of eolian quartz sand grains from: **(A)** a wedge fill near Douglas, Wyoming (site PR 8, p. 42); **(B)** stabilized dune in the Sand Hills of Nebraska. (From Nissen, 1985.)

(4) Big Hollow deflation basin, (5) Harmony bench, (6) Pahlow strath and terrace, and (7) Stock Farm terrace. Except for the Big Hollow, the numbered surfaces, capped by cobbles and gravels, are interpreted as relic fluviatile land forms: benches, terraces, and an abandoned valley. They record late Cenozoic topographic inversions, where the less resistant Mesozoic sedimentary rocks of intervening hills and uplands were gradually eroded to lower levels than the cobble- and gravel-armored former floodplains of the Laramie River and its tributaries (Mears, in press). Stream captures and drainage diversions created

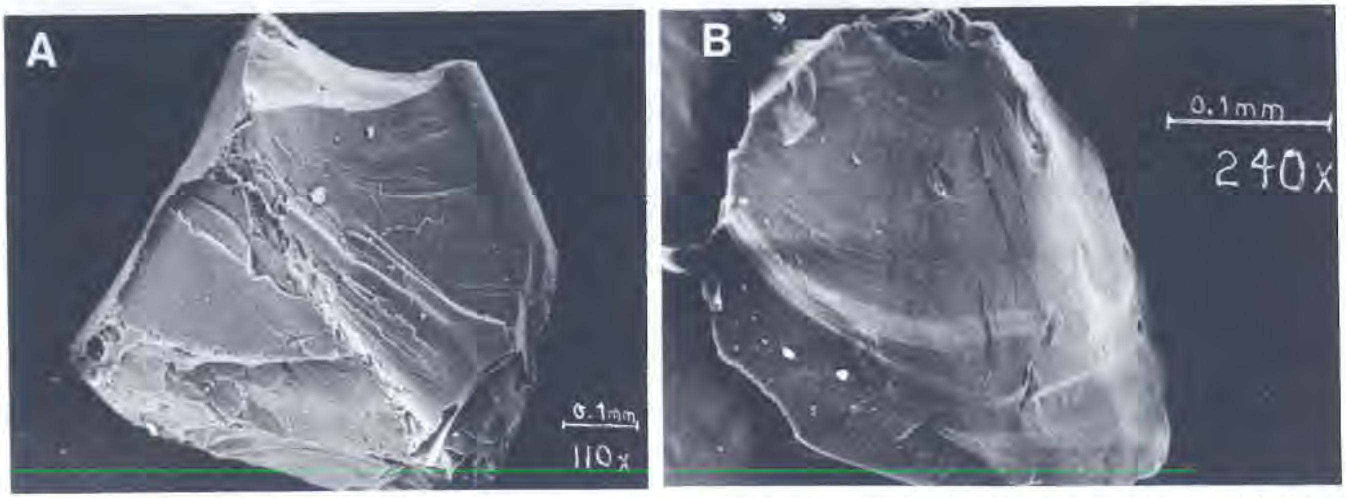


Figure 7. SEM images illustrating (A) typical quartz grains from medium- to coarse-grained sand fractions of periglacial wedge fills showing sharp dish-shaped conchoidal fractures; (B) typical bladey, conchoidally fractured quartz particle, probably flaked from a larger grain, in the finer grained sand fraction of the wedge fill. (From Nissen, 1985.)

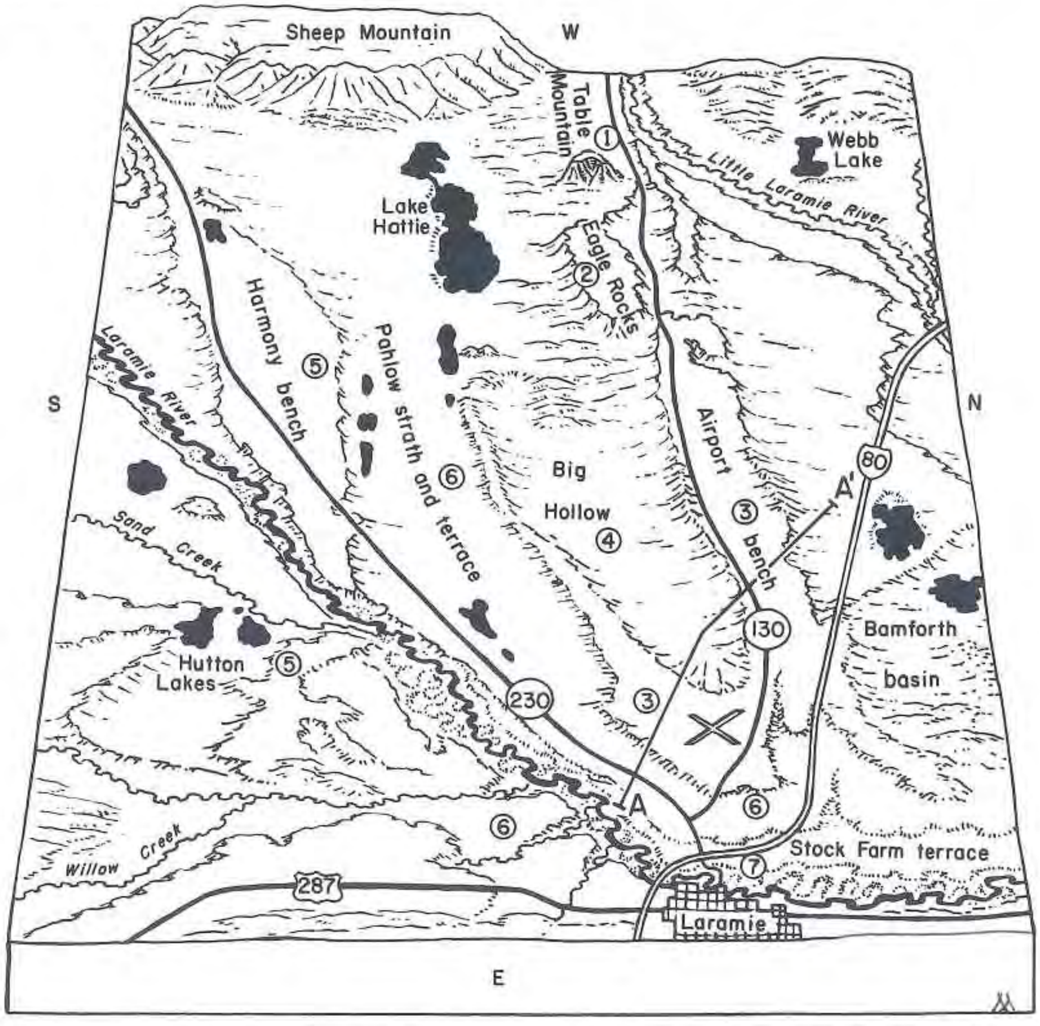


Figure 8. Pleistocene terraces and benches and major deflation features in the central part of the southern Laramie Basin, viewed toward the west. Cross section A-A' is seen in **Figure 9.** Area represented is approximately 20 by 25 mi (32 by 40 km) wide. (Drawing by Anne C. Mears).

such features as the Airport bench and the stream-abandoned Pahlow strath (**Figure 8**). The surfaces range in elevation above the present Laramie River from 530 ft (160 m) at Table Mountain (of possible Pliocene or early Pleistocene age) to 10 ft (3 m) at the Stock Farm terrace (carbon and fossil dated as Wisconsin). Pronounced eolian erosion, mainly in Cretaceous shales, produced abundant deflation basins, ranging in size from a few tens of feet in diameter to the nine- by three-mi (15 by 5 km) wide, 150-ft (46 m) deep Big Hollow, whose sides and floor contain sand-wedge relics.

Except for the relatively small Table Mountain surface, where suitable exposures have not been available, wedges have been found on all pre-Holocene Quaternary surfaces and their associated slopes, from the Eagle Rocks surface down to, and including, the Stock Farm terrace, as well as the Big Hollow deflation basin. However, an 11-mi (18 km) traverse (**Figure 9**) along the Trailblazer gas-pipeline trench (**Figure 1**) and a 20-mi (32 km) traverse along a trench for the city of Cheyenne's aqueduct (**Figure 1**), clearly established that wedges, although abundant, are not continuously and uniformly distributed across the Pleistocene topography. Rather, they occur in groups or clusters of varying numbers and extent, which are separated by expanses where wedges are absent on the same or comparable surfaces.

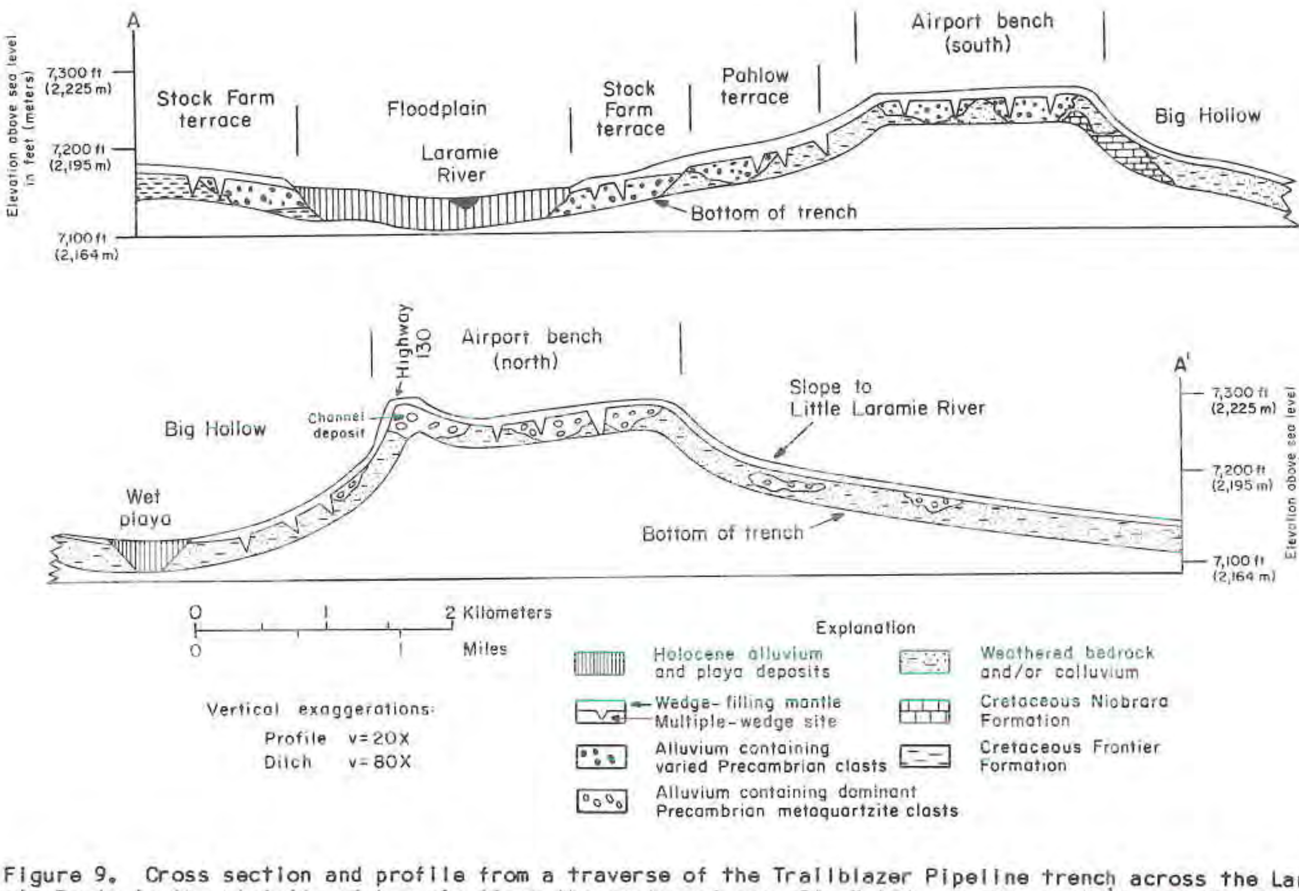


Figure 9. Cross section and profile from a traverse of the Trailblazer Pipeline trench across the Laramie Basin in the vicinity of Laramie (from the center of sec. 24, T.16N., R.75W. to NW1/4 sec. 19, T.15N., R.73W.). This schematic diagram (note vertical exaggerations) illustrates the general distribution of periglacial wedges in differing host materials and on the various geomorphic surfaces. Cross section is approximately located on **Figure 8**. (Drawing by Anne C. Mears.)

Wedges are absent in well-consolidated rocks, for example ridge-forming sandstones and limestones such as the Cretaceous Cloverly and Pennsylvanian Casper Formations. Otherwise, the lithology of the host bedrock is not the primary factor in determining the concentration or absence of wedges. In moderately to poorly consolidated bedrock units, whatever their lithologies, wedges are present in places and absent in others. Similar distributions are also found in Pleistocene deposits. An exception is the total absence of wedges in the ten-ft (3 m) thick channel deposit of large quartzite cobbles that caps the highest part of the Airport bench (see **Figure 9**). Wedges were also absent in a similar cobbly mass capping the Arlington bench, about 35 miles (56 km) northwest of Laramie. However, in all other Quaternary deposits, wedges penetrated alluvium and colluvium ranging from silt-sized material, through arkosic "pea" gravels, to sandy gravels containing some small or moderate-sized cobbles.

Based on continuous traverses along pipeline trenches, the absence of wedges in some areas probably reflects their removal by erosion, followed by the deposition of younger deposits. In other cases, the discontinuous distribution of wedges across several levels of terraces, benches, and adjacent slopes is tentatively attributed to variations in the Pleistocene snow cover. Assuming late Pleistocene glacial times were at least as windy as the present, winter snow would have been unevenly distributed. As on the present windswept plains, bare or thinly covered ground would have separated areas where three- to four-ft (1 to 1.3 m) deep snow drifts insulated the ground from the penetrating cold that caused contraction cracking and wedge development. The orientation of slopes may also have affected snow accumulations. Along the Trailblazer pipeline trench the north-facing slopes, flanking the north side of Airport bench and the south side of Big Hollow, lack wedges; whereas, wedges are present on faces sloping south, east, and west (**Figure 9**). Possibly, with the low sun angles of winter, the shaded and snow-covered north-facing slopes were subjected to less drastic temperature fluctuations than those with other orientations, and thus were not subjected to cycles of permafrost expansion and contraction, punctuated during cold snaps by the thermal cracking that builds ice and sand wedges.

Paleotemperature estimates

Mean annual air temperatures (MAATs) during Wyoming's wedge-forming episodes were estimated as about 18° to 24°F (10 to 13°C) colder than the present (Mears, 1981). The calculation was based on the difference between the MAATs of 40.7°F (4.8°C) and of 46.8°F (8.2°C) from weather-station records at Laramie and Powell, respectively, and the 23°F (-5°C) that Washburn (1980) proposed as capable of producing ice wedges. For representative temperature and precipitation data from selected Wyoming weather stations, see **Table 2**.

Uncertainties in any such calculations include the extrapolation of present arctic data to middle-latitude Pleistocene environments and the 1.8° to 10.8°F (1 to 6°C) difference between the colder MAATs and those of the ground surface where ice wedges develop (Gold and Lachenbruch, 1973). Moreover, calculations for Pleistocene air-temperature depression depend on the particular temperature that is selected for wedge growth. No single temperature applies to all situations because of various factors, evaluated by Washburn (1980, p. 135-140). In addition to MAAT, commonly used because of its ready availability, wedge development depends on several critical factors including:

Table 2. Representative temperature and precipitation data from selected weather stations in Wyoming, 1951-1980.

Location	Elevation	Mean annual temperature	Minimum low temperature	Maximum high temperature	Mean annual precipitation
Cheyenne (high plains) 41.15°N., 104.82°W.	6,126 ft (1,867 m)	45.7°F (7.6°C)	-27°F (-32.8°C)	100°F (37.8°C)	13.29 in (33.76 cm)
Farson (Green River Basin) 41.12°N., 109.45°W.	6,595 ft (2,010 m)	37.3°F (2.9°C)	-52°F (-46.7°C)	97°F (36.1°C)	6.93 in (17.60 cm)
Gillette (Powder River Basin) 44.28°N., 105.93°W.	4,556 ft (1,389 m)	44.9°F (7.2°C)	-34°F (-36.7°C)	104°F (40.0°C)	15.77 in (40.06 cm)
Laramie (Laramie Basin) 41.32°N., 105.68°W.	7,266 ft (2,215 m)	40.7°F (4.8°C)	-50°F (-45.6°C)	94°F (34.4°C)	10.17 in (25.83 cm)
Powell (Bighorn Basin) 44.75°N., 108.77°W.	4,378 ft (1,334 m)	46.6°F (8.1°C)	-30°F (-34.4°C)	102°F (38.9°C)	6.56 in (16.66 cm)
Rawlins (Rawlins uplift) 41.80°N., 107.20°W.	6,736 ft (2,053 m)	42.2°F (5.7°C)	-36°F (-37.8°C)	98°F (36.7°C)	8.94 in (22.71 cm)
Rock Springs (Rock Springs uplift) 41.60°N., 109.07°W.	6,741 ft (2,055 m)	42.6°F (5.9°C)	-37°F (-38.3°C)	96°F (35.6°C)	8.84 in (22.45 cm)

[1] Data from Martner (1986). (Note that locations are in degrees, not degrees and minutes.)

1. Rapidity, severity, and frequency of temperature changes in the upper part of the permafrost (Péwé, 1966);

2. Topographic situation and air drainage (Mears, 1981);

3. Depth of insulating snow cover (MacKay, 1974);

4. Ice content of the host material (Black, 1976);

5. Particle sizes in the host material (Romanovskij, 1973).

Host particle size is particularly important. Silt-rich materials crack and develop ice wedges at higher temperatures than do sand, gravel, and bedrock. The relative sensitivity of different materials to thermal cracking is demonstrated by observations in the present (non-periglacial) basin floors of Wyoming. Cold-season cracking is common here in unconsolidated silty material (**Figure 10**) but has not been observed in gravel or exposed clastic bedrock. The cracks form in unvegetated bare ground, often near melting snow banks, following sharp cold snaps that bring near or below zero °F (-18°C) temperatures. With the exception of one site in an active dune field (location P 2, p. 73), such cracking does not normally create wedges; none have been observed in Wyoming's Holocene deposits because the modern cracks close in the spring, without noticeable clastic infilling, and cracking in subsequent winters does not follow the earlier crack patterns. In contrast, thermal cracks penetrating down into permafrost are preserved as planes of weakness. Ice wedges are able to form where these planes of weakness control repeated subsequent crackings in the same locations (Lachenbruch, 1962).

Because the widespread Wyoming wedge casts cut gravel and bedrock as well as highly sensitive silty materials, the author's original estimate of a late Pleistocene periglacial environment that was 18° to 23°F (10° to 13°C) colder than the present is, with minor modifications, defensible. Hamilton and others (1983) described active late-Holocene ice wedges in peat and underlying silts in the discontinuous zone of permafrost around Fairbanks, Alaska, where the prevailing MAAT is 26°F (-3.5°C). Thus they

Figure 10. Present-day seasonal frost cracks along dirt road to Mears ranch, seven mi (11 km) southwest of Laramie. Geological hammer is about 11 in (28 cm) long.

reject Péwé and others (1969) assumption that ice-wedge casts indicate previous 21°F (-6°C) or colder temperatures and continuous permafrost. However, Troy L. Péwé noted (personal communication, 1985) that the site studied by Hamilton and others (1983) is in a depression where the microclimate is colder than that at the recording station. In any case, the original calculation of the Pleistocene temperature depression in Wyoming is justified because the host material cut by wedges includes gravel and bedrock.

Estimates of Pleistocene temperatures have also depended on the particular weather stations, near wedge sites, from which the present data was selected (Table 2). My original estimate of 18° to 23°F (10° to 13°C) lower temperatures, mentioned above, used the Laramie (40.7°F, 4.8°C) and Powell (46.8°F, 8.2°C) records. Péwé (1983) suggested 16° to 19.4°F (8.9° to 10.8°C) lower temperatures based on the Farson (37.2°F, 2.9°C) and Laramie records. Both calculated ranges are conservative. The temperature departure calculated from the Powell data, in the warmer and topographically lower Bighorn Basin, may represent the overall air cooling that affected all of the Wyoming Basin floors. If so, MAATs were no less than 25°F (14°C) colder during the late Pleistocene wedge-forming episodes. Such a temperature lowering is not excessive compared to other estimates based on the presence of ice-wedge casts. Washburn (1980) tabulated 30 estimates for worldwide localities, adjusted to a common wedge-making temperature of 23°F (-5°C). The calculated temperature lowerings ranged from 12.6° to 36°F (7° to 20°C) with a mean of 24°F (13.3°C).

The Wyoming temperature departure based on periglacial phenomena is supported by other estimates from independent data. Based on CLIMAP Project (1976) determinations of oceanic temperature patterns, glacial distributions, albedo of land and ice, and ice-age topography -- Gates (1976) recorded a 23°F (13°C) lower July temperature for the Wyoming region in his computer-generated map simulating the global atmospheric circulation for 18,000 years ago (late Pinedale time in Wyoming). His study also indicated that the maximum westerly wind zone (now at 60°N latitudes) had been displaced into the 40°N latitudes, which include Wyoming, peripheral to the continental ice-sheet margins.

From his comprehensive study of the history and dynamics of glaciation in the Yellowstone National Park region, Pierce (*in* Porter and others, 1983) proposed 18° to 27°F (10° to 15°C) colder late Pleistocene summer temperatures in the Wyoming region. He notes that previous estimates of 11° to 17°F (6° to 9°C) colder temperatures were based on the traditional method in glacial studies (see Richmond, 1965), where the temperature lapse rate[2] is multiplied by the difference in altitude between present snow lines and those determined, from geologic evidence, for glacial times. In this method, greater Pleistocene snowfall is implicit in the assumption that temperatures and snow accumulations at present-day elevated snow lines are comparable to those that existed at the 3,200-ft (1,000 m) lower snow lines of glacial times. However, above the depressed Pleistocene snow lines, the progressive increase of snow depths at successively greater heights in the mountains would have required markedly greater total precipitation than that of the present day. But unlike ice-wedge casts, which are proxy evidence for snow depths no greater than the present, the geologic features used in reconstructing the former extent of glaciers and snow line depression provide no evidence for distinguishing the relative effect of deeper snow accumulation from that of lower temperatures during the glacial maxima. As Pierce (*in* Porter and others, 1983) suggested, Pleistocene air masses reaching the Rockies from source areas over the North Pacific Ocean would have been drier because surface waters were 3.6° to 7.2°F (2° to 4°C) cooler than the present (CLIMAP Project, 1976). He concluded that the previous estimates of temperature departure in the Rockies, based on glacial data and simple lapse rate calculations, are too conservative and that an 18° to 27°F (10° to 15°C) depression of summer temperatures is possible.

In a broader perspective, for North America south of the continental glaciers and east of the Rockies, Wright (1984) suggested that evidence from palynology and vertebrate paleontology indicates that the late Wisconsin glacial maxima were characterized by cool summers and relatively mild winters. He also proposed that North America south of the Wisconsin ice caps might have experienced fewer extreme cold snaps during Wisconsin glacial times because the continental ice domes blocked southward bursts of cold winter air, which characterize present winters, and diverted them eastward to the North Atlantic Ocean and the broad zone in northern Europe where abundant ice-wedge casts indicate periglacial conditions. If so, the widespread and abundant ice-wedge casts and sand-wedge relics, features indicative of rapid and severe cold snaps (Péwé, 1966), which occur as far as 400 mi (650 km) south of the Wisconsin continental glacier fronts in Wyoming's intermontane basins, are of special interest.

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[2]Lapse rate: 3.5°F decrease in air temperature per 1,000 ft increase in altitude, or 6°C per 1,000 m. Present snow line: equilibrium-line altitude determined from lower limit of firn on glaciers during the summer ablation season. Pleistocene snow line: determined from the altitudes of the lowest abandoned cirques or taken as the median altitude between end moraines and cirque heads.

Site descriptions

Wedge sites in the following descriptions are grouped according to individual geomorphic basins and uplands in the intermontane and piedmont plains of Wyoming, and are numbered sequentially. Within the general Wyoming Basin Province (Fenneman, 1931), the subdivisions used are my informal designations of *geomorphic units*, that may or may not conform with previous designations of sedimentary and structural basins (e.g., Love, 1960).

Heading information includes the site number and a descriptive local name. The location paragraph lists the relevant U.S. Geological Survey topographic quadrangle(s); designation by the U.S. Land Survey System (quarter section, section, township, and range of the 6th Principal Meridian or Wind River Meridian); site elevation; and the type of excavation, geomorphic setting, and local relief.

Description of host material and nature of the wedge fill follows. Photographs (where available) and(or) diagrams document most sites. Unless otherwise stated, the scale in photos is a yardstick (0.91 m). In most photographs, the boundary between wedge host and wedge fill is easily apparent. Boundaries at several wedge sites have been accentuated by shallow trenching. Dashed lines were drawn on a few of the photographs where differences between fill and host were not easily discernible. In cross sections, the vertical and horizontal scales are the same unless otherwise indicated. Permission from *Quaternary Research* to republish photos and (or) diagrams from some sites is appreciated (LBS 3, 10, 11, 12, 13, 16, and 18; BB 1; CB 3 and 4).

Acknowledgments

This compilation would have been far less complete without the help of friends who, alert to their significance, provided information on wedge localities. The following contributed data for some sites, a few of which I did not examine: Thomas S. Ahlbrandt, Donald A. Coates, Mary L. Gillam, Dennis N. Grasso, Katherine A. Hilton, Cheryl C. Jaworowski, Frank B. Kistner, Robert Lebruska, Charles M. Love, Marlin E. Lowry, Michael L. McFaul, Wayne L. Miller, Anthony Morgan, Larry C. Munn, Gerald E. Nelson, Thomas C. Nissen, James H. Nyenhuis, Marith C. Reheis, Richard G. Reider, Lowell K. Spackman, Kent A. Sundell, Danny Walker, Thomas N. Westerfeldt, and William Wood.

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Laramie Basin, southern part (LBs)

Site LBs 1, Alsop Lake. Alsop Quadrangle; NW1/4 sec. 2, T.16N., R.75W.; 7,158 ft (2,182 m); small gravel pit in a terrace of the Little Laramie River, standing 30 feet (9 m) above a nearby tributary to the Little Laramie River.

Host is alluvial silty sand and gravel with powdery secondary carbonate, some of which penetrates the wedge fills. Deformation of the host abutting the wedges, warped upward against margins, is indicated by gravel lenses and soil carbonates. The wedge fills of silty sand containing some pebbles were derived from a surface mantle of overbank and(or) eolian material, across which a moderately strong brown soil is developed.

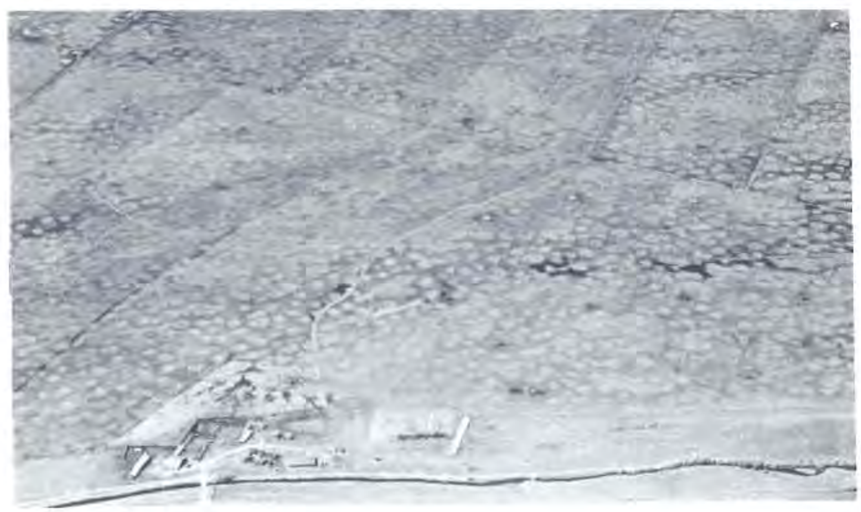
Site LBs 1, Alsop Lake

Site LBs 2, Carroll Ranch. Bamforth Lake Quadrangle; NE1/4 sec. 35, T.17N., R.75W.; 7,134 ft (2,174 m); a 90-ft (27.5 m) long trench in a pre-Wisconsin terrace, 30 ft (9 m) above the Laramie River.

Host is alluvial silt, sand, and gravel, with visible secondary carbonate (light colored material in photograph), which in places emphasizes deformation of host materials, commonly warped upward against wedge margins. Fills are slightly pebbly silty sand with secondary carbonates, but no caliche. Spackman and Munn (1984), who did detailed work at the site, obtained radiocarbon ages of about 13,000 years from soil carbonates in the wedge fills. Assuming a reasonable time for accumulation of the secondary carbonate, they estimated that the wedge-forming episode was from about 18,000 to 26,000 years ago.

The site is unique; it is the only one where an excavation exposes wedges in conjunction with mounds, approximately two ft (60 cm) high and 15 ft (5 m) in diameter, which are very abundant on many gravel-capped surfaces in the Laramie Basin. Somewhat similar appearing mounds, variously called Mima mounds, pimpled prairies, hog wallows, etc., are found from the Gulf Coast to Alaska and have been attributed to rodents and various physical processes. Stratigraphic and pedologic evidence indicates the mounds at this Laramie Basin site postdate the wedge-forming episodes; however, Spackman and Munn (1984) suggested that the mounds resulted from cryostatic pressures, upward injections of thawed gravels underlain by permafrost or shale, through downward freezing from the surface of an active zone.

Site LBs 2, Carroll Ranch



Mounds in southern Laramie Basin

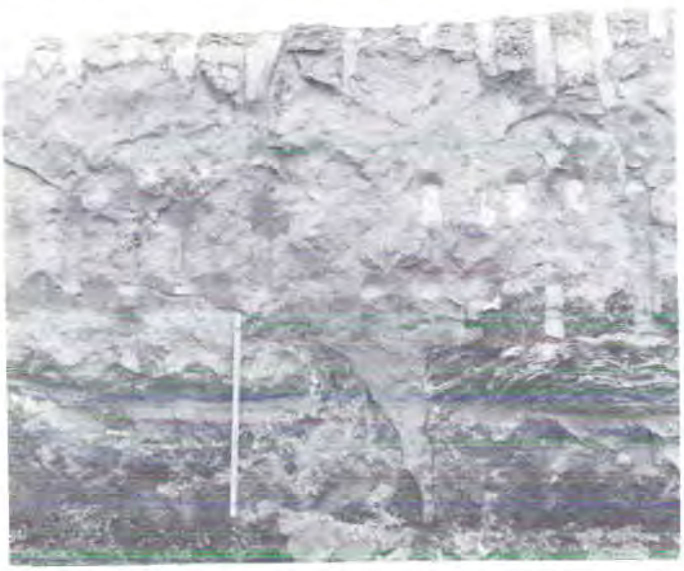
Site LBs 3, Laramie city dump. Laramie Quadrangle; NW1/4 sec. 22, T.16N., R.73W.; 7,240 ft (2,207 m); sanitary landfill wall, 120 ft (37 m) above the nearby Laramie River.

Host is Triassic Chugwater Formation; bleached sandstone lenses in the redbeds clearly demonstrate that the host bends upward against the wedge. Fill is slightly pebbly silty sand derived from a surface mantle having a moderately strong development of brown soil. (Site is more fully described in Mears, 1981.)

Site LBs 3, Laramie city dump

Site LBs 4, 568 North Third Street, Laramie. Laramie Quadrangle; SW1/4 sec. 33, T.16N., R.73W.; 7,160 ft (2,182 m); foundation excavation for bank building in a terrace standing 30 ft (9 m) above the Laramie River.

Host is Triassic Chugwater Formation, markedly bent up against the wedge margins. The fill is silty sand derived from a near-surface mantle that is disconformably overlain by a thin fluviatile gravel. (Vertical marks in photo are from the excavating machine.)



Site LBs 4, 568 North Third Street, Laramie

Site LBs 5, Dutton Creek Road. Laramie SW Quadrangle; SW1/4 sec. 20, T.16N., R.74W.; 7,298 ft (2,224 m); road barrow pit 2.9 mi (4.6 km) northwest of airport, 176 ft (54 m) above the nearby Laramie River and on the middle to early Pleistocene Airport bench.

Host is the Niobrara Formation, a Cretaceous chalk. The wedge-delineated polygons are emphasized by vegetation that favors the silty sand in the wedge fills where the wedge-filling mantle has been stripped off in the barrow pit to expose the selenium-bearing host of light-colored soft limestone. (Man in photograph is six ft [1.8 m] tall.)

Site LBs 5, Dutton Creek Road

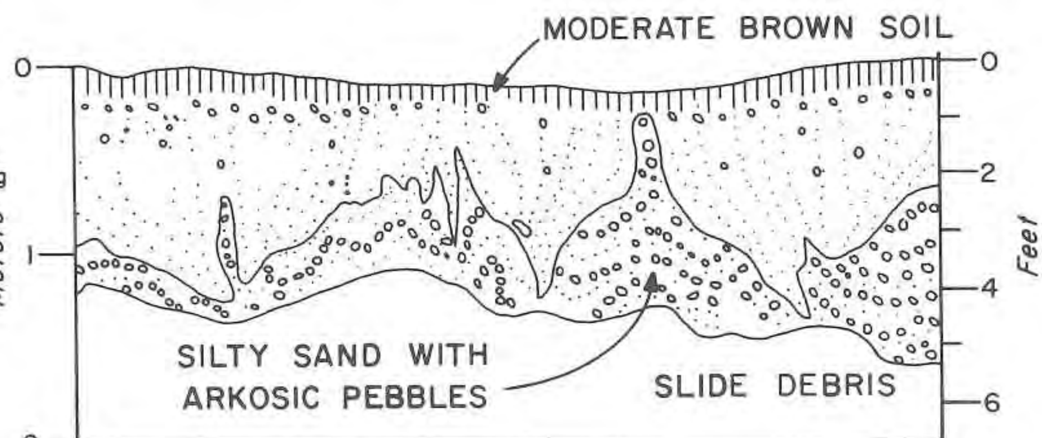
Site LBs 6, Paradise Stock Farm, University of Wyoming. Laramie SW Quadrangle; SE1/4 sec. 12, T.15N., R.74W.; 7,150 ft (2,180 m); gravel pit in lowest (Stock Farm) terrace standing nine ft (2.7 m) above mean level of the Laramie River.

The terrace material is dated as late Wisconsin from camel and mammoth bones found in a gravel pit about 1.5 mi (2.4 km) to the south, across the Laramie River (identified by Paul O. McGrew, personal communication, 1964).

The wedge host is alluvium containing clayey silty sand with arkosic pebbles; arkosic lenses of rounded pebbles; and cross-stratified, hematite-stained sand lenses. Some gleyed zones in the clayey silty sands emphasize involutions in the host between wedges; moderate upwarping is evident in host materials abutting wedges.

The wedge fills are silty sands containing pebbles; they have the vertical fabric characteristic of periglacial sand wedges. Before the discovery of the wedge locality, Reider and others (1974) proposed that the soils, developed on materials that provide the wedge fills, were probably earliest Holocene or latest Wisconsin in age based on their textural B horizons. (Site is more fully discussed in Nissen, 1985.)

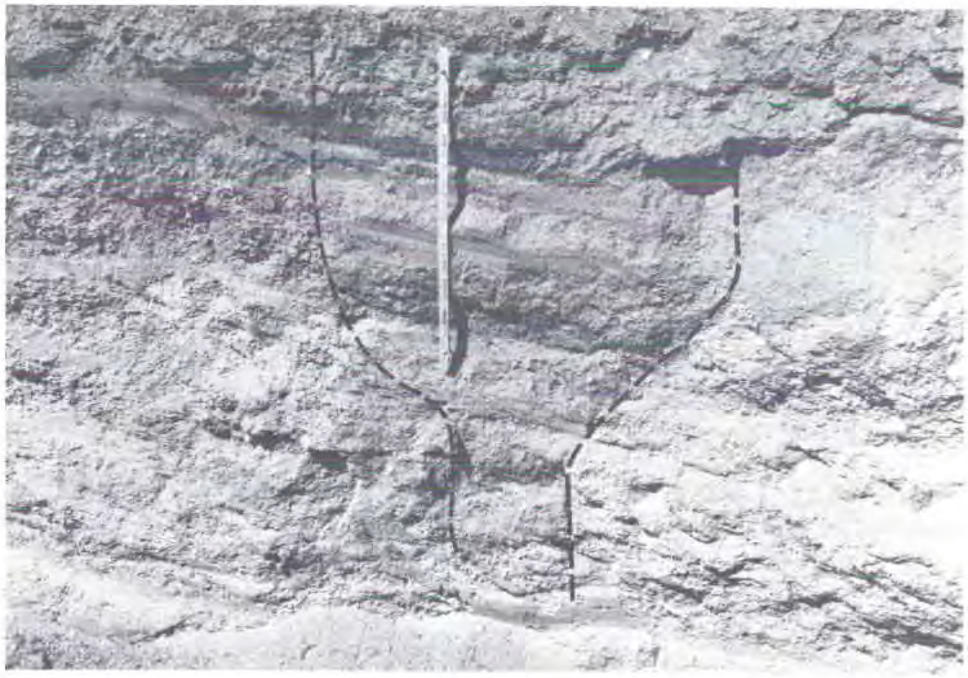
Site LBs 6,
Paradise Stock Farm,
University of Wyoming



Site LBs 7, near Monolith cement plant. Laramie Quadrangle; SE1/4 sec. 13, T.15N., R.74W.; 7,170 ft (2,185 m); Trailblazer Pipeline trench in Wisconsin-age Stock Farm terrace, 20 ft (6 m) above adjacent Laramie River.

Host is Quaternary alluvium of silt, sand, and gravel. Fill is silty sand with some pebbles from host. Moderately strong surface soil is developed across wedge-filling material. In photograph, host appears lighter colored than fill (dashed line delineates wedge boundary). (See also notes from site LBs 8 and **Figure 9**).

Site LBs 7, near Monolith cement plant



Site LBs 8, near Monolith cement plant. Laramie Quadrangle; SW1/4 sec. 19, T.15N., R.73W.; 7,180 ft (2,188 m); Trailblazer Pipeline trench in terrace 30 ft (9 m) above Laramie River level.

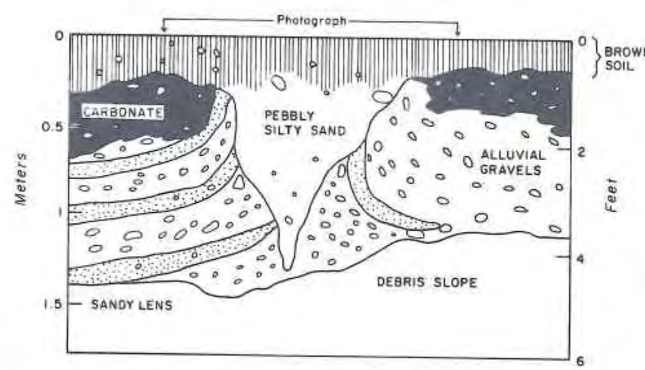
Host is weathered shale and thin-bedded sandstone of the Cretaceous Frontier Formation. Fill is silty fine-grained sand with some pebbles from the surface mantle and a few chips from host.

For about a mile (1.6 km) along the trench that exposes sites LBs 7 and 8, the host includes alluvium, which in places extends below the bottom of the trench (>7 ft, or 2 m deep) in channels and elsewhere lies on bedrock within two ft (0.6 m) of the terrace surface. Weathered bedrock of the Cretaceous Frontier and Mowry Formations and the Jurassic Morrison Formation also hosts wedges. Wedges are absent in places along the trench. About eight wedges were counted in a sample distance of 100 ft (30 m) where wedges did occur. Deformation of the host against the wedges, mainly bending up, is evident where slabby sands or carbonaceous (coal) lenses are present. In some wedges vertical fabric is evident.

Site LBs 8, near Monolith cement plant

Site LBs 9, Monolith Cement Company quarry, east end. Hutton Lake Quadrangle; center sec. 6, T.14N., R.74W.; 7,240 ft (2,207 m); quarry wall, 50 ft (15 m) above adjacent Laramie River, pre-Bull Lake alluvium-capped Harmony bench.

Host is alluvium containing silty, medium- to fine-grained sand with abundant pebbles and cobbles of Precambrian crystalline rocks; alluvium is six to nine ft (1.8 to 2.7 m) deep. A lens of 700,000-year-old Bishop Tuff (identified and dated by Izett and Naeser, 1976) lies at the base of the alluvium. Host contains powdery masses of secondary carbonate. Upturning of host against wedges is evident from oriented pebbles and sandy lenses in gravely deposits. Wedge fill of silty, fine- to medium-grained sand with some host pebbles has a moderately strong surface soil. (Site is more fully discussed in Mears, 1981.)

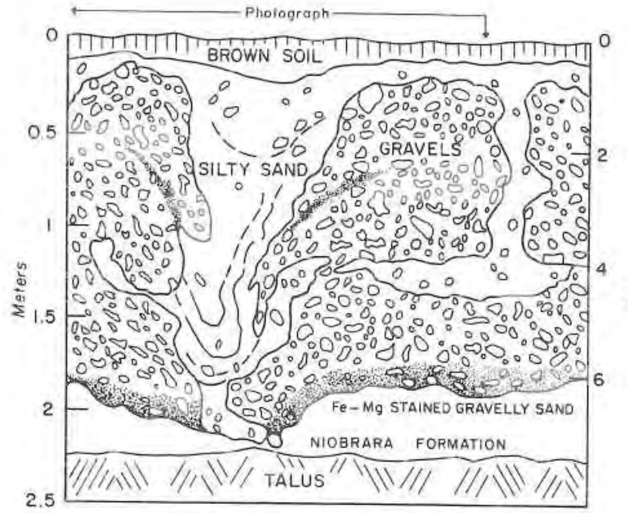


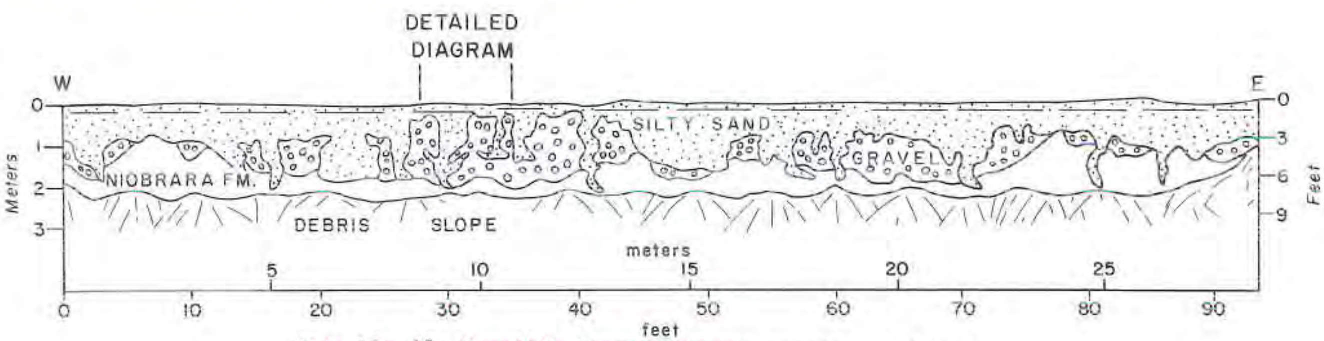
Site LBs 9, Monolith Cement Company quarry, east end

Site LBs 10, Monolith Cement Company quarry, west end. Caldwell Lake Quadrangle; NW1/4 sec. 12, T.14N., R.75W.; 7,240 ft (2,207 m); quarry wall, pre-Bull Lake Harmony bench, 50 ft (15 m) above nearby Laramie River.

Host includes Quaternary alluvium similar to site LBs 9, here one to six ft (0.3 to 1.8 m) deep. In places the host is the underlying weathered Cretaceous chalk of the Niobrara Formation. Host gravels, which contain some powdery secondary carbonate and iron- and manganese-stained zones, are warped down against the wedges (possibly reflecting ground-water influence during thawing of permafrost).

Fill is also comparable to previous site LBs 9. The wedge fill, which in one wedge contains a three-in (8 cm) cobble, exhibits concave-down laminae, suggesting subsidence into the space left by thawing ice wedges. (Site is more fully discussed in Mears, 1981.)

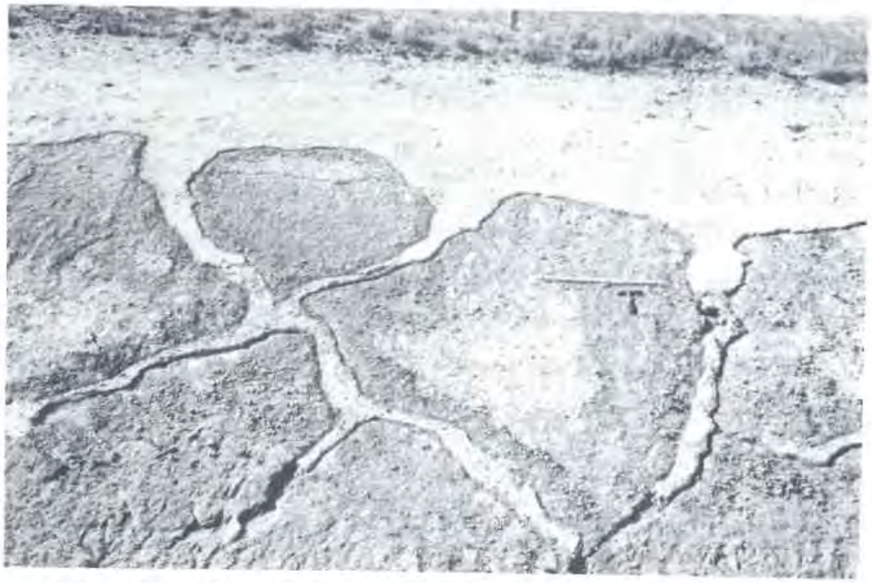




Site LBs 10, Monolith Cement Company quarry, west end

Site LBs 11, Twelve Mile Hill. Caldwell Lake Quadrangle; NW1/4 sec. 12, T.14N., R.75W.; 7,250 ft (2,210 m); highway barrow pit 0.7 mile (1.2 km) north of previous site, on Harmony bench, 60 ft (18 m) above level of Laramie River.

Same host and fill as at two preceding sites. Polygons (in 9°-sloping cut) were as much as 19 ft (5.8 m) in diameter. (Site is more fully discussed in Mears, 1981.)



Site LBs 11, Twelve Mile Hill

Site LBs 12, Sand Creek Road. Hutton Lake Quadrangle; NW1/4 sec. 1, T.14N., R.74W.; 7,260 ft (2,213 m); polygons exposed in dirt-road barrow pit on gentle hill slope, 40 ft (12 m) above nearby creek bottom.

Host is mudstone of the Jurassic Morrison Formation. Fill, derived from a thin surface blanket with moderately developed surface soil, is silty fine- to medium-grained sand with a few small pebbles.

Several other sites were observed along this county road. A desiccation origin was considered; however, a three-in (7.6 cm) clast embedded in a fill suggests that at least some of the original fractures were ice filled.

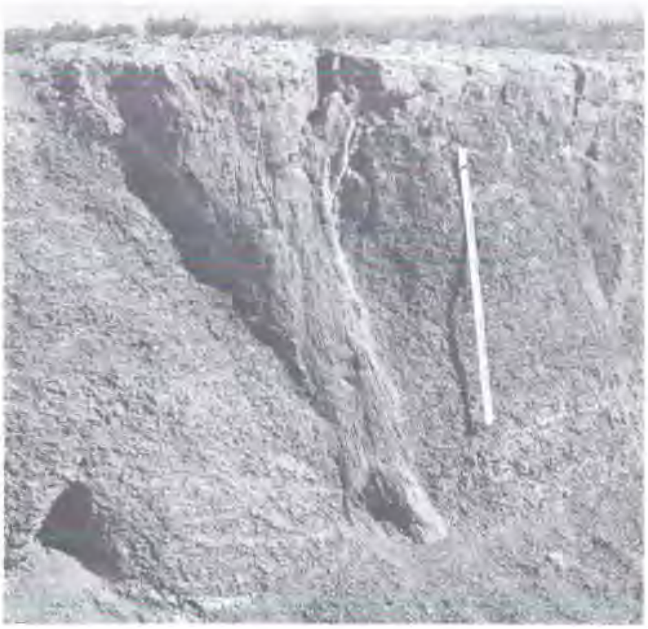
Site LBs 12, Sand Creek Road

Site LBs 13, Idealite Light-Aggregate Company quarry. Hutton Lake Quadrangle; SW1/4 sec. 4, T.14N., R.74W.; 7,245 ft (2,208 m); alluvium-capped Harmony bench with eolian cover, 70 ft (21 m) above nearby Laramie River.

Host is dark shale of the Cretaceous Frontier Formation, in places cut at the top by isolated channels of strongly iron-stained Quaternary gravels. Host abutting wedges is commonly bent downward but in places upturned.

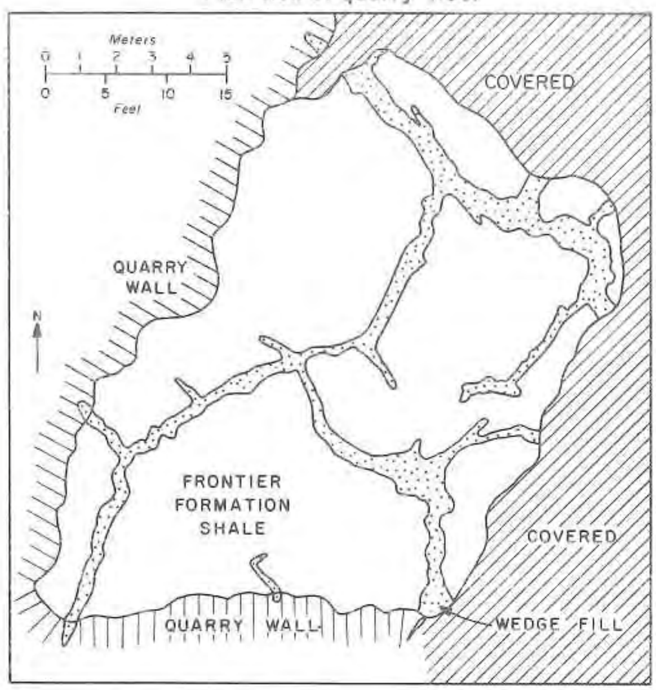
Wedge fill is slightly pebbly silty sand, exhibiting a vertical fabric of thin crack fillings about 0.5 in (1 to 1.5 cm) wide (photograph). Wedge-filling mantle has a moderately strong surface soil.

Polygons, as much as 30 ft (10 m) in diameter, were observed where gravel has been stripped from the top of the shale (diagram). (Site is more fully discussed in Mears, 1981.)



Site LBs 13, Idealite Light-Aggregate Company quarry

Plan view of quarry floor



Site LBs 14, Creighton Lake. Hutton Lake Quadrangle; NW1/4 sec. 16, T.14N., R.74W.; 7,200 ft (2,195 m); wave-cut scarp about eight ft (2.4 m) high in photograph area, along east side of the lake. Upper slope of large deflation basin cut into same alluvium-capped bench as at site LBs 13. (Photograph by D.L. Blackstone, Jr.)

Host is dark shale of the Cretaceous Frontier Formation, which is mainly bent down against the wedges. In a detailed study of this locality, Grasso (1979) determined that the wedge fill (which is similar to site 13) contains from 80 to 90 percent quartz sand, with minor amounts of other minerals, and that the silt- and clay-sized fractions are predominantly quartz with only minor amounts of clay minerals. The wedge-filling mantle has a moderately developed surface soil.

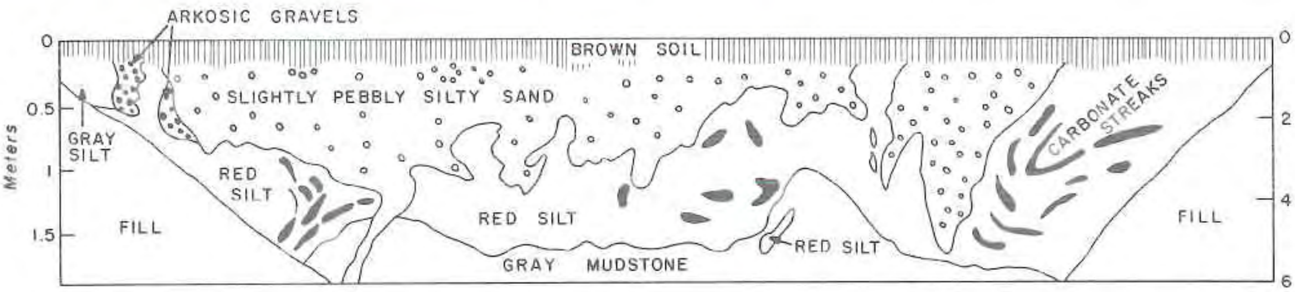
Site LBs 14, Creighton Lake

Note: *Sites LBs 15 through 18 were selected from hundreds of wedges observed along about 20 miles (32 km) of the six- to ten-ft (2 to 3 m) deep trench across the southern Laramie Basin for Cheyenne's aqueduct pipeline (see* ***Figure 1****).*

Site LBs 15, east of Antelope Creek. Johnson Ranch Quadrangle; SE1/4 sec. 5, T.13N., R.74W.; 7,410 ft (2,259 m); pipeline ditch on the flank of bench where the gravel cap eroded away, 90 ft (27 m) above nearby Antelope Creek.

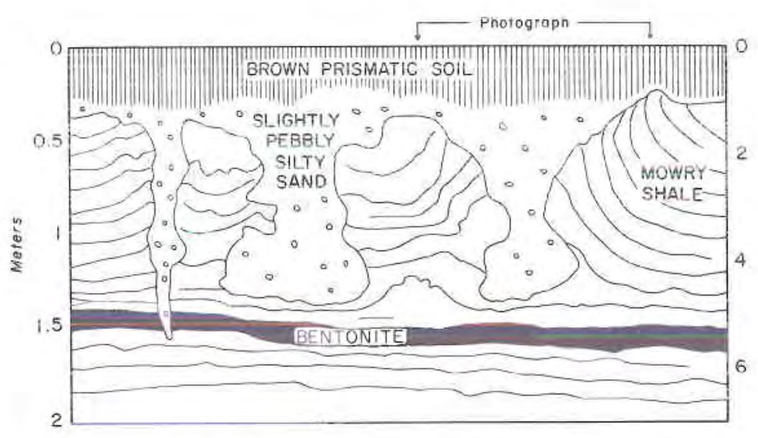
Host is weathered mudstone of the Jurassic Morrison Formation. Homogeneous host is warped up against the wedge, as indicated by secondary carbonates (diagram). Fill is silty sand with small pebbles derived from the nearby Cretaceous Cloverly Formation, and has a moderately well-developed soil across the wedge-filling mantle. Photograph location is adjacent to, but not on, the line of cross section. (Scale in photograph is one ft long. Filled rodent hole along the right side of the wedge is a krotovena. Dashed line delineates wedge boundary.)

Site LBs 15, east of Antelope Creek



Site LBs 16, west of Sand Creek Road. Downey Lakes Quadrangle; SW1/4 sec. 1, T.13N., R.75W.; 7,327 ft (2,233 m); pipeline ditch in bench, 56 ft (17 m) above nearby Sand Creek, where arkosic Quaternary gravel cap is breached by a shallow swale containing wedge-fill mantle.

Host is Cretaceous Mowry Shale, whose siliceous laminations clearly indicate upturning against the wedges. Fill is slightly pebbly silty sand extending down from a surface mantle having a moderately well-developed soil. (Photograph scale one ft long.) (Site is more fully discussed in Mears, 1981.)

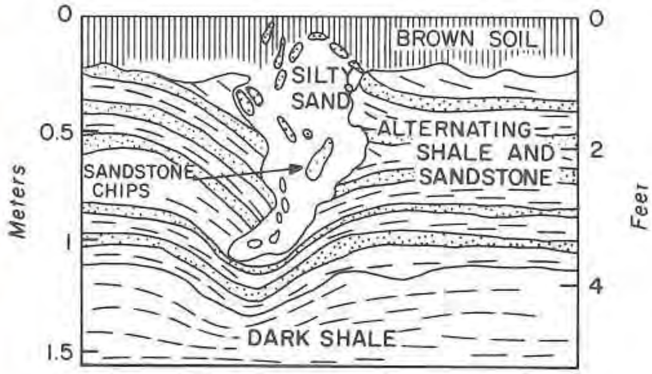


Site LBs 16, west of Sand Creek Road

Site LBs 17, south of Fellhauer Ranch. Jelm Mountain Quadrangle; SE1/4 sec. 3, T.13N., R.76W.; 7,344 ft (2,238 m); pipeline ditch in gently sloping upper margin of a terrace, 34 ft (10 m) above the adjacent Laramie River to the north.

Host consists of interlayered slabby sandstone and shale of the Cretaceous Frontier Formation. A moderate-sized quartzite cobble near base of silty sand-wedge fill in photograph probably fell in during thawing of an ice wedge. (Curved marks are from excavating machine; scale is one ft, 0.3 m, long.)

The diagram illustrates relations in a nearby wedge where sandstone chips were injected upward. They may reflect cryostatic pressure developed in still-thawed material during downward seasonal freezing from the surface, in an active zone underlain by a permafrost table.

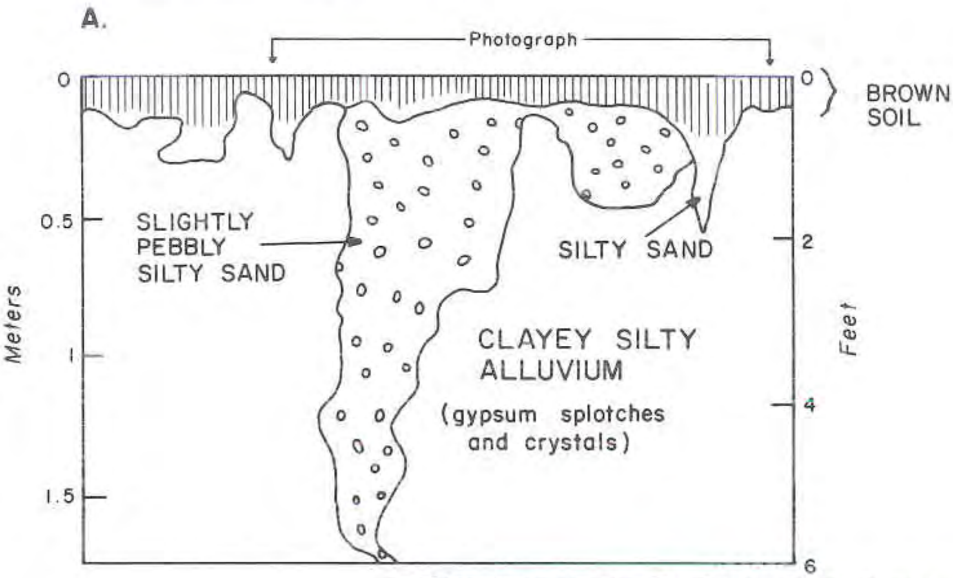


Site LBs 17, south of Fellhauer Ranch

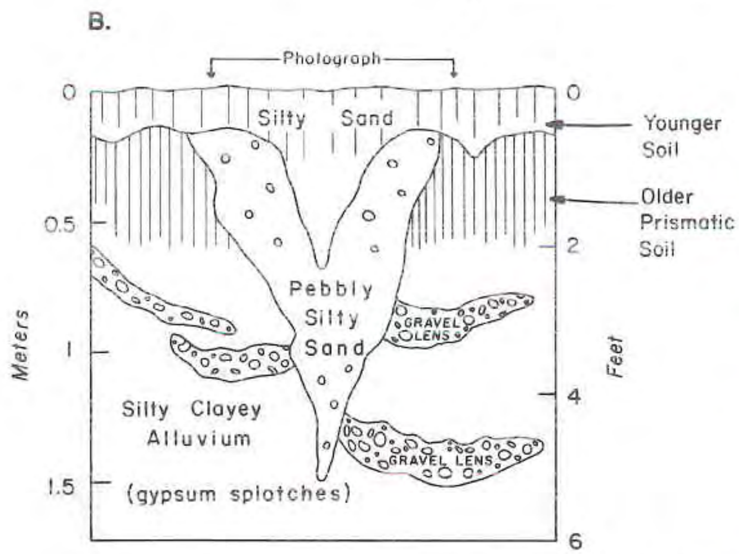
Site LBs 18, northeast of Jelm Mountain. Jelm Mountain Quadrangle; SW1/4 sec. 4, T.13N., R.76W.; 7,360 ft (2,243 m); pipeline trench, two closely spaced wedge localities along the margin of a bench, about 52 ft (16 m) above the Laramie River to the north.

At locality A, host was cut out to expose the angular junction of wedges. At locality B, about 150 ft (46 m) to the west, two sets of *two-storied wedges* (of Romanovskij, 1973) were present. At both localities, the host was silty alluvium or colluvium containing splotches of gypsum.

In the two-storied wedge sets, the fill of the larger and deeper wedges was silt and fine sand with abundant quartz and feldspar pebbles, which was impregnated with secondary carbonate. These wedges were crosscut by the small upper set, whose fills were silt and fine sand with a few pebbles and less carbonate. They extended down from the surface mantle, which had a moderately developed surface soil. The wedges were interpreted as of two generations, the older and deeper being filled from a more pebbly surface mantle that was largely stripped by erosion before development of the upper cross-cutting set. (Site is also described in Mears, 1981.)



Site LBs 18A, northeast of Jelm Mountain



Site LBs 18B, northeast of Jelm Mountain

Site LBs 19, Sodergreen Lake. Sodergreen Quadrangle; SW1/4 sec. 21, T.14N., R.76W.; 7,380 ft (2,250 m); wave-cut scarp in low hillside, 10 ft (3 m) above the surface of Harmony bench, which stands 70 ft (21 m) above the Laramie River, 1.5 mi (2.4 km) to the south.

Wedge host is weathered chalk of the Cretaceous Niobrara Formation, overlain by alluvial sandy cobbles and gravel derived from Precambrian crystalline rocks. In places, the gravel is contorted and slightly folded down into the chalks. The host is bent up against the wedges. The wedge fill is a pebbly silty sand having well-defined vertical fabric. The mantle providing the fill has been stripped by erosion. (Scale is a meter stick, casting curved shadow.)

Site LBs 19, Sodergreen Lake

Site LBs 20, Gelatt Lake. Caldwell Lake Quadrangle; NE1/4 sec. 29, T.15N., R.75W.; 7,255 ft (2,211 m); cut for irrigation ditch in a low hill reflecting an anticline.

Host is Cretaceous Frontier Formation, which exhibits periglacial pressure deformation, bending both up and down against wedges. Wedge fill is silty sand, containing secondary carbonate, as well as small Frontier Formation shale chips, whose steep inclinations indicate a vertical fabric. The mantle providing the fill has a moderate surface soil development, and is overlain by wind-polished gravels and cobbles.

Photograph A shows the normal exposure of wedges in the field; photograph B shows a wedge from which removal of an elvacite peel accentuated the vertical fabric of the sand-wedge fill. (Site is more fully discussed in Nissen, 1985.)

Site LBs 20, Gelatt Lake

Site LBs 21, Big Hollow Road. Miller Quadrangle; SW1/4 sec. 7, T.15N., R.75W.; 7,270 ft (2,216 m); roadcut in low bench surface, or pediment, sloping into the large deflation basin of Big Hollow.

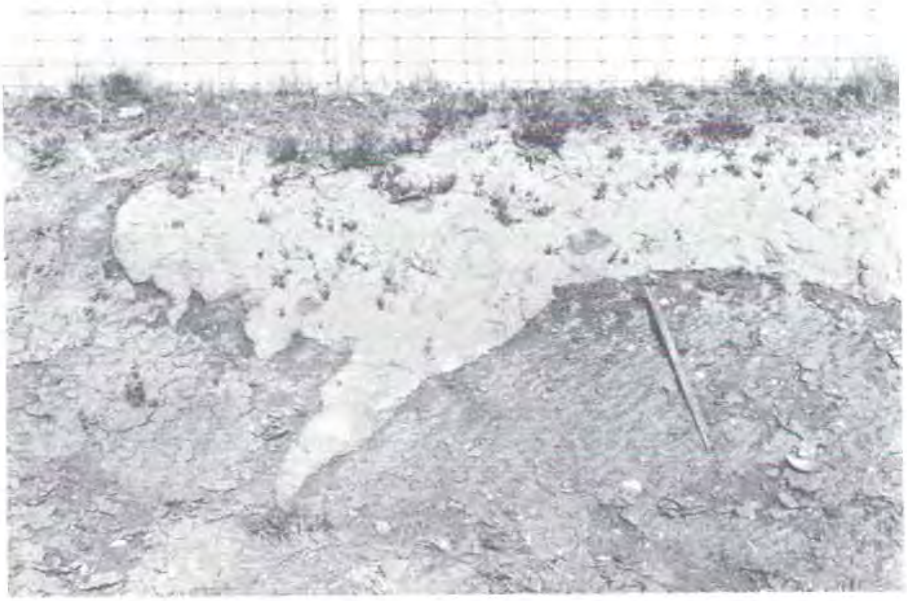
Host includes weathered shale of the Sage Breaks member of the Cretaceous Niobrara Formation and colluvium-alluvium derived from the shale. Numerous wedges along this and nearby roadcuts have silty sand fills derived from a mantle that has a moderately well-developed soil. Cobbles transported from the higher benches to the north are scattered across the mantle. (Site described in Nissen, 1985.)

Site LBs 21, Big Hollow Road

Site LBs 22, Big Hollow Road. Miller Quadrangle; NW1/4 sec. 6, T.15N., R.75W.; 7,425 ft (2,263 m); sloping roadcut on a pediment, descending southeastward toward Big Hollow, which was littered with wind-abraded quartzite cobbles washed down from the nearby Eagle Rocks bench.

Twelve wedges were counted in a sample distance of 100 ft (30 m). The wedge host material, Cretaceous Steele Shale, was upturned against wedge margins and contorted between the wedges. The wedges penetrate as much as four ft (1.2 m) into the shale host. Poorly exposed polygons were observed nearby where the surface had previously been stripped for road materials.

The wedge fill was derived from a mantle of silty sand, about one ft (30 cm) thick that is overlain by the quartzite cobbles. The mantle materials had a very pale brown (10 YR 7/3) surface soil containing visible, but weakly developed carbonate.



Site LBs 22, Big Hollow Road

Site LBs 23, Eagle Rocks bench. Millbrook Quadrangle; SW1/4 sec. 10, T.15N, R.76W.; 7,765 ft (2,367 m); wind-stripped surface 365 ft (110 m) above the Little Laramie River, which is 3.5 mi (5.6 km) to the northwest.

The site is deflated to a calichified Cca soil horizon which, 300 ft (90 m) to the north, is mantled by much younger wedge-filling eolian silty sand. The exposed polygons are about 36 ft (11 m) in diameter. They are emphasized by grassy vegetation that is very sparse in the polygon centers and favors the wedge-filling material. Cross sections were not available; however, the wedge tops, as determined on the ground surface, are about two ft (60 cm) wide. The host material is an early to middle Pleistocene alluvial deposit containing abundant metaquartzite pebbles and cobbles. On the ground surface, ventifacts are common, and many clasts have well-developed caliche cups on their under-sides.

Site LBs 23, Eagle Rocks bench

Site LBs 24, near Little Laramie River. Millbrook Quadrangle: NE1/4 sec. 32, T.16N., R.76W.; 7,480 ft (2,280 m); railroad cut on slope towards Little Laramie River (at tree belt in middle distance) from flank of higher bench.

Host is fine-grained colluvium derived from uppermost Steele Shale(?) and(or) basal Mesaverde Formation (both Cretaceous). Fill is silty sand with a few small pebbles derived from a mantle having moderate surface soil development. Some meta-quartzite cobbles, washed down from the higher Eagle Rocks bench, are scattered across the mantle.

Site LBs 24,
near Little Laramie River

Laramie Basin, northern part (LBn)

Site LBn 1, near wind-turbine generators south of Medicine Bow. Pine Ridge Quadrangle; SW1/4 sec. 25, T.22N., R.79W.; 6,750 ft (2,057 m); barrow pit beside dirt road on broad bench surface, 130 ft (40 m) above Medicine Bow River, 1.5 mi (2.4 km) to the north.

Host is dark Cretaceous Steele Shale, and is contorted (bent up) against the wedges delineating the polygons. Wedges exceed six ft (1.8 m) deep, extending below the bottom of the sloping roadcut. Wedge margins in upper part of cut are impregnated with powdery secondary carbonate.

Wedge fill is silty fine sand containing some small shale stringers that indicate a vertical fabric. The fill was derived from a thin, one- to two-ft (30 to 60 cm) thick, eolian cover that has moderate soil development. Abundant pebbles, as large as two in (5 cm) in diameter litter the bench surface, which contains shallow deflation hollows.

Site LBn 1, near wind-turbine
generators south of Medicine Bow

Site LBn 2, near County Road 402 exit from I-80. TL Ranch Quadrangle; NW1/4 sec. 23, T.20N., R.80W.; 7,240 ft (2,207 m); pipeline trench in a shallow valley cut into Wagonhound bench, standing 240 ft (73 m) above the Medicine Bow River, 1.5 mi (2.4 km) to the north.

In a sample distance of 100 ft (30 m), seven wedges were counted. The host is the uppermost part of the Steele Shale and, in places, colluvium derived from it. Upturning of the host against some wedges is evident.

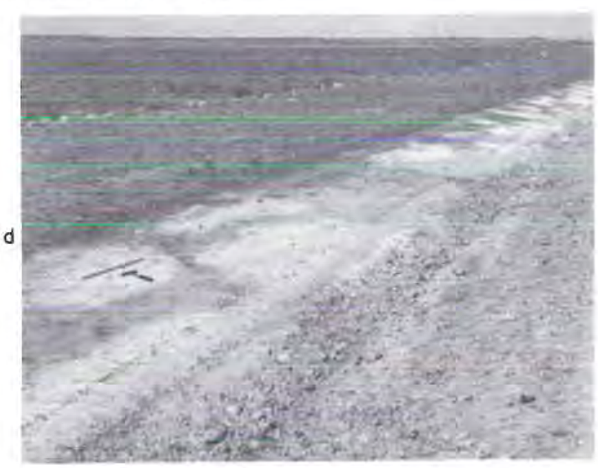
The wedge fill is pebbly silty sand, slightly indurated by secondary carbonate. Internal fabric was not discernible (curved marks in photograph from excavating machine).

Site LBn 2, near County Road 402 exit from I-80

Site LBn 3, north of Rock Creek oil field. McFadden Quadrangle; NW1/4 sec. 27, T.20N., R.78W.; 7,184 ft (2,190 m); narrow barrow pit along dirt road on first major terrace, 64 ft (20 m) above, and north of, Rock Creek.

Host of wedge-polygons is weathered Cretaceous Steele Shale in the Rock Creek anticline. Wedge fill is slightly pebbly fine- to medium-grained sand with moderate soil development across wedge-filling mantle. The terrace surface is littered with metaquartzite cobbles, as much as 15 in (38 cm) across, which were washed down from the high-standing Arlington bench to the north.

Site LBn 3, north of Rock Creek oil field



Site LBn 4, north of Bosler. Cooper Lake North Quadrangle; NW1/4 sec. 2, T.19N., R.75W.; 7,122 ft (2,171 m); roadcut (25° slope) of U.S. Highway 30 on gently rounded hilltop, 100 ft (30 m) above adjacent playa.

Host is weathered silty claystone of the Eocene Wind River Formation. Wedge-polygon fill is silty sand from a mantle, probably eolian, that has a moderately developed surface soil (scale is army entrenching pick).

Site LBn 4, north of Bosler

Site LBn 5, near Wheatland Reservoirs. McGill Lakes Quadrangle; N1/2 sec. 26, T.22N., R.74W.; 6,960 ft (2,121 m); along ditch between Wheatland Reservoirs 2 and 3, in surface, slightly above Laramie River level, extending northwest to the rim of a large but shallow deflation hollow.

Host is Triassic Chugwater Formation. Multiple wedges, cut at various angles, contain silty sand-wedge fills derived from a surface mantle having a moderately developed surface soil (mantle is overlain by material excavated from the ditch).

Laramie Mountains (LM)

Site LM 1, near Ames Monument. Sherman Mountains Quadrangle; NW1/4 sec. 31, T.31N., R.71W.; 8,120 ft (2,475 m); pipeline trench on the rolling upland of the Sherman erosion surface on the Laramie Mountains.

This unique site has the only wedges that have been observed to cut Precambrian crystalline rocks. Two wedge localities, each extending about 300 ft (100 m), were about 250 ft (76 m) apart. There were about ten wedges in the 100-ft (30 m) measured sample distance.

The wedge host is an extremely weathered, very friable, grayish brown gneiss characterized by markedly decomposed ferromagnesian minerals. Chemical weathering probably dominated; however, some less-weathered potassium feldspar crystals may indicate accompanying mechanical disintegration of the grus.

The wedge fill, a reddish brown (2.5 YR 5/4), fine- to coarse-grained sand, contains pebbles of 0.5 in (1.3 cm) and smaller diameters that are largely granite-derived feldspar and quartz. A moderately well-developed textural B horizon, about one ft (30 cm) thick marks the soil of the wedge-filling mantle.

Wedges are restricted to the very weathered rocks at the site. No wedges were observed in moderately weathered, coarse-grained, pink Sherman Granite along a two-mi (3.2 km) traverse west of the site, nor in the three-mi (5 km) traverse to the east of the site.

Site LM 1, near Ames Monument

High plains (HP)

Site HP 1, Warren Air Force Base. Cheyenne North Quadrangle; midway along boundary between secs. 15 and 22, T.14N., R.67W.; 6,210 ft (1,893 m); small excavated pit near Crow Creek.

A four-in (10 cm) wide, 17-in (43 cm) deep wedge is interpreted as the lower part of a periglacial sand wedge whose upper part has been removed by erosion. The host is interpreted as eolian silt and sand containing a stone line penetrated by the tip of the wedge. The wedge is dated as Pleistocene, based on the degree of soil development on an adjacent and lower geomorphic surface. (All data from Morgan, 1986.)

Site HP 2, near Pershing Boulevard, just east of Cheyenne. Archer Quadrangle; SW1/4 sec. 30, T.14N., R.65W.; 6,065 ft (1,850 m); gravel pit on a bench 185 ft (56 m) above Crow Creek, which is 1.6 mi (2.6 km) to the south.

Three wedges were counted in a distance of about 20 ft (6 m). Wedge host is alluvial pebbly sand containing occasional cobbles as large as 10 by 12 by 8 in (25 by 30 by 20 cm). Iron-stained reddish yellow (5 YR 7/6) sand in the host as well as the height of the bench gravels above Crow Creek indicate a pre-Wisconsin age for the host. It is warped upward against the wedge near the top and is in places, near the bottom of the wedge, warped downward. The silty sandy wedge fills, which have no apparent internal fabric, have moderate development of secondary carbonate.

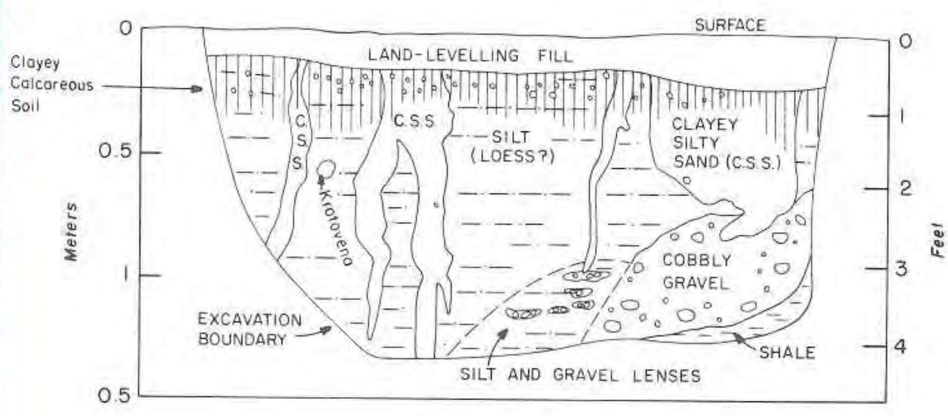
The wedge host and fills are unconformably overlain by a very pale brown (10 YR 7/3) silty layer, possibly loess, that is one ft (30 cm) thick and has marked prismatic soil structure. This silt is in places overlain by a lens of dark bog deposits as much as 12 in (30 cm) thick, which are in turn overlain by very pale brown silt having weak polygonal structure. (Discovered by Maurice E. Cooley.)

Site HP 2, near Pershing Boulevard, just east of Cheyenne

Powder River Basin (PR)

Site PR 1, Sheridan Elks Club Cemetery. Sheridan Quadrangle; NW1/4 sec. 34, T.56N., R.84W.; 3,880 ft (1,183 m); 4.5-ft (1.4 m) deep grave excavation on Pleistocene bench, 125 ft (38 m) above Big Goose Creek.

Host is silt, interpreted as loess, having cobbly alluvial gravels, associated with mammoth bone at the base. The upper part of the loess was removed during leveling of the site; however, secondary carbonate in the loess was interpreted as in a B or C soil horizon. The wedge fill is pebbly, fine- to medium-grained sand. Photograph is from an excavation near the one depicted in the cross section. (Data from Walker, in press; photo and cross section by R.G. Reider.)

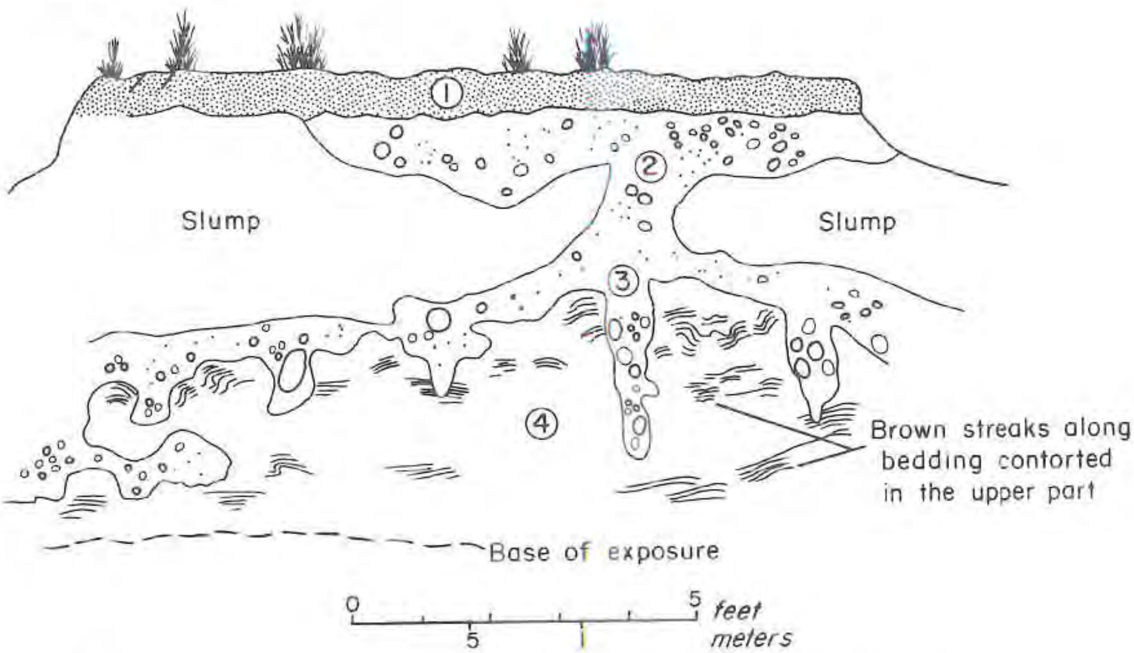


Site PR 1, Sheridan Elks Club Cemetery

Site PR 2, north of Arvada. Arvada Quadrangle; sec. 16, T.54N., R.77W.; 3,700 ft (1,128 m); roadcut in a terrace, 55 ft (17 m) above the nearby Powder River.

Based on their study of this site, Leopold and Miller (1954) made the first suggestion of a *frost climate* and possible ice-wedge casts in a Wyoming basin floor.

Host is soft sandstone of the Paleocene Fort Union Formation. Contortions were noted in the upper part of the host adjacent to wedges. The fill is interpreted as cobbly coarse sand and weathered clasts of the late Pleistocene Arvada "formation" (Leopold and Miller, 1954) having secondary carbonate and gypsum. The surface of their Arvada "formation" has a paleosol that is disconformably overlain by the post-Altithermal (?) Kaycee "formation" (diagram and descriptions modified from Leopold and Miller, 1954).



"Kaycee" formation	1. Colluvium and alluvium, brown silty sand; loose, without caliche.
"Arvada" formation	2. Red-brown and yellow cobbly gravel, weathered; and gypsum in irregular fibrous masses and coating underside of pebbles, grades into—
	3. Red-brown and yellow cobbly coarse sand with less caliche and gypsum; fossil ice wedges in contorted lower boundary.
Fort Union Formation	4. Gray-white sand streaked with brown stain along bedding; contorted in upper part; no caliche or gypsum; grades downward into uncontorted poorly cemented sandstone of same color.

Site PR 2, north of Arvada

Site PR 3, near Gillette. Gillette East Quadrangle; center of sec. 29, T.50N., R.71W.; 4,500 ft (1,400 m).

Host is Eocene Wasatch Formation(?). Wedge fill is sand. (Site observed by D.S. Fullerton and Donald A. Coates, personal communication, 1978.)

Site PR 4, east of Gillette. Rozet SE Quadrangle; NE1/4 sec. 31, T.50N., R.68W.: 4,280 ft (1,305 m); gravel pit in a bench 80 ft (24 m) above nearby Donkey Creek.

Host is Pleistocene cobbly gravel. Fill is silty sand. (Site recorded and photographed by Marith Reheis, personal communication, 1981. Lens cap for scale.)

Site PR 4, east of Gillette

Site PR 5, Springer Ranch. Hilight Quadrangle; W1/2 secs. 14 and 23, T.44N., R.71W.; 4,850 ft (1,480 m); barrow pit along graded dirt road.

Host is Wasatch Formation; wedge fill is sandy. (Site observed by Donald A. Coates, personal communication, 1978.)

Site PR 6, Thunder Basin Coal Company's Black Thunder mine. Reno Reservoir Quadrangle; SW1/4 sec. 17, T.43N., R.70W.; 4,700 ft (1,433 m); railroad cut.

Host is Eocene Wasatch Formation; wedge fill is silty sand. (Site observed by Donald A. Coates, personal communication, 1978.)

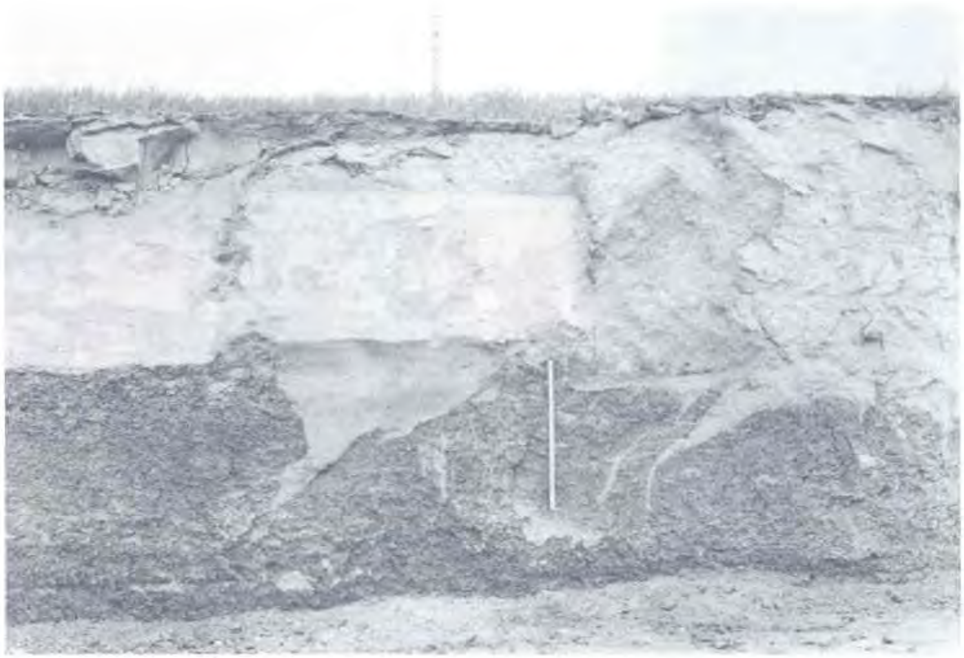
Site PR 7, Thunder Basin Coal Company's Black Thunder mine. Reno Reservoir Quadrangle; NE1/4 sec. 17, T.43N., R.70W.; 4,700 ft (1,433 m); roadcut of mine road on low rolling upland having shallow deflation hollows and small sand dunes. Surface is 165 ft (50 m) above nearby creek bottom.

Host is Eocene Wasatch Formation. Wedge fill is silty sand.

Site PR 7, Thunder Basin Coal Company's Black Thunder mine

Site PR 8, west of Douglas. Douglas Quadrangle; NW1/4 sec. 7, T.32N., R.71W.; 4,980 ft (1,518 m); Highway Department gravel pit. The wedges occupy a gentle fan-shaped slope, incised into a higher surface, and are 200 ft (61 m) above the nearby North Platte River.

Peels made at the site show two wedge generations. The host for the lower and older wedges is mudstone of the Paleocene Fort Union Formation. Their fill is pebbly sand, coarser textured than the fill of the younger wedges. The younger wedges penetrate finely laminated sand of fluvial or eolian origin, which is bent up against the wedges, and in places they penetrate the lower older wedges. Photograph shows the older generation of wedges. (Site in Nissen, 1985.)



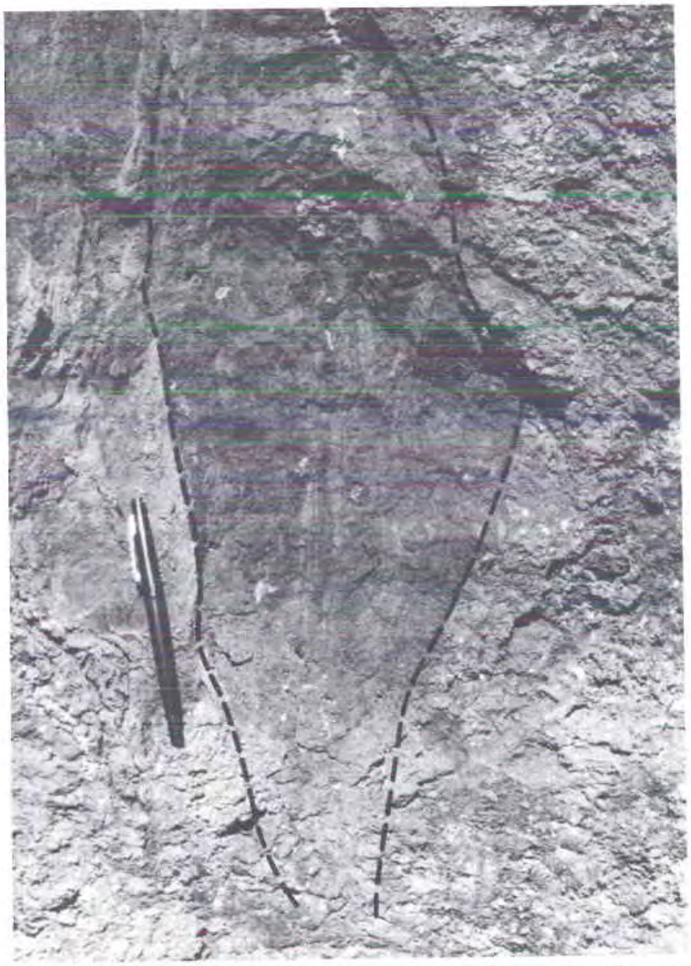
Site PR 8, west of Douglas

Casper arch (CA)

Site CA 1, Former Labelle's Department Store parking lot construction site, Casper. Casper Quadrangle; NW1/4 sec. 10, T.33N., R.79W.; 5,160 ft (1,573 m); wedge polygons at construction site on a terrace 60 ft (18 m) above the North Platte River.

The host material is weathered Cretaceous Cody Shale. The wedge fill is pebbly fine- to medium-grained sand that has a well-developed vertical fabric (close-up photograph; dashed line delineates wedge boundary.) Gerald E. Nelson (personal communication, 1981) observed several other wedge sites at excavations in the city of Casper. (Site reported and photographed by Gerald E. Nelson.)

Site CA 1, wedge polygons, Former Labelle's Department Store parking lot construction site

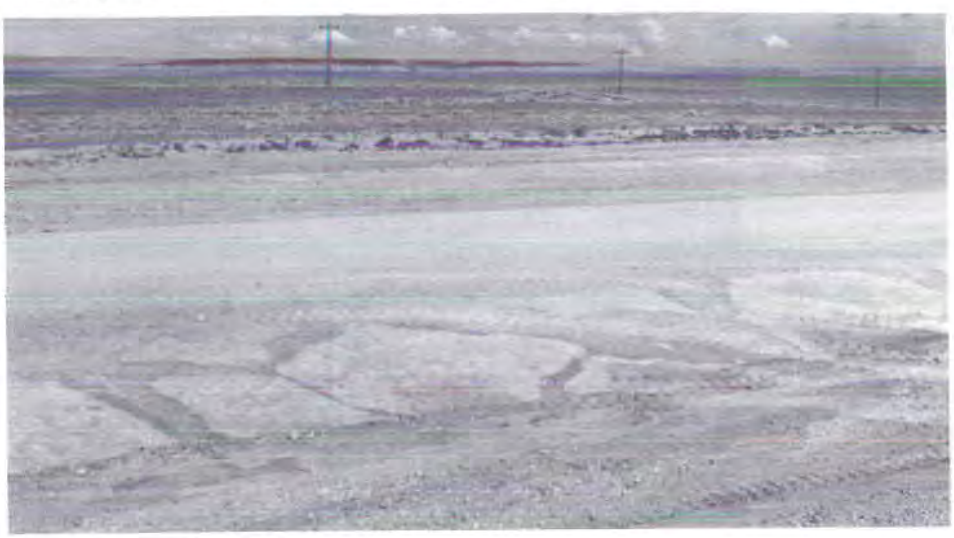


Site CA 1, wedge cross section (close-up)

Site CA 2, five miles north of the town of Powder River. Powder River Quadrangle; SW1/4 sec. 12, T.36N., R.85W.; 5,628 ft (1,715 m); dirt road barrow pit on surface 83 ft (25 m) above adjacent valley bottom.

Host is weathered Cretaceous Cody Shale. Some wedge polygons are associated with joints in the host rock. The fill is pebbly silty sand. (Reported and photographed by Gerald E. Nelson, personal communication, 1981.)

Site CA 2, five miles north of the town of Powder River



Sites CA 3, 4, 5, and 6; two miles south of Kaycee. All information and photographs for these sites were provided by James H. Nyenhuis (personal communication, 1986).

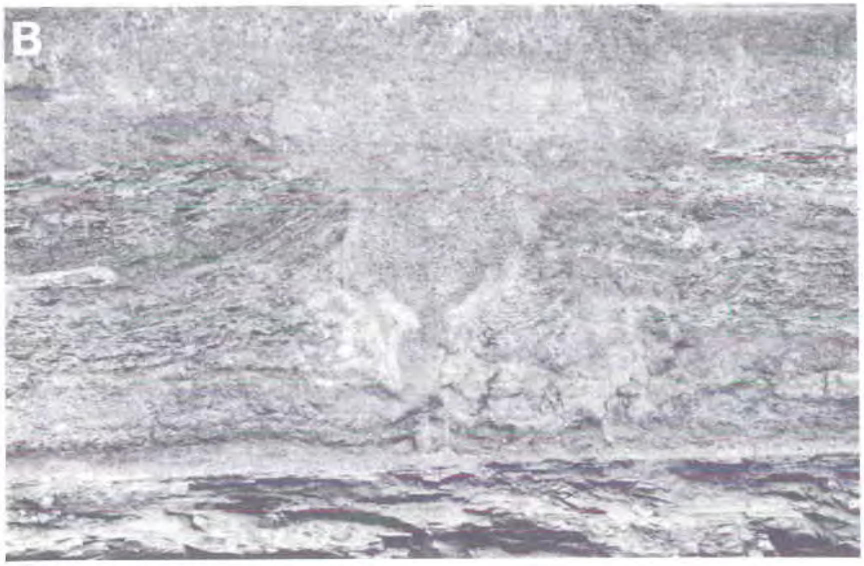
Four separate wedge localities were exposed in the walls of bentonite mine pits, as much as 1.6 mi (2.6 km) apart, west of the Triple-T exit off I-25. Maps are Barnum and Red Fork Powder River Quadrangles. The quarries are, respectively, in the SW1/4 sec. 10; NW1/4 sec. 11; NE1/4 sec. 11; and SE1/4 sec. 2 of T.42N., R.83W. Elevations range from 5,135 to 5,540 ft (1,566 to 1,689 m). The sites, in the foothills of the Bighorn Mountains, occupy gentle eastward slopes that stand 150 to 540 ft (46 to 165 m) above the Middle Fork of Powder River, which is one to two mi (1.6 to 3.2 km) to the north.

A composite description from the separate quarry sites, each of which displayed well-developed wedges, is presented because of the similar natures of the geologic settings and the wedges. Counts of wedges along sample distances of the quarry walls, sites CA 3, 4, 5, and 6 respectively, were ten in 150 ft (46 m), 18 in 270 ft (82 m), 15 in 300 ft (91 m), and 15 in 115 ft (35 m).

The host material of the wedges in photographs A (site CA 3) and B (site CA 6) is shale of the Cretaceous Frontier Formation, commonly bent upward, in some cases downward, against the wedge margins. The wedges penetrate the host shales to depths of six to eight ft (1.8 to 2.4 m). The wedge fills display the vertical fabric (photograph C, site CA 3) emphasized by oriented shale chips from the host, which characterizes sand-wedge relics.

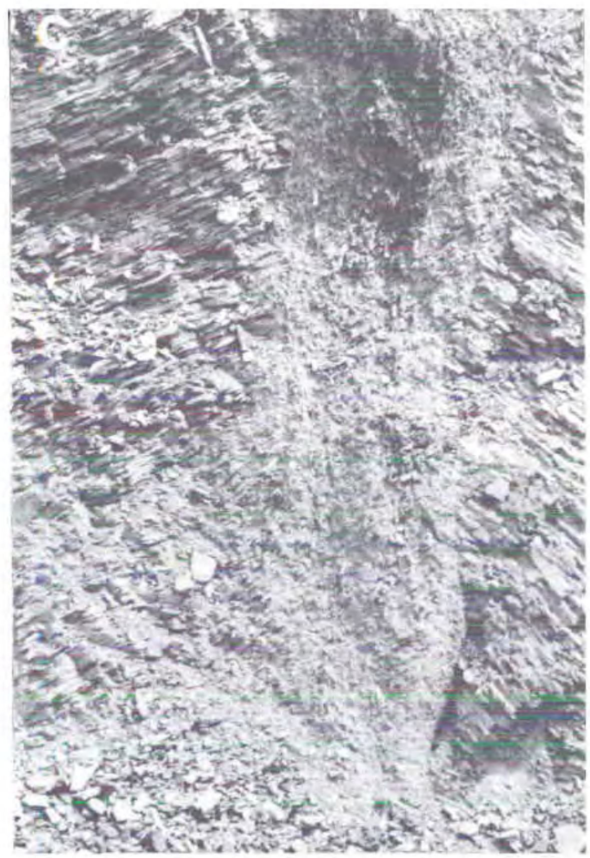
Quaternary deposits overlying the wedge-bearing shales range from 2.5 to 7.5 ft (0.8 to 2.3 m) thick. Although stripped back from the shales at the top of the quarry walls, the Quaternary mantles truncate the wedge-filling deposits. The well-developed soils on the mantles have argillic horizons (>35 percent clay) above secondary-carbonate horizons that overlie the shale. Taxonomic classifications of the soils are: fine, montmorillonitic, mesic aridic argiustoll and fine-loamy, mixed, mesic aridic argiustoll.

Site CA 3



Site CA 6

Site CA 3



Bighorn Basin (BB)

Site BB 1, Polecat Bench. Elk Basin Quadrangle; SW1/4 sec. 15, T.57N., R.99W.; 4,870 ft (1,484 m); pipeline trench on bench surface, 770 ft (235 m) above master drainage of the Shoshone River, to the south.

In a sample distance of 100 ft (30 m), 20 wedges, cut at various angles, were counted. Bifurcation of wedges across the trench bottom (photograph) indicate a polygonal pattern and penetration appreciably below the five-ft (1.6 m) deep trench.

Host is Pleistocene alluvium containing volcanic clasts from the Absaroka Plateau, 27 mi (44 km) to the southwest. Some cobbles are rotated up against the wedges. The wedge fill is pebbly sandy silt, containing powdery secondary carbonate derived from a surface mantle that has a moderately well-developed soil. (Site described in Mears, 1981.)

Site BB 1, Polecat Bench

Site BB 2, Polecat Bench. Deaver Reservoir Quadrangle; SE1/4 sec. 12, T.15N., R.99W; about 4,820 ft (1,470 m); in a backhoe pit on the bench surface, 0.75 mi (1.2 km) from the south flank of Polecat Bench.

The host materials and wedge fill are similar to those at Site BB 1, which is 0.85 mi (1.4 km) to the west and south on the same bench surface. Deformation of the host materials against the wedge was indicated by upturning of a small elongate cobble. Robert Lebruska (personal communication, 1985), of the U.S. Soil Conservation Service, discovered the site and identified the surface soil as the Spomer fine sand loam series, not yet a correlated series, which is classified as a fine-loam over sand or sand skeletal, mixed, mesic family of Ustollic Haplargids.

Site BB 2, Polecat Bench

Site BB 3, Powell Terrace near Bitter Creek. Byron Quadrangle; NW1/4 sec. 12, T.55N., R.98W.; 4,220 feet (1,286 m); pipeline trench on the surface and rising inner margin of a terrace about 20 ft (6 m) above the main Powell terrace and about 100 ft (30 m) above adjacent Bitter Creek.

Numerous wedges were observed along the trench. The host is weathered Paleocene Fort Union Formation and Quaternary colluvial and alluvial deposits derived from it. The wedge fill is silty sand derived from a mantle that has a moderately developed surface soil. Deformation of the fine-grained homogeneous host against wedges could not be determined.

Site BB 3, Powell Terrace near Bitter Creek

Site BB 4, Jim Bridger Trail. Gilmore Hill SE Quadrangle; SE1/4 sec. 31, T.54N., R.97W. and NE1/4 sec. 6, T.53N., R.97W.; 4,500 to 4,560 ft (1,372 to 1,390 m); pipeline trench along gently rounded hilltop on surface above a 160-ft high (49 m) descending scarp.

Thirty-one wedges were counted along a 500-ft (152 m) sample distance of the trench. Host is weathered Eocene Willwood Formation. Wedge fill described as whitish sand. (Reported by Katherine A. Hilton and Thomas N. Westerveldt, personal communication, 1975.)

Site BB 5, Jim Bridger Trail. Gilmore Hill SE Quadrangle; NE1/4 sec. 20, T.53N., R.97W.; 4,520 ft (1,378 m); pipeline trench 3.2 mi (5 km) south of site BB 4, along a surface above a descending 100-ft high (30 m) scarp.

Along a 150-ft (46 m) sample distance of the trench, six wedges were counted. Wedge host is weathered shaley sandstone of the Eocene Willwood Formation. Wedge fills described as brown sand. (Reported by Katherine A. Hilton and Thomas N. Westerveldt, personal communication, 1975.)

Site BB 6, south of YU Bench. Sheets Flat Quadrangle; NE1/4 sec. 1, T.50N., R.99W.; about 5,220 ft (1,590 m); roadcut about 200 ft (61 m) above the Greybull River, which is 0.3 mi (0.5 km) to the south.

The wedge-polygons cut colluvium from the YU Bench, and are stratigraphically about 15 to 20 ft (4.5 to 6 m) above Greybull River terrace gravels that overlie the Eocene Willwood Formation. (Reported and photographed by Marlin E. Lowry, personal communication, 1986.)

Site BB 6, south of YU Bench

Wind River Basin (WR)

Site WR 1, near Lysite. Along a dirt road just south of the Owl Creek Mountains, east of the Wind River, probable wedge polygons were evident in a barrow pit. No exact location or data are available because no stop was made there on a conducted geologic field excursion.

Host material is Wind River Formation. (Observed by Kent A. Sundell, personal communication, 1979.)

Site WR 2, southwest of Riverton. Arapahoe Quadrangle; SW1/4 sec. 2, T.1S., R.3E. (Wind River Base Line); 5,260 ft (1,595 m); gravel pit on a mid-Pleistocene(?) terrace about 260 ft (80 m) above the Wind River and 300 ft (90 m) above the Little Wind River.

The wedge contains vertically imbricated, sandy pebble gravel, overlain by as much as five ft (1.5 m) of sand with variable gravel content. Both contain the calcic horizon of a strongly developed buried soil. The strongest carbonate accumulation (2 to 3 ft, 60 to 90 cm) is in the gravely sand, but locally it extends down into the sandy gravel. A thin cap of younger eolian sand contains the A and weakly argillic B horizons of the modern soil.

Other possible periglacial features at this site include involutions of the contact between the gravely sand and underlying sandy gravels. The involutions, about one to two ft (30 to 60 cm) wide and deep, occur where overlying deposits are thin and the zone of strongest carbonate accumulation directly overlies the basal gravels. The fills of some involutions contain pendants of carbonate, suggesting that carbonate displacement is partly responsible for the lower gravel content and lack of imbrication in the involutions; however other fills contain relatively weak carbonate. The laterally uneven carbonate distribution, partial truncation of the calcic soil, and probable middle Pleistocene age of this terrace suggests that the involutions reflect multiple cycles of carbonate accumulation, leaching, surface erosion, and cryoturbation. (Site described by Mary L. Gillam, personal communication, 1986.)

Sweetwater graben of Granite Mountains (SW)

Site SW 1, old road to Sweetwater Crossing. Sweetwater Station Quadrangle; SW1/4 sec. 26, T.30N., R.85W.; 6,580 ft (2,005 m); barrow pit along dirt road. Photograph location, 50 ft (15 m) above Sweetwater River to the north, is on a gentle northward slope towards the terrace standing 25 ft (8 m) above the nearby floodplain.

Wedges are locally exposed along about 15 mi (24 km) of the barrow pit, and in places form polygons across the freshly bladed road. Ten wedges were counted in a sample 100 ft (30 m) long near the illustrated location. The host is carbonate-impregnated, fine-grained, possibly eolian, Quaternary sand derived from the Miocene Split Rock Formation. The wedge fill, whose fabric was indeterminable, is a fine-grained sand that has a moderate surface soil development.

Site SW 1, old road to Sweetwater Crossing

Site SW 2, near Cranner Rock and Bureau of Land Management historical site. Split Rock Quadrangle; SE1/4 sec. 25, T.29N., R.90W.; 6,220 ft (1,896 m); roadcut in rounded hilltop, 90 ft (27 m) above the Sweetwater River to the north.

Host is weathered soft sandstone of the Miocene Split Rock Formation. Wedge-polygon fill is fine- to medium-grained sand, derived from a mantle that has moderate surface-soil development.

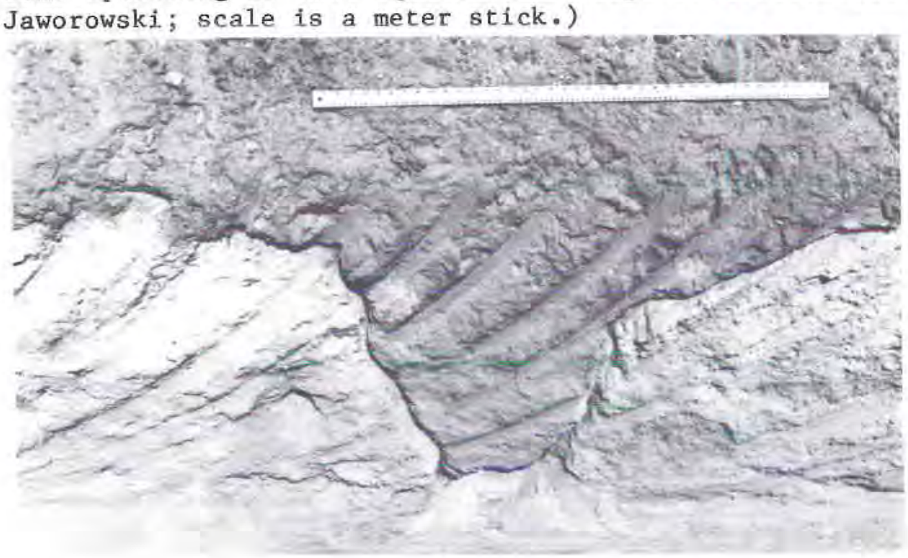
Site SW 2, near Cranner Rock and Bureau of Land Management historical site

Site SW 3, Sweetwater graben. Fourteen localities (Jaworowski, 1985) were observed along a pipeline trench from north of Green Mountain near Crooks Gap to, and across, the Sweetwater River east of the U.S. Bureau of Land Management historical site near Split Rock. Maps include Split Rock NE, Split Rock, and Bucklin Reservoirs Quadrangles; from the SW1/4 sec. 3, T.28N., R.91W. to the NW1/4 sec. 21, T.29N., R.89W.; ranging from 6,550 ft (1,996 m) to 6,180 ft (1,884 m). The localities were mainly on gentle slopes, and were absent from the coarse boulder caps of benches near Green Mountain. Sites were from 420 ft (128 m) to 50 ft (15 m) above the master drainage of the Sweetwater River. All localities exhibited multiple wedges; sample counts included five wedges in 60 ft (18 m) to 16 in 520 ft (158 m).

The wedge host is weathered, soft, fine-grained sandstone of the Miocene Split Rock Formation. In some places surficial deformation within the host materials was interpreted as disturbance of soil by strong frost action (cryoturbation). Penetration of wedges into the host ranged from many that were about three ft (1 m) to greater than five ft (1.5 m) deep - the depth of the excavation.

The wedge fill and associated mantle are mainly pebbly silty sand. Wedge fabric was not obvious, except in one large wedge where pebble lines indicated down-sagging, suggesting an ice-wedge cast.

The wedge in the photograph is cut at an oblique angle. It is located in the SW1/4 sec. 30, T.29N., R.89W. Curved marks are from the excavating machine; however, some upturning of host against the wedge is discernible. (Photograph by Cheryl C. Jaworowski; scale is a meter stick.)



Site SW 3, Sweetwater graben

Carbon Basin (CB)

Site CB 1, south of Rawlins. Bridger Pass Quadrangle; NE1/4 sec. 14, T.20N., R.88W.; 7,200 ft (2,195 m); floor of shallow excavation for gravel near State Highway 71, on very gentle slope about 40 ft (12 m) above adjacent lake in deflation hollow.

Diameters of wedge-polygons are as much as 20 ft (6 m). Host, Cretaceous Steele Shale, has deformed laminae at boundary with wedges. Fill is slightly pebbly, silty fine-grained sand. (Site reported and photographed by Marlin E. Lowry, personal communication, 1971.)

Site CB 1, south of Rawlins

Site CB 2, Sinclair town dump. Rawlins Quadrangle; NE1/4 sec. 17, T.21N., R.86W.; 6,600 ft (2,012 m); small sanitary landfill on a 3°-sloping terrace, 45 ft (14 m) above adjacent Sugar Creek.

Host is shale of the Cretaceous Frontier Formation and a thin Quaternary unit of pebbly sand. The shale is warped down against the wedges.

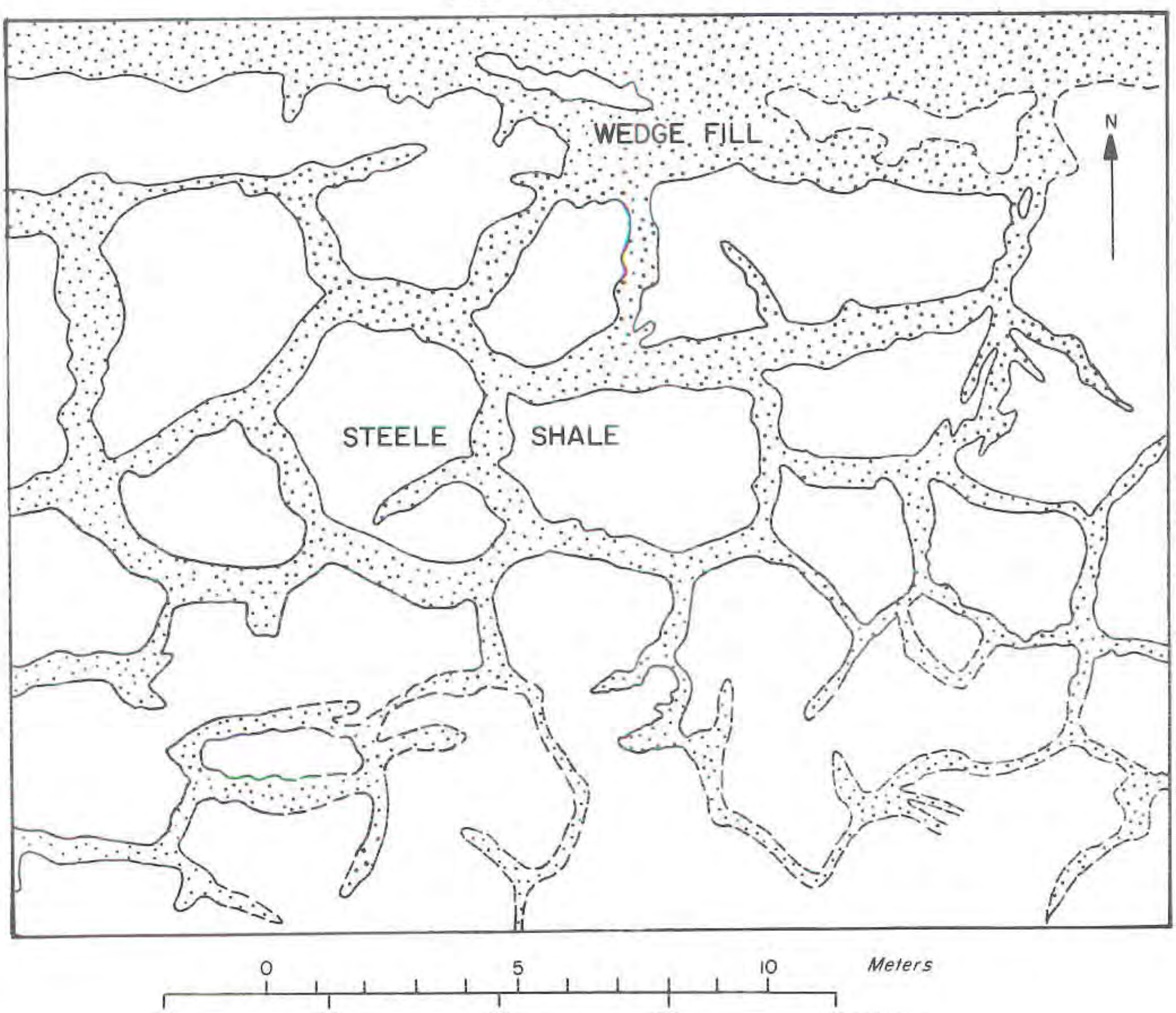
Fill is silty fine- to medium-grained sand containing a few pebbles and chips of shale. The chips are vertically oriented in the lower part of the wedges and flare out near the top. The mantle providing the fill has a moderate soil development at the top and is disconformably overlain by a pebbly sand with weak soil development and carbonate-coated pebbles.

Site CB 2, Sinclair town dump

Site CB 3, Walcott Junction (Front cover). Meads Quadrangle; SE1/4 sec. 33, T.21N., R.84W.; 6,770 ft (2,063 m); roadcut along I-80 on broad rounded hilltop 60 ft (18 m) above adjacent bottom; 270 ft (82 m) above North Platte River, which is 3.5 mi (5.6 km) to the west.

Host is Cretaceous Steele Shale, warped up against polygon margins, as indicated by shale laminae and some small concretions in the shale. Wedge-polygon fill is slightly pebbly, silty, fine-grained sand, having moderate secondary carbonate, and was derived from an eolian mantle extending across the hilltop. (Site is more fully discussed in Mears, 1981.)

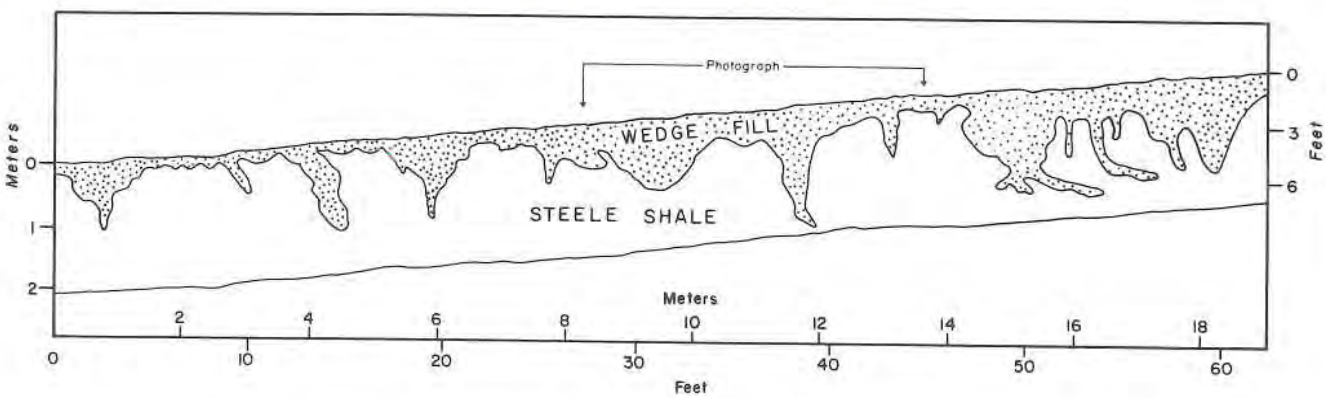
Plan view



Site CB 3, Walcott Junction

Site CB 4, north of Walcott Junction. Meads Quadrangle; NE1/4 sec. 33, T.21N., R.84W.; 6,765 ft (2,062 m); pipeline trench 1,300 ft (400 m) north of site CB 3, in sloping (5°) sides of a shallow strike valley in the Steele Shale.

Thirty-three wedges, cut at various angles, were counted along 300 ft (90 m) of trench wall. The fill and host are the same as at site CB 3, except that some wedges cut weathered slabby sandstone in a 30°-dipping ridge bounding the valley on the south. Upturning of the host against wedges is marked by near-vertical shale stringers between closely spaced wedges. (Site is more fully described in Mears, 1981.)



Site CB 4, north of Walcott Junction

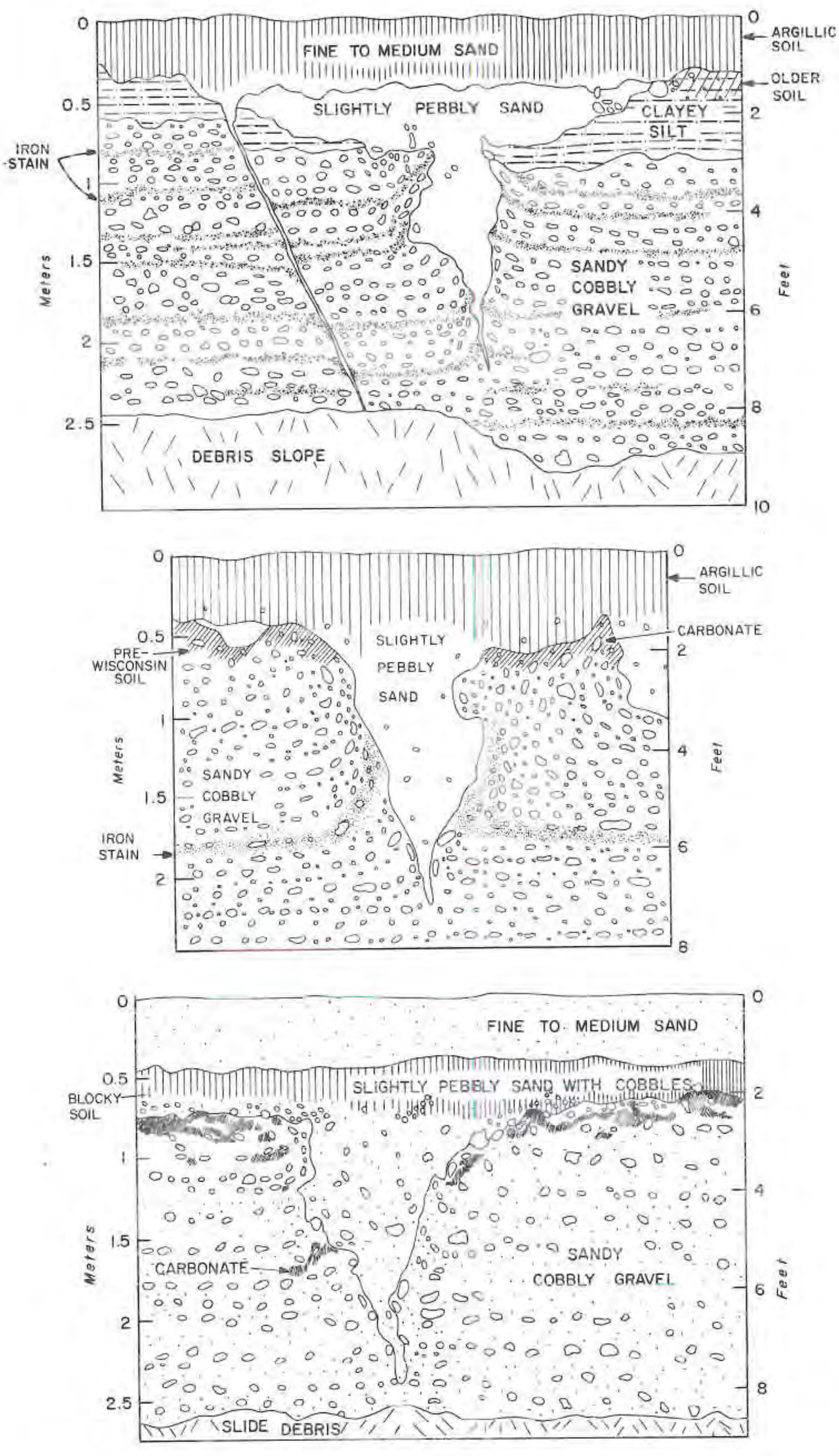
Rawlins uplift (R)

Site R 1, Rawlins city dump (Back cover). Rawlins Quadrangle; SE1/4 sec. 34, T.22N., R.87W.; 6,920 ft (2,110 m); sanitary landfill excavation in a broad stream-abandoned valley, about 120 ft (37 m) above the local base level, and some 460 ft (140 m) above the master drainage of the North Platte River, 10 mi (16 km) to the east.

Thirty-four wedges, cut at various angles, were counted along 500 ft (152 m) of the excavation's west wall. The wedge host is sandy alluvial gravel, with some cobbles; it has hematite-stained horizons and a moderate development of powdery secondary carbonate. Rare clasts of Paleozoic quartzites and limestones and weathered clasts of local Miocene tephra were derived from nearby rocks in the Rawlins Hills. The dominant pebbles and cobbles (95 percent or more) are Precambrian crystalline rocks. Mafic schists and gneisses are very weathered. Coarse-grained felsic gneisses are somewhat less decomposed and fine-textured crystalline clasts are almost unweathered. Extreme weathering of some clasts and the topographic setting of the deposit indicate a probable pre-Wisconsin age of deposition for the host materials. The host gravels and the hematitic and carbonate horizons are turned up strongly against the wedges.

The valley surface, marked by broad shallow deflation hollows, has a thin cover of stabilized eolian sand. The wedge fill is fine- to medium-grained sand, which in impregnated thin sections displays no internal fabric (Larry C. Munn, personal communication, 1985). Scattered cobbles, as large as 4.75 by 2.5 by 2 in (11.4 by 5.7 by 5 cm), within the wedge fills indicate that ice originally occupied the spaces. Pebbles are most common in the upper parts of wedges and the mantle providing the fill. In places, the pebbles form stone lines, indicating minor episodes of erosion during the general eolian deposition. The moderate, argillic surface soil on the wedge-filling mantle indicates a Wisconsin, possibly Illinoian, age of deposition.

Photographs of four periglacial wedges at the Rawlins sanitary landfill excavation (site R 1)



Diagrammatic sketches of three periglacial wedges at the Rawlins sanitary landfill excavation (Site R 1)

Great Divide Basin (GD)

Site GD 1, southwest of Crooks Gap. Brenton Springs Quadrangle; NW1/4 sec. 32, T.27N., R.93W.; 6,960 ft (2,120 m); pipeline trench, several sites along the Pleistocene surface extending southward from the base of Green Mountain. The illustrated location is 20 ft (6 m) above nearby Arapahoe Creek and 120 ft (37 m) above the main drainage of Crooks Creek, to the east. (Scales in photograph are a meterstick and a yardstick.)

The host is reworked fluvial and eolian silty sand from the Eocene Battle Springs Formation, having a few organic carbon-bearing lenses dated at about 25,000 years (Brechtel and others, 1984). The wedge fill is fine- to medium -grained sand, which in some wedges exhibits a well-defined vertical fabric. (The site is more fully discussed in Nissen, 1985.)

Site GD 1, southwest of Crooks Gap

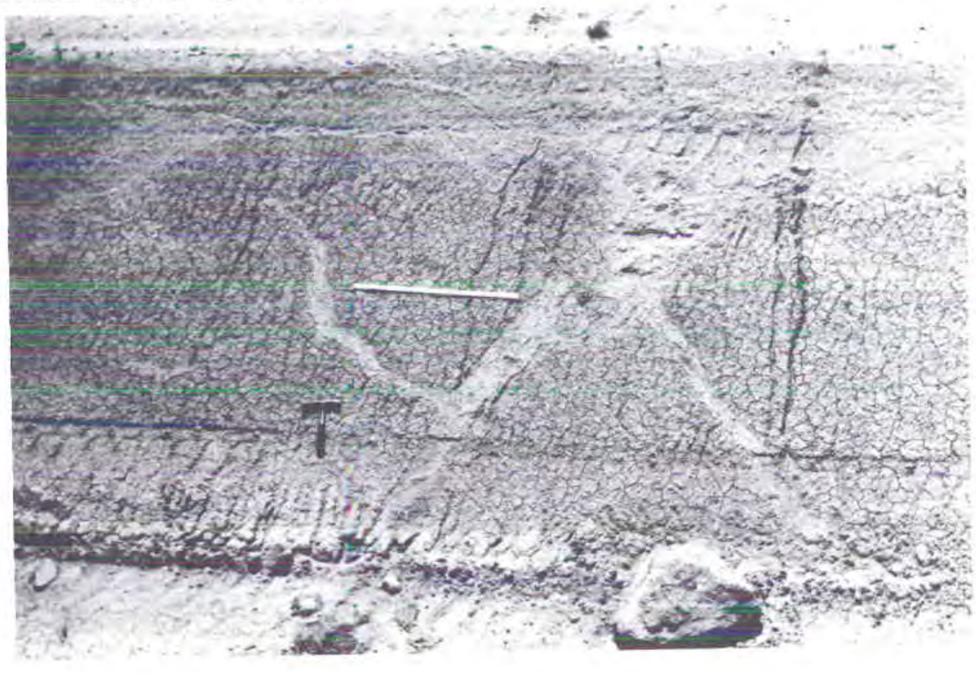
Site GD 2, east of Crooks Gap, south of Green Mountain. Osborne Well Quadrangle; NE1/4 sec. 14, T.26N., R.92W.; 7,350 ft (2,240 m); carbon dioxide pipeline trench on broad bench littered with Precambrian cobbles derived from Eocene deposits.

Numerous wedges, cut at various angles, were exposed by the trench. Host is weathered Eocene Battle Springs Formation and Quaternary deposits derived from it. Wedge fill is silty sand containing some pebbles as large as 1.5 in (3.8 cm). Soil on the wedge-filling mantle was moderately well developed, and contrasted with weakly developed soils on stabilized dune sands exposed along the trench about one mi (1.6 km) to the west.

Site GD 2, east of Crooks Gap, south of Green Mountain

Site GD 3, Union Minerals Exploration Company road. Buck Draw Quadrangle; SE1/4 sec. 1, T.23N., R.90W.; 6,620 ft (2,018 m); roadcut on gentle (2°) slope eastward into Separation Flats, 170 ft (52 m) above an adjacent playa.

Host is mudstone of weathered Eocene Wasatch Formation having small (3-in, 8-cm diameter) surficial desiccation cracks. Fill is medium- to coarse-grained sand containing small, wind-frosted pebbles. Relatively wide-flared upper parts of wedges contain larger frosted pebbles, as much as 2.5 in (6 cm) in longest dimension. Most exposures are covered by slopewash; however, wedges are probably abundant along the cut for about two mi (3.2 km).



Site GD 3, Union Minerals Exploration Company road

Site GD 4, Separation Flats just north of the Bell Springs fault. Rawlins Peak Quadrangle; NW1/4 sec. 4, T.23N., R.88W.; 6,600 ft (2,012 m); barrow pit along dirt road on a gentle slope to the floor of Separation Flats, which lies 80 ft (24 m) below and to the north.

The wedge host is Cretaceous Cody Shale. The wedge fill is pebbly silty sand. (Site reported by Gerald E. Nelson, personal communication, 1981.)

Site GD 4, Separation Flats just north of the Bell Springs fault

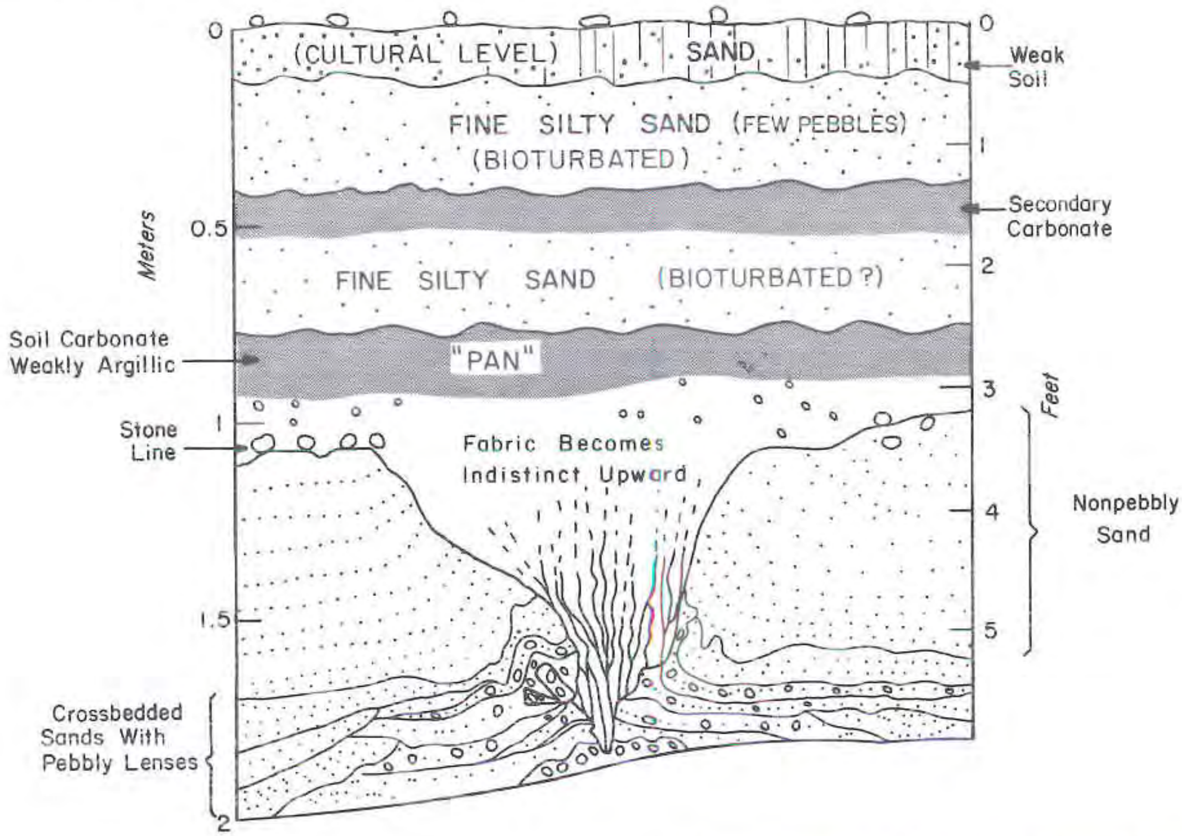
Site GD 5, six miles north of I-80 Red Desert exit. Red Desert Quadrangle; NE1/4 sec. 4, T.20N., R.95W.; 6,700 ft (2,042 m); archaeological excavation pit in a gently rounded hilltop, 85 ft (26 m) above a dry wash bottom one mi (1.6 km) to the west.

This site exposed archaeological materials and wedges in the same excavation and is the only one, to date, where the host is largely Pleistocene eolian sand. Host material includes a well-crossbedded lower sand having pebbly fluviatile stringers and lenses and an upper nonpebbly sand, probably eolian, whose crossbedding becomes less well defined upward, possibly from bioturbation. The bedding of these sands is warped, mainly bent up against wedge margins. Preservation of this bedding during warping may reflect its frozen condition during deformation.

The wedge fill was derived from a sand mantle, about one ft (30 cm) thick. The base of this mantle contains somewhat angular, carbonate-coated pebbles as much as 1.5 in (3.8 cm) in longest dimension. The top of the mantle is enriched in secondary carbonate and has a buried argillic soil (pan) of probable Pleistocene age that is disconformably overlain by 2.4 ft (76 cm) of younger eolian sands. A well-defined vertical fabric at the bottom of the wedge fills becomes less clear upwards because of bioturbation. (In photograph of wedge bottom, scale is six in, 15 cm, long; holes are krotovenas.)

The silty fine-grained sands above the wedge-filling mantle contain disconformities, indicating that general aggradation was interrupted by episodes of deflation. The lower of these buried erosion surfaces is underlain by a powdery carbonate-enriched horizon, possibly of Altithermal age. Ross Hillman (personal communication, 1980) determined that a cultural level in the archaeological pit (possibly deflated before burial) contains artifacts dated at 2,050 to 250 years old in the uppermost eight in (20 cm), and that nearby to the west, McKean artifacts (about 400 years old) were obtained at about one ft (30 cm) below the ground surface.

Overall, the argillic horizon, or pan, is interpreted as late Pleistocene, overlain by early Holocene eolian sands having Altithermal soil carbonates, which are overlain by artifact-bearing neoglacial eolian sands. (The aid and counsel of Ross Hillman at this site is much appreciated.)



Site GD 5, six miles north of I-80 Red Desert exit

Site GD 6, near Red Desert exit off I-80. Red Desert Quadrangle; NE1/4 sec. 4, T.19N., R.95W.; 6,750 ft (2,057 m); pipeline trench along a gentle hill crest, 85 ft (26 m) above a deflation hollow to the north.

Eleven wedges were counted in a sample of 100 ft (30 m). Wedges of various sizes, some greater than seven ft (2 m) deep (the depth of the ditch), were cut at various angles. Host is shale of the Eocene Green River Formation lake beds that is bent upward, in places downward, against wedges, and displays some randomly oriented folding between wedges.

Fill is silty sand (cut by krotovenas) containing powdery secondary carbonate. On the approximately two-ft (0.6 m) thick mantle providing the wedge fills there is a moderately well-developed surface soil.

Site GD 6, near Red Desert exit off I-80

Site GD 7, Wamsutter exit off I-80. Wamsutter Quadrangle; N1/2 sec. 27, T.20N., R.94W.; 6,790 ft (2,070 m); pipeline trench on broad, gently rounded hilltop, 90 ft (27 m) above adjacent Latham Draw.

Abundant wedges of various sizes, as much as six ft (1.8 m) deep, were observed. Host is weathered silty clay derived from the top of the Eocene Wasatch Formation. Fill is fine- to medium-grained sand.

Site GD 8, near Continental Divide exit off I-80. Creston Quadrangle; SE1/4 sec. 8. T.20N., R.92W.; 7,140 ft (2,176 m); pipeline trench in broad shallow depression standing 310 ft (94 m) above present drainage level.

Many wedges ranging from three to six ft (1 to 1.8 m) deep were cut at various angles. Host is Quaternary silty clay interpreted as pond deposits, which in places contain small iron- and manganese-stained pebbly channels and some dark organic zones as much as two ft (60 cm) thick and five ft (1.5 m) wide. Powdery secondary carbonates are, in places, contorted against wedges. The host is deformed in the upper seven ft (2 m) of the eight-ft (2.4 m) deep trench. Fill is a silty sand having a moderate development of soil across the wedge-filling mantle.

Site GD 8, near Continental Divide exit off I-80

Site GD 9, Standard Draw. High Point Quadrangle; NE1/4 sec. 2, T.18N., R.93W.; 6,810 ft (2,076 m); pipeline trench.

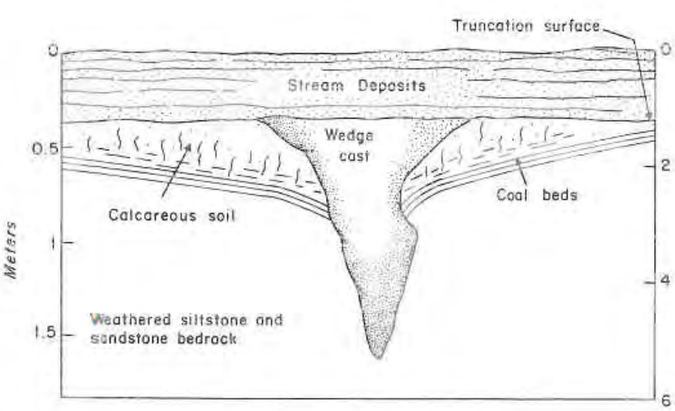
Five wedges, observed within a distance of 30 ft (9 m) on either side of Standard Draw, cut a buried paleosol and Pleistocene lacustrine deposits adjacent to Fivemile Lake. The largest wedge penetrates 44 in (1.1 m) deep, and appears to be 24 to 32 in (60 to 80 cm) wide where cut on an oblique angle. Soil horizons and sedimentary deposits adjacent to wedges were bent down, presumably due to sagging that accompanied thawing of permafrost. The alluvial host material is gently warped up between successive wedges, probably reflecting compression during wedge development.

Wedge fill is noncalcareous, medium to fine-grained, pebbly sand. No evidence of vertical fabric, which would suggest a sand-wedge origin, was detected.

Following wedge development, the upper parts of wedges and enclosing lacustrine host material were truncated by fluvial erosion and subsequently buried by 14 to 16 in (35 to 40 cm) of Holocene alluvial sands that were deposited in the migrating channel of Standard Draw.

(Site described and illustrated by Dennis N. Grasso, personal communication, 1982.)

Site GD 9, Standard Draw



Site GD 10, Government Reservoir. Eightmile Lake Quadrangle; SW1/4 sec. 16, T.18N., R.93W.; 6,740 ft (2,054 m); pipeline trench 800 ft (243 m) south of the reservoir. Wedges and involutions occupy a small knoll south of an Early Archaic archaeological site.

A paleosol, containing a strong calcic horizon, is cut by the sediment-filled wedges and overlain by eolian sands, across which a less calcareous soil has developed. Overlying this sequence is more than three ft (1 m) of eolian sand, deposited during the last 6,600 years, which contain two dated levels of Altithermal archaeological materials, as well as a dated Neoglacial hearth. Radiocarbon dates, by Beta Analytic (1984), are: 6,600 ± 230 years, 6,270 ± 150 years, 6,150 ± 120 years for a lower 36-in (95 cm) horizon; 6,260 ± 230 years, 5,810 ± 130 yrs, 5,130 ± 120 years for a higher 17-in (45 cm) horizon; and 1,020 ± 60 years for the hearth located eight in (20 cm) below the ground surface. (Dashed line delineates wedge boundary.)

Site GD 10, Government Reservoir

The chronology of events at the site is interpreted as:

(1) Carbonate-rich soil formed on a late Pleistocene surface;

(2) Ice-wedge polygons developed, possibly in late Wisconsin time;

(3) Thawing of ice wedges, accompanied by sediment infilling during latest Wisconsin or earliest Holocene, produced ice-wedge casts during deposition of lowermost eolian sands;

(4) Weak soil developed on the eolian sands and wedge fills;

(5) During subsequent deposition of eolian sands, humans occupied the area repeatedly between 6,600 and 5,130 years ago and again about 1,020 years ago.

This site provides evidence for pre-Altithermal deposition of eolian sand that, in turn, clearly postdated the episode of active ice-wedge generation. (Site described and illustrated by Dennis N. Grasso, personal communication, 1982.)

Site GD 11, north of Overland Trail. Mexican Flats Quadrangle; S1/2 sec. 8, T.17N., R.93W.; 6,000 to 6,650 ft (1,828 to 2,027 m); pipeline trench. Numerous wedges and involutions occur along a gentle slope west of an ephemeral-stream draw.

The wedges penetrate weathered green shale and sandstone of the Eocene Green River Formation and, farther east, buff-colored alluvial and colluvial Quaternary sands. The host materials are bent both upward and, in places, downward. The downward bending is attributed to sagging adjacent to wedge margins, which is especially common in stratified sandy alluvium. Involutions are ubiquitous, exhibiting considerable mixing of brown, clayey alluvial sand with underlying, fine-grained green sand. The wedge fill is medium-grained, brown quartz sand containing pebbles and green sandstone clasts, the latter derived from the host material. (Dashed line delineates wedge boundary.) (Site described and illustrated by Dennis N. Grasso, personal communication, 1982.)

Site GD 11, north of Overland Trail

Site GD 12, North Barrel Springs Draw. Mexican Flats NW Quadrangle; SW1/4 sec. 4, T.17N., R.93W.; 6,570 ft (2,000 m); pipeline trench. Periglacial wedges and involutions were observed where Amoco Production Company's Wamsutter Pipeline crosses the North Barrel Springs Draw floodplain and its lowermost terrace remnants.

Host material includes about 25 in (64 cm) of alluvial silt, sand, and gravel (derived from underlying weathered rock) and the Tertiary bedrock of greenish gray clayey and silty sandstone. The largest wedge, filled with silty sand, penetrates to a depth 40 in (100 cm) and has an apparent width of 23 in (58 cm). A radiocarbon date of 1,710 $\pm$ 80 years (Beta Analytic, personal communication to Grasso, 1982) was obtained from a nearby 16-in (40 cm) deep hearth, dug into late Holocene alluvium that disconformably overlies a moderately well-developed soil on the wedge-bearing horizons. (Dashed line delineates wedge boundary; arrow points to pen for scale.) (Site described and illustrated by Dennis N. Grasso, personal communication, 1982.)

Site GD 12, North Barrel Springs Draw

Rock Springs uplift (RS)

Site RS 1, near junction of Tri-Territory Road with dirt road across White Mountain. Boars Tusk Quadrangle; NW1/4 sec. 9, T.23N., R.104W.; 6,640 ft (2,024 m); pipeline trench in low east-sloping terrace, 3/4 mi (1.2 km) west of and 40 ft (1 2 m) above Killpecker Creek.

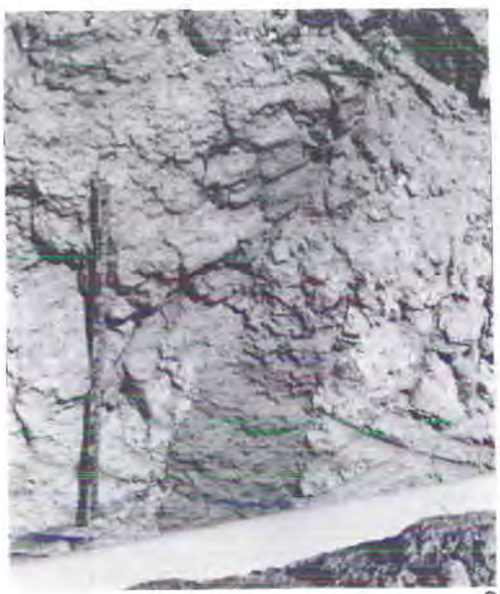
In 60 ft (18 m) of unfilled ditch, eight wedges were counted. The host is colluvium showing some contorted pebble lenses, and has moderate development of secondary carbonate. The wedge fill is a fine- to medium-grained sand with a few small pebbles, some of which indicate a vertical fabric that is otherwise not discernible.

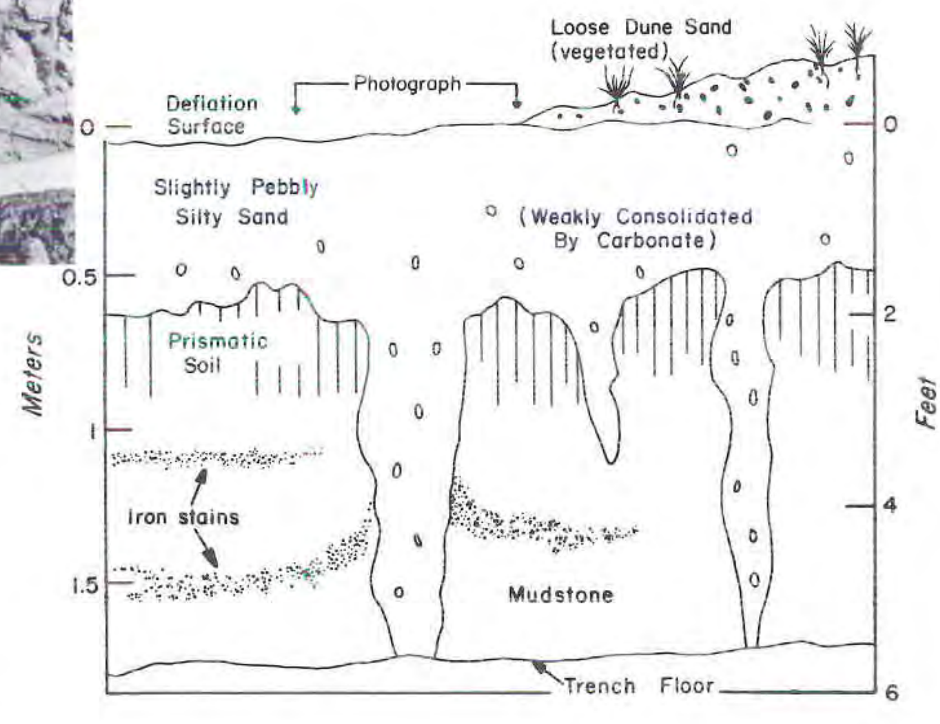
Site RS 1, near junction of Tri-Territories Road with dirt road across White Mountain

Site RS 2, Pine Canyon Road. Boars Tusk Quadrangle; NW1/4 sec. 25, T.23N., R.104W.; 6,760 ft (2,060 m); pipeline trench across the northwest side of Rock Springs uplift. Location is 120 ft (37 m) above the intermittent Killpecker Creek, in a gentle westward slope marked by shallow deflation hollows and the southern edge of stabilized dune sands.

In a sample 100 ft (30 m) along the trench, 12 wedges were counted. The wedge host is weathered mudstone of the Eocene Wasatch Formation, whose top has prismatic soil structure two to three in (5 to 8 cm) in diameter and 12 to 18 in (30 to 46 cm) deep. Deformation of the host was not discernible in the fine-grained materials, except in a few hematite-stained horizons. Wedges had various depths of penetration; however, most extended below the bottom of the six-ft (1.8 m) deep trench.

The wedge fill is a slightly pebbly, fine- to medium-grained sand; no fabric was discernible although a few small pebbles had vertical orientations. The fills are moderately coherent because of a slight content of secondary carbonate cement and have moderate surface soil development. In contrast, the overlying sands of stabilized dunes are completely loose and readily flowed to a repose angle. Thus the wedge-filling episode was followed by an interval of soil development prior to deposition of the overlying, and now vegetation-stabilized (Altithermal?) sands in the presently inactive dunes of the Killpecker dune field.



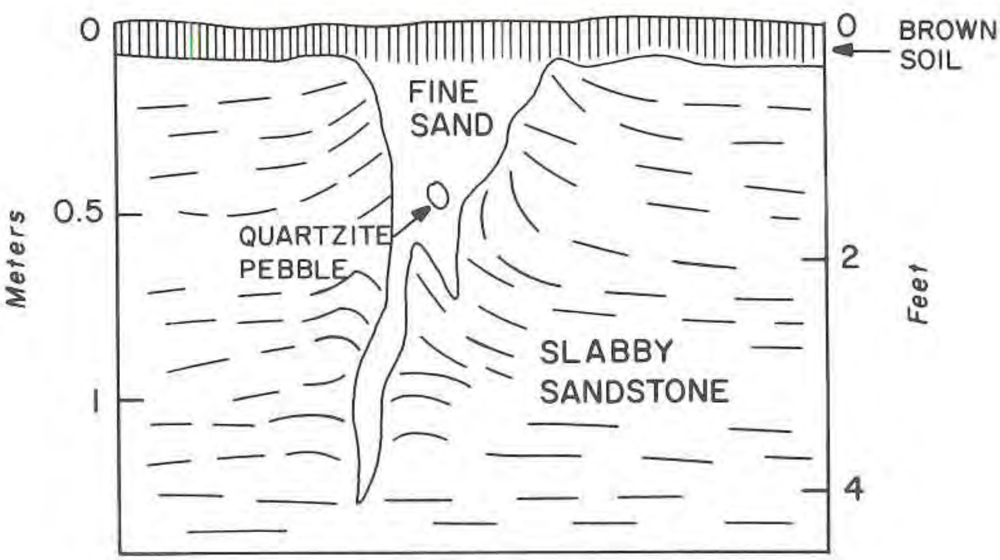


Site RS 2, Pine Canyon Road

Site RS 3, Rock Springs Airport. Baxter Quadrangle; SW1/4 sec. 19, T.19N., R.103W.; 6,715 ft (2,047 m); electric cable trench in a mesa top 415 ft (126 m) above Bitter Creek, which is 1.2 mi (1.9 km) to the north.

In a sample distance of 500 ft (152 m), 12 wedges cut at various angles were counted. Wedges range from about three ft (.8 m) to more than 4.8 ft (1.2 m) (trench depth was 4.8 ft). Host is slabby sandstone, with shale partings, of the Airport Member of the Cretaceous Baxter (Cody) Shale. The sandstone is bent up and in some places crushed against the wedges.

Wedge fill is fine- to medium-grained sand, containing some quartz and feldspar pebbles. Fabric in the fill was not evident; however, a pebble two in (5 cm) in longest dimension suggested the wedges are ice-wedge casts. The wedge-fill mantle has a moderate development of surface soil. Photograph and diagram are of two different wedges.



Site RS 3, Rock Springs Airport

Green River Basin (GR)

Site GR 1, Marbleton. Big Piney East Quadrangle; SW1/4 sec. 29, T.30N., R.111W.; 6,820 ft (2,078 m); barrow pit.

Host is alluvial gravel having moderate carbonate development at eight to 16 in (20 to 40 cm) below the ground surface. The wedge fills, which have weak carbonate development, were derived from a reddish yellow (7.5 YR 6/6), very gravely sandy clay. The wedges were interpreted as ice-wedge casts because clasts in their fills exhibit downward-sagging alignments. (Site described by Michael L. McFaul, personal communication, 1984.)

Site GR 2, north of Hams Fork and south of Highway 30N. Moxa Quadrangle; SW1/4 sec. 3, T.19N., R.112W.; 6,440 ft (1,963 m); archaeological site in an upper river terrace north of, and 105 ft above, Hams Fork immediately southwest of U.S. Highway 30.

The terrace contains more than eight ft (2.4 m) of Quaternary alluvial sand and gravel, and is veneered by late Quaternary colluvium. Colluvium varies in thickness, becoming thickest to the north near its source, which is a higher alluvial-veneered terrace. The wedges penetrate both the colluvial and alluvial deposits to depths ranging from six to seven ft (1.8 to 2.1 m) and they disrupt a calcic soil horizon and the alluvial host. Host materials are bent up and down against the wedges. Compression associated with wedge development probably bent the host up, whereas sagging during thawing of permafrost bent it down.

Five wedges, containing brown sand and pebbles, were studied. Wedges interpreted as primary are regularly spaced and of similar widths; they form surface polygons ranging from 12 to 14 ft (3.7 to 4.2 m) in diameter. Smaller wedges, thought to be secondary, occur between the larger wedges. (Site described by Dennis N. Grasso, personal communication, 1982).

Site GR 3, south of Hams Fork and north of Blacks Fork. Moxa Quadrangle; NE1/4 sec. 16, T.19N., R.112W.; 6,425 ft (1,958 m); archaeological site in alluvial-fan deposits derived from a higher early Pleistocene terrace, which forms the local divide between Hams Fork and Black Fork rivers.

Four wedges, penetrating from three to six ft (1 to 2 m) into the host materials, cut a calcic soil horizon developed in the sands and gravels that veneer Tertiary bedrock. The wedge-host deposits, which contain some vertically oriented pebbles, are bent down against the wedge fills. Involutions occur in the host materials.

The wedge fill contains cobbles and pebbles in a reddish brown sand matrix. The coarseness of the clasts and red color are more pronounced than at other localities observed in the southern part of the Green River Basin. Pedogenic weathering had sufficient time to oxidize iron-bearing minerals and produce the deep red coloration. The strong soils and the mature landscape associated with the high terraces and coalescing fans support a possible pre-Wisconsin age for this periglacial episode. (Site described by Dennis N. Grasso personal communication, 1982.)

Site GR 4, Porter Hollow. Verne Quadrangle; NW1/4 sec. 3, T.18N., R.112W.; 6,320 ft (1,926 m); pipeline trench west of the confluence of Hams and Blacks Forks.

Four wedges were studied along an upper river terrace south of, and 50 ft (15.2 m) above, Blacks Fork. Such higher terraces along the Blacks Fork are underlain by Tertiary bedrock that is veneered by Quaternary alluvium. The wedges cut cross-bedded sands and gravels. A strong calcic soil horizon in the alluvium is bent down adjacent to the wedges.

The wedge fill is reddish brown sand containing quartzite pebbles and gravels ranging in diameter from 0.15 to 0.80 in (4 to 20 mm). Vertical fabric indicative of sand-wedge casts was lacking in the wedge fills; gravels and pebbles were randomly distributed.

The wedges are probably ice-wedge casts infilled by local and eolian sediments during thawing of permafrost. Adjacent to the wedges, vertically oriented pebbles indicate initial pressure effects and bent down host materials suggest either initial pressures during ice-wedge growth or subsequent sagging during thawing of permafrost. (Site described by Dennis N. Grasso, personal communication, 1982.)

Site GR 4, Porter Hollow

Site GR 5, near Blacks Fork river. Millersville Quadrangle; SW1/4 sec. 34, T.18N., R.113W.; and NE1/4 sec. 3, T.17N., R.113W.; 6,460 ft (1,970 m); Frontier Pipeline trench north of I-80. Along the west side of the Blacks Fork River, several sites of abundant wedges occupy terraces and their associated slopes, ranging from 110 ft (34 m) to 25 ft (8 m) above the river.

The wedge hosts include weathered mudstone of the Eocene Bridger Formation and fluvial Pleistocene sand having varying numbers of cobbles, mainly quartzite, derived from the Uinta Mountains. The wedge fills (pebbly sands) exhibit vertical fabric, and have moderate impregnation by secondary carbonates and moderate surface soil development (Nissen, 1985).

Site GR 5, near Blacks Fork river

Site GR 6, Milich Ditch. Buck Fever Ridge Quadrangle; NW1/4 sec. 32, T.13N., R.155W.; 8,400 ft (2,560 m); vertical face of irrigation ditch deepened by erosion. Site is in slope grading down to the head of the Lyman Bench (Gilmer, 1986), and is 140 ft (43 m) above Little Dry Creek, about one mi (1.6 km) to the west.

The host is alluvial and colluvial silty sand containing occasional quartzite pebbles and small cobbles, including some highly weathered arkosic clasts derived from the Precambrian Uinta Group. Upwarping of the host against some wedges is emphasized by deformed soil carbonates. Richard G. Reider (personal communication, 1985) described the paleosol on the host as containing calcic-grade carbonate, which does not completely plug the host.

The wedge fill is a fine- to medium-grained sand that in places contains vertical stringers of small pebbles. The disconformable mantle providing the wedge fill has a weak to moderate development with a cambic, not textural, B horizon, and weak carbonate development.

Site GR 6, Milich Ditch

Possible and nonperiglacial polygons (P)

The Green River Basin also contains two other areas of patterned ground: one exposes large polygons of undetermined origin and the other exhibits sand-filled polygons that probably originated from cold-thermal cracking but is not a permafrost phenomenon.

P 1, central Green River Basin east of the Big Sandy River. Gasson Bridge Quadrangle; NE1/4 sec. 15, T.15N., R.108W.; 6,320 ft (1,926 m); topographic bench standing 50 ft (15 m) above the Big Sandy River, which is about one mile (1.6 km) to the west.

In his study of the Eocene Bridger Formation, Kistner (1973) reports distinctive patterned ground. Polygons from 100 to 130 ft (30 to 40 m) were originally discerned on aerial photographs. His field work demonstrated that the polygons occupy a deflated surface, exposing the Bridger Formation, and are emphasized by better growth of vegetation along the polygonal nets than in the exposed Tertiary materials. No vertical cuts were available to determine details of the polygon cross section. If the polygons are periglacial features or, alternatively, desiccation phenomena, they have the largest diameters so far observed in Wyoming for either type of polygon.

P 2, Opal dune field. Fontenelle Quadrangle; SE1/4 sec. 14, T.22N., R.112W.; 6,480 ft (1,975 m); gravel-capped terrace ten ft (3 m) above Shute Creek. Opal Quadrangle; SE1/4 sec. 12, T.21N., T.114W.; 6,670 ft (2,033 m); gravel-capped terrace ten ft (3 m) above Craven Creek.

Sand-filled wedges exposed by back-hoe trenches at the Shute and Craven Creek sites, about 14 miles (23 km) apart, were discussed by Ahlbrandt and Downing (1984) in their report on the Opal dune field. The dunes are mainly barchans, less than 50 ft (15 m) high, now largely vegetated by grass and shrubs, and are separated by broad windswept areas of desert pavement. The sands contain radiocarbon-dated archaeological sites as old as 6,300 years, or late Altithermal (T.S. Ahlbrandt, personal communication, 1987). The trenches cut downward through dune sands, which provided fills for wedges that penetrate a maximum of 24 inches (60 cm), commonly less, into claystones of the Eocene Bridger Formation.

In places on trench floors, the wedges form polygons having maximum diameters of about 40 inches (100 cm). The largest polygons, estimated from the spacing of wedges along trench walls, are five ft (1.5 m) in diameter. Thus the features in the Opal dune field are considerably smaller than the confirmed relics of periglacial ice-and sand-wedge polygons that penetrate downward as much as six ft (2 m) or more and are as much as 30 ft (10 m) in diameter. (The photograph was taken near, but not on, the line of cross section.)

The wedge fills are post Pleistocene. They are derived from the stabilized dunes that Ahlbrandt (*in* Ahlbrandt and Downing, 1984) considers of largely Altithermal age. Although the fills are generally devoid of cultural materials, one wedge contained charcoal hearth material that had fallen into its fill (Thomas S. Ahlbrandt, personal communication, 1987).

The development of these wedge polygons could reflect desiccation cracking of the Bridger Formation claystones; however, these strata are clearly susceptible to thermal cracking. Following a sharp cold snap with temperatures well below freezing, cracks several millimeters wide opened, primarily in claystones along wedge contacts and to some extent in the wedge fills (Ahlbrandt and Downing, 1984). Thus wedges in the Opal dune field could reflect the filling by sand of repeated thermal cracks (hand in photo points to thermal cracks) along wedge margins under the present-day cold-temperate, but nonperiglacial environment of the Wyoming basin floors.

P 2, Opal dune field

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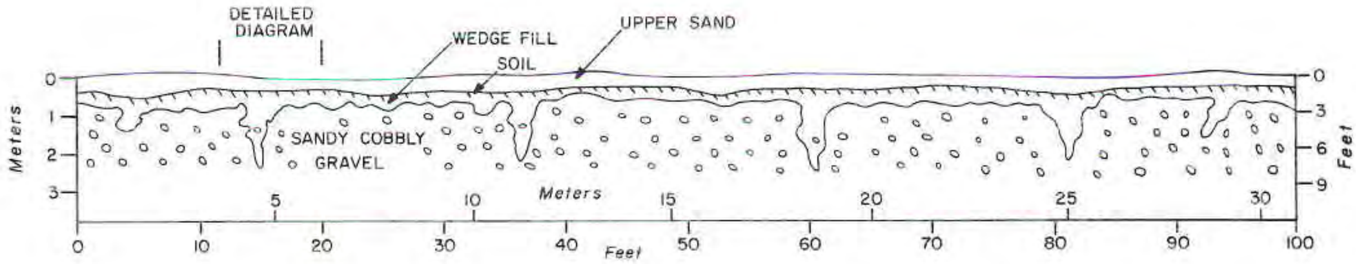

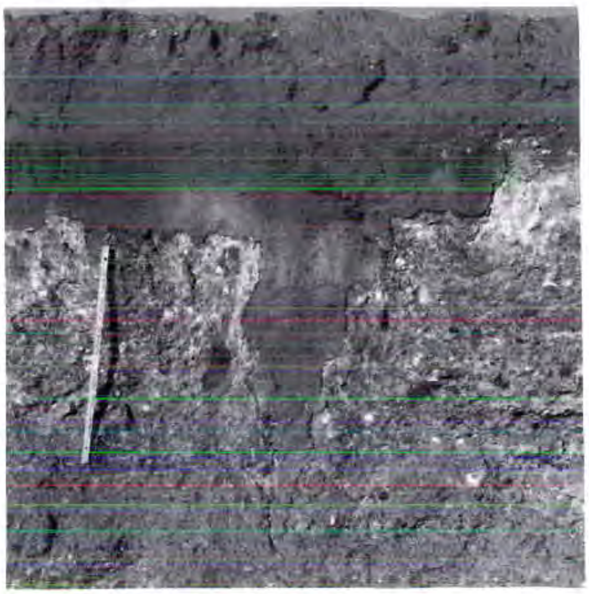

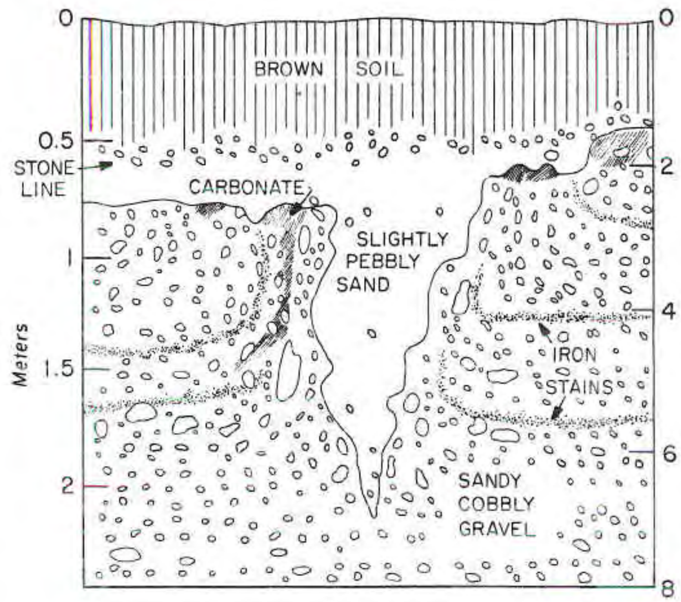

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Late Pleistocene periglacial wedge sites in Wyoming

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