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

REPORT OF INVESTIGATIONS NO. 15

GEOLOGY OF THE HEADWATER AREA OF THE NORTH FORK OF OWL CREEK, HOT SPRINGS COUNTY, WYOMING

by

Kent A. Sundell

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Front cover. Bedding fault development in lower Tepee Trail strata. See page 22.

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INTRODUCTION

This report describes the geology of an area of poorly known, well exposed Absaroka volcaniclastic rocks that are not close to a major vent area. Objectives of the investigation were: (1) to describe well exposed outcrops of the Aycross, Tepee Trail, and Wiggins Formations in the North Fork of Owl Creek; (2) to prepare a detailed geologic map of the volcaniclastic terrain; and (3) to assemble available stratigraphic, structural, geomorphic, petrologic, paleontologic, and other data pertinent to the local, and possibly regional, geology of the Absarokas.

LOCATION

The study area covers 21 square miles in townships 44 and 45 north, ranges 101 and 102 west, and includes the drainage of the North Fork of Owl Creek and adjacent areas in western Hot Springs County, Wyoming (Figure 1). Elevations in the study area range from 7,200 feet to 11,500 feet along the rugged margin of the southeastern Absaroka Range; some adjacent areas are much higher.

Access was obtained by driving 8 miles northwest on State Highway 120 from Thermopolis, proceeding 25 miles westward along State Highway 170 to the end of the pavement, and continuing the remaining 12 miles on dirt roads and trails along the North Fork of Owl Creek to the middle of the study area.

The area was chosen and briefly studied in the summer of 1978 as part of a National Science Foundation research project. Detailed mapping was done in the summer of 1979. Field mapping was compiled on portions of the Cottonwood Peak, Milk Creek, Willow Creek, and Eagle Nest Ranch 7.5-minute U.S.G.S. topographic quadrangle maps.

PREVIOUS INVESTIGATIONS

Prior to this project, no publication had dealt with the detailed geology of the study area, although Darton (1906), Love et al. (1955), and Masursky (1952) published geologic maps of all or parts of the area on a regional scale. The most valuable information about nearby volcaniclastic areas is that of Love (1939) and of Wilson (1963, 1964, 1975). While my work was in progress, the U.S. Geological Survey was investigating the southeast margin of the Absarokas in the Bighorn Basin and mapping along the southeast border of my study area (Bown, in press). Jeff Eaton (1980) worked concurrently with me in the North Fork of Owl Creek area.

TERMINOLOGY

The terminology used for volcaniclastic rocks follows Fisher's (1961) classification. Terminology for volcanic breccias follows Fisher (1960a) and Parson (1969). A tuff, by my definition, is a rock composed of more than 75 percent pyroclastic material less than 2 millimeters in diameter, deposited by epiclastic or pyroclastic processes. Tuffaceous rocks include more than 20 percent fine-grained pyroclastic material, usually as light-colored ash matrix. Paraconglomerates are defined as having a matrix-supported framework, in contrast to orthoconglomerates which have a clast-supported framework (Pettijohn, 1957).

All comments referring to time and age, and their relationship to the North American land mammal ages, are based on work by Berggren et al. (1978).

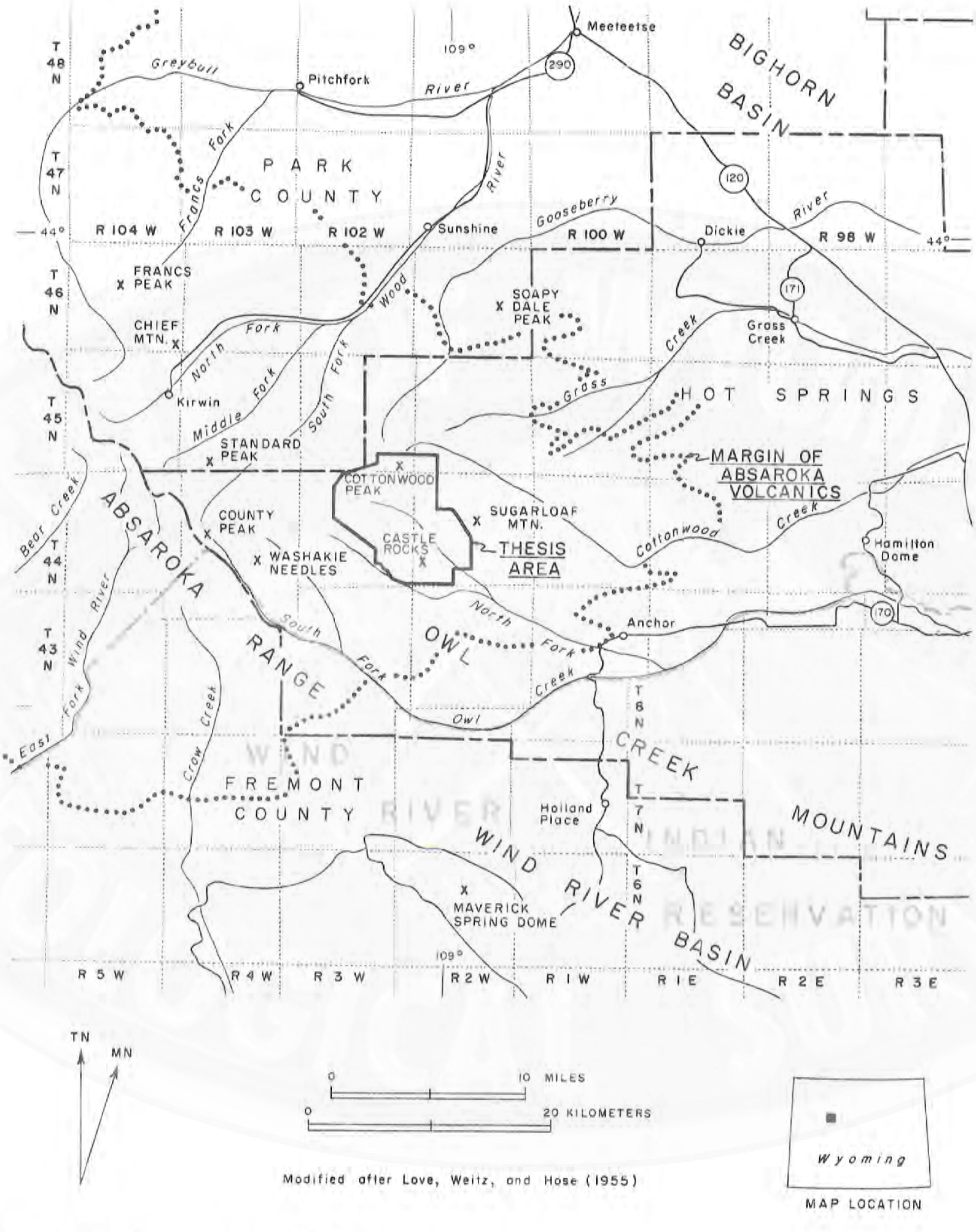

Figure 1. Regional location map.

STRATIGRAPHY

A thick sequence of Tertiary volcaniclastic rocks unconformably overlies folded Mesozoic and Paleozoic beds in the North Fork of Owl Creek area. The Tertiary sequence consists of volcanic siltstones, sandstones, conglomerates, and breccias. The underlying pre-Tertiary rocks are unexposed in the map area, but do crop out several miles to the southeast. Thin veneers of Quaternary rocks locally unconformably overlie all older rocks (Figure 2).

PRE-TERTIARY ROCKS

Love (1939) and Hewett (1926) describe the Mesozoic and Paleozoic stratigraphy of the Wind River and Bighorn Basins, respectively. An up-to-date listing of formations is given by the Wyoming Geological Association (1978). Assuming a continuation of regional structural trends under the overlapping Absaroka volcanics, some Mesozoic and most Paleozoic formations common to the Wind River and Bighorn Basins should underlie the study area. Pre-Tertiary rocks are a local source of material for the basal Aycross Formation and are discussed under Economic Geology.

TERTIARY ROCKS

More than 8,000 feet of Tertiary volcaniclastic rocks, including the Aycross, Tepee Trail, and Wiggins Formations, were secondarily derived from primary Absaroka volcanic rocks during the middle and late Eocene and are now well exposed in the North Fork of Owl Creek area (Plate I). Volcanic sandstones predominate, with lesser volcanic conglomerates, breccias, siltstones, claystones, and tuff beds (Table I). No in situ volcanic flows are exposed.

The lower Eocene Willwood Formation (Van Houten, 1944), composed mostly of nonvolcanic material, unconformably overlies the Mesozoic rocks to the northeast (Bown, in press) and possibly underlies the study area. The thickness of the Willwood Formation is 65 to 330 feet 6 miles to the northeast (Bown, in press), but it is absent 4 miles to the south and southwest; if present under the study area, the Willwood Formation is very thin. More than 1,000 feet of the Aycross Formation, 2,500 feet of the Tepee Trail Formation, and 2,500 feet of the Wiggins Formation successively overlie the Willwood Formation (Figure 2).

For local mapping, the Tepee Trail Formation was informally divided into the lower Tepee Trail, Holy City beds, Foggy Day beds, and upper Tepee Trail, and the Wiggins Formation into the lower Wiggins, allochthonous Wiggins, Castle Rocks chaos, and upper Wiggins beds.

Aycross Formation

The name Aycross Formation was proposed by Love (1939) for middle Eocene rocks lying unconformably between lower and upper Eocene rocks in the northwestern Wind River Basin. The rocks are nonresistant, variegated, multicolored clays, shales, and sandstones, with several andesite conglomerates and considerable andesitic "tuff"*, and extensively altered mafic minerals, throughout the sequence at the type locality. The unit's lithologic character changes greatly over short horizontal distances

* The term "tuff", as used by Love (1939), refers to rocks composed of predominantly volcanic material less than 2 mm. in diameter and includes volcanic sandstones, siltstones, claystones, and tuff as defined previously.

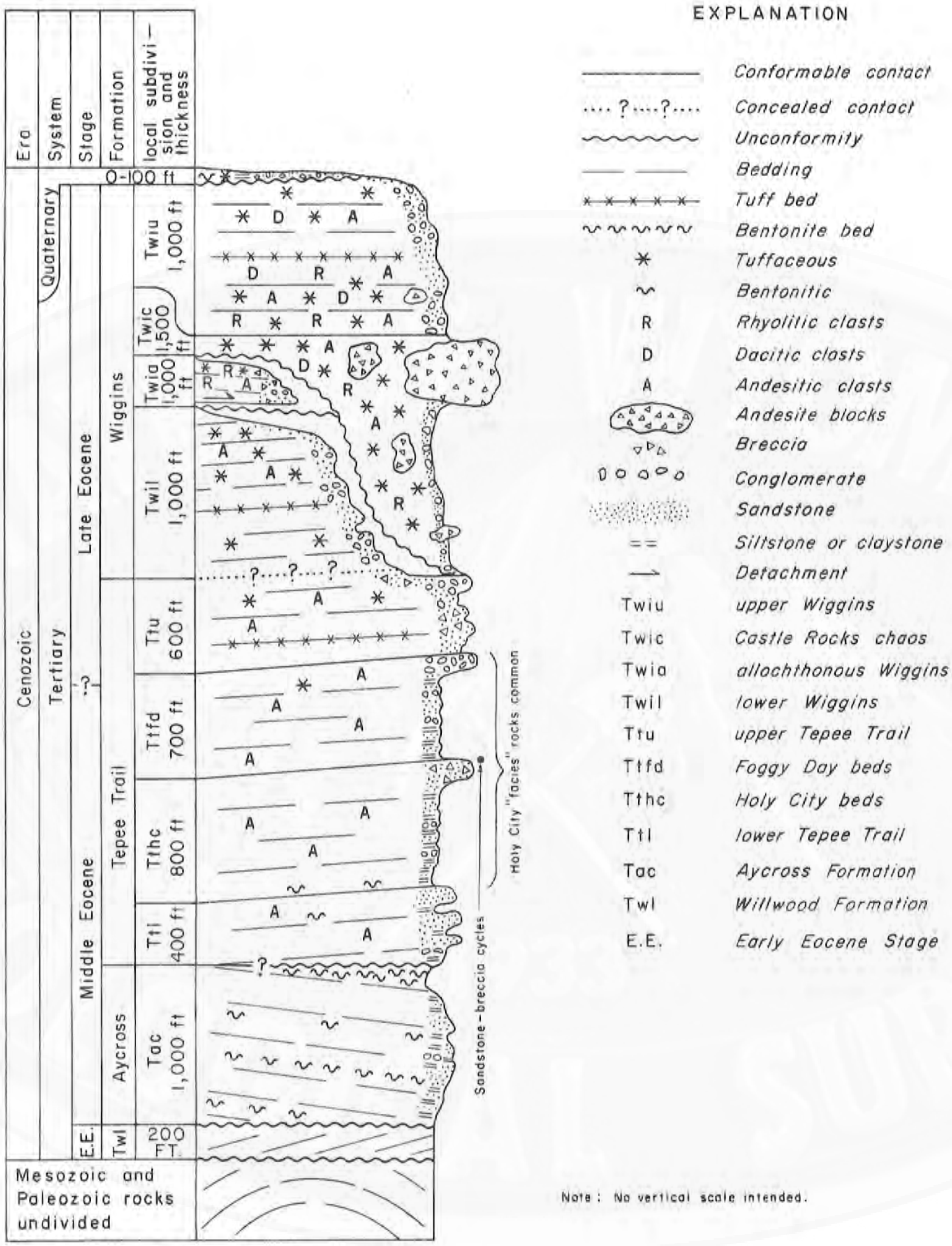

Figure 2. General composite stratigraphic section.

Table I. Comparative, general descriptions of the Aycross, Tepee Trail, and Wiggins Formation in the headwater area of the North Fork of Owl Creek.

	Aycross Formation	Tepee Trail Formation	Wiggins Formation
Measured Thickness*	980 feet (300 m.+)	2,500 feet (760 m.)	2,000 feet (610 m.+)
Lithology	Predominantly volcanic siltstones and claystones, with lesser amounts of volcanic sandstone, minor volcanic conglomerates and breccias, and abundant bentonite beds.	Predominantly volcanic sandstones, with lesser amounts of volcanic breccia and conglomerates, minor volcanic siltstones and claystones, and rare tuffs, limestones, and bentonite beds.	Predominantly volcanic conglomerates and sandstones, minor volcanic breccias and tuff beds, and rare volcanic siltstones and claystones.
Key Marker Beds	A thick, white sequence of bentonites and bentonitic claystones and siltstones at the top and several thinner, bentonitic sequences in the lower Aycross.	Rare, thin bentonitic tuffs in the lower half and rare, thin, less altered tuffs towards the top. Sandstone-breccia cycles.	The Castle Rock chaos, Sugar Loaf tuff beds, and other, thin, infrequent tuff beds.
Composition	Andesitic and basaltic clasts and probably dacitic clasts. Local Paleozoic clasts at the base.	Predominantly andesitic with possible rare basaltic and dacitic clasts towards the base.	Predominantly andesitic at the base, some detached rhyolitic beds (Sugar Loaf tuff beds), and abundant andesitic and dacitic, clasts, with lesser rhyolitic clasts at the top.
Alteration	Extensive alteration of mafic minerals in clasts and matrix and alteration of tuffaceous material to bentonite.	Grades from bottom to top with increasing alteration of mafic minerals in clasts and matrix and decreasing clay alteration in tuffs. Common, secondary silicification and blue-green argillic alteration in conglomerates.	Minor alteration of tuffs. Abundant secondary silicification and blue-green argillic alteration of conglomerates at the base.
Color	Moderately colorful, consisting of predominantly white to tan beds with interbedded and variegated blue-green, purple, reddish-brown, green, red, yellow, and dark brown beds.	Predominantly olive-drab with minor tan to buff beds at the base and lime-green to blue-green beds at the top.	Predominantly white to grey beds with blue-green and minor olive-drab beds at the base, minor yellowish-green and pink beds in the middle, and yellowish-brown to brown beds at the top.
Geomorphic Expression	Nonresistant, gentle, rolling slopes with abundant mass-movements.	Step-like, resistant cliffs or benches and nonresistant steep slopes.	Steep slopes and cliffs at the base with gentle slopes and rolling topography in the upper alpine areas.
Fossils	Bridgerian mammals.	Change from Bridgerian to Uintan mammals near the base.	Uintan mammals
Environment of Deposition	Relatively low energy overbank and meandering stream environment.	Change from relatively low energy to high energy environment of deposition.	Moderate to high energy environment of deposition. Abundant ashfall and lahars.

* These thicknesses do not agree with others (p. 3 and 4) because these are *measured* and do not include highly variable units such as the Castle Rocks chaos and Sugar Loaf tuff beds.

and is controlled by local source rocks. In the Wind River Basin, the Aycross contains bentonites, carbonaceous beds (interbedded shales and coals), crystal and lithic tuffs, quartzite clasts, and andesitic and dacitic material (Love, 1939; Hay, 1956). The name was first applied to rocks in the Bighorn Basin by Masursky (1952), and was recently used by Bown (in press). The Aycross Formation is middle Eocene in age, on the evidence of fossil mammals (Wood, Seton, and Hares, 1936; Love, 1939; MacGinite, 1974; Eaton, 1980), floras (Berry, 1930; Love, 1939; MacGinite, 1974), and radiometric dates (Love, Leopold, and Love, 1978).

The name, Aycross Formation, is applied in the North Fork of Owl Creek to a thick (1,000 feet), well exposed section of nonresistant, variegated, volcanic claystones, siltstones, sandstones, and minor conglomerates with carbonaceous beds, thick bentonites, Bridgerian vertebrate fossils, and locally reworked Paleozoic material at the base. The base of the Aycross Formation is not exposed (it unconformably overlies Paleozoic rocks in the Middle Fork of Owl Creek to the south). Faults and mass gravity features conceal much of the Aycross Formation, so detailed stratigraphic sections were not measured. The general Aycross stratigraphy in the North Fork of Owl Creek area consists of a purple and white variegated basal sequence, a sandstone sequence, a buff and blue-green variegated sequence, and an uppermost white, bentonitic sequence.

The oldest exposed section of Aycross rocks includes more than 250 feet of white, tan, red, purple, and gray volcanic claystones, siltstones, and sandstones and is best exposed in NE¼ sec. 5, T.43N., R.101W. These rocks include abundant bentonite and several thick, bentonitic claystone beds which could be confused with the uppermost bentonitic sequence except for their association with purple and white variegated beds. Locally, there are thin carbonaceous beds within the basal sequence.

The overlying sandstone sequence contains approximately 250 feet of moderately resistant, reddish-brown to dark brown, discontinuous sandstone lenses with interbedded minor claystones, siltstones, and conglomerates, and a few thin, resistant, continous sandstones. The sandstone sequence is the most resistant unit in the Aycross, and its outcrops are commonly tree covered.

A buff and blue-green variegated sequence approximately 230 feet thick overlies the sandstone sequence and contains interbedded white, tan, gray, reddish-brown, bright green, and blue-green volcanic claystones, siltstones, sandstones, and conglomerates. Green to blue-green and white to tan siltstones generally produce the variegated appearance. Nonresistant, discontinuous, light brown sandstones occur sporadically throughout the sequence.

Large basalt blocks, up to 80 feet in diameter, weather out of the tan to blue-green variegated sequence in the North Fork of Owl Creek area. Masursky (1952) mapped many of these blocks as intrusive vents, but the author observed no baked contacts, alteration aureoles, or intrusive relationships with surrounding rocks around the blocks. Rather, the blocks commonly exhibit primary brecciation (autobrecciation?); extensive secondary alteration of mafic minerals and the addition of calcite and other secondary minerals which did not affect surrounding sediments; and, sometimes, slickensides, breccia, and gouge in the sediments underneath the blocks, related to secondary emplacement after initial brecciation and alteration.

The apparent recent downslope movement of some blocks may have caused some deformation. However, the frequent presence of smaller, identical pebbles and cobbles in laterally equivalent conglomerates supports the idea of distribution by mudflows and other mass gravity movements during the deposition of the buff and blue-green, variegated sequence.

Several basaltic blocks such as the one in $NW\frac{1}{4}SE\frac{1}{4}$ sec. 8, T.43N., R.101W. may prove to be vents, but the contacts are covered by colluvium and vegetation. No similar, large basaltic blocks were observed within or on top of Tepee Trail or Wiggins strata in the North Fork of Owl Creek.

The uppermost bentonitic sequence, a distinct marker directly below the Tepee Trail - Aycross contact, is traceable over a great distance (4 miles). The upper bentonitic sequence consists of 65 to 130 feet of white, yellow, and tan very bentonitic, volcanic claystones and siltstones with thin (less than 6 feet) bentonite beds. The bentonite beds are extensively altered tuff beds and contain predominantly montmorillonite clay. The sequence is very nonresistant and commonly weathers to unvegetated, unstable earth-flow slopes.

Tepee Trail Formation

The Tepee Trail Formation of Love (1939) unconformably overlies the Aycross Formation and all older rocks and is unconformably overlain by the Wiggins Formation. At the type section along the East Fork of the Wind River (Figure 1) the Tepee Trail consists of generally olive-drab, well-bedded claystones, siltstones, sandstones, conglomerates, breccias, thin flows, and abundant "tuffs". Biotite-augite and hypersthene-augite andesite clasts predominate, and the formation locally contains hypersthene basalt and biotite-hornblende andesite clasts. Love (1939) applied the name Tepee Trail Formation to rocks extending from Togwotee Pass to the North Fork of Owl Creek along the southern margin of the Absarokas. Subsequent workers (Masursky, 1952; Bown, in press) have extended the formation within the Bighorn Basin, while others (Hay, 1956; Wilson, 1963) believe that it grades into the Pitchfork and Wiggins Formations. Mammalian fossils, collected 500 feet above the base of the type section, are from the North American Uintan land mammal age (Love, 1939; McKenna, 1980; McFadden, 1980; Eaton, 1980).

A 2,500 feet thick stratigraphic section of the Tepee Trail Formation in the North Fork of Owl Creek consists largely of olive-drab, volcanic sandstones, lesser amounts of breccias and conglomerates, minor siltstones and claystones, and rare limestones, tuffs, and bentonite beds (Sundell, 1980). Much of the formation is lithologically similar to the type section 9 miles to the west (Love, 1939). A general current direction of S40°E in the study area is indicated by cross beds, current lineations, prod marks, and cobble imbrication throughout the Tepee Trail stratigraphic section.

Apparent angular unconformities exist between the Tepee Trail and Aycross Formations in the North Fork of Owl Creek, but the original depositional relationships have been distorted by extensive faulting and development of detachments and slump blocks. The two formations may be structurally juxtaposed along most of their exposed contacts. Evidence supporting a conformable contact includes decreasing grain size and increasing alteration towards the base of the Tepee Trail and the consistent presence of the upper bentonitic Aycross sequence below the Tepee Trail.

For mapping purposes, the Tepee Trail is subdivided into the lower Tepee Trail, Holy City beds, Foggy Day beds, and upper Tepee Trail, on the basis of key marker beds. These subdivisions were not recognizable in the South Fork of Owl Creek to the south or Cottonwood Creek to the north and should not be correlated out of the immediate area of study.

Figure 3. Holy City "facies" rocks at "The Holy City" (SE¼ sec. 21, T.44N., R.101W.).

Lower Tepee Trail

As described by Sundell (1980), a 400-feet-thick section of lower Tepee Trail beds in SE¼NE¼ sec. 29, T.44N., R.101W. contains four 50-feet-thick, olive-drab, well-bedded, continuous, resistant sandstones separated by nonresistant siltstones, sandstones, and thin conglomerate lenses. Abundant leaf imprints, carbonaceous wood, and thin (4 inches thick) carbonaceous lenses are present in the basal sandstones, siltstones, and claystones. The second major sandstone bed below the top of the lower Tepee Trail usually forms a prominent cliff and provides a laterally continuous marker. It consists of a massive, well-bedded, sheet-like volcanic sandstone sequence, 80 feet thick, which contains excellent ripple cross beds and small-, medium-, and large-scale, low-trough cross beds. An underlying micaceous shale parting and a nonresistant, pocky-weathering, bioturbated sandstone help identify this marker bed.

Holy City Beds

The Holy City beds in sec. 20, T.44N., R.101W. are 820 feet thick (Sundell, 1980). They are dominantly interbedded thin volcanic sandstones and siltstones, and form spectacular, precipitous badland areas such as "The Holy City," located in sec. 21, T.44N., R.101W. (Figure 3).

The basal bed, which conformably overlies the uppermost thick sandstone in the lower Tepee Trail, is a yellowish-buff, bentonitic, volcanic sandstone with abundant altered biotite and feldspar crystals, which is interpreted as reworked, altered tuff. It is traceable throughout the area. A sequence of nonresistant, thinly bedded siltstones, sandstones, and claystones dominates the lower section, which locally contains calcareous concretions, thin limestone lenses, and plant, invertebrate, and vertebrate fossils.

The Holy City beds also contain thin calcite veins derived from calcium carbonate leached from overlying calcareous

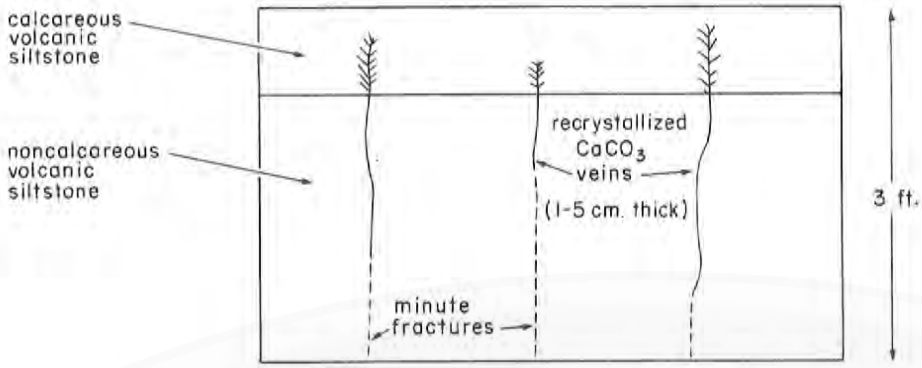

Figure 4. Calcite veins in the Holy City beds.

beds. The calcium carbonate recrystallized along vertical fractures in underlying units (Figure 4).

*The Holy City "facies".** The Holy City "facies" is geomorphically and lithologically distinct from the exposed Tepee Trail at the type section in the East Fork Basin (Love, 1939). It consists of interbedded and intercalated volcanic sandstones, siltstones, and conglomerates and probably represents a local environment of deposition (Figure 3). The sandstones are generally olive-drab, nonresistant, poorly sorted, and poorly cemented, and form steep slopes under resistant siltstone beds. The thin, greenish-gray siltstones generally crop out as resistant benches; but, if abundant soft clay matrix is present, they may form nonresistant parting planes. Conglomerates in the Holy City "facies" are usually paraconglomerates with rounded to subrounded, pebble- and cobble-size, andesite clasts in a very poorly cemented, olive-drab sandstone matrix. The conglomerates occur in lenses and channel fills throughout the sequence. The sandstones may grade laterally or vertically into conglomerates or siltstones, and sharp bedding planes are rare. Duplicate sections of Holy City "facies" beds in locations which are bounded by key markers show a general continuity of the facies, but the total bed thickness varies greatly, and individual siltstones, sandstones, and conglomerates are laterally continuous only over short distances (Sundell, 1980). The Holy City "facies" beds are interpreted as channel fill and overbank deposits in a rapidly aggrading, volcaniclastic terrain. Similar exposures of the Holy City "facies" are present in the South Fork and the North Fork of Owl Creek and the South Fork of Cottonwood Creek. The Holy City "facies" probably represents a particular environment of deposition and not a continuous rock stratigraphic unit.

Sandstone-breccia cycle. A unique sedimentation unit is present in the Tepee Trail Formation in the North Fork of Owl Creek (Figure 5). A 65-feet-thick sequence containing six sandstone-breccia cycles caps the Holy City beds and forms a distinct, mappable contact between the Foggy Day and Holy City beds. Sandstone-breccia cycles show these characteristics (Figure 6): (1) each cycle forms a resistant, well-bedded, laterally continuous unit with distinct parting planes above and beneath, but no breaks within, a cycle; (2) grain size increases symmetrically (vertically) towards the middle region of a cycle; (3) rounding of softer clasts increases symmetrically towards the middle of a cycle; (4) sorting decreases symmetrically towards the middle of a cycle; (5) lithologic composition seemingly does not change

*The Holy City "facies" is not synonymous with the Holy City beds. Rocks of the Holy City "facies" are common in both the Holy City beds and the Foggy Day beds.

Figure 5. A sandstone-breccia cycle (NE¼ sec. 19, T.44N., R.101W.).

within a cycle; (6) maximum clast size in the middle region increases with increasing thickness of each cycle; (7) the top and bottom of each cycle, no matter how thick, have some sand-size material with local cross-bedding; (8) the cycles are very resistant to weathering and commonly show a pocky middle region because of large, nonresistant clasts.

Each sandstone-breccia cycle was probably deposited from a slurried aqueous medium which increased and later decreased (at the same rate) its competence to transport larger clasts. Each cycle probably represents a single depositional event which produced thick, coarse breccias near the source that, fanning out in a sheet-like manner, became thinner and finer-grained away from the source. A change in the viscosity of the transporting medium may be a major factor. A similar sequence of much thicker breccias was observed in the uppermost drainage of Gooseberry Creek, but no correlation was attempted.

Foggy Day Beds

The Foggy Day beds, named after the Foggy Day vertebrate fossil locality (University of Wyoming locality number V-77022, NW¼NW¼SW¼ sec. 19, T.44N., R.101W.), consist of olive-drab volcanic sandstones, conglomerates, and siltstones with rare tuff beds at the top. The Foggy Day beds measure 690 feet thick, are lithologically very similar to the Holy City beds, and are separated mainly on the basis of marker beds. A distinct, mappable, conformable contact is present between the underlying resistant, bench-forming sandstone-breccia cycles in the Holy City beds and the overlying nonresistant Foggy Day beds. A thick, dark brown volcanic sandstone overlying typical Holy City "facies" beds, both overlying a sequence of interbedded resistant blue-green and nonresistant olive-drab sandstones near the base of the Foggy Day beds, was used for exact correlation between two stratigraphic sections measured by Sundell (1980). The Foggy Day beds have more conglomerates than the Holy City beds do, and show an increasing amount of tuffaceous material, and rare tuff beds, near the top.

An 80-feet-thick sequence of interbedded and intercalated orthoconglomerates caps the Foggy Day beds. The orthoconglomerates contain rounded to subrounded andesite boulders and cobbles in an olive-drab volcanic sandstone matrix and are commonly secondarily cemented by chalcedony and minor calcite. This orthoconglomerate

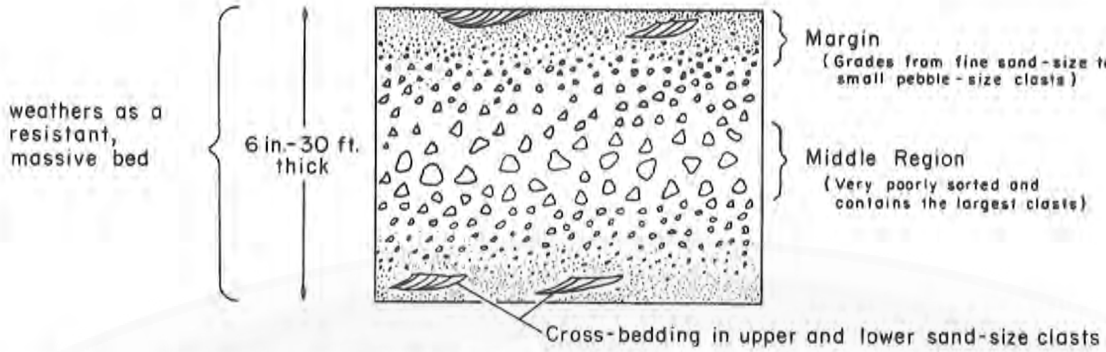

Figure 6. Schematic diagram of sandstone-breccia cycle.

sequence forms a dark-brown to black, resistant cliff or structural bench.

Upper Tepee Trail

The upper Tepee Trail beds contain 590 feet of volcanic sandstone, conglomerates, breccias, minor siltstones, and rare tuff beds. A soft basal sandstone sequence with several tuff beds conformably overlies the resistant orthoconglomerate sequence of the Foggy Day beds. The top of the orthoconglomerate sequence forms a locally distinct, mappable contact, but, because of rapid lateral changes and multiple orthoconglomerates in the section, other criteria were used to assure correct correlations throughout the area. These criteria include the presence of tuff beds and breccias, abundant conglomerates, a general light bluish-green color, and increasing tuffaceous material above the contact; and, below the contact, a thick orthoconglomerate, decreasing tuffaceous material, and a general olive-drab color. Abundant tuffaceous material gives the upper Tepee Trail beds their light bluish-green color. Blue-green, cyclic sandstone-breccias and other breccias are interbedded within the middle and upper parts of the Tepee Trail. The upper Tepee Trail lithologies grade into lower Wiggins lithologies at their contact.

Wiggins Formation

The name, Wiggins Formation, was proposed by Love (1939) for the white and light-colored sequence of rocks unconformably overlying the Tepee Trail and comprising the highest divides throughout the southern Absaroka Range. No type section was designated because of great variation in lithology. A measured section on Steamboat Rock (Love, 1939) consists of volcanic conglomerates, "tuffs" (primarily reworked, tuffaceous, volcanic sandstones), and thin flows. The dominant rock type at Steamboat Rock is biotite-hornblende andesite, but other andesites, dacites, rhyolites, and basalts are important elsewhere (Love, 1939; Keefer, 1957; Wilson, 1963). The erosional thickness of the Wiggins Formation varies from 0 to more than 3,900 feet (Love, 1939; Wilson, 1964). Reported ages of the Wiggins Formation vary from middle Eocene to Oligocene (Love, 1939; Keefer, 1957; Houston, 1964; Rohrer and Obradovich, 1969; Love, McKenna, and Dawson, 1976; Love, Leopold, and Love, 1978; Eaton, 1980). The great variability in lithology and age interpretations certainly reflects complex stratigraphic relationships within the unit.

The Wiggins Formation is more than 2,000 feet thick in the North Fork of Owl Creek. There it consists predominantly of light-colored, tuffaceous volcanic conglomerates and sandstones

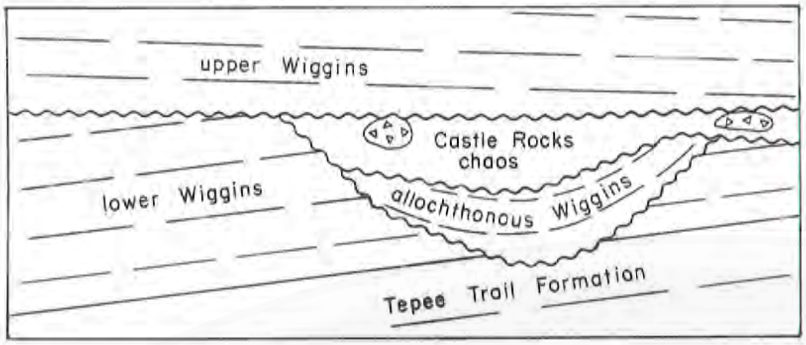

Figure 7. Schematic diagram of stratigraphic relationships in the Wiggins Formation (see Figure 2 for an explanation of symbols).

with minor primary and slightly reworked tuff beds. This formation comprises all ridges above 9,800 feet within the area, but may locally occur below 8,900 feet. The erosional thickness varies from 0 to 2,600 feet.

The emplacement of large allochthonous Wiggins masses created abundant structural contacts and obscured the original depositional contact between the Tepee Trail and Wiggins Formations. However, the relationship is thought to be conformable, on the following evidence: (1) the base of the lower Wiggins section grades downward toward the upper Tepee Trail with decreasing tuff content and increasing olive-drab and blue-green colors; (2) the top of the Tepee Trail section grades upward with increasing conglomerates, increasing tuffaceous material, decreasing olive-drab colors, and increasing blue-green colors; (3) exposed rocks in the South Fork of Cottonwood Creek (sec. 6, T.44N., R.101W.) grade from Tepee Trail into Wiggins without a noticeable unconformity; and (4) fossils indicative of the Uintan land mammal age were found throughout the Tepee Trail and Wiggins Formations.

A sequence of bright blue-green, tuffaceous volcanic sandstones, breccias, and conglomerates occurs at the contact between the Tepee Trail and Wiggins Formations. Typical olive-drab Tepee Trail sandstones can occur in or above the blue-green sequence and typical white, tuffaceous Wiggins sandstones can occur within or beneath it: establishment of the exact contact is difficult. The contact between the Tepee Trail and Wiggins Formations was placed in the center of the blue-green sequence.

The Wiggins Formation was subdivided into the lower Wiggins, allochthonous Wiggins, Castle Rocks chaos, and upper Wiggins for mapping. A distinct angular unconformity exists between the lower and upper Wiggins. The allochthonous Wiggins and Castle Rocks chaos locally fill more than 1,650 feet of paleotopography which developed before deposition of the upper Wiggins (Figure 7).

Lower Wiggins

Lower Wiggins strata, more than 1,000 feet thick, consist largely of volcanic conglomerates and sandstones with minor breccia and tuff beds. The basal sequence contains interbedded blue-green, white, gray, and minor olive-drab volcanic sandstones and conglomerates. Orthoconglomerates near the base commonly include subangular to rounded andesite cobbles and boulders, show cut-and-fill into underlying sediments, and form resistant benches. Most of the lower Wiggins consists of white, gray, buff, or yellowish-green sandstones and conglomerates with abundant reworked sand- to pebble-size tuff clasts thoughout. A thick sequence of very tuffaceous,

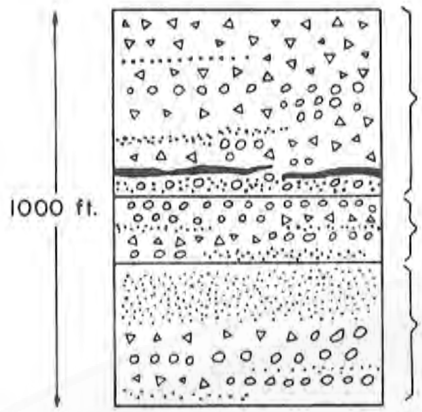

Figure 8. Composite section of the allochthonous Wiggins.

buff sandstones lies unconformably beneath the contact with the upper Wiggins at NE$\frac{1}{4}$NW$\frac{1}{4}$ sec. 1, T.44N., R.102W. (Sundell, 1980).

Allochthonous Wiggins

The allochthonous Wiggins includes large, detached plates of well-bedded Wiggins lithologies that could not be correlated with the rest of the Wiggins depositional sequence. However, lithologies can be correlated between detached plates of allochthonous Wiggins on the basis of a set of key marker units, especially the Sugar Loaf tuff beds, a lithologically distinct, conspicuous sequence (Figure 8). Locally, 330 feet of allochthonous Wiggins may underlie the Sugar Loaf tuff beds and 500 feet may overlie it.

The allochthonous strata underlying the Sugar Loaf tuff beds are best exposed in SW$\frac{1}{4}$ sec. 24, T.44N., R.102 W., where they consist of andesitic, buff to greenish-gray volcanic sandstones and light blue-green volcanic conglomerates and breccias. Detachment faults commonly occur in a 65-feet-thick sequence of clayey, tuffaceous, buff volcanic sandstone immediately underlying the Sugar Loaf tuff beds. A sequence of very tuffaceous breccias and conglomerates may underlie the buff sandstone beds.

The Sugar Loaf tuff beds are best exposed in the North Fork of Owl Creek and the South Fork of Cottonwood Creek within 3 miles of Sugar Loaf Mountain (Figure 1). In sec. 18, T.44N., R.101W., 160 feet of measured Sugar Loaf tuff beds consist of interbedded white and lime-green, very tuffaceous volcanic conglomerates, breccias, and sandstones (Sundell, 1980). Crossbedding and graded bedding were observed in the sandstone layers. The clasts consist of distinctive gray, flow-laminated rhyolite fragments, white to lime-green rhyolite tuff, and minor reworked andesitic material. Distinctive cryptofelsitic, banded rhyolite fragments and rhyolite tuff clasts, which compose more than 80 percent of the sequence, are interpreted as reworked clasts from either a sequence of rhyolite flows and tuffs or a welded ash flow tuff. Identical reworked tuff beds were observed in the South Fork of the North Fork of Owl Creek, Rock Creek, South Fork of Owl Creek, South Fork of Cottonwood Creek, and Lake Creek. The Sugar Loaf tuff beds are a very conspicuous marker and may help solve regional stratigraphic and structural problems in the southeast-

Figure 9. Castle Rocks chaos at Castle Rocks (E½ sec. 26, T.44N., R.102W.).

ern Absarokas.

The allochthonous rocks overlying the Sugar Loaf tuff beds, best exposed in NW¼ sec. 18, T.44N., R.101W., consist of volcanic conglomerates, breccias, sandstones, thin andesite flows, and rare tuffs with distinctive reworked, laminated rhyolite clasts throughout. The thickness and lithology of allochthonous strata overlying the Sugar Loaf tuff beds vary greatly, but two general relationships were observed. A sequence of nonresistant conglomerates with interbedded thin andesite flows usually overlies the Sugar Loaf tuff beds, and a thick sequence of resistant, tuffaceous breccias, conglomerates, and sandstones overlies the thin andesite flows. The detachment in SE¼ sec. 14, T.44N., R.102W. includes only the uppermost resistant breccia, conglomerates, and sandstone sequence.

The allochthonous Wiggins locally overlies lower Wiggins, upper Tepee Trail, Foggy Day, and Holy City beds and is overlain by the Castle Rocks chaos.

Castle Rocks Chaos

The Castle Rocks chaos is well exposed on Castle Rocks (secs. 25 and 26, T.44N., R.102W.) as a massive, unsorted breccia containing boulders and very large blocks of allochthonous material in a heterogeneous matrix (Figure 9). The matrix is composed of allochthonous or locally derived, unsorted, volcaniclastic material, including volcanic sand, pebbles, cobbles, boulders, and abundant tuff fragments (Figure 10). Allochthonous Wiggins and lower Wiggins rocks are locally incorporated in the matrix. The totally allochthonous material in the matrix consists of boulders to very large blocks (up to 1,000 feet on an edge) of hornblende andesites, andesite breccias (by autobrecciation?), andesite flows, breccias, and interbedded volcanic strata. The allochthonous material and general matrix are totally unsorted and intermixed in the Castle Rocks chaos.

The Castle Rocks chaos unconformably overlies allochthonous Wiggins, lower Wiggins, upper Tepee Trail, and Foggy

Figure 10. Unsorted Castle Rocks chaos matrix.

Day beds and is overlain by the upper Wiggins. The basal contact varies from structural (slickensided fault plane) to depositional (gradational matrix). The unit is generally a sheet-like mass 500 to 1,000 feet thick, but may locally exceed 1,650 feet where it fills paleotopography. More detailed descriptions and interpretations of the manner of emplacement are included below under "Structural Geology".

Upper Wiggins

The upper Wiggins unconformably overlies either the Castle Rocks chaos or the lower Wiggins and consists of volcanic conglomerates, sandstones, laharic breccias, and tuff beds. Abundant clasts of the Castle Rocks chaos and lower Wiggins are reworked into the basal upper Wiggins. A 490-feet-thick stratigraphic section measured by Sundell (1980) includes a basal sequence of pink, buff, and gray volcanic sandstones and tuff breccias which locally contains abundant fossil mammal bones and teeth. A 330-feet-thick sequence of interbedded volcanic sandstones and laharic breccias composes most of the upper Wiggins stratigraphic section.

Laharic Breccias. The laharic breccias, interpreted as cold mudflows, contain unsorted, angular to rounded andesite, dacite, and minor rhyolite pebbles, cobbles, and boulders in a very tuffaceous, sandy matrix (Figure 11). The shape of the breccia deposits varies from small (3 x 10 feet) channel fills to large (150 x 3,000 feet) sheet-like masses. The matrix generally composes more than 30 percent of the rock and is predominantly sand-size, lithic fragments with abundant crystal tuff and altered ash. The matrix fines upwards at the very top of the breccia. Few large boulders were observed at the top or bottom of a laharic breccia. Locally reworked sandstones with good cross-bedding commonly separate successive laharic breccias.

Upper Wiggins strata more than 1,000 feet thick are well exposed on Mudstone Peak in the southwest corner of sec. 28, T.44N., R.102 W. (Figure 12). More than 250 feet of white to gray, very tuffaceous volcanic sandstone with abundant tuff beds overlie the laharic breccia sequence on Mudstone Peak. More than

Figure 11. Laharic breccias in the upper Wiggins on Cottonwood Peak (SE¼ sec. 25, T.45N., R.102W.).

Figure 12. Upper Wiggins at Mudstone Peak (SE¼ sec. 29, T.44N., R.102W.).

500 feet of moderately bedded, buff to white volcanic conglomerates and sandstones compose the top of Mudstone Peak and form the uppermost sequence of Wiggins strata in the headwater area of the North Fork of Owl Creek.

QUATERNARY ROCKS

Quaternary strata are local, thin patches and veneers of poorly consolidated alluvial, colluvial, and mass-gravity-movement material. They unconformably overlie all other rocks.

STRUCTURAL GEOLOGY

The Absaroka Range is a unique mountain range within the Wyoming tectonic province. It is a northwest trending belt of volcanic and volcaniclastic rocks unconformably overlying folded, faulted, and truncated Precambrian, Paleozoic, Mesozoic, and Early Tertiary rocks (Figure 13). The position of the Absaroka volcanic field is probably controlled by zones of structural weakness in underlying Precambrian rocks.

The Absaroka volcanic field overlaps the Washakie and Owl Creek uplifts to the south, the Bighorn Basin to the east, and the Beartooth and Gallatin uplifts to the north (Figure 13). The Absaroka Range is overlapped by the younger volcanics of the Yellowstone Volcanic Plateau to the west.

REGIONAL STRUCTURES WITHIN THE ABSAROKA RANGE

The position of the Absaroka volcanic field is controlled by north to northwest trending belts of intrusive and extrusive source rocks which probably reflect deep-seated structural weaknesses in the earth's crust (Rouse, 1940; Chadwick, 1970; Smedes and Prostka, 1972; Love, Kudo and Love, 1976). Regional mapping of stratigraphic relationships (Smedes and Prostka, 1972) and a few radiometric dates (Chadwick, 1969; Love, Kudo, and Love, 1976) suggest a general southeast progression of volcanism from the early Eocene to Oligocene. The presence of large basalt blocks and possible vents in the middle Eocene Aycross Formation (Masursky, 1952; Sundell, 1980) and in the stratigraphically equivalent Pitchfork Formation (Wilson, 1964, 1970) in the southeastern Absarokas suggests local complications of the southeast progression of volcanism during the Tertiary.

Later episodes of Pliocene and Quaternary volcanism created the Yellowstone Volcanic Plateau and buried the western margin of the Absaroka Range (Christiansen and Blank, 1972). A few remnants of Pliocene (Blackstone, 1966) and possibly younger volcanics (Love, 1939) cap the southern Absarokas; their genetic relationship to either the Absaroka volcanic field or the Yellowstone Volcanic Plateau is not known.

Other structural complications within the volcanic field include north to northwest trending, low, broad warping (Love, 1939; Wilson, 1964; Ketner and Fisher, 1968), spectacular detachment faults (Pierce, 1941, 1978; Wilson, 1975), and abundant smaller structures (Rouse, 1937; Dunrud, 1962; Wilson, 1964; Pierce, 1978; Bown, in press).

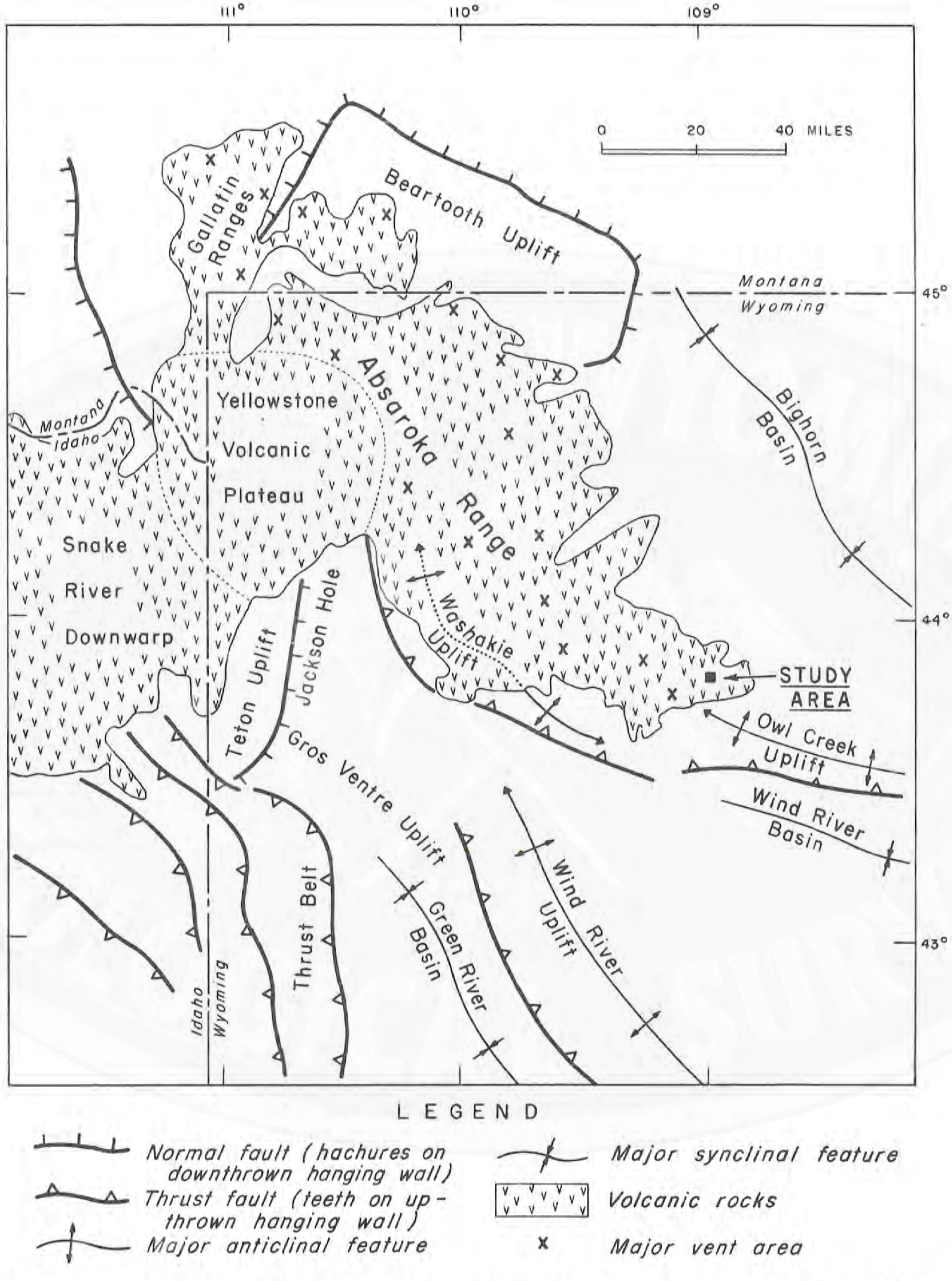

Figure 13. Generalized regional tectonic map of the Absaroka Range area (modified from Cohee, 1962).

REGIONAL STRUCTURES BENEATH THE SOUTHEASTERN ABSAROKA RANGE

Regional structural boundaries of the southwestern Bighorn Basin, northwestern Wind River Basin, western Owl Creek Range, and eastern Washakie Range merge beneath the southeastern Absaroka Range (Figure 13). The dominant westward trends of the anticlinal Owl Creek uplift and synclinal Wind River Basin change to northwest near the Absaroka Range (see, e.g., Cohee, 1962). The anticlinal Washakie uplift (Love, 1939), now largely covered by the Absaroka volcanic field, generally trends west to northwest. The synclinal Bighorn Basin trends northwest along much of the eastern margin of the Absarokas. These major structural features in the Wyoming foreland province developed during the Laramide Orogeny, from latest Cretaceous to early Eocene, prior to volcanic activity in the southeastern Absarokas.

A system of west to west-northwest trending faults is developed along the southern margin of the Owl Creek and Washakie uplifts, and major east to northeast trending faults occur in the Bighorn Basin. Similar structural trends are present in the study area. For further information on the distribution and development of these regional structural features see Blackstone (1948, 1963), Chamberlain (1940, 1945), Fanshawe (1939, 1971), Gard (1969), Keefer (1965), Love, (1939, 1978), Thomas (1965), Stearns (1971), Pierce (1978), and Cohee (1962).

Certain regional structures which trend under the Absaroka volcanic sequence may directly or indirectly affect the geology within the study area. The Washakie uplift (Love, 1939) trends northwest from Black Mountain and exposes a Precambrian core 11 miles to the southwest. The northwestern tip of the Owl Creek uplift trends N50°W and plunges beneath the Absaroka Range 6 miles to the south. The study area probably overlies the northeast-dipping flank of the Owl Creek uplift along the southwest margin of the Bighorn Basin. A series of west to northwest trending anticlinal structures affects Mesozoic and Paleozoic rocks along the southwest margin of the Bighorn Basin.

Masursky (1952) mapped several distinctive structural patterns in Paleozoic strata along the western Owl Creek Mountains, 6 miles south of the study area, including several northwest trending anticlines and synclines and three major fault systems. The dominant system trends N50°W and is cut by a later system which trends west in the eastern half of Masursky's map area but changes to a predominantly N60°E trend westward. Many of the structural trends within the study area may be indirectly controlled by these underlying structural trends; but no structures in the Absaroka sequence were directly traced into Mesozoic and Paleozoic rocks.

DETAILED STRUCTURES OF THE NORTH FORK OF OWL CREEK AREA

Folds, abundant normal faults, reverse faults, detachment faults, and a unique structural and depositional event (the Castle Rocks chaos) were recognized in the Absaroka volcaniclastic sequence and are depicted on the geologic and tectonic maps (Plates I and II) and related geologic cross sections (Plates III and IV).

Folds

A very low, broad anticline in the lower Wiggins Formation (in secs. 1,2, and 3, T.44N., R.102W.; see Plate II) trends N28°W and plunges 4 degrees to the northwest. This anticlinal feature may extend southeastward to the Castle Rock horst (in secs. 35 and 36, T.44N., R.102W.), but later faulting has obscured this relationship. The anticline is shown in the sequence of cross sections D-D', E-E', F-F' on Plate IV. An adjacent low, broad syncline in the lower Wiggins and Tepee Trail Formations (in contiguous secs. 1, 36, 31, and 6, Tps. 44-45N., Rs.101-102W.) trends N26°W and plunges 10 degrees to the northwest. These structures developed after deposition of the lower Wiggins but before deposition of the upper Wiggins, and preceded most faulting.

An anticline and two flanking synclines are present in allochthonous Wiggins strata in secs. 17, 18, 19, and 20, T.44N., R.101W. (see Plate II). The syncline to the northwest trends N28°E and plunges 8 degrees to the northeast. The central anticline trends N42°E and plunges 2 degrees northeast. The syncline to the southeast trends N56°E and plunges 4 degrees northeast, and has a steeper southeast limb. Although these folds are not present in the underlying Tepee Trail Formation or overlying Wiggins Formation, their trends are subparallel to faults in the Tepee Trail Formation. They may have formed during emplacement of the allochthonous Wiggins strata onto a paleotopography, or have been deformed by subsequent movement along underlying fault systems, or both.

Normal Faults

Four major trends (N1-4; see Table II) and several random patterns (N5-6) of normal faults were recognized. The N1a and N1d faults (in secs. 25 and 36, T.44N., R.102W.) strike west to northwest and bound the Castle Rocks horst block. The northern fault (N1a) is locally composed of several closely spaced parallel faults (N1b-c) having 40° to 50° northeast dips and more than 1,500 feet of total stratigraphic displacement. The N1 faults were cut by later northeast (N2) and north (N3) trending faults.

A parallel sequence of three major faults (N2a, N2f, and N2h) and many lesser faults (N2b-e, N2g, and N2i-k) strike N30°E, perpendicular to the North Fork of Owl Creek. Most are downthrown on the southeast side. Fault N2a is well exposed in secs. 14 and 23, T.44N., R.102W. The fault plane strikes N35°E, dips 40°E, and contains slickensides which pitch 90°. It shows more than 900 feet of stratigraphic separation and contains 0.5-2 inches (1-5 centimeters) of clay gouge along the fault plane. The N2a fault extends to the northeast under allochthonous Wiggins strata in sec. 12, T.44N., R.102W. The N2a fault does not cut the detached mass, but its later movement may have been diverted along the northwest side of the detached mass. Fault N2b forms a small slice along the N2a fault plane.

The N2c-e faults show very little offset and many minor complications. Fault N2c is downthrown on the northwest side. The N2e fault is inferred from abundant aligned springs in the Tepee Trail Formation. Fault N2f has 800 feet of stratigraphic separation, but allochthonous Wiggins strata (underlain by fault D1f), more than 2,000 feet out of stratigraphic order, obscure the N2f fault plane along its entire length. Fault N2g is probably a southwest extension of N2f. Fault N2h is also a major covered fault with approximately 900 feet of stratigraphic separation beneath a mass of allochthonous Wiggins strata. Fault N2i is inferred on the basis of stream trends and a break in the N1d fault. No displacement of the Aycross Formation was observed across the N2i fault. The N2j and N2k faults continue the sequence of northeast trending faults, but N2k has displacement

Table II. Fault information (see Plate II for map locations).

Labeling of specific faults	Classification of faults	Trend of faults	Strata involved at the surface (map abbreviations)	Maximum stratigraphic separation	Relative order of occurrence: 1=youngest
N1a-e		N70-90W (N1)	Tac, Ttl, Tthc, Ttfd, Ttu	1,100 ft.	7 (oldest)
N2a-k		N30-40E (N2)	Ttl, Tac, Ttfd, Ttu, Twil?,Twia?	900 ft.	6
N3a-d	Normal (N)	N0-20W (N3)	Tac, Ttl Tthc, Ttfd	500 ft.	
N4a-b		N30W (N4)	Twil, Twiu	100 ft.	2
N5a-c		Various (N5)	Tac, Ttl, Tthc	300? ft.	6?
N6a-l	(Slumps)	Various (N6)	Ttl, Tac, Ttfd, Twic	800 ft.	1 & 6?
Ra		N30E	Ttfd, Twil, Twia	50 ft.	
Rb	Reverse (R)	N45E	Tac	100 ft.	5?
Rc		N80E	Tthc	50 ft.	
Dla-q	Detachment (D)	Various	Tthc, Ttfd, Ttl, Twil, Twia	2,500 ft.*	4
† C1	Low angle normal, low angle reverse, and detachment	Various	Ttfd, Ttu, Twil, Twia, Twic	2,300 ft.	3
† C2	Medium to low angle normal	NE-SW	Ttfd, Ttu, Twil, Twia, Twic	2,300 ft.	

† C1 and C2 are related to emplacement of the Castle Rocks chaos.

* Minimum horizontal displacement is 5 miles

Figure 14. Bedding fault development in lower Tepee Trail strata (S½ sec. 4, T.43N., R.104W.).

opposite that of N2j. The down block to the west of the N2k was probably affected by the N1a fault and possibly by emplacement of the block underlain by Dli.

The N2a, N2f, and N2h faults are all interpreted as major, concave-upward faults which flatten at depth and become major bedding plane faults on top of or within the soft, bentonitic Aycross Formation (Plate III, cross sections A-A', B-B', C-C'). A detachment plane probably exists between most of the Tepee Trail and Aycross rocks southeast of N2f. The following evidence supports these interpretations: (1) all the faults are similar in trend, scale, relative motion, amount of displacement, strata involved, and time of motion; (2) all the faults directly underlie allochthonous Wiggins rocks, which were emplaced on a paleoerosion surface; (3) N2a, which has a well exposed fault plane, dips at a low angle (38-45°) and shows slickensides parallel to maximum dip; (4) similar low angle faults of recent time in equivalent strata flatten in the lower Tepee Trail, detach in either the lowest Tepee Trail or upper Aycross, and form detached plates along the present erosional Tepee Trail - Aycross margin (Figure 14); (5) the lowest Tepee Trail strata are commonly missing or concealed by having sunk into the soft upper Aycross, and infrequently show bedding plane slickensides perpendicular to the strike of N2 faults; (6) the Aycross Formation creates an excellent detachment surface because it has water-saturated bentonite beds near the top; (7) the exposed Aycross Formation in the southeastern part of the study area has ubiquitous, small-scale internal deformation not present in overlying Tepee Trail strata.

The N3a-d faults all strike north to northwest, have nearly vertical fault planes, and have uncertain relationships with other structures in the area. The N4a-b faults strike northwest, dip northeast, and are the only faults that offset the upper Wiggins. Faults N5a-c are generally small and have uncertain relationships to other structures. The N6a-l faults are easily visualized as bounding slump blocks which have backwards rotation. The concave-upward fault planes are approximately perpendicular to maximum dip on each block.

Reverse faults

Only three reverse faults (Ra-Rc) were observed in the area. Fault Ra has a 64-65°W dip, has variable slickenside directions, and strikes N30°E, parallel to normal fault system N2c-e. The emplacement of the allochthonous Wiggins strata (underlain by fault D1b) may have reactivated a previous normal fault, but causing displacement in the opposite sense. Fault Rb strikes N70°E, dips 50-60° NW, and shows clear drag folds, but cannot be traced into the Tepee Trail Formation. Fault Rc has a shallow-dipping fault plane (35°) with very little stratigraphic separation (50 feet) and is well exposed in The Holy City (sec. 21, T.44N., R.101W.).

Allochthonous masses bounded by detachment faults

Seven large masses (more than one half square mile) and 10 smaller masses of allochthonous strata were mapped (D1a-q, Plates I and II). *The detached masses are referred to by the label of their underlying fault planes.* Other, lithologically similar detached masses were observed during reconnaissance throughout a 100-square-mile area surrounding the study area. Structurally similar Heart Mountain and related detachments 30 miles to the north, described by Bucher (1947), Dake (1918), Greenburg (1973), Hewett (1920), and Pierce (1941, 1957, 1960, 1963, 1975) involve different rocks, different times of emplacement, and possibly different mechanisms of emplacement.

Later detachment faulting in the Castle Rocks chaos is a separate, unique structural and depositional phenomenon discussed in the Castle Rocks chaos section, below.

Strata involved

Allochthonous Wiggins, lower Wiggins, and upper Tepee Trail strata were observed in detached masses (Plate II, D1a-q). A small, isolated plate of lower Wiggins strata, D1e (in SW¼ sec. 7, T.44N., R.101W.), was probably locally mobilized during emplacement of the surrounding allochthonous Wiggins. A similar plate of upper Tepee Trail strata (D1d) showed little displacement and was probably formed during the emplacement of the overriding D1c mass. The D1d and D1e masses are detached, but they represent locally derived strata, not part of the primary allochthonous Wiggins detachment.

Allochthonous Wiggins strata, which compose more than 95 percent of the detached material, are more than 1,000 feet thick. None of the allochthonous Wiggins strata match the measured Wiggins - Tepee Trail stratigraphic section; the rocks are similar to other Wiggins rocks but were emplaced during a major erosional episode between deposition of the lower and the upper Wiggins. The allochthonous Wiggins rocks were either deposited and later totally removed by detachment and erosion from the original stratigraphic sequence or are totally allochthonous and were never deposited within the study area. I believe the latter to be correct. The Sugar Loaf tuff beds, in all detachments except D1c-e and D1j, form a key marker within the allochthonous Wiggins strata. The detached plates locally overlie lower Wiggins, upper Tepee Trail, Foggy Day, and Holy City beds.

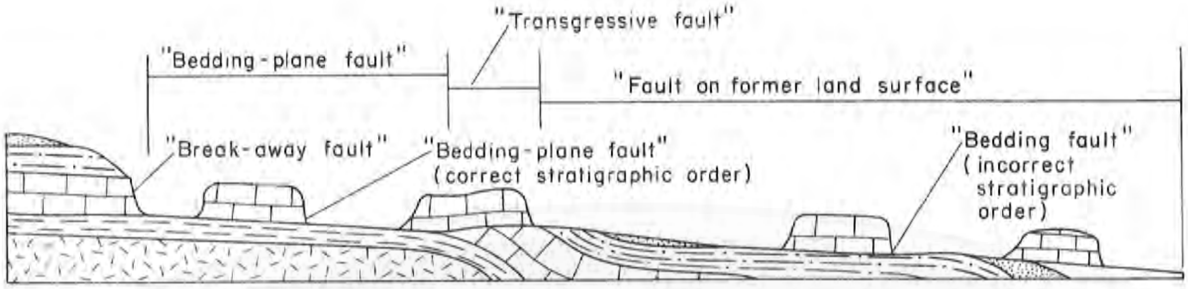

Figure 15. Schematic cross section of a detachment fault. Modified after Pierce (1960).

Fault planes

Overriding plates, such as Dlh, Dlj, and Dlk, and several different stratigraphic planes of detachment are evidence that more than one fault plane is present. The detachments were emplaced as several independent plates on a former land surface and no original "breakaway," "bedding-plane," or "transgressive" faults, as described by Pierce (1960), were observed. However, bedding in allochthonous strata can be parallel to bedding in autochthonous strata and separated by a bedding fault which is not the original "bedding-plane" fault (Figure 15). These bedding faults are special cases of a "fault on a former land surface," in which bedding in autochthonous strata is parallel to the former land surface. Such bedding faults were extremely difficult to recognize in the field except by stratigraphic disorder.

That the observed detachment fault planes are very irregular and do not form flat planes is evidence that allochthonous masses were displaced across a topography of considerable relief or were deformed after emplacement.

The detachment fault contacts vary from a 100-feet-wide zone of deformed and contorted strata to a ½-inch-thick (1-centimeter-thick), sharp contact. Slickensides are locally common where resistant beds in the upper and lower plates are in contact. Nonresistant beds commonly produce a transitional contact without slickensides. Remarkably little brecciation was observed along fault contacts.

The bottom surface of a resistant bed in an overriding plate is infrequently studded with small pebbles. The pebbles are embedded in the upper fault surface and appear analogous to roches moutonnées of glacial origin. These pebbles are resistant remnants, formed by abrasion along the bottom of the overriding plate during transportation (Figure 16).

Deformation in the detached plates

Deformation is greater in the overriding plates than in the lower plates. Small-scale fracturing with less than 10 feet of displacement occurs intermittently in the upper plates, but does not cross into footwall rocks. Strikes and dips of well-bedded units in the overriding plates are much more variable than those in underlying strata. Fracturing and minor contortion of bedding increases towards the bottom of a detached mass.

Large-scale deformation is present in many of the detached masses. Faults

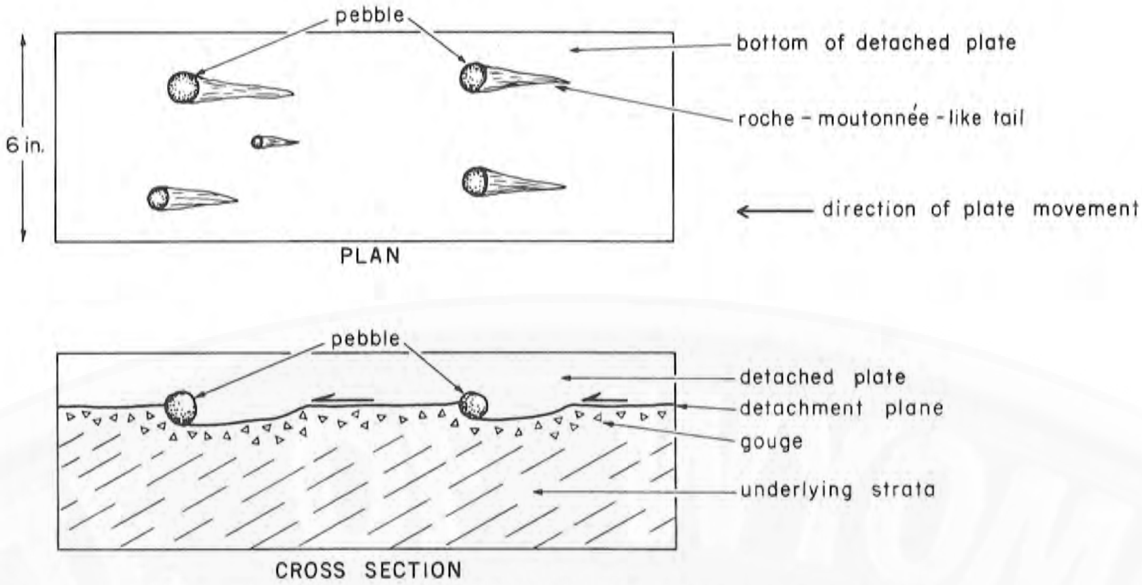

Figure 16. Small pebbles along the bottom of a detachment surface.

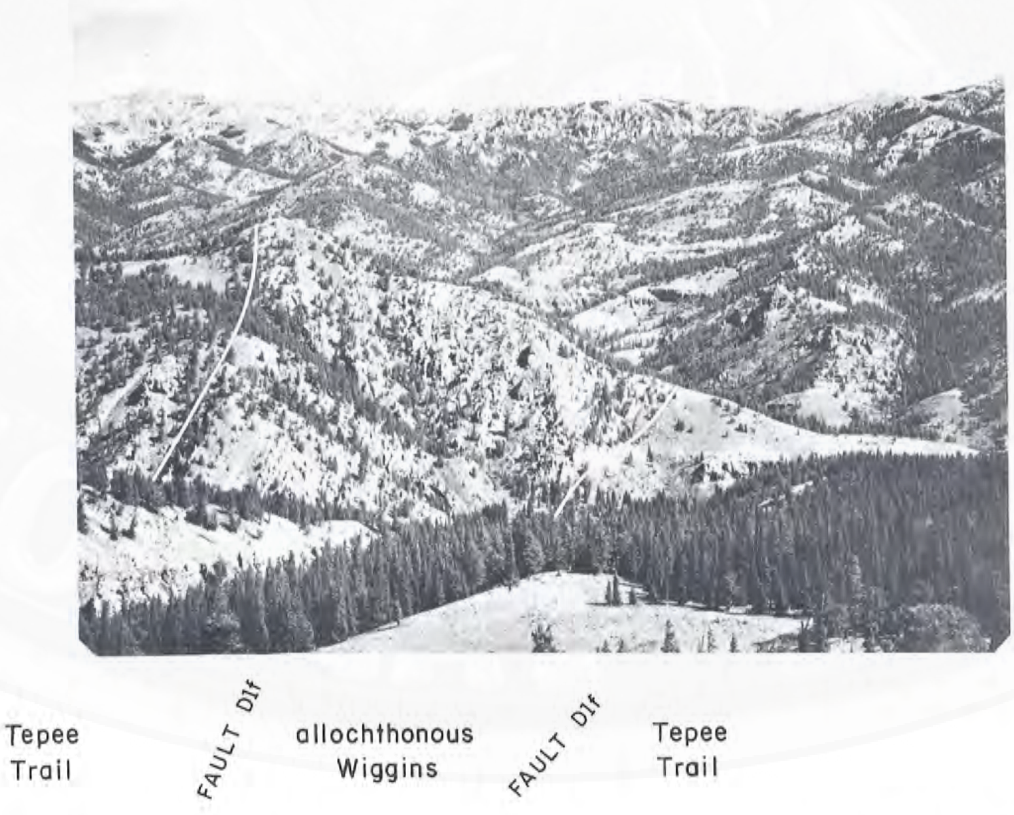

Figure 17. Secondarily deformed allochthonous Wiggins mass Dlf (N½ sec. 24, T.44N., R.102W.).

Dlg-i are folded into broad synclinal and anticlinal structures. Because these folds are not present in the overlying Castle Rocks chaos and upper Wiggins or the underlying Tepee Trail, I believe they formed during or soon after emplacement of the detached masses. In general, bedding within a detached mass parallels the fault plane. However, Dlf, the most deformed mass in the area, contains nearly vertical beds which grade into a massive breccia to the southeast (Figure 17). The steep dips and extreme deformation in Dlf were possibly caused by later emplacement of Dlc and Dld. Locally, Dla and Dlg show no deformation above bedding faults.

Deformation beneath the detachments

In general, remarkably little deformation was observed beneath exposed detachment faults: in most areas, no fracturing, brecciation, or drag of underlying strata occurred. The two windows in SE¼ sec. 18, T.44N., R.101W. showed only minor gouge directly beneath the detachment plane. Slight drag folding, which may extend 15 feet beneath the detachment plane, is the most common type of deformation. In places, zones of unsorted, slightly brecciated material less than 10 feet thick are trapped between the overriding plate and undeformed underlying strata. These zones may represent breccias developed beneath the fault plane or trapped colluvium on an old erosion surface (Figure 18).

Paleovalleys or later deformation?

The detachment planes show large-scale undulations as deep as 2,000 feet: therefore, the detached masses either moved over a pronounced paleotopography or were deformed after emplacement. Many detached masses are aligned along the northeast-trending N2 fault systems; the thickest sections of allochthonous strata occur above N2f and N2h. Cross sections (Plate III) of these northeast trends indicate a synclinal form in the detached masses and a faulted Tepee Trail section beneath. The N2 faults do not noticeably cut the overlying allochthonous Wiggins, and the detachment planes dip less than 40 degrees towards the bottom of a syncline.

These relationships support the concept of emplacement along a paleovalley which had previously been eroded along the N2 faults and probably drained to the northeast (Figure 19A). Greater deformation would be expected in rocks above and below the detachment plane if the allochthonous Wiggins masses had been emplaced down 30-degree, ½-mile-long slopes into the bottom of a paleovalley as suggested by present fault slopes.

Alternatively, the allochthonous Wiggins may have been emplaced on an essentially flat topographic surface, later movement along the N2 faults having caused the allochthonous strata to drape into synclinal folds along the fault trend (Figure 19B). This theory is supported by folding within the allochthonous Wiggins subparallel to the fault trends and by a general lack of extreme deformation in the detached masses; but in this case, movement along the N2 faults would probably have broken the detached masses.

A combination of the two theories may best explain the evidence: the allochthonous Wiggins was emplaced on topography of low to moderate relief, and subsequent movement along the N2 faults was distributed along the northwest limb of the synclinal detachment fault, rather than breaking the allochthonous strata (Figure 19c).

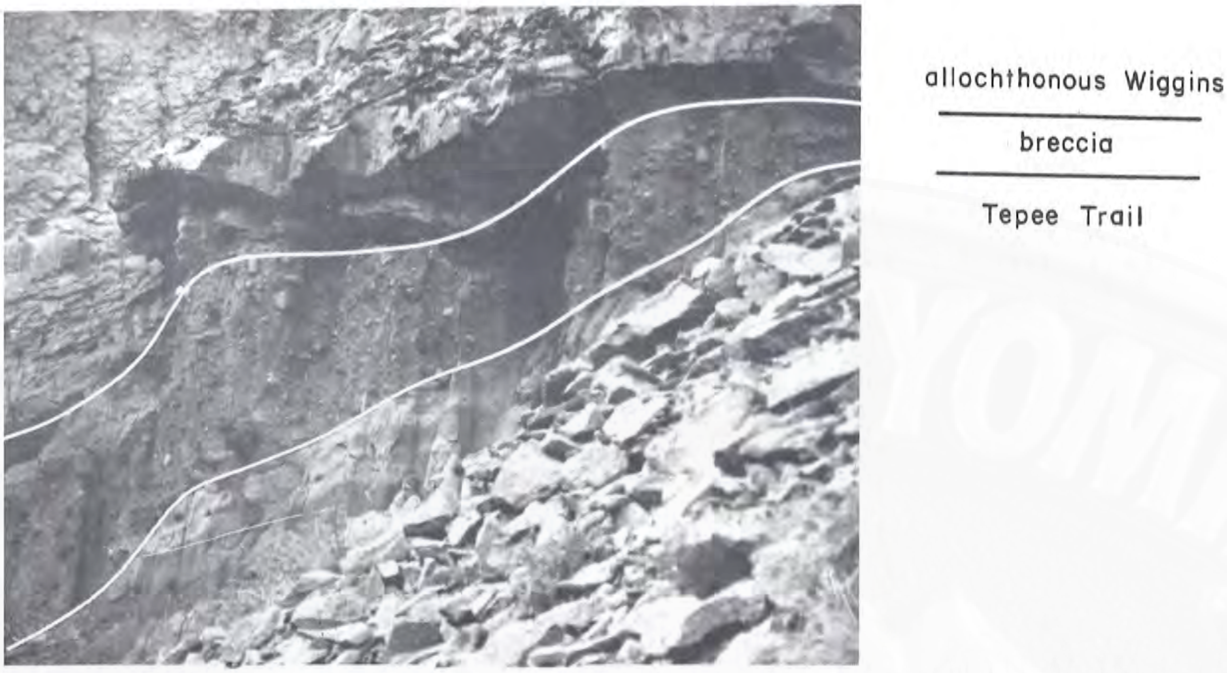

Figure 18. Possible colluvium or breccia beneath allochthonous Wiggins mass Dli (SE¼ sec. 24, T.44N., R.102W.).

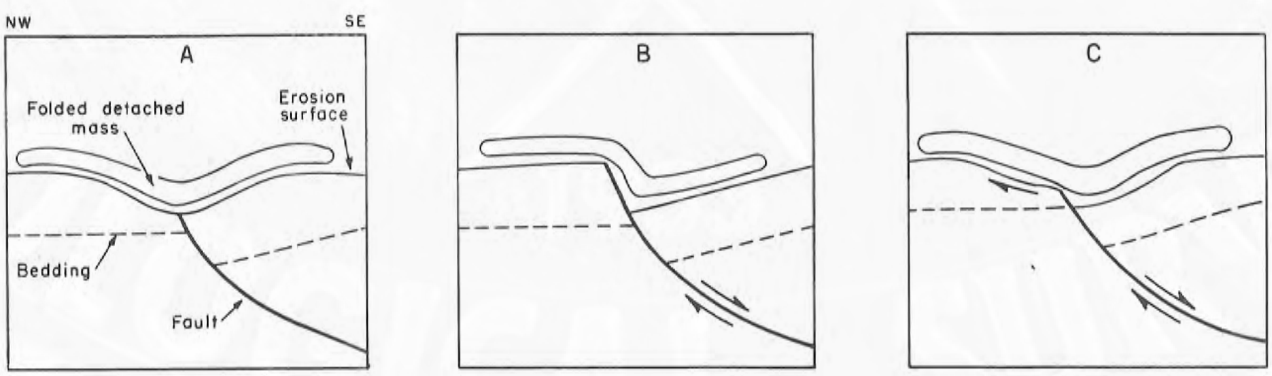

Figure 19. Three possible explanations of folded allochthonous Wiggins: (A) emplacement along a pre-existing paleovalley; (B) emplacement on a flat topographic surface which was later faulted; (C) emplacement along a pre-existing paleovalley which experienced a second and later episode of faulting.

Time, direction, and mode of emplacement

The detached masses were emplaced during a period of major erosion after deposition of the lower Wiggins and before deposition of the Castle Rocks chaos or upper Wiggins. Emplacement occurred during the middle or possibly late Eocene (on the basis of the occurrence of Uintan fossil mammals in strata underlying and overlying the detached masses). Deformation, especially minor slickenside directions in the Dlf mass, suggests emplacement from the west or southwest. The closest source is more than 5 miles away from some detached masses; however, reconnaissance mapping suggests a much greater distance of transportation. The general mode of emplacement was some form of gravity silde phenomenon. Many theories have been proposed for the mechanisms of emplacement of large, gravity detached masses (Pierce, 1975). Sufficient information was not obtained to determine the exact mechanism of emplacement for the detached masses in the headwaters area of the North Fork of Owl Creek. Many of the smaller masses (Dlj-q) may have moved several times during emplacement of the overlying Castle Rocks chaos.

Castle Rocks Chaos

The Castle Rocks chaos represents a unique structural and depositional event which occurred during the middle or possibly late Eocene in the southeastern Absaroka Range. This widespread, unsorted, heterogeneous jumble of volcanic debris contains large (1,000 feet on an edge) masses and blocks of highly contorted allochthonous andesite in an unsorted tuffaceous breccia matrix. The term chaos does not imply a genesis similar to that of "chaos" as originally described by Nobel (1941), but it does imply similar descriptive characteristics. It also includes characteristic features similar to those described for lahars (Fisher, 1960b), megabreccias (Longwell, 1951), and large gravity detachments (Pierce, 1975). The chaos was emplaced by combined landslide and debris flow processes. Similar clastic material in the East Fork Basin, 10 miles to the southwest, photographed and described by Love (1934, 1939), may prove to be equivalent to the Castle Rocks chaos.

Distribution

The Castle Rocks chaos exposed within the study area probably represents only a very small part of the area affected (Plate I and Figure 20); it continuously crops out along an arc from Castle Rocks*, around the head of the North Fork of Owl Creek, to Sugar Loaf Mountain. Small remnants suggest that it covered a much larger area before development of the North Fork of Owl Creek drainage. Reconnaissance mapping of similar lithologies, structures, and stratigraphic relationships, and data from J.D. Love and W.H. Wilson (personal communications), suggest that emplacement of the Castle Rocks chaos (or very similar units) occurred throughout a 400-square-mile area in the southeastern Absaroka Range. Large, contorted masses of andesite were observed in the head of Cottonwood Creek, in the head of Gooseberry Creek, along the South Fork of the Wood River, along the East Fork of the Wind River, and throughout the Absaroka Range east of those occurrences (Figure 20).

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*Not to be confused with Castle Rock, 11 miles to the west, in the East Fork of the Wind River drainage.

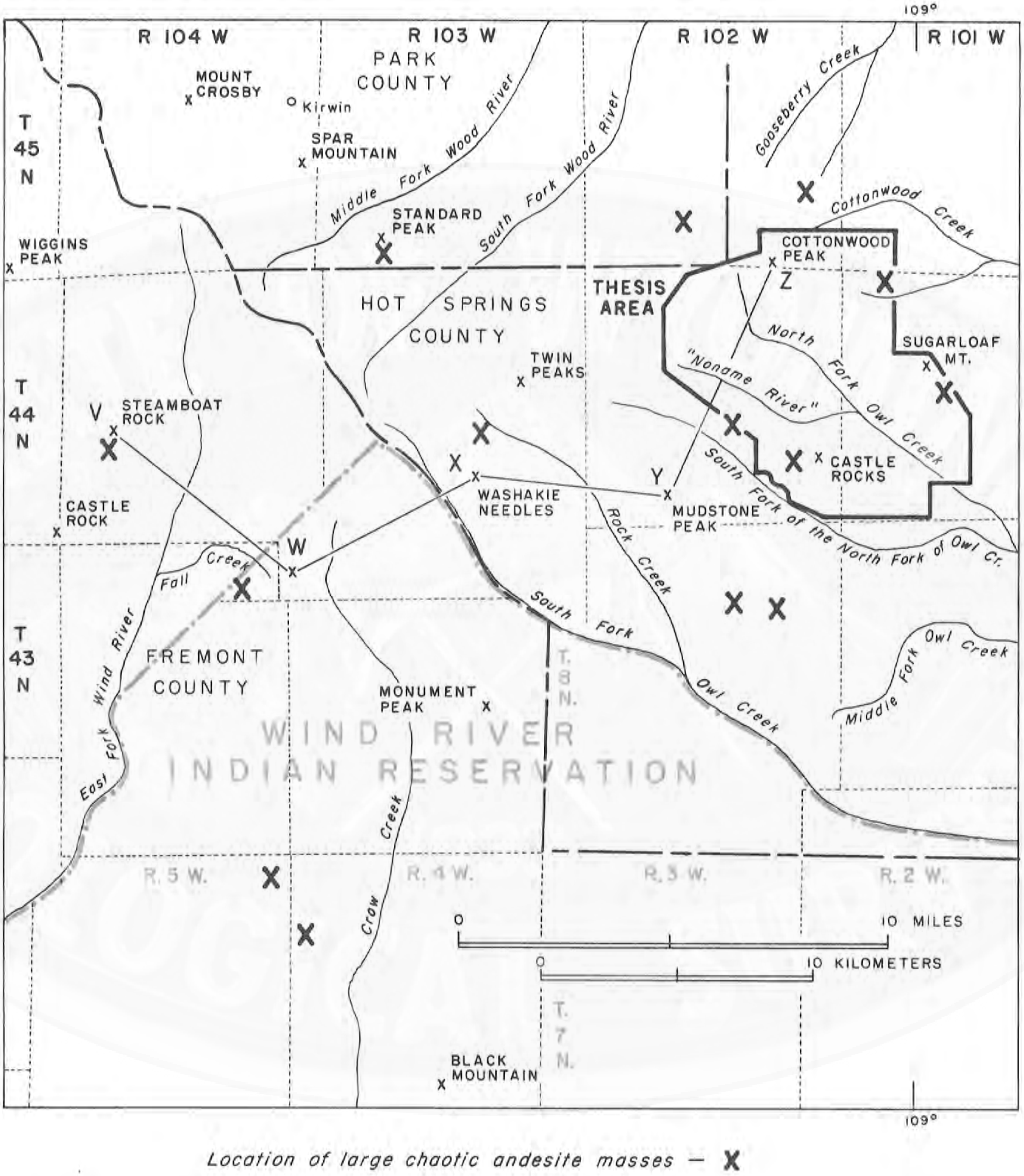

Figure 20. Regional map showing the possible distribution of the Castle Rocks chaos. See Figure 26, page 34, for sections V, W, X, Y, and Z.

Figure 21. Large andesite blocks in the Castle Rocks chaos (sec. 17, T.44N., R.101W.).

Lithology

The Castle Rocks chaos contains rock types foreign to the study area as well as material incorporated from local underlying units. Foreign material is mostly distinctive, reddish-brown, hornblende andesite in a heterogeneous, unsorted, tuffaceous matrix. The andesite occurs as angular to subangular cobbles, boulders, large blocks, and gigantic, contorted masses, transported in the finer-grained matrix (Figure 21).

Locally incorporated material is rounded to subangular pebbles, cobbles, and boulders of various andesites, dacites, and minor rhyolite in a fine-grained, heterogeneous, tuffaceous and lithic clast matrix. This material was derived from volcanic sandstones and conglomerates in lower Wiggins and allochthonous Wiggins strata. The Castle Rocks chaos matrix also includes abundant carbonized wood fragments and large carbonized tree trunks. The matrix composition changes by mixing with underlying local material; apparently, the overriding foreign chaos material mobilized and incorporated poorly lithified underlying Wiggins sediments into the moving mass. The inclusion of the exotic andesite blocks in an unsorted, heterogeneous matrix is the primary key to recognition of the Castle Rocks chaos.

Structural and depositional features

Shape. Overall, the Castle Rocks chaos deposit is an irregular, tabular body, 1,000 feet thick (Figure 22), which thickens to the west and southwest. A 1,000-feet-thick, U-shaped band of chaos trends east-west through secs. 1, 2, 3, and 10, T.44N., R.102W. (C2 on Plate II) and probably fills a paleovalley. The lenses and pods of chaos andesite between the upper and lower Wiggins in the northern part of the area are, in my opinion, remnants of an initially continuous sheet.

Basal contact. The basal contact of the Castle Rocks chaos is topographically very irregular; its relief can vary more than 1,300 feet in less

Figure 22. Tabular shape of the Castle Rocks chaos (sec. 21, T.44N., R.102W.).

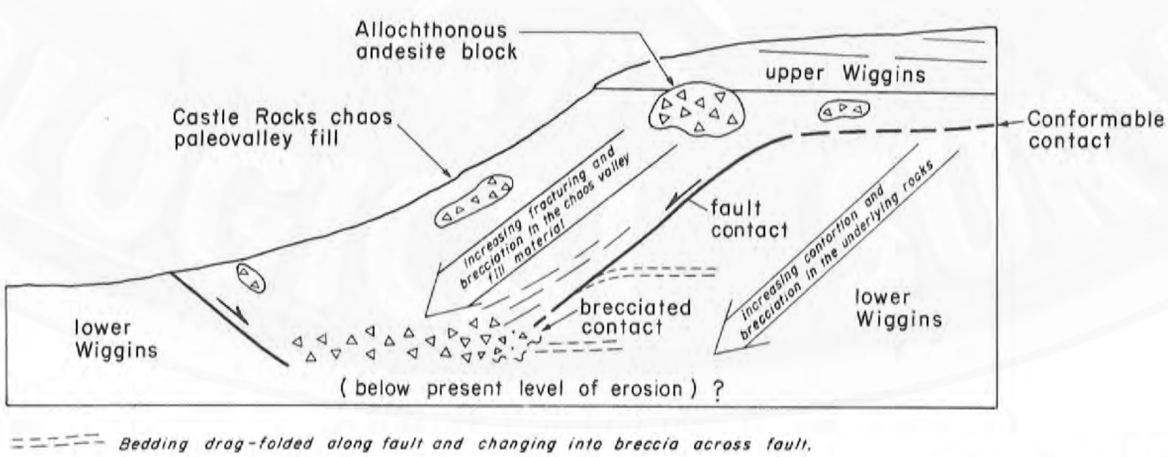

Figure 23. Structural and depositional contacts along the Castle Rocks chaos paleovalley fill (along C2, Plate II).

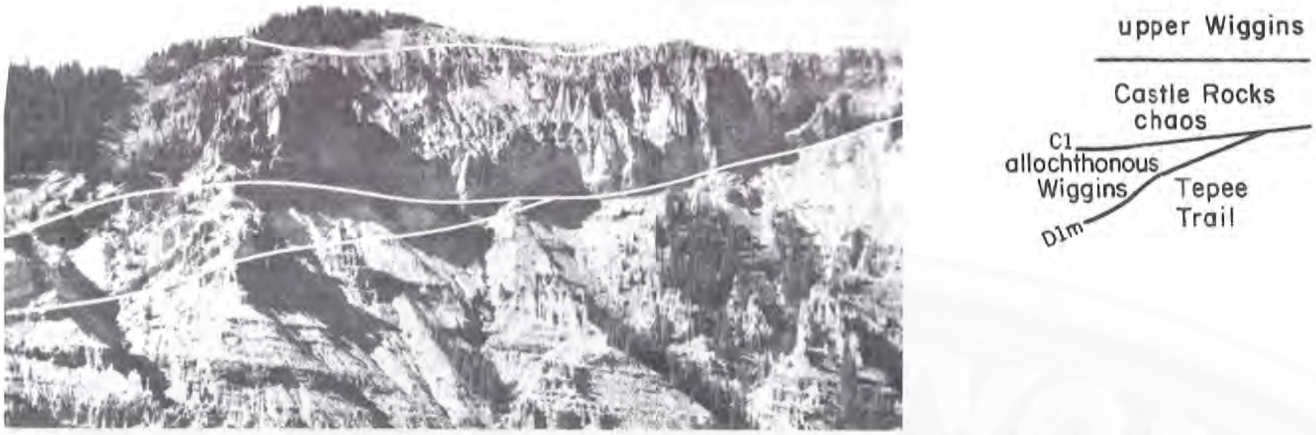

Figure 24. A slice of allochthonous Wiggins strata along the Castle Rocks chaos basal contact (N½ sec. 7, T.44N., R.101W.).

than 3,000 feet (Figure 22). Basal fault contacts are common: low-angle reverse, horizontal, low-angle normal, and moderate-angle normal. The fault contacts commonly occur beneath large, resistant blocks and masses of allochthonous andesite. Evidence of faulting is absent where the basal chaos is composed largely of soft matrix. A gradational contact, which shows increasing deformation between underlying Wiggins and totally unsorted, locally derived chaos material, occurs in secs. 15 and 16, T.44N., R.102W. A sharp depositional contact may also develop between soft chaos matrix and underlying strata. The basal contact of the chaos along the paleovalley in secs. 1, 2, 9, and 12, T.44N., R.102W. appears to grade from structural to depositional (from a fault to a laharic breccia contact) (Figure 23).

Upper contact. The upper contact, an unconformable depositional contact with the overlying Wiggins (Figure 22), is generally an easily traced planar surface dipping gently toward the east and northeast. Resistant andesite blocks locally form topographically higher bumps in the upper contact.

Structural features within the Castle Rocks chaos. Grooved and slickensided contacts are common along the bottom and sides of allochthonous andesite blocks in the chaos matrix. Abundant folding, fracturing, brecciation, and contortion of primary volcanic strata were observed within the allochthonous andesite blocks, but such primary deformation is absent in surrounding chaos matrix. The largest allochthonous masses remain right side up, but smaller blocks of allochthonous material and of locally derived material and petrified trees are randomly rotated within the matrix. Local minor fracutring and brecciation increase towards the basal contact of the chaos.

Structural features beneath the Castle Rocks chaos. Evidence of drag folding of underlying strata occurs locally, but seldom affects beds more than 50 feet below a structural contact. Minor faulting also occurs beneath structural contacts, decreasing in density and intensity away from the contact. Small slices of intensely fractured allochthonous Wiggins occur directly beneath the Castle Rocks chaos (Dlm-q, Plate II and Figure 24). A brecciation of underlying strata, which shows a gradation upward into typical chaos material, can also be observed locally (Figure 25). All types of deformation beneath structural contacts die out at depth; usually, no deformation was observed in rocks beneath depositional

Figure 25. Brecciation of strata beneath the Castle Rocks chaos (NW¼ sec. 6, T.44N., R.101W.).

contacts.

Source

The source of the Castle Rocks chaos is to the west or northwest, as inferred from slickenside data from the bottoms of large andesite masses (Plate II). Reconnaissance field mapping, petrographic comparisons, general stratigraphic and regional location, and discussions with W.H. Wilson, suggest that the basal sequence of andesite flows on Standard Peak may be the source of the distinctive hornblende andesite blocks in the Castle Rocks chaos (Figure 20). If so, horizontal movement of 15 miles is indicated.

Mode of emplacement

As inferred from data from a small part of the total area covered by the Castle Rocks chaos, it began as a large gravity detachment mass near topographically higher vent sources to the northwest. The original detachment contained primary hornblende andesite flows which broke into many smaller blocks during transportation. As the detached masses progressed, they incorporated underlying poorly lithified, tuffaceous sediments which then formed the matrix, engulfing the blocks. The matrix-rich Castle Rocks chaos then continued to move by both gravity sliding and viscous flow. The large, allochthonous andesite blocks rafted and slid within an unsorted, cold, laharic breccia matrix.

Time of emplacement

The time of emplacement is restricted to the middle or possibly late Eocene by the presence of Uintan fossil mammals in the underlying Tepee Trail and overlying upper Wiggins Formations.

Stratigraphic significance

The Castle Rocks chaos was emplaced during a major erosional episode between deposition of the lower and upper Wiggins members, after emplacement of allochthonous Wiggins masses. The Castle Rocks chaos is interpreted as a rapid, single event of large-scale mass-gravity movement. If the other large masses of contorted andesite, observed throughout a 400-square-mile area, were emplaced during the same event, then the Castle Rocks chaos represents a regional time-stratigraphic rock unit and is a valuable marker bed. If it is a continuous time-stratigraphic rock unit between the East Fork Basin and the North Fork of Owl Creek, then the measured Wiggins section on Castle Rock (Love, 1939) should be stratigraphically equivalent and closely time equivalent to the lower Wiggins in the study area (Figure 26).

Future investigations of the Castle Rocks chaos should be directed toward: (1) mapping its regional extent, (2) finding or confirming its source (Standard Peak?), (3) understanding the mechanisms of its emplacement, and (4) understanding its regional stratigraphic significance.

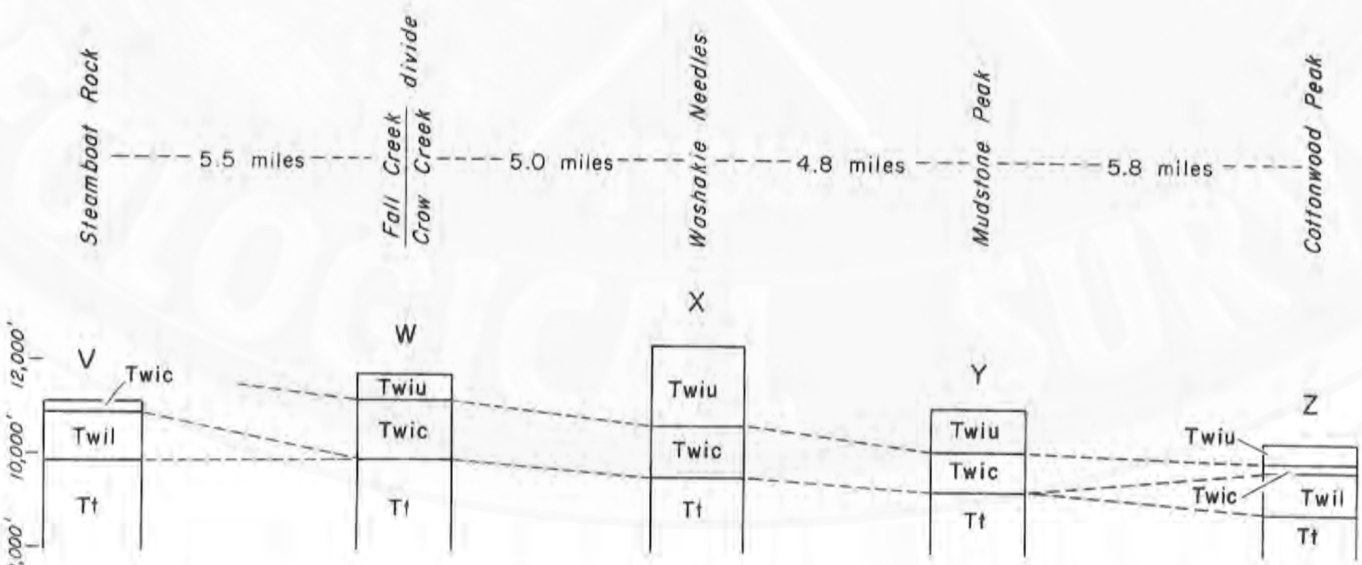

Figure 26. Regional correlation of the Wiggins Formation. The location of the line of section VWXYZ is plotted on Figure 20 (page 29). Tepee Trail Formation (Tt), lower Wiggins (Twil), Castle Rocks chaos (Twic), and upper Wiggins (Twiu).

PETROLOGY

Since in-place volcanic flows were not found in the study area, reworked clasts within volcanic sandstones, conglomerates, and breccias were used to determine the primary volcanic source rocks and for lithologic correlation.

Felsic to basic andesite predominates, with minor rhyolite and basalt (Table III). The cementing matrix, composed of crystals, lithic fragments, and tuff, has largely been altered to montmorillonite, mixed layer chlorite, and minor illite. Alteration generally decreases upward in the section. No zeolites were recognized in any of the thin sections or in the few X-ray diffractograms of volcaniclastic material that were made.

Petrologic features of the volcaniclastic rocks, in stratigraphic order from oldest to youngest, are as follows:

The Aycross Formation was not studied in detail. Andesitic, dacitic, and basaltic material were observed. The basaltic material commonly occurs as large blocks of pyroxene basalt (Table III). Similar basalt blocks were mapped by Masursky (1952) and Wilson (1970) more than 20 miles away.

The Tepee Trail Formation contains predominantly diverse andesitic material. Rare dacitic and basaltic clasts are reworked into the lower Tepee Trail. Secondary silicification of conglomerates and chalcedony veining are common.

The lower Wiggins contains generally more acidic andesite than the Tepee Trail. Secondary quartz is common in the rock fragments but is insignificant in the matrix.

The Sugar Loaf tuff beds are an important lithologic marker in the allochthonous Wiggins strata. Their distinctive rhyolite fragments are easily recognized in the field by their light color, hardness, and distinctive laminar flow banding. The rhyolite fragments are generally angular, but have become rounded by reworking into younger strata. Identical rhyolite clasts were observed throughout a surrounding 60-square-mile area.

The Castle Rocks chaos contains allochthonous blocks of very distinctive hornblende andesite. The hornblende generally has a reddish-brown color and extensive corrosion borders, and composes more than 25 percent of the andesite. Biotite, hypersthene, and augite occur rarely in the hornblende andesite. Five thin-sections of hornblende andesite from the lower sequence of flows on Standard Peak 6 miles to the northwest were virtually identical to thin-sections of andesite from the Castle Rocks chaos.

The upper Wiggins contains largely acidic andesite, dacite, and reworked clasts of the Sugar Loaf tuff rhyolite.

CONCLUSIONS

(1) The volcaniclastic rocks were derived from a diverse assemblage of acidic to basic andesite with locally important basalt and rhyolite.

(2) The sources of volcanic material are located northwest of the study area.

(3) Distinctive rock types have been reworked throughout younger overlying strata.

(4) Basalt blocks in the Aycross Formation, rhyolite clasts in the Sugar Loaf tuff beds, and distinctive hornblende andesite in the Castle Rocks chaos can be used as markers within the volcaniclastic sequence.

Table III. Petrography of rock fragments in volcaniclastic rocks.

Rock unit	Number*	Rock fragments: Composition	Texture: Phenocrysts	Texture: Groundmass	Minerals present	Rock types present
upper Wiggins	3,12	andesitic	seriate porphyritic	pilotaxitic	pl(An52-55), sa, ag, hy, hb, bi, mt	bi-hb-hy-and, hb-and, hb-ag-and, ag-and, bi-bh-and
		dacitic	porphyritic	felsitic	pl(An32-41) sa, q, hb, bi, mt	dacite
		rhyolitic	(Same as Sugar Loaf tuff beds)			
Castle Rocks chaos	5,18	andesitic	seriate porphyritic	pilotaxitic	pl(An33-52), hb, bi, mt	hb-and
		rhyolitic	(Same as Sugar Loaf tuff beds)			
Sugar Loaf tuff beds	4,2	rhyolitic	none-porphyritic	fluidal cryptofelsitic	pl(An30-37), sa, q, bi, hb, mt	rhyolite
lower Wiggins	4,5	ande sitic	seriate porphyritic	felted pilotaxitic	pl(An32-41), sa, hy, ag, hb, bi, mt	bi-hb-and, hy-hb-and, hb-and, ag-and
Tepee Trail	9,3	andesitic	seriate porphyritic	felted to pilotaxitic	pl(An40-55), sa, hy, ag, pi?, hb, bi, mt	bi-hb-and, hy-hb-and, ag-hb-and, ag-hy-and, pi?-ag-hy-and, bi-hb-ag-and
Aycross	0,3	basaltic	porphyritic	pilotaxitic to intergranular	pl(An50-59), ag, hy, mt, ca, ol?	pyroxene basalt

hb - hornblende
bi - biotite
ca - calcite
mt - magnetite

and - andesite
pl - plagioclase
An - plagioclase composition
sa - sanidine

ag - augite
hy - hypersthene
pi - pigeonite
ol - olivine
q - quartz

*Number of thin sections (matrix, clasts).

PALEONTOLOGY

Fossil mammals, invertebrates, and plant material occur within the volcaniclastic sequence of the Absaroka Range in the North Fork of Owl Creek (Figure 27; also see Appendix A in Sundell, 1980).

MAMMALS

Vertebrate fossils were collected by J. Eaton, G. Winterfeld, J. Conard, M. Bertolino, D. Cargil, and the author during the 1977-79 field seasons. Tentative faunal lists of these fossils and their stratigraphic implications are presented by Eaton (1980). Most of the fossils were collected from middle Aycross, lower Holy City, Foggy Day, and upper Wiggins strata. Vertebrate fossils occurred most frequently in volcanic sandstones and siltstones as isolated teeth and bone fragments, but partial skulls and jaws were occasionally preserved.

Preferential preservation of vertebrate fossil material was apparently locally controlled by both environment of deposition and effects of diagenesis. Fine-grained siltstones, claystones, and limestones in the Aycross, lower Tepee Trail, and Holy City beds commonly preserved delicate micromammal bones and teeth, while coarser sandstones, conglomerates, and breccias in the Foggy Day and upper Tepee Trail strata contained predominantly broken and, sometimes, rounded fragments of large mammal bones and jaws. The complete left upper tooth row of a large titanothere was found relatively undisturbed at the Invisible Skull locality (V79026; see Figure 27). No bone was present to hold the teeth in place. This suggests that all the bone was preferentially removed by a diagenetic process after burial of the skull.

INVERTEBRATES

Abundant invertebrate fragments and a few complete freshwater gastropods and pelecypods were observed within thin limestone lenses in the lower Holy City beds. The limestones are well exposed 150 feet below the major hilltop located in SE$\frac{1}{4}$ sec. 4, T.43N., R.101W., and locally contain mixed vertebrate fossils and invertebrate remains. The invertebrate assemblage is unstudied to date.

PLANT MATERIAL

Fossil wood, leaves, and other plant material are found throughout the volcaniclastic sequence. The Aycross contains locally abundant plant material and several thin carbonaceous beds. Both agatized and carbonized wood are found in the formation. The Tepee Trail Formation contains abundant plant material at the base, but a decrease in plant material appears to accompany a general increase in grain size upsection, both caused by a changing environment of deposition. Excellent leaf localities at the bases of the lower Tepee Trail and Holy City beds in SE$\frac{1}{4}$ sec. 4, T.43N., R.101W. remain unstudied.

Agatized wood was not observed in the Tepee Trail Formation, but the upper Wiggins contains predominantly agatized and opalized wood. The underlying Castle Rocks chaos contains disoriented, large carbonized tree trunks and locally small, disturbed masses of carbonaceous plant material. Dr. N. Fredricksen (U.S. Geological Survey, Reston, VA) is currently working on pollen samples from the area, and Dr. E. Wheeler (North Carolina State University) is studying the fossil wood.

Mammal Age	Formation	Local subdivision and thickness	Paleontology	University of Wyoming locality numbers
Uintan	Wiggins	upper Wiggins 1,000 feet	V Wa Wo V	V-78044-45 V-77026 V-78020-21
		Castle Rocks chaos 1,500 feet	Wc,P	V-79004,20
		allochthonous Wiggins 1,000 feet		
		lower Wiggins 1,000 feet	V V	V-79026 V-78018
		· ? · ? ·		
	Tepee Trail	upper Tepee Trail 600 feet	V	V-78011,34
		Foggy Day beds 700 feet	V V V	V-78003,05,17,30 V-77022-23,25 V-78007 V-79023,24
		Holy City beds 800 feet	V V,I,L	V-78024 V-78004 V-79022
··?··		lower Tepee Trail 400 feet	V Wc P,L	V-78013
Bridgerian	Aycross	· ? · ? · Aycross 1,000 feet	V,WA V P Wc Ir	V-78022,41 V-77052

EXPLANATION

depositional contact	———
uncertain contact	· ? · ? ·
unconformity	～～～
fossil mammals	V
plant material undivided (pollen, leaves, wood)	P
carbonaceous wood	Wc
agatized wood	Wa
opalized wood	Wo
fossil leaves	L
invertebrates (gastropods & pelecypods)	I
reworked invertebrates (from Paleozoic formations)	Ir

Figure 27. Stratigraphic and paleontologic composite section.

SUMMARY OF CENOZOIC EVENTS

The author has determined the following depositional, erosional, and tectonic events solely from the geology within the study area. Cenozoic events not represented in the study area are not considered. From oldest to youngest events:

(1) At least 1,000 feet of the Aycross were deposited during the middle Eocene (based on the occurrence of Bridgerian fossil mammals within the sequence).

(2) Local volcanic activity occurred during deposition of the upper Aycross (based on the presence of large, angular basalt blocks).

(3) 2,500 feet of the Tepee Trail Formation were deposited during the middle and possibly late Eocene (based on the occurrence of dominantly Bridgerian fossil mammals in the lower Tepee Trail and dominantly Uintan fossil mammals in the middle and upper Tepee Trail).

(4) More than 1,000 feet of the lower Wiggins were deposited during the late middle or late Eocene (based on Uintan fossil mammals).

(5) A significant period of tectonism and related erosion, which exposed at least 2,500 feet of underlying strata, occurred after deposition of the lower Wiggins.

(6) Folding preceded or was contemporaneous with faulting, and N1 faults developed before N2 and N3 faults.

(7) Large masses of allochthonous Wiggins were emplaced on a paleoerosion surface, burying N2 and N3 faults.

(8) Minor movement along the N2 faults may have occurred after emplacement of the allochthonous Wiggins.

(9) After emplacement of the allochthonous Wiggins masses, the Castle Rocks chaos was emplaced on a paleotopography with at least 1,500 feet of relief.

(10) An episode of erosion planated the upper surface of the Castle Rocks chaos and left resistant andesite blocks as erosional remnants.

(11) More than 1,000 feet of upper Wiggins, with Uintan fossil mammals at the base, were deposited during the late or middle Eocene.

(12) The area was epeirogenically uplifted after deposition of the upper Wiggins.

(13) The N4 faults developed after deposition of the upper Wiggins (but their relationship to epeirogenic uplift is uncertain).

(14) The present erosion cycle probably began with epeirogenic uplift.

(15) Thin deposits of poorly consolidated alluvial and colluvial material were deposited during the Quaternary along the present stream valleys.

(16) Abundant mass movements, including large slump blocks (N6), developed during the present erosion cycle — but some of these blocks may represent recently exhumed features that were formed by erosional and tectonic events during the Eocene.

GEOMORPHOLOGY AND RELATED GEOLOGIC HAZARDS

Previous and ongoing fluvial, weathering, eolian, glacial, and mass-gravity processes have sculpted abundant, diverse landforms from the easily eroded volcaniclastic terrain. The following summary of these dominantly erosive local landforms and processes is condensed from Sundell, 1980. Several mass gravity movements are discussed in detail because they have created potential geologic hazard sites.

Figure 28. Flutes and solution pans developed in the Upper Wiggins (SE¼ sec. 1, T.44N., R.102W.).

LANDFORMS OF FLUVIAL, WEATHERING, AND EOLIAN PROCESSES

The high relief, steep slopes, v-shaped valleys, small flood plains, waterfalls, and abundant cliffs throughout the area indicate a youthful stage of geomorphic development. Alluvial fans, terraces, structural benches, abandoned valleys, and subparallel, dendritic, and angular stream patterns are also locally important fluvial features.

Weathering processes create flutes, rills, and solution pans on resistant rock outcrops (Figure 28). Impressive and rugged badlands with steep cliffs, abundant waterfalls, hoodoos, and spires form on unvegetated, easily eroded slopes.

Eolian processes form small blowout pans in fine-grained, poorly consolidated material on well-exposed ridges and contribute significantly to slope erosion in unvegetated areas.

Although evidence of glacial activity exists in adjacent drainages (Sundell, 1980; Breckenridge, 1974; Wilson, 1964), more recent fluvial and mass-gravity processes have buried or destroyed such evidence in the study area. See Landforms of Glacial Processes, below.

LANDFORMS OF MASS-GRAVITY PROCESSES

Mass-gravity movements occur throughout the Absaroka Range (Love, 1939; Keefer, 1957; Wilson, 1964; Pierce, 1968; Breckenridge, 1974; Love and Keefer, 1975; Bown, in press), and evidence of slow flowage, rapid flowage, and landslides is present in the study area. Locally, mudflows, debris avalanches, earthflows, and landslides pose serious geologic hazards. Developers should be aware of these problems and use the following information (and Plate V in Sundell, 1980) to avoid or minimize disturbance or development of hazardous areas.

Figure 29. Earthflow at the Tepee Trail-Aycross contact (E½ sec. 5, T.43N., R.101W.).

Flow Phenomena

Slow flowage locally produces curved tree trunks, hummocky sod, contorted bedding, terracettes, solifluction lobes, and stone nets by soil creep, talus creep, rock creep, and frost controlled processes.

Rapid flowage features include small mudflows in unvegetated badlands areas and debris avalanche scars in gulleys and heavily vegetated areas near timberline. Although no recent mudflow deposits were recognized, the easily eroded volcaniclastic material and moderate to steep slopes combined with extensive defoliation and heavy rainfalls are ideal conditions for disasterous mudflows.

Earthflows

Earthflows are well developed wherever plastically deforming, bentonitic claystone beds in the Aycross Formation are exposed in the study area (Figure 29). Earthflows covering from 100 square feet to over one square mile were observed. The smaller earthflows occur on north-facing slopes below small exposures of bentonitic claystones or as separate episodes of larger mass movements. A complete gradation from soil creep through earthflow to mudflow, reflecting increasing water content of the flow material, was observed.

Some larger earthflows, derived from the upper Aycross, flow for miles down gentle slopes. Most outcrops of the upper Aycross in the South Fork of the North Fork of Owl Creek are undergoing slow flow characterized by hummocky terrain, jumbled stratigraphy, deformed vegetation, ponded areas, and furrows and ridges aligned with the direction of flow. A recent, rapid earthflow, located in the southeast corner of sec. 29 T.44N., R.101W., advanced hundreds of feet over slower earthflows, left a U-shaped channel behind it, and incorporated vegetation into the flow. Earthflows directly related to landsliding are discussed below.

Landslide Phenomena

Rockslides

Rockslides on a small scale are ubiquitous, but large rockslides are concentrated along the contact between the Tepee Trail and Aycross Formations. Large-scale rockslides associated with slumping and earthflows have produced several spectacular mass-movement areas (Figure 30). Slow earthflow in the upper Aycross Formation beneath the base of the Tepee Trail Formation commonly triggers landsliding: plastically deforming bentonite beds in the upper Aycross are believed to squeeze out like toothpaste, undermining the overlying Tepee Trail basal section (Figure 31). Loss of supporting material from under the Tepee Trail Formation helps form potential slide masses by producing tensional stresses and fractures in these coherent, brittle rocks.

A lubrication zone is also present at the contact of the Tepee Trail with the Aycross Formation. Sandstone in the Tepee Trail Formation allows downward percolation of water which concentrates along the impermeable top of the Aycross section. Abundant springs mark this contact. Water-saturated clays and bentonites in the upper Aycross Formation produce the lubrication zone beneath the structurally unstable Tepee Trail lower erosional contact.

Slow flow continues in the Aycross Formation, and large blocks of Tepee Trail sandstone periodically slump, crumble, and disintegrate into rockslides of large boulders in a fine, sandy matrix; this material, derived from the Tepee Trail sandstones, rides upon, and is incorporated into, the slower earthflows. The contact between the Tepee Trail and Aycross Formations may be roughly mapped on air photos by the presence of ongoing mass movements. The largest recent rock slide, with other associated mass movements, covers most of sec. 4, T.43N., R.101W. Episodes of rocksliding are documented by sequential changes in vegetation growth within a large area of mass movement.

Slumps

Slumps occur in several situations other than those which produce rockslides. Most earthflows in well-vegetated terrain grade into slumping at the source. A classic slump developing along the North Fork of Owl Creek (NE$\frac{1}{4}$ sec. 11, T.43N., R.101W.) exhibits backwards rotation of the main block, a spoon-shaped slip plane, a fresh headward scarp cutting terrace gravels, and gradation into a earthflow at the toe (Figure 32). Landis Webber, owner of the Red Creek Ranch, noted the initial movement in 1971 and has observed gradual changes in exterior morphology since then. Numerous older slump remnants exist along the southeast valley wall of the North Fork of Owl Creek.

Large-scale slumping which occurred during the Pleistocene or the Eocene involved extremely large blocks (up to 1,000 feet on an edge) of coherent Tepee Trail lithology (see N6 faults, Plate II). The blocks show backwards rotation and slip planes dipping towards the toe of the block as well as minor folding and fracturing within each block. Since most of the slump blocks lie along the Tepee Trail and Aycross contact, I presume that they formed under conditions similar to those producing previously described landslides. However, the slump blocks are much larger, and remained coherent blocks after movement; moreover, some developed within middle and lower Tepee Trail rocks, above the observed lubrication zone.

Although recent small-scale movements are common along the margins of

Figure 30. Rockslide in the lower Tepee Trail (SE¼ sec. 36, T.44N., R.102W.).

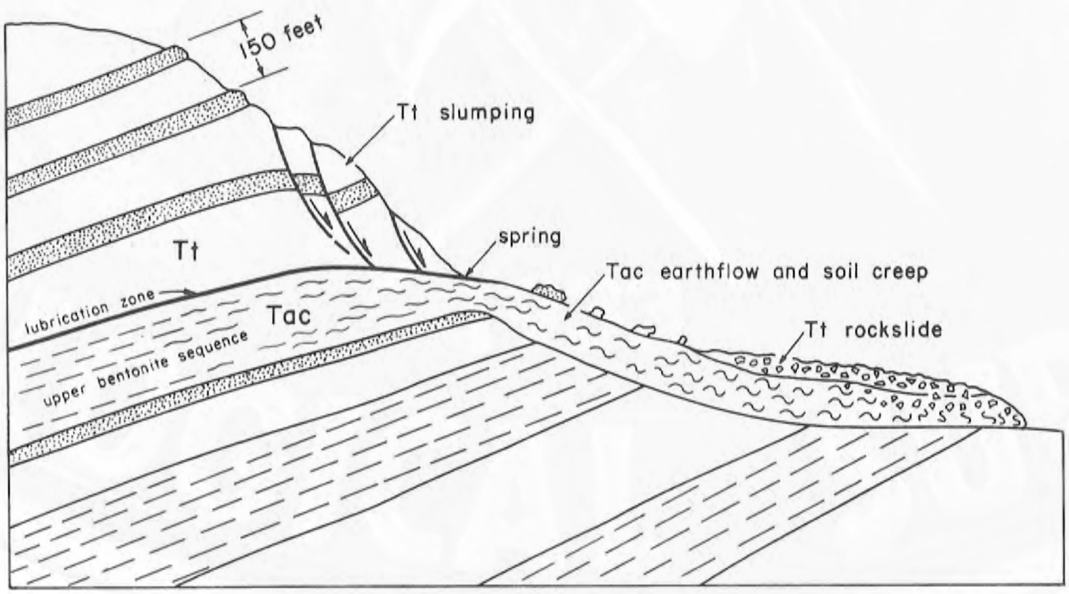

Figure 31. Schematic cross section of mass movements developed along the contact between the Tepee Trail (Tt) and Aycross (Tac) Formations.

Figure 32. Slump and earthflow along the North Fork of Owl Creek (NW¼ sec. 11, T.43N., R.101W.).

slump blocks, there is no evidence of recent movement of the large blocks. Rapid erosion and active mass wasting have obscured evidence of Pleistocene movement. The large slump blocks may have formed during regional faulting and slump-block development in the Eocene. Reactivation of Eocene slump blocks during the Quaternary is also possible. Extremely detailed field work and absolute age dating might solve this time problem.

LANDFORMS OF GLACIAL PROCESSES

Glacial processes were active in the southeastern Absaroka Range during the Quaternary (Wilson, 1964; Breckenridge, 1974), but no definite glacial features were found within the study area. No moraines were recognized, but fluvial erosion and the very active mass gravity movements may have destroyed or buried such features. The straight valleys, which are not U-shaped in cross section, were probably structurally controlled.

Adjacent areas do have evidence of glaciation. The Wood River drainages bordering the Owl Creeks on the northwest have well developed cirques, U-shaped and straightened valleys, and some permanent icefields (Wilson, 1964; Breckenridge, 1974). The head of Rock Creek (in the South Fork of Owl Creek drainage), located directly west of the

South Fork of the North Fork of Owl Creek, has a U-shaped straightened valley, hanging tributary valleys, striated bedrock and boulders, and other glacial features.

The preservation of glacial features in the South Fork of Owl Creek and destruction of equivalent features in the North Fork of Owl Creek may reflect different rates of erosion. Erosion by the South Fork of Owl Creek was impeded by its superposition into resistant Paleozoic and Precambrian rocks, whereas the North Fork of Owl Creek cut softer, easily eroded Tertiary rocks. The excellent terrace sequence observed further down the North Fork of Owl Creek may reflect interglacial episodes (Blackwelder, 1915). Thus, the North Fork of Owl Creek could have been glaciated, but no evidence has survived later erosion and mass movements.

ECONOMIC GEOLOGY

Oil and gas are of primary economic concern in the study area. Coal, bentonite, gold and radioactive minerals are also of interest.

OIL, GAS, AND COAL

Significant oil and gas deposits remain undiscovered in the southwestern Bighorn Basin beneath the Absaroka Range. Only minor carbonized wood and a few thin (less than 15 inches thick) shaley coals (30-80 volume percent coal) and carbonaceous shales were observed within the Tepee Trail and Aycross Formations in the study area. Minor dry gas may be associated with these organic-rich beds, but the inferred immaturity and general lack of organics suggest that economic deposits of oil and gas have not been generated within the volcanic sequence. However, the underlying Mesozoic and Paleozoic sections contain abundant oil and gas in the adjacent Wind River and Bighorn Basins. Hamilton Dome and Grass Creek, major oil and gas fields in Wyoming, lie 20 miles to the east and northeast of the study area, along the margin of the Absaroka volcaniclastic rocks (Figure 1). Production in the two fields has been recorded from ten different sands and formations, including the Frontier, Darwin, Chugwater, Crow Mountain, Embar, Tensleep Phosphoria, Madison, and Bighorn. Total production from these two fields is nearly 400 million barrels of oil and 7 trillion cubic feet of natural gas.

All of the Paleozoic section and part of the Mesozoic section should underlie the study area. The amount of Mesozoic rocks present is not exactly known, but recent wells drilled two miles east of the study area in secs. 14 and 23, T.44N., R.101W. entered the Frontier Formation beneath the volcanic rocks. An angular unconformity is present between the Mesozoic strata and the overlying Willwood Formation (if present) or the bentonitic Aycross Formation. These formations should provide an impermeable caprock and tectonism, which possibly caused hydrocarbon migration, did occur in the study area after deposition of the Aycross Formation. The determination of the relationship between structures in the volcaniclastic sequence and those in the underlying rocks requires further regional mapping. In my opinion, most structures in the volcaniclastics formed during volcanism to the west and northwest, but some indirectly reflect previous structures in the underlying Mesozoic and Paleozoic rocks.

The development and testing of seismic techniques capable of filtering out or "seeing through" the overlying volcanic rocks will probably be instrumental in the search for oil and gas beneath the Absaroka Range. Unfortunately, rugged topography, complex surface structures, complex stratigraphic relations, and poorly known velocities in the volcanic rocks will complicate seismic interpretation. Foreseeable structural problems may include the general complexity of faulting, recognition of detached masses, and determining the relationship between structures in the volcanic rocks and those in the underlying Mesozoic and Paleozoic rocks. Foreseeable stratigraphic problems may include recognition of the major volcanic-nonvolcanic unconformity, lateral variations in lithology within the volcaniclastic rocks, and the effects bentonites in the Aycross Formation and thick well-cemented conglomerate and breccia lenses in the Tepee Trail and Wiggins Formations will have on velocity profiles of the volcanic rocks.

Oil explorationists have had to consider wildcat drilling, relatively shallow wells (1,500 to 8,000 feet deep), low pressures, hydrogen sulfide, and low gravity oil. Shallow test holes on top of the Castle Rocks horst and in SE$\frac{1}{4}$ sec. 11, T.44N., R.102W. would disclose the stratigraphic sequence and structural orientation of the underlying Mesozoic and Paleozoic formations and provide control for seismic surveys that might lead to significant oil discoveries in the region.

Although there is no evidence of minable coal in the exposed rocks of the study area, upper Cretaceous rocks do contain economically valuable coal in the adjacent Bighorn and Wind River basins, and coal has been mined from the Mesaverde Formation 10 miles to the east. If Mesaverde Formation rocks underlie the study area as well, they probably contain coal. The economic value of any coal beneath the Absaroka Range, however, would be significantly diminished by it remoteness and depth of burial.

BENTONITE

Thick sequences of interbedded bentonite and bentonitic siltstone and claystone are present in the Aycross Formation throughout the North Fork of Owl Creek area. X-ray diffractograms of several samples from the uppermost Aycross show montmorillonite as the primary clay mineral. Several thin beds 3 feet thick contain readily suspendable clays, but minor lithic fragments compose 1-3 percent of the sample. However, the samples were taken at shallow depth (1 foot) and the lithic fragments were very heterogeneous, so the samples may have been nonrepresentative or contaminated. These bentonite beds and others throughout the Aycross Formation warrant detailed study to determine their possible commercial use. The bentonite could at least be used locally for ditch lining material.

GOLD

Gold was reported in the head of the Owl Creek drainage by Osterwald et al. (1966). However, the many pan concentrates taken by the author thoughout the headwaters of the North and South Forks of Owl Creek contained no visible gold. Large areas of iron-stained andesites, locally abundant in the Castle Rocks chaos, were the most promising source areas, but samples of the brecciated, silicified, and pyritized material analyzed by the U.S. Geological Survey contained no significant amount of gold (data from J.D. Love, 1980, personal communication).

The Absarokas are probably not the source of the gold found in terraces along the lower Owl Creeks. Areas of Precambrian rocks in the Owl Creek

Mountains which drain into the lower Owl Creeks are a more likely source.

RADIOACTIVE MINERALS

Radioactive minerals were not prospected for in detail, but some data were obtained by foot traverse with a scintillometer held at waist height. Counts per second above thick orthoconglomerates in the Wiggins and Tepee Trail Formations were double the background values. No significant increase in radioactivity was observed above the andesites or the iron-stained areas in the Castle Rocks chaos. Thin beds of carbonaceous plant material (15 inches thick) in the Aycross Formation showed readings three to four times background values. No pan concentrates from the North and South Forks of Owl Creek showed significant enrichment in radioactive minerals.

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

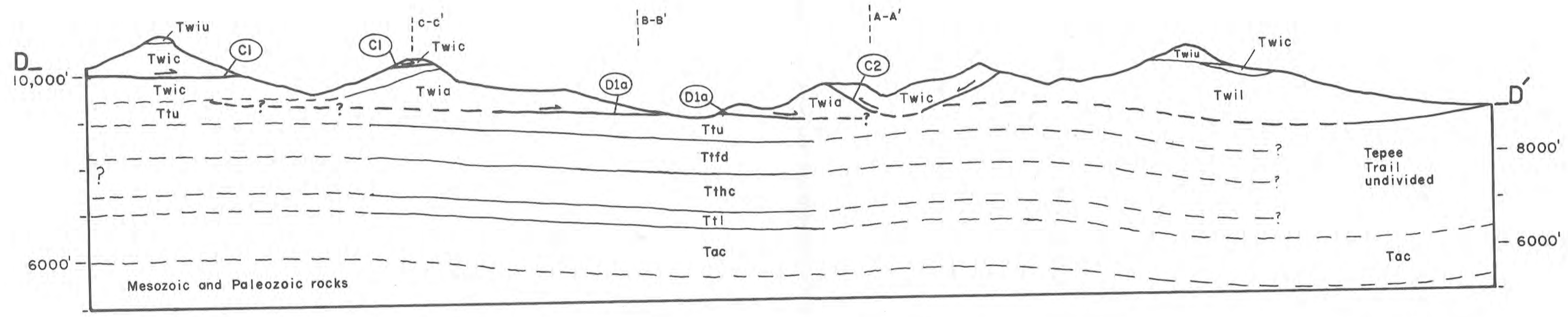
GEOLOGIC CROSS SECTIONS D-F
HEADWATER AREA OF THE NORTH FORK OF OWL CREEK
Hot Springs County, Wyoming

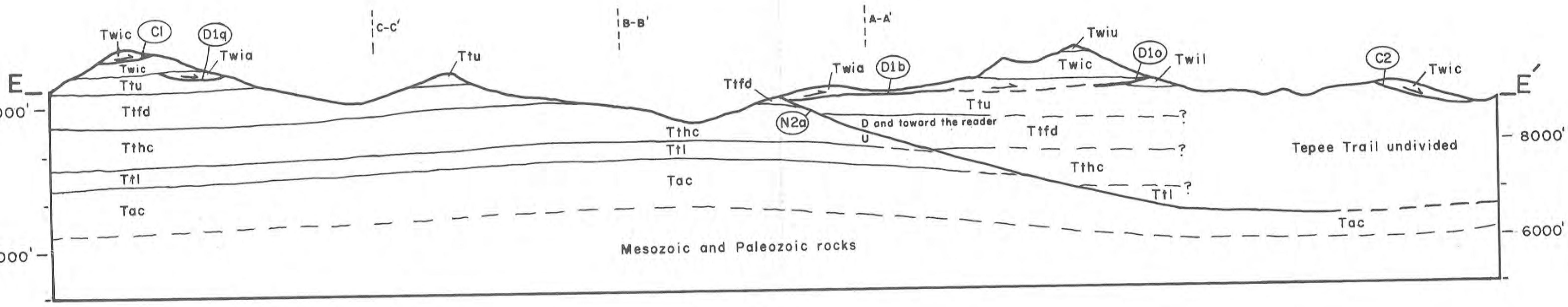
by Kent A. Sundell

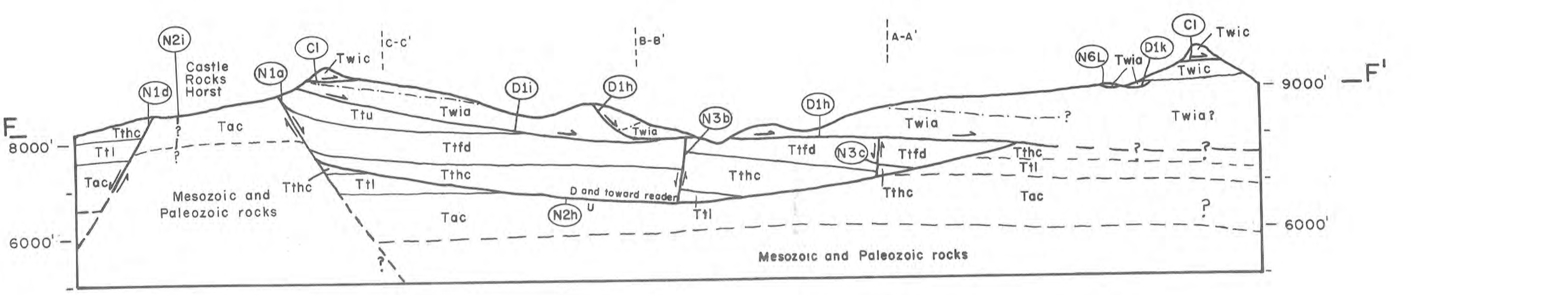
SCALE 1:24,000

1 0 1 mile

1 0 1 km.







Lines of section are on Plates I and II

An arrow along a fault indicates a component of motion.

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

GEOLOGIC CROSS SECTIONS A-C
HEADWATER AREA
OF THE NORTH FORK OF OWL CREEK

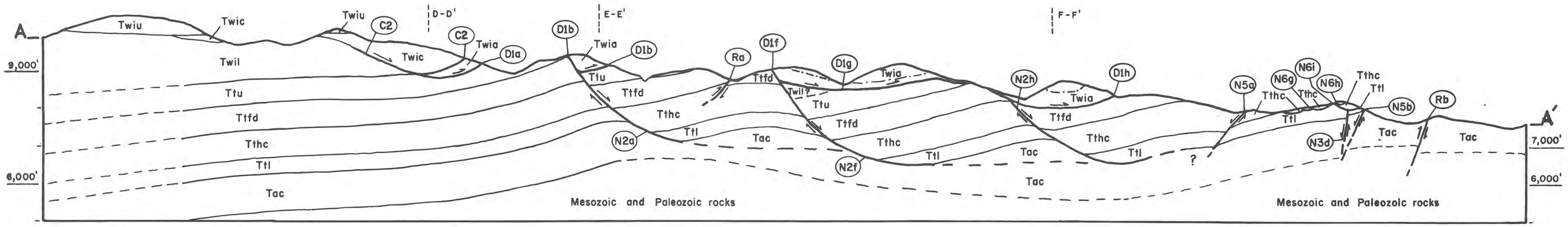
Hot Springs County, Wyoming

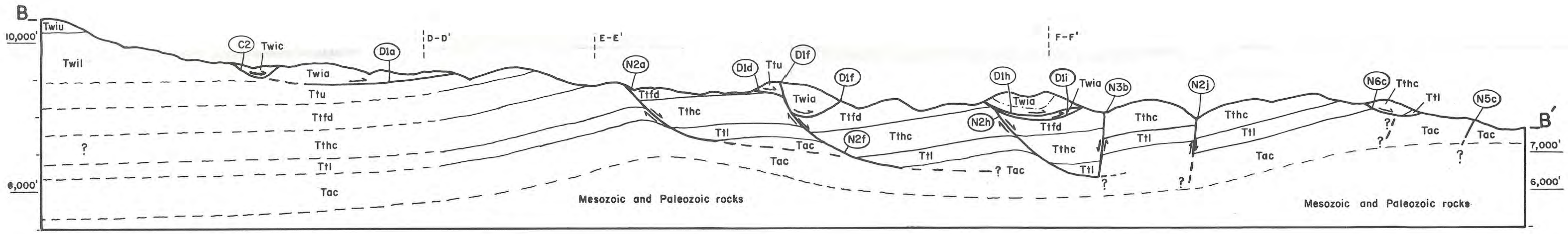
by Kent A. Sundell

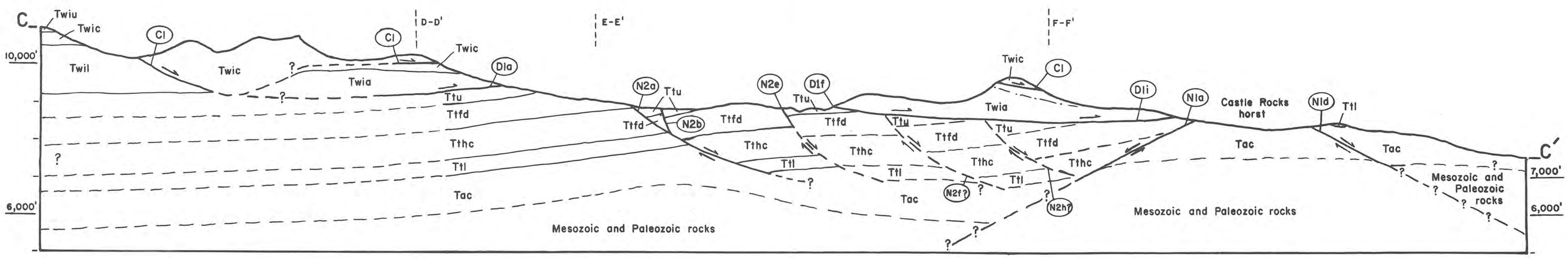
SCALE 1:24,000

1 0 1 mile

1 0 1 km.







Lines of section are on Plates I and II.

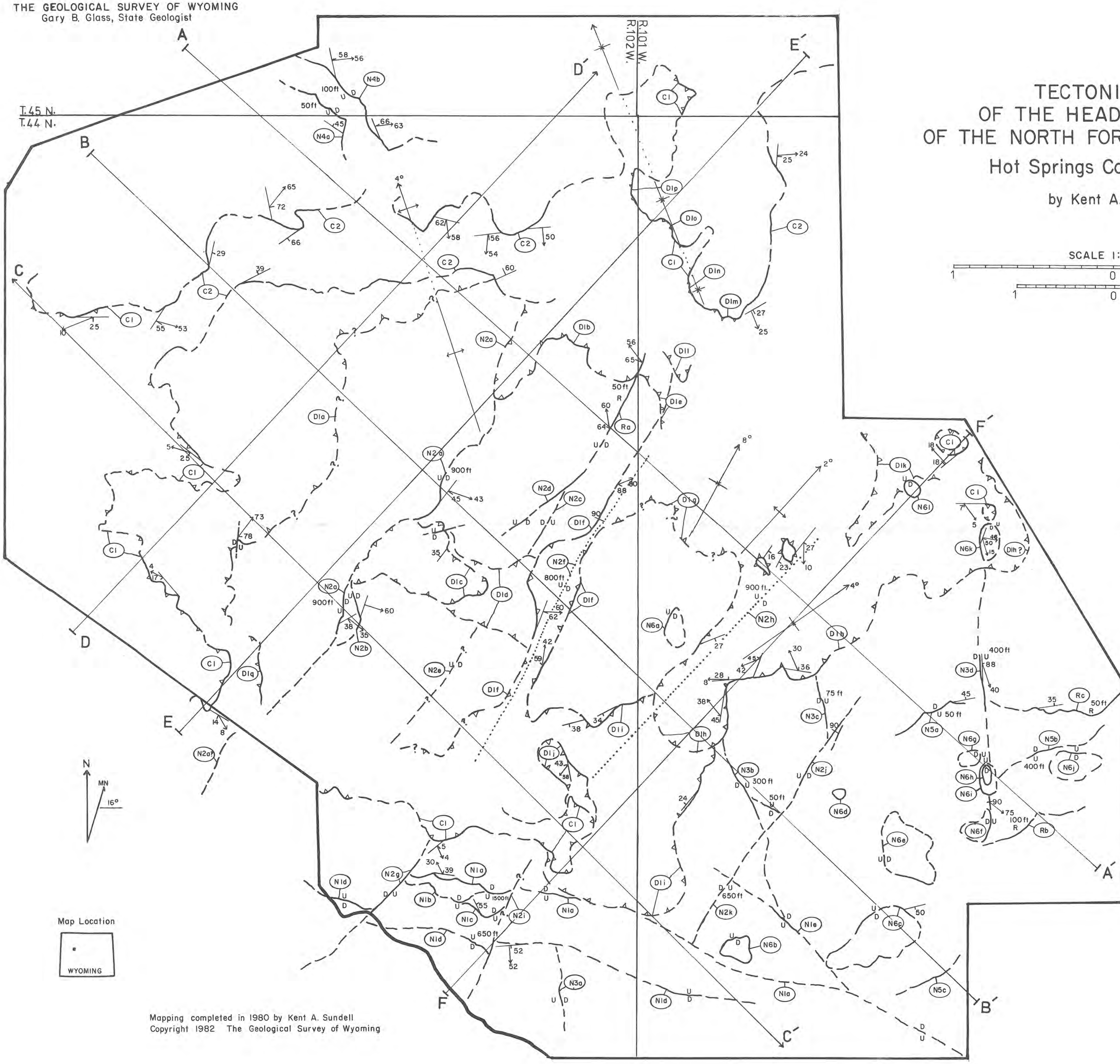
Arrow along a fault indicates a component of motion.

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

TECTONIC MAP OF THE HEADWATER AREA OF THE NORTH FORK OF OWL CREEK

Hot Springs County, Wyoming

by Kent A. Sundell



SCALE 1:24,000

1 0 1 mile

1 0 1 km.

EXPLANATION

20° Anticlinal axis, showing amount and direction of plunge. Dotted where concealed.

15° Synclinal axis, showing amount and direction of plunge. Dotted where concealed.

(up) U 150ft (down) D Normal fault, showing stratigraphic separation. Dashed where approximately located.

(up) R 50ft (down) Reverse fault, showing stratigraphic separation. Dashed where approximately located.

Detachment fault, dashed where approximately located. Queried where inferred.

Fault data.
53 Strike and dip of the fault plane
42 Plunge of the lineation features

FAULT LABELS
(See Table II)

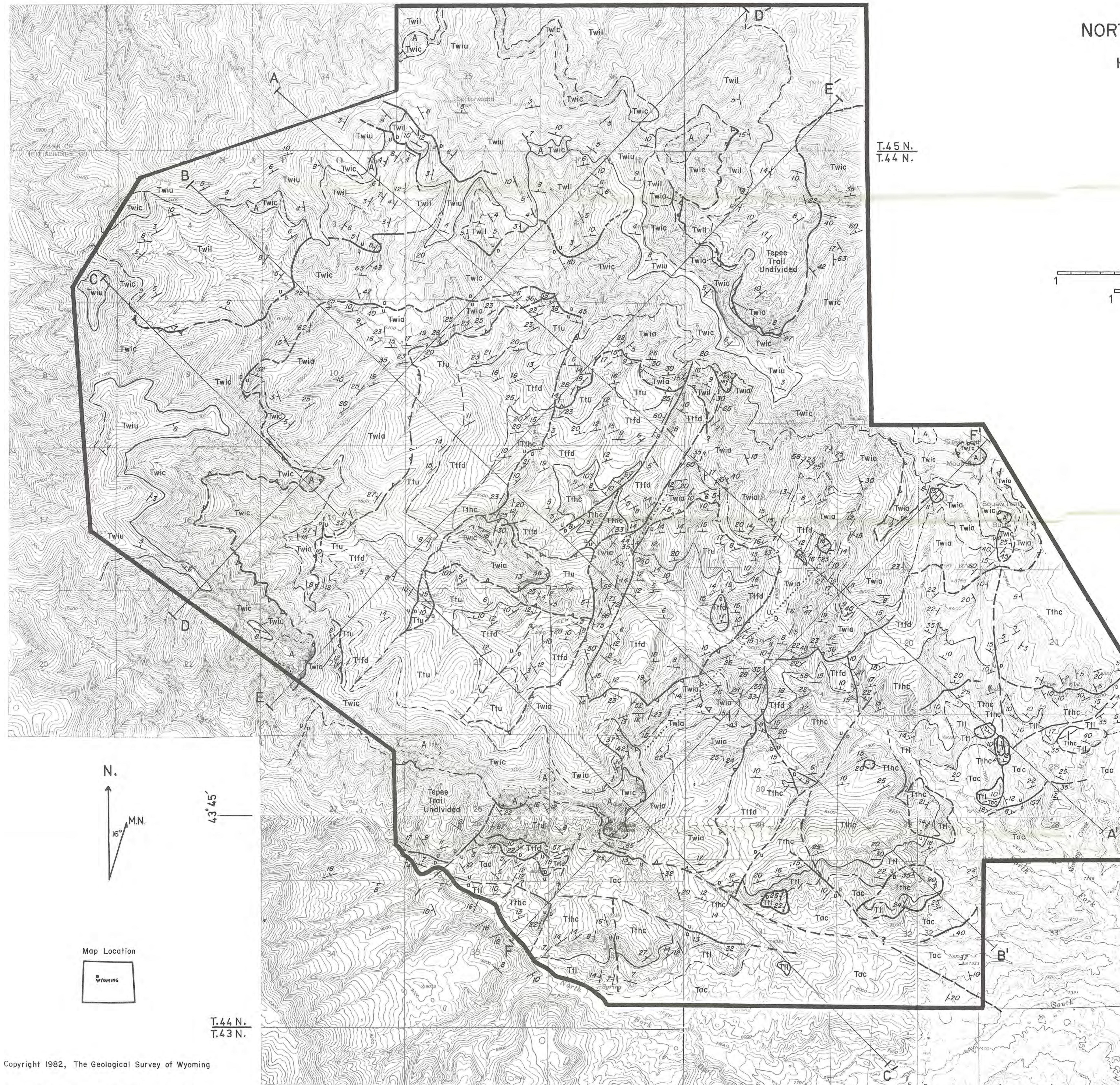
N1a-e	N.90-70°W. trend	Normal faults
N2a-k	N.30-40°E. trend	Normal faults
N3a-d	N.20-0°W. trend	Normal faults
N4a-b	N.30°W. trend	Normal faults
N5a-c	Others	Normal faults
N6a-l	Slump blocks	Normal faults
Ra-c	Reverse faults	
Dla-q	Detachment faults	
C1,C2	Castle Rocks chaos basal faults	

Mapping completed in 1980 by Kent A. Sundell

GEOLOGIC MAP OF THE HEADWATER AREA OF THE NORTH FORK OF OWL CREEK

Hot Springs County, Wyoming

by Kent A. Sundell



SCALE 1:24,000

1 0 1 mile

1 0 1 km.

EXPLANATION

EOCENE

Twiu	Upper Wiggins	Wiggins Formation
Twic	Castle Rocks chaos	Wiggins Formation
Twia	Allochthonous Wiggins	Wiggins Formation
Twil	Lower Wiggins	Wiggins Formation
Ttu	Upper Tepee Trail	Tepee Trail Formation
Ttfd	Foggy Day beds	Tepee Trail Formation
Tthc	Holy City beds	Tepee Trail Formation
Ttl	Lower Tepee Trail	Tepee Trail Formation
Tac	Aycross Formation	

Contact, dashed where approximately located.

Base of the Sugar Loaf tuff beds

Fault, dashed where approximately located, dotted where concealed, and queried where inferred.

Detachment fault, dashed where approximately located and queried where inferred.

10 Strike and dip of bedding

(A) Allochthonous andesite masses

Base map compiled from U.S. Geological Survey Quadrangles: Cottonwood Peak, Milk Creek, Willow Creek, and Eagle Nest Ranch.

Geologic mapping completed in 1980 by Kent A. Sundell.