The Red Butte Conglomerate— A Thrust-Belt-Derived Conglomerate of the Beaverhead Group, Southwestern Montana

U.S. GEOLOGICAL SURVEY BULLETIN 1945

U.S. DEPARTMENT OF THE INTERIOR
March 3, 1849

AVAILABILITY OF BOOKS AND MAPS OF THE U.S. GEOLOGICAL SURVEY

Instructions on ordering publications of the U.S. Geological Survey, along with prices of the last offerings, are given in the current-year issues of the monthly catalog "New Publications of the U.S. Geological Survey." Prices of available U.S. Geological Survey publications released prior to the current year are listed in the most recent annual "Price and Availability List." Publications that are listed in various U.S. Geological Survey catalogs (**see back inside cover**) but not listed in the most recent annual "Price and Availability List" are no longer available.

Prices of reports released to the open files are given in the listing "U.S. Geological Survey Open-File Reports," updated monthly, which is for sale in microfiche from the U.S. Geological Survey, Books and Open-File Reports Section, Federal Center, Box 25425, Denver, CO 80225. Reports released through the NTIS may be obtained by writing to the National Technical Information Service, U.S. Department of Commerce, Springfield, VA 22161; please include NTIS report number with inquiry.

Order U.S. Geological Survey publications **by mail** or **over the counter** from the offices given below.

BY MAIL

Books

Professional Papers, Bulletins, Water-Supply Papers, Techniques of Water-Resources Investigations, Circulars, publications of general interest (such as leaflets, pamphlets, booklets), single copies of Earthquakes & Volcanoes, Preliminary Determination of Epicenters, and some miscellaneous reports, including some of the foregoing series that have gone out of print at the Superintendent of Documents, are obtainable by mail from

U.S. Geological Survey, Books and Open-File Reports
Federal Center, Box 25425
Denver, CO 80225

Subscriptions to periodicals (Earthquakes & Volcanoes and Preliminary Determination of Epicenters) can be obtained ONLY from the

Superintendent of Documents
Government Printing Office
Washington, D.C. 20402

(Check or money order must be payable to Superintendent of Documents.)

Maps

For maps, address mail orders to

U.S. Geological Survey, Map Distribution
Federal Center, Box 25286
Denver, CO 80225

Residents of Alaska may order maps from

Alaska Distribution Section, U.S. Geological Survey,
New Federal Building - Box 12
101 Twelfth Ave., Fairbanks, AK 99701

OVER THE COUNTER

Books

Books of the U.S. Geological Survey are available over the counter at the following Geological Survey Public Inquiries Offices, all of which are authorized agents of the Superintendent of Documents:

- **WASHINGTON, D.C.**--Main Interior Bldg., 2600 corridor, 18th and C Sts., NW.
- **DENVER, Colorado**--Federal Bldg., Rm. 169, 1961 Stout St.
- **LOS ANGELES, California**--Federal Bldg., Rm. 7638, 300 N. Los Angeles St.
- **MENLO PARK, California**--Bldg. 3 (Stop 533), Rm. 3128, 345 Middlefield Rd.
- **RESTON, Virginia**--503 National Center, Rm. 1C402, 12201 Sunrise Valley Dr.
- **SALT LAKE CITY, Utah**--Federal Bldg., Rm. 8105, 125 South State St.
- **SAN FRANCISCO, California**--Customhouse, Rm. 504, 555 Battery St.
- **SPOKANE, Washington**--U.S. Courthouse, Rm. 678, West 920 Riverside Ave..
- **ANCHORAGE, Alaska**--Rm. 101, 4230 University Dr.
- **ANCHORAGE, Alaska**--Federal Bldg, Rm. E-146, 701 C St.

Maps

Maps may be purchased over the counter at the U.S. Geological Survey offices where books are sold (all addresses in above list) and at the following Geological Survey offices:

- **ROLLA, Missouri**--1400 Independence Rd.
- **DENVER, Colorado**--Map Distribution, Bldg. 810, Federal Center
- **FAIRBANKS, Alaska**--New Federal Bldg., 101 Twelfth Ave.

The Red Butte Conglomerate— A Thrust-Belt-Derived Conglomerate of the Beaverhead Group, Southwestern Montana

By J.C. HALEY and W.J. PERRY, JR.

This report formalizes the youngest mappable unit found so far in the Beaverhead Group—the Red Butte Conglomerate—and discusses the depositional setting and tectonic implications of this new formation

U.S. GEOLOGICAL SURVEY BULLETIN 1945

U.S. DEPARTMENT OF THE INTERIOR
MANUEL LUJAN, JR., Secretary

U.S. GEOLOGICAL SURVEY
Dallas L. Peck, Director

UNITED STATES GOVERNMENT PRINTING OFFICE: 1991

For sale by the
Books and Open-File Reports Section
U.S. Geological Survey
Federal Center
Box 25425
Denver, CO 80225

Library of Congress Cataloging-in-Publication Data

Haley, J. Christopher.
The Red Butte Conglomerate—A thrust-belt-derived conglomerate of the Beaverhead Group, southwestern Montana / by J.C. Haley and W.J. Perry, Jr.
p. cm. — (U.S. Geological Survey bulletin ; 1945)
Includes bibliographical references (p.)
Supt. of Docs. no.: I 19.3:1945
1. Geology, Structural—Montana—Beaverhead County. 2. Conglomerate—Montana—Beaverhead County. 3. Red Butte Conglomerate (Mont.) I. Perry, W.J., Jr. II. Title. III. Series.
QE75.B9 no. 1945
[QE627.5.M9]
[557.3 s—dc20]
[5521.5]
90-13880
CIP

CONTENTS

FIGURES

The Red Butte Conglomerate— A Thrust-Belt-Derived Conglomerate of the Beaverhead Group, Southwestern Montana

By J.C. Haley *and* W.J. Perry, Jr.

Abstract

The Red Butte Conglomerate is herein defined as the uppermost formation of the Beaverhead Group. The Red Butte includes dominantly limestone conglomerate and minor interbedded sandstone and siltstone shed from the frontal thrust belt in southern Beaverhead County, Montana. The Red Butte can be distinguished from the Lima Conglomerate and other similar conglomerates of the Beaverhead Group by the included clasts of recycled limestone conglomerate and an admixture of well-rounded quartzite clasts recycled from older quartzite conglomerates of the Beaverhead. The Red Butte Conglomerate overlies a sequence of older Beaverhead limestone conglomerate and quartzite conglomerate with angular discordance, and it is cut by the frontal Tendoy thrust system from which it was largely derived. East of the Tendoy Mountains in the Sage Creek basin, the Red Butte Conglomerate is overlain unconformably by Tertiary sedimentary and volcanic rocks of the Sage Creek basin. In the absence of datable palynomorphs, these relationships suggest that the Red Butte Conglomerate contains the youngest rocks in the Beaverhead Group—from latest Cretaceous to early Tertiary in age. The Red Butte Conglomerate provides evidence that eastward movement along the Tendoy thrust—the frontal major thrust fault in the area—was the latest major compressional event in the structural development of this part of the Cordilleran thrust belt.

The Red Butte Conglomerate was deposited as alluvial fans flanking, then overridden by, the frontal thrust belt. Matrix-supported boulder-cobble conglomerates, flat-laminated sandstones extensively disrupted by roots, and deeply incised, flat-bottomed channels suggest that these fans were dominated by debris flows and shallow ephemeral floods. In contrast, the older Lima Conglomerate, derived from the Blacktail-Snowcrest uplift, probably was deposited by braided streams.

Manuscript approved for publication May 18, 1990.

INTRODUCTION

The Beaverhead Formation was named by Lowell and Klepper (1953). It was given group rank and its limits were redefined by Nichols and others (1985) who included chiefly conglomerate-dominated strata within it. The Beaverhead Group was formally redefined by Perry and others (1988) to include a complex of synorogenic conglomerates, sandstones, and limestones of Late Cretaceous age in southwestern Montana and adjacent Idaho. This redefinition of the group makes it approximately equivalent to the Beaverhead Formation of previous authors (Lowell and Klepper, 1953; Scholten and others, 1955; Ryder and Scholten, 1973). The elevation to group status by Nichols and others (1985) was prompted by the recognition that the Beaverhead Formation is made up of several genetically distinct units that are recognizable in the field (Haley, 1983a,b). The only formal stratigraphic unit previously defined within the Beaverhead Group is the Lima Conglomerate that flanks the Blacktail-Snowcrest foreland uplift (fig. 1). This conglomerate, dated as middle Campanian by Nichols and others (1985) based on a palynomorph collection from the top of the unit, was shed from and gently deformed by the rising Blacktail-Snowcrest uplift.

The present report defines a second formation—the Red Butte Conglomerate. The Red Butte Conglomerate is named for Red Butte just east of Dell, Montana (E½ sec. 10, T. 13 S., R. 9 W.), its type area and the most prominent outcrop of the formation (fig. 1). Rocks of this formation were formerly placed in several different informal lithologic units of the Beaverhead by Ryder and Scholten (1973). Northeast of the Red Rock Valley, the Red Butte was formerly termed Lima limestone conglomerate by Ryder and Scholten (1973). Southeast of the Red Rock Valley, Ryder and Scholten (1973) placed these rocks in two informal units: the McKnight conglomerate and the Chute Canyon sandstone.

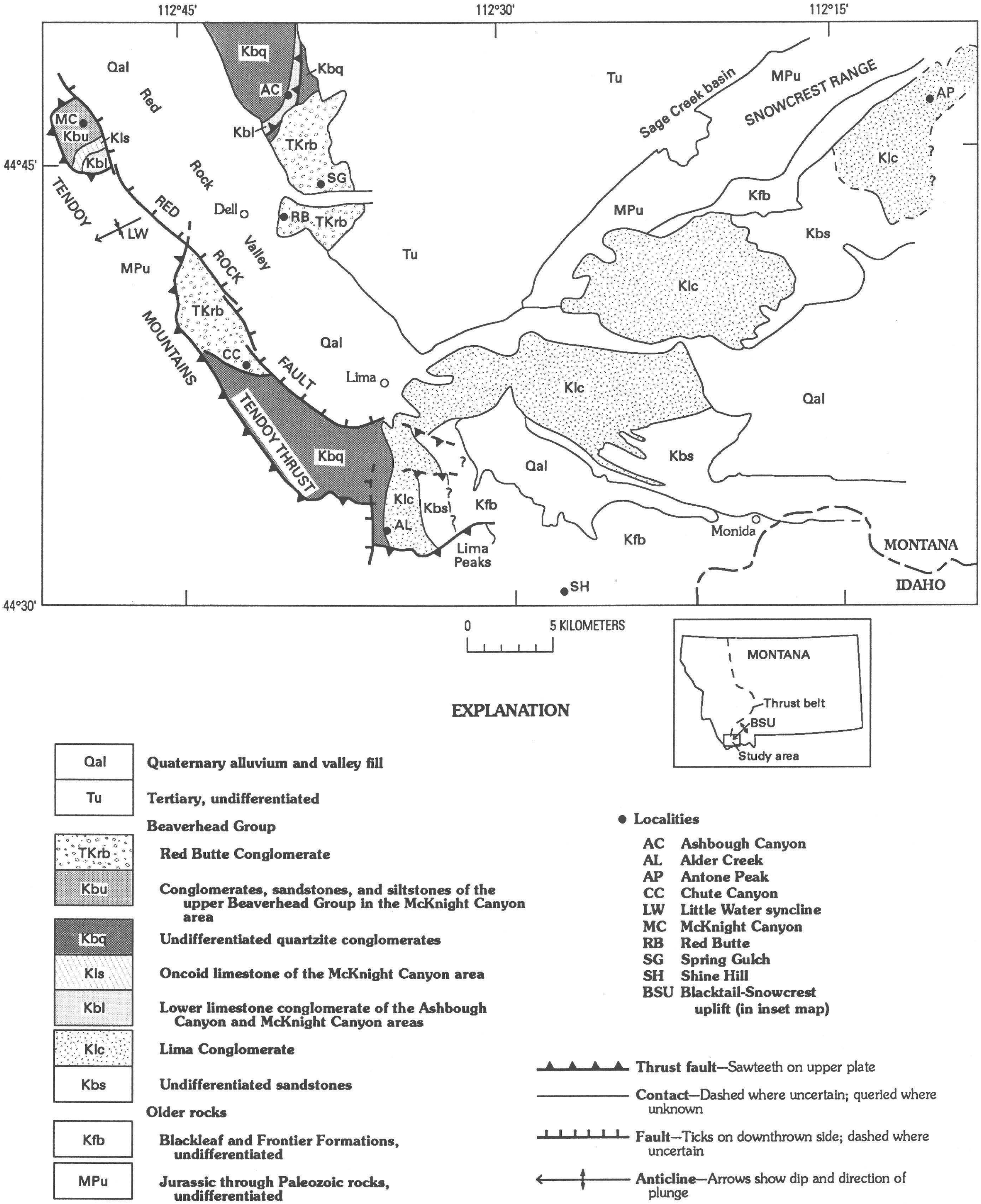


Figure 1. Map of Lima region generalized and modified from Ryder and Scholten (1973, fig. 3) showing major structural features, distribution of the Red Butte and Lima Conglomerates and adjacent informal Beaverhead Group lithologies, and important locations mentioned in the text.

This new unit was first recognized and described by Haley (1986) and was defined as an informal unit within the upper part of the Beaverhead Group by Perry and others (1988). Designation of the Red Butte Conglomerate further organizes the Beaverhead Group into genetically meaningful stratigraphic units. Study of this unit furthers our understanding of the deformational and depositional history of a highly complex part of the Cordillera, particularly regarding the interaction of foreland basement and thrust-belt deformation, and suggests a significant change in depositional style from braided stream to ephemeral-flood- and debris-flow-dominated fans at the close of the Cretaceous.

DISTRIBUTION AND CONTACTS OF THE RED BUTTE CONGLOMERATE

The Red Butte Conglomerate crops out in Beaverhead County, Montana, where the northwest-southeast-trending Idaho-Montana thrust belt impinges upon the southwest-plunging, Laramide-style, Blacktail-Snowcrest uplift. The Red Rock Valley, a Quaternary graben (Johnson, 1981, fig. 7), divides the unit into two outcrop belts. The northeast outcrop belt stretches from Ashbough Canyon south to the southern edge of Red Butte (fig. 1). The highly deformed southwest outcrop belt extends from southeast of the Little Water syncline southeast to just beyond Chute Canyon. No marker horizons are present to correlate strata across the Red Rock Valley. However, a distinctive clast composition provides the criteria for recognition of the Red Butte Conglomerate, as is discussed later in this report.

The base of the Red Butte Conglomerate is exposed only in a small unnamed gully just east of Ashbough Canyon (W½ sec. 11, T. 12 S., R. 9 W.; A on fig. 2). There it overlies, in a spectacular angular unconformity, an older, undifferentiated limestone conglomerate of the Beaverhead Group (fig. 3). This is the first reported synorogenic unconformity within the Beaverhead strata, and this exposure provides a key to our understanding of the complexity of the synorogenic sequence in this area. On the northeast side of the Red Rock Valley, the Red Butte Conglomerate is unconformably overlain by Tertiary basalt and reworked semiconsolidated gravels of the Sage Creek basin (Tu of figs. 1 and 2). The outcrop belt of the Red Butte on the southwest side of Red Rock Valley appears completely fault bounded (fig. 1): The top of the unit is cut out by the Tendoy thrust to the northwest and west. To the south, the Red Butte is brought adjacent to quartzite conglomerate along an apparent reverse fault. The Red Rock normal fault truncates the eastern exposures of the unit along the west side of Red Rock Valley (fig. 1).

At the extreme southern end of the southwest outcrop belt, Red Butte strata are unconformably overlain by a fairly well cemented gravel composed of reworked limestone and quartzite clasts and conglomerate boulders. This gravel was mapped as a tongue of Beaverhead quartzite conglomerate by Ryder (1968). More likely, it is a younger Tertiary to Quaternary conglomerate associated with old Red Rock Valley alluvial fans now truncated by the Red Rock fault.

Like many other synorogenic deposits, no complete section of the Red Butte Conglomerate is exposed. Ryder (1968) reported about 200 m (meters) of rocks at Red Butte and 300 m at Chute Canyon, which we herein place in the Red Butte Conglomerate (fig. 1). At neither of these localities is the base or top exposed. Red Butte is herein designated the type area.

GENERAL CHARACTER OF THE RED BUTTE CONGLOMERATE

The Red Butte Conglomerate is dominated by boulder and cobble conglomerate with minor sandstone and siltstone interbeds (fig. 4*A*) in its type area and farther north as well as in the central and northern part of the southwest outcrop belt. A sandstone-dominated unit, the informal Chute Canyon sandstone of Ryder and Scholten (1973), is herein included in the Red Butte Conglomerate (fig. 4*B*). This informal unit is present at the extreme southern end of the southwest outcrop belt where faults separate it from other Beaverhead units.

The Red Butte Conglomerate, like other limestone conglomerates within the Beaverhead Group, is characterized by a clast assemblage dominated by limestone of Mississippian through Triassic age. Unlike the other limestone conglomerates, however, there is an admixture of very well rounded Middle Proterozoic Belt quartzite cobbles and very coarse pebbles (figs. 5, 10), which generally makes up less than 25 percent of the clast population but in some lenses can make up more than 50 percent. These clasts are generally 5–25 cm (centimeter) long and are predominately composed of rose-colored vitreous quartzite and maroon siliceous siltite. Clasts of well-cemented limestone pebble conglomerate, containing pebbles derived almost exclusively from the Mississippian Madison Group, are also locally common, but constitute less than 10 percent of the total clast assemblage. These conglomerate clasts were unreported by previous workers. However, the largest boulders in the Red Butte Conglomerate and the only ones longer than 1 m consist of this reworked limestone conglomerate (fig. 6).

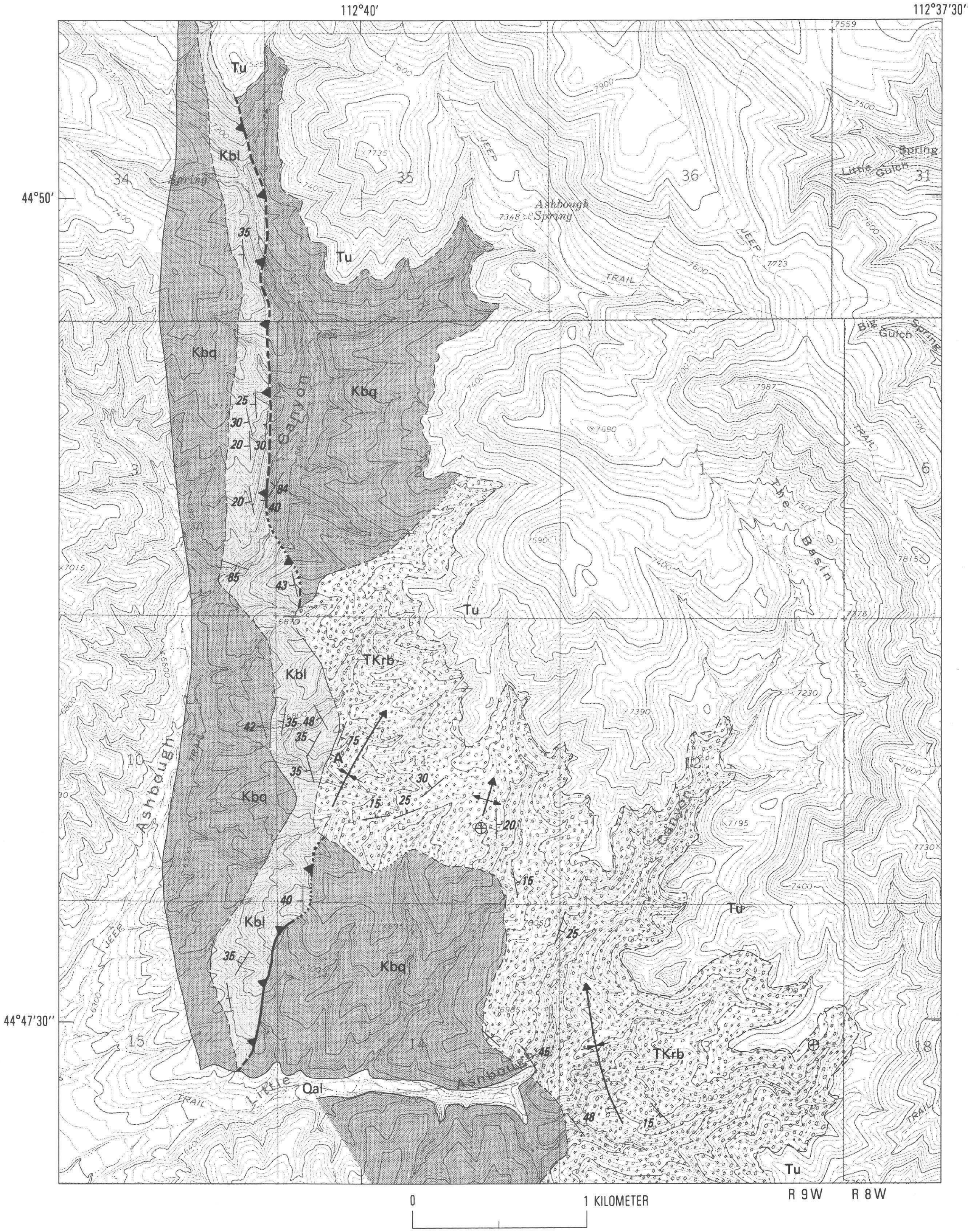


Figure 2 (above and facing page). Geologic map of Ashbough Canyon area. Base from Briggs Ranch, Montana 7½-minute quadrangle. Contour interval, 20 feet. National geodetic vertical datum of 1929.

EXPLANATION

Qal	Quaternary alluvium
Tu	Tertiary rocks of the Sage Creek basin, undivided
TKrb	Tertiary? to Upper Cretaceous Red Butte Conglomerate
Kbq	Cretaceous Quartzite conglomerate of Beaverhead Group, undivided
Kbl	Lower limestone conglomerate unit of Beaverhead Group

Contact—Dashed where inferred; dotted where uncertain

Thrust fault—Dashed where inferred; dotted where uncertain

Fold axes

Anticline—Arrows show dip and direction of plunge

Syncline—Arrows show dip and direction of plunge

Strike and dip

35 Inclined strata

Horizontal strata

Vertical strata

A Exposure of Red Butte Conglomerate—(See also figure 3)

The Red Butte Conglomerate can be readily recognized for mapping purposes by this unusual clast assemblage. The practice of using clast assemblage alone to distinguish conglomerate deposits is, in general, dangerous because a conglomerate, and especially a fanglomerate, can have several local source areas, each contributing a slightly different set of clasts. In addition, a clast assemblage within a conglomerate commonly changes as unroofing of the source area constantly makes new formations available for erosion.

Three lines of evidence suggest that those conglomerates with the just-described clast assemblage do constitute a separate and distinct deposit from other limestone conglomerates in the Beaverhead. First, the unconformable relationship between the Red Butte Conglomerate and an underlying limestone conglomerate near Ashbough Canyon is observable in outcrop (fig. 3). The underlying limestone conglomerate has neither conglomerate boulders nor quartzite clasts. Second, detailed analysis of depositional environments (Haley, 1983a,b, 1986) indicates that the Lima Conglomerate was deposited in braided-stream-dominated fans, and the Red Butte Conglomerate was deposited in ephemeral-flood- and debris-flow-dominated fans. Third, the Lima Conglomerate and the Red Butte Conglomerate had different source areas.

SOURCE OF THE RED BUTTE CONGLOMERATE

The coarseness and angularity of many limestone clasts of the Red Butte Conglomerate require a proximal source, either from the Blacktail-Snowcrest uplift to the east or nearby thrust sheets to the west. Most of the clasts are not particularly useful in determining a source area because the formations represented are present in both the foreland and thrust belt (W.J. Sando, written commun., 1983). These limestone clasts are predominately of early Mesozoic and late Paleozoic age. In this area, the Middle Proterozoic Belt Supergroup outcrops only in the thrust belt west and northwest of the Tendoy Mountains. Therefore, the ultimate source for Belt clasts must be from thrust sheets in these hinterland areas. However, in the Red Butte Conglomerate these very well rounded, polished clasts were codeposited with large angular limestone clasts that clearly have a shorter transport history. This textural inversion indicates that the Belt clasts were recycled and thus do not indicate a primary western thrust-belt source for the Red Butte (such as Proterozoic Belt exposures).

A few "key" clasts require a source terrane in which older Beaverhead rocks were exposed. These clasts make up less than 1 percent of the total assemblage but are of such unique composition as to restrict the source area. Each of these clast types taken individually may suggest more than one conceivable source, but, taken together, they point to a western, thrust-belt source. The clasts are (1) brown oncoid limestone, (2) boulders of recycled limestone pebble-cobble conglomerate (figs. 6, 7), and (3) sheared quartzite cobbles (fig. 5).

Oncoid Limestone

Two boulder-size clasts of oncoid limestone have been found: one at Red Butte at the southern edge of the northeast outcrop belt and one in the northeastern part of the southwest outcrop belt. Identical oncoid limestones outcrop within Beaverhead strata in the partial window beneath the Tendoy thrust at McKnight Canyon (unit Kls, fig. 1), locally termed McKnight thrust by Williams and Bartley (1988). Oncoid limestone in the Beaverhead Group also occurs more than 40 km (kilometers) northeast of Red Butte (Achuff, 1981; Pecora, 1981) but is apparently absent in the Ashbough Canyon area (fig. 2) between the two localities. The coarseness and angularity of the oncoid limestone clasts in southwestern exposures of the Red Butte argue against a source 40 km to the northeast. The only known occurrence of this limestone in the study area is at McKnight Canyon where it has been uplifted and then cut by the Tendoy thrust.

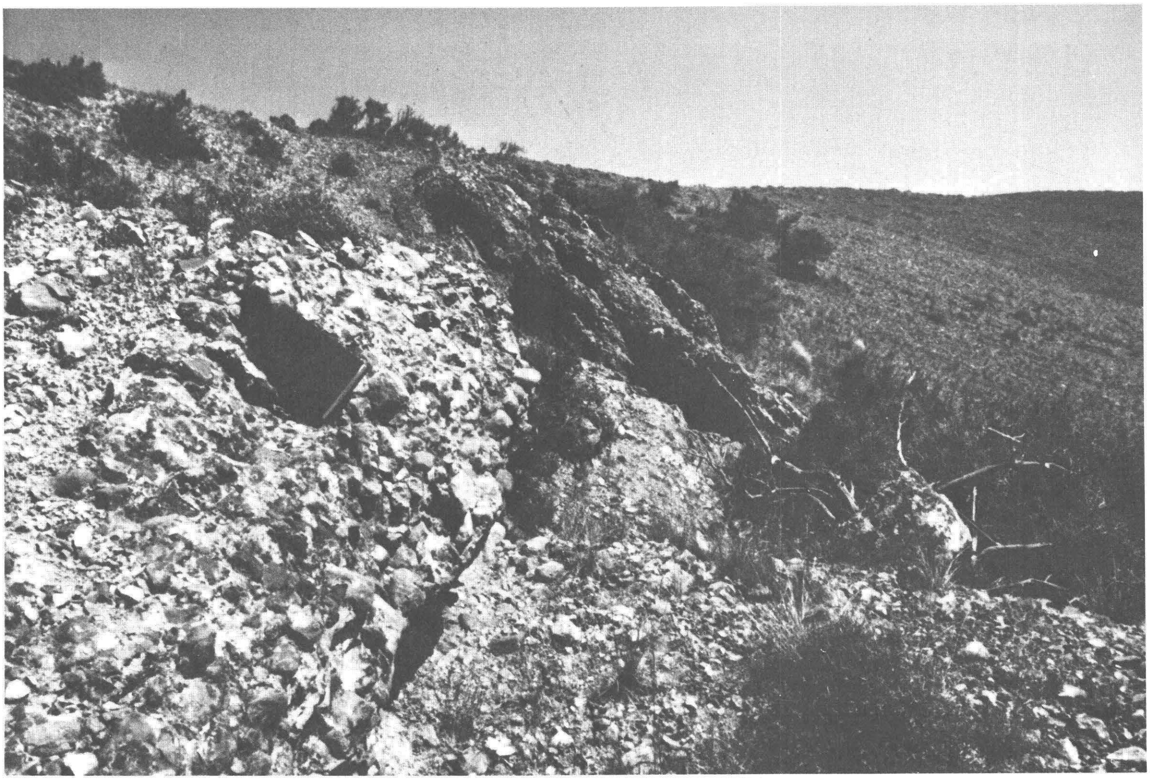


Figure 3. Angular unconformity near Ashbough Canyon between southeast-dipping conglomerates of the Red Butte Conglomerate (background, darker color) and underlying, northwest-dipping limestone conglomerates (foreground, under notebook). View to the northeast.

Recycled Limestone Conglomerate

Two explanations for the recycled limestone conglomerates are possible. (1) They are recycled, early-cemented fan gravels that were uplifted by small faults, eroded, and redeposited farther down on the fan. (2) They may be from a different deposit altogether. We believe that the second explanation is more likely. No limestone pebble conglomerate clasts contain quartzite clasts: hence, they differ compositionally from the host conglomerate. Also, the limestone conglomerate clasts are similar compositionally to the limestone conglomerate that is overlain unconformably by the Red Butte Conglomerate near Ashbough Canyon. This older limestone pebble-cobble conglomerate is composed of clasts from no higher in the section than the Mississippian Madison Group and thus is the most attractive source for the conglomerate clasts.

Deformation of these older conglomerates beneath the unconformity produced north-south trending structures (fig. 2). A north-striking low-angle thrust fault brings limestone pebble-cobble conglomerate over quartzite conglomerate in the Ashbough Canyon area. The strike of this fault is oblique to the regional trend of the Blacktail-Snowcrest uplift, but it is compatible with that of the thrust belt to the west. There, the trace of the Tendoy thrust changes locally to north-south and even northeast-southwest (fig. 1) near the Little Water syncline and McKnight Canyon. Unpublished mapping by Perry north of McKnight Canyon illustrates a similar change in strike for a large segment of the thrust belt. Quite likely, the deformed conglomerates beneath the Red Butte Conglomerate represent thrust-belt deformation; thrust uplift of the older limestone conglomerate provided recycled limestone conglomerate clasts to the Red Butte Conglomerate, and the Red Butte Conglomerate ultimately onlapped these older conglomerates.

Sheared Quartzite Clasts

Many recycled Belt clasts show signs of shearing and annealing (fig. 5). This deformation is necessarily predepositional with respect to the Red Butte, because typically only one clast in a bed of Red Butte Conglomerate will be sheared, and the adjacent matrix and clasts will be undeformed. Sheared Belt clasts are common in the quartzite conglomerate under the Tendoy thrust (Tanner, 1963, 1964) and along the low-angle thrust in Beaverhead conglomerates unconformably overlain by the Red Butte Conglomerate east of Ashbough Canyon (figs. 1, 2).

Paleocurrent Indicators

Paleocurrents measured in the Red Butte Conglomerate by previous authors (Ryder, 1968; Wilson, 1970) differ, as these authors measured different features. Wilson (1970, fig. 10) measured the direction and plunge of incised channels at Red Butte. Incised channels in alluvial fans, as reviewed by Haley (1986), are typically straight and therefore make excellent paleocurrent indicators. Wilson's results strongly suggest a northwest source area.

Ryder (1968, pl. 4) measured clast orientations at three localities in the Red Butte Conglomerate on the northeast side of the Red Rock Valley (in rocks included in his informal Lima limestone conglomerate) and at three localities on the southwest side (in rocks included in his informal McKnight limestone conglomerate). Those measurements from the northeast outcrop belt suggest a northeast-to-southwest flow direction, and those from the southwest outcrop belt suggest a northwest-to-southeast or west-to-east flow direction. Ryder (1968) thought the deposits were separately derived and grouped them in different informal lithostratigraphic units. The deposits are, however, lithologically quite similar and have the same unusual "key" clasts. Ryder's plotted imbrication data show significant scatter about the center of the stereonet (that is, the maxima are weak at best). Furthermore, northeast of Dell, Haley observed many conglomerate lenses whose clasts have an obvious preferred west dip, indicating eastward transport (fig. 8). As will be discussed in a separate section on depositional environments, the conglomerates of the Red Butte show characteristics consistent with deposition on ephemeral fans that have a significant debris-flow component. The fine matrix of a debris flow is commonly winnowed out. The result is a clast-supported gravel in which the clasts have no preferred orientation. Measurement of clasts in beds of such an origin may be one cause of the scatter in Ryder's data.

Wilson's (1970) results agree more closely with the mapped distribution of the Red Butte Conglomerate (fig. 2) (especially the unconformity beneath the Red Butte), the key clast composition, and Haley's own observations. Given the alluvial fan environment, we believe that incised channel orientations probably yield a more reliable paleocurrent direction than clast orientation. Therefore, given the data with all its ambiguities, we believe that a northwestern thrust-belt source is most likely for the Red Butte Conglomerate.

AGE OF THE RED BUTTE CONGLOMERATE

Because we lack direct biostratigraphic or isotopic age data, we can only date the Red Butte Conglomerate indirectly. Four samples from the Chute Canyon sandstone subunit of this formation in the southwestern outcrop area were processed for palynological analysis but were barren. Dates from other Beaverhead strata and from the younger Bridgerian Sage Creek Formation (middle Eocene) provide certain constraints as outlined next.

Nichols and others (1985) dated the uppermost Lima Conglomerate as middle Campanian based on palynological data from locality AL (fig. 1). Perry and others (1988) suggested that the limestone conglomerate overlain with angular unconformity by the Red Butte Conglomerate (fig. 3) is Lima Conglomerate, based on its clast composition (predominance of Mississippian limestone clasts and abundance of Early Mississippian Lodgepole Limestone clasts) as well as its relative stratigraphic position in the Beaverhead Group northeast of Dell with respect to that south of Lima. However, we cannot demonstrate continuity with the type Lima Conglomerate on the south flank of the Blacktail-Snowcrest uplift.

The Red Butte Conglomerate is considerably younger than the Lima Conglomerate based on the following independent observations. The Lima Conglomerate and its distal equivalents (undifferentiated sandstones of the Beaverhead Group in figure 1, the informal Snowline and Monida sandstones of Ryder and Scholten, 1973, and the Monida Formation of Wilson, 1970) lie unconformably on Lower Cretaceous and younger rocks. Except for fairly thin conglomeratic lenses in the Frontier Formation south of Lima Peaks (Dyman and others, 1989), rocks beneath the Lima Conglomerate are devoid of Belt quartzite cobbles. The informal Divide quartzite conglomerate of Ryder and Scholten along the Continental Divide 19 km southwest of Lima may in part be time-equivalent to the Lima Conglomerate, but it was never cut by the frontal thrust system that evidently supplied detritus to the Red Butte Conglomerate. The first major influx of quartzite detritus into the area north and northwest of Lima, the probable source area for the Red Butte Conglomerate, occurred in late Campanian time. The resultant thick quartzite conglomerate, which contains abundant pink and maroon Belt quartzite cobbles typical of the recycled Belt cobbles found in the Red Butte Conglomerate, conformably overlies the Lima Conglomerate at Alder Creek and a similar limestone conglomerate at Ashbough Canyon (fig. 1; Ryder and Scholten, 1973; Nichols and others, 1985; Haley, 1986). This quartzite conglomerate, demonstrably younger than the Lima Conglomerate, was cut, overridden, and

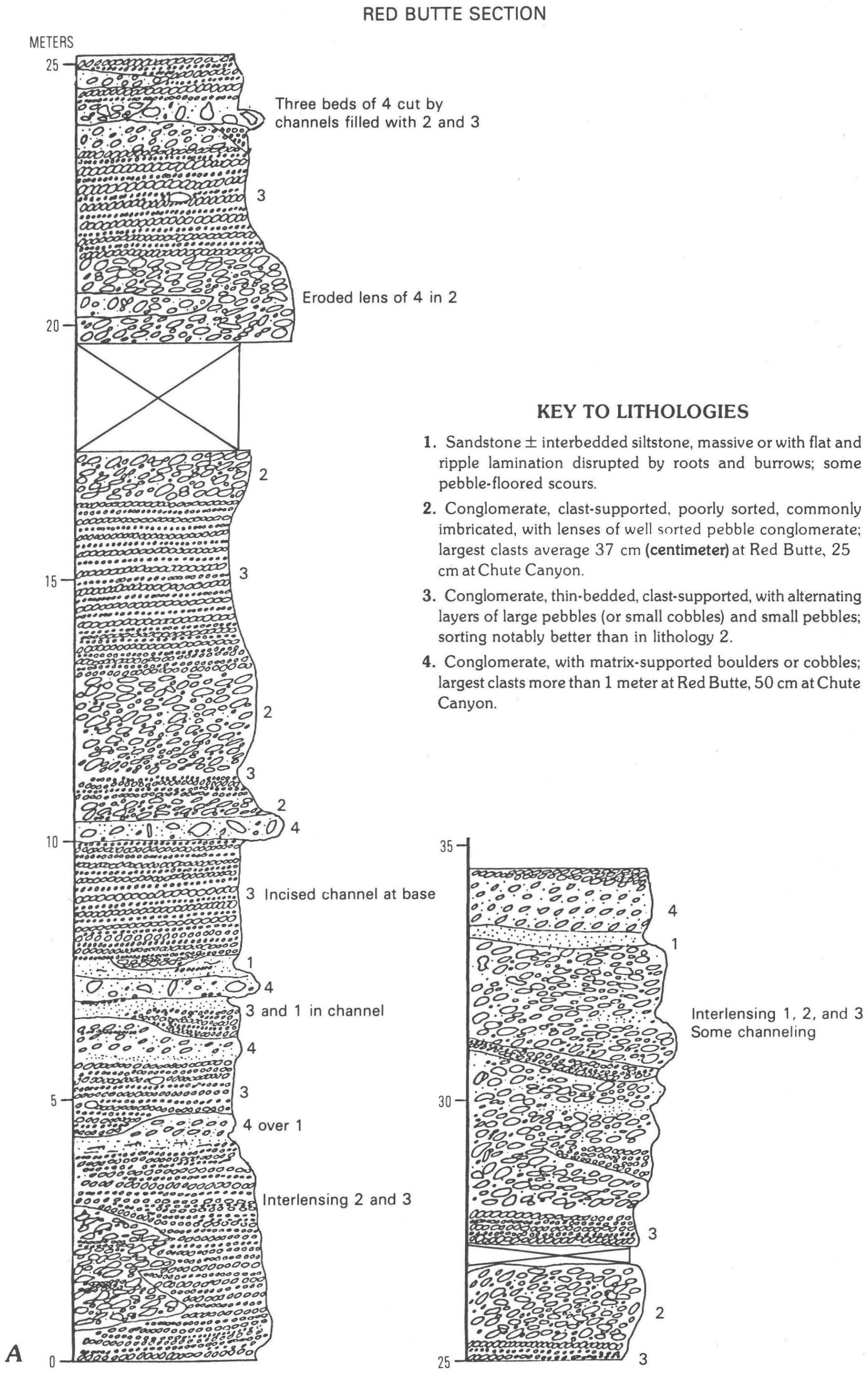
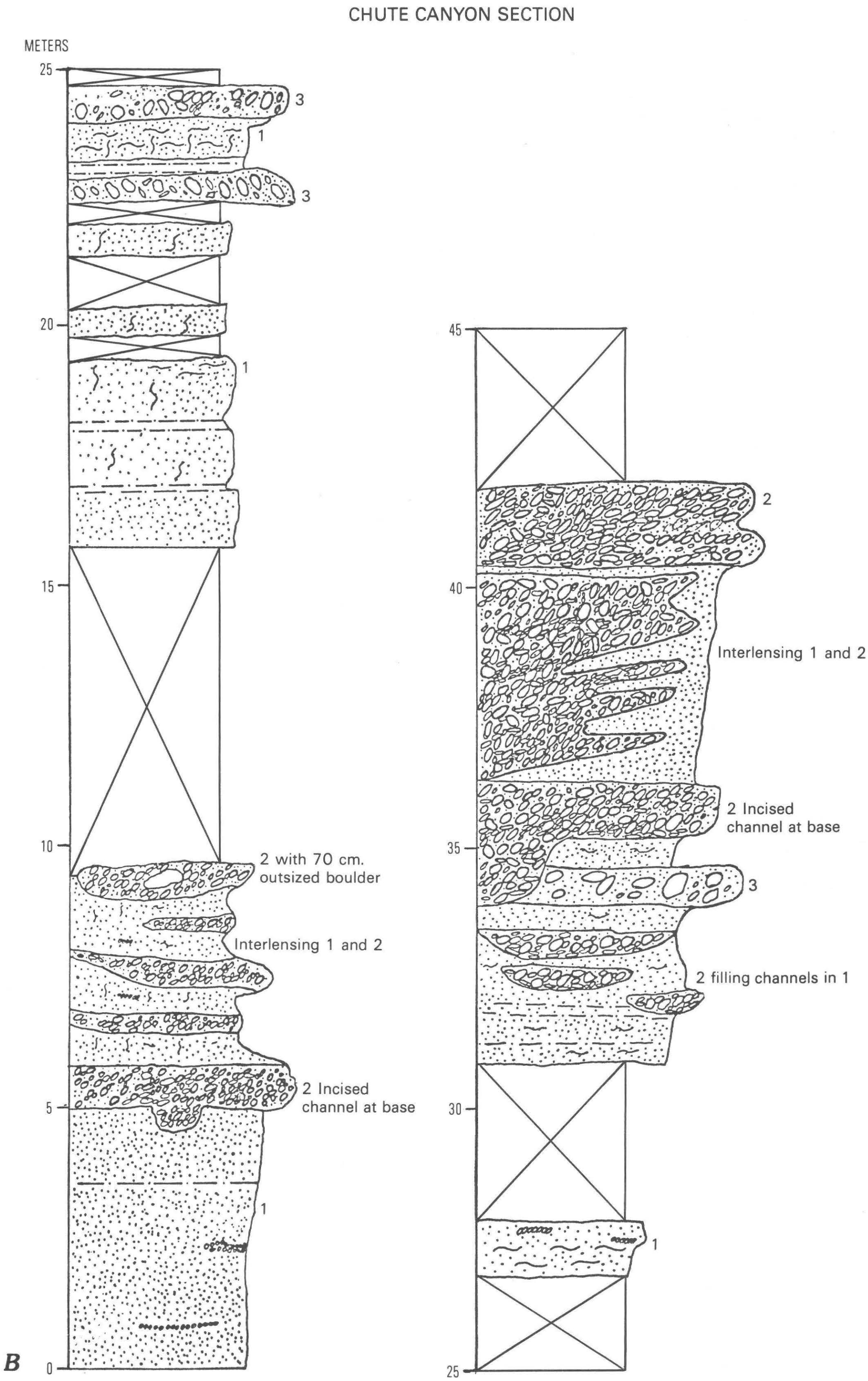


Figure 4 (above and facing page). *4A*, Partial section of the Red Butte Conglomerate in its type area (sec. 10, T. 13 S., R. 9 W.) showing features typical of the conglomerate facies of the Red Butte Conglomerate.



4*B*, Partial section of the Chute Canyon reference section (sec. 4, T. 14 S., R. 9 W.) showing features typical of the interbedded sandstone-conglomerate facies of the Red Butte Conglomerate.

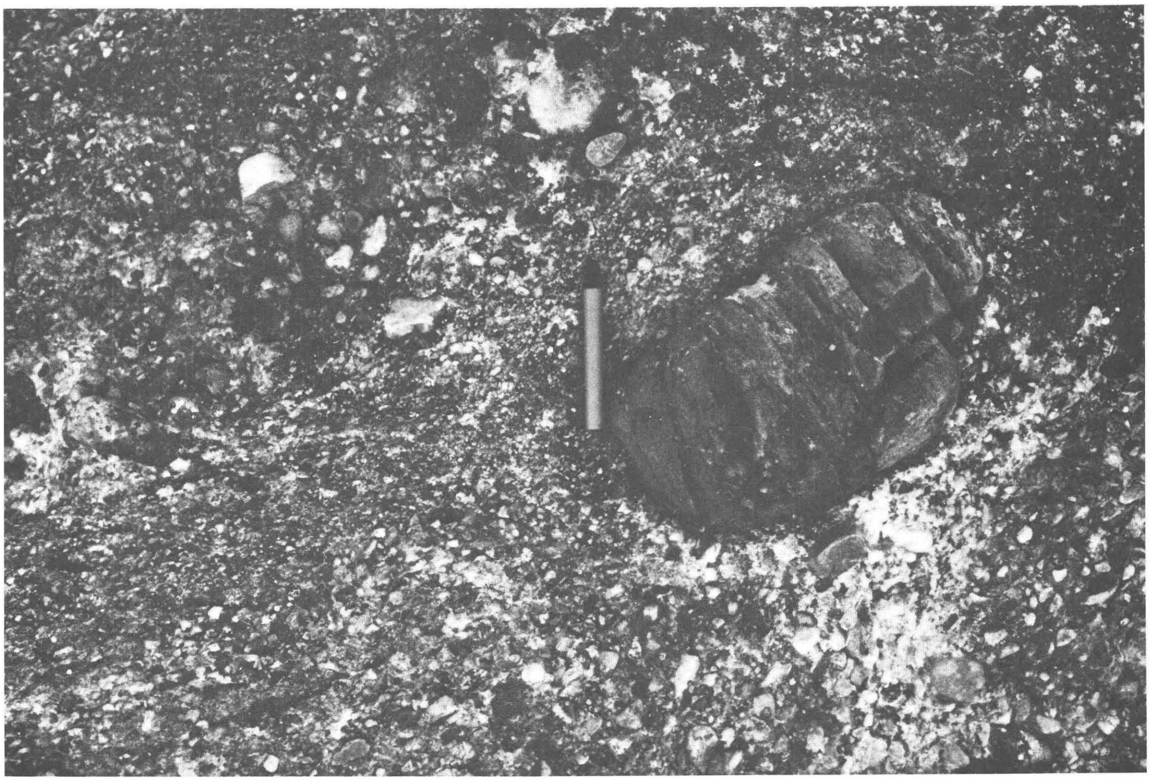


Figure 5. Cobble of sheared Middle Proterozoic Belt quartzite in a pebble conglomerate dominated by smaller limestone clasts. Marking pen is about 11 centimeters long.

sheared by the Tendoy thrust as well as the thrust in Ashbough Canyon (fig. 2). It was then later eroded to supply detritus, including the sheared quartzite clasts, to the Red Butte Conglomerate (fig. 5). The relative stratigraphic positions of the various units of the Beaverhead Group are shown schematically in figure 9.

The upper conglomerate of the Beaverhead sequence at McKnight Canyon, composed predominately of Triassic and Permian limestone clasts, lacks the key clast composition of the Red Butte. The basal part of this more than 1-km-thick upper conglomerate was dated as Late Campanian to Maastrichtian based on palynological data (Perry and others, 1988). As outlined by Perry and others (1988), after this upper conglomerate was deposited, the entire Beaverhead sequence in the McKnight Canyon area (fig. 9) was tilted to the northwest as part of the hanging wall of the northwest-dipping, Laramide-style, blind Kidd thrust (Perry, 1986; Perry and others, 1988) and at least 1,680 m of structural relief was formed. The subsurface Kidd thrust and associated homoclinal tilting of the Beaverhead sequence of the McKnight Canyon area was inferred to be Maastrichtian to very early Tertiary by Perry and others (1988) based on the pollen date from the basal part of the upper conglomerate in McKnight Canyon. After this tilting, the eastward-propagating Tendoy thrust cut the Beaverhead of the McKnight Canyon area. These events require the McKnight sequence, including the oncoid limestone (of the lower part of the limestone and siltstone of fig. 9), to have been uplifted as part of the hanging wall of the Tendoy thrust. The sequence was then partially eroded and redeposited as part of the Red Butte Conglomerate. The Red Butte Conglomerate is younger than the Beaverhead sequence of the McKnight Canyon area because of the oncoid limestone included in the clast assemblage, as discussed previously, and is Maastrichtian or younger based on the pollen date from the base of the upper conglomerate at McKnight Canyon.

The Red Butte can be no younger than middle Eocene based on its relationship to the overlying Sage Creek Formation, dated as middle Eocene (Bridgerian) by Fields and others (1985, fig. 4 and Appendix A). The Sage Creek Formation is the basal unit of the Tertiary Sage Creek basin formed during extensional tectonics that followed thrusting. It underlies the Eocene Challis-equivalent basalt of Hall Spring (Fields and others, 1985). Although A.R. Tabrum (oral and written communs., 1987 and 1989) believes that the contact between the Red Butte Conglomerate and the Sage Creek Formation is entirely faulted, Perry believes, based on field observations, that it is in part faulted and is in part an angular unconformity at which the Sage Creek Formation rests unconformably on the Red Butte Conglomerate. Because of these disagreements and the

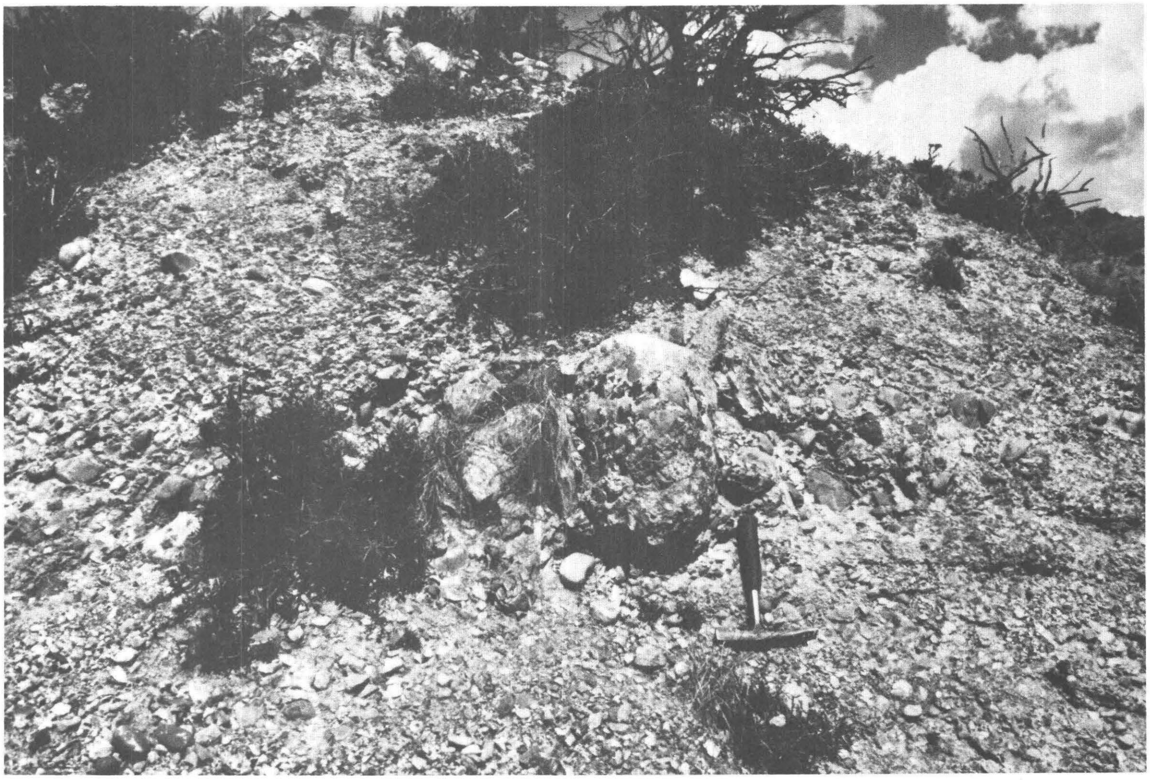


Figure 6. Cluster of large boulders of reworked limestone conglomerate. The largest boulders in the Red Butte Conglomerate are composed of such clasts. Note that these boulders are "outsized" in that they are far larger than the surrounding cobble conglomerate.

importance of this unit in the tectonic history of the region, the structural relations of the Sage Creek Formation as well as its sedimentology and petrology deserve further study. The date of the youngest thrust-belt deformation in Montana is 57 Ma (Paleocene; Harlan and others, 1988). A Maastrichtian to Paleocene age for the Red Butte Conglomerate as well as for Tendoy thrust development thus appears likely, although an early Eocene minimum age cannot at this point be ruled out.

DEPOSITIONAL ENVIRONMENT OF THE RED BUTTE CONGLOMERATE

We interpret the Red Butte as a product of deposition on alluvial fans dominated by ephemeral sheetfloods and debris flows similar to alluvial fans of the Basin and Range region of the arid southwestern United States. This depositional setting contrasts with that of the large-scale, braided-stream-dominated fans of the Lima Conglomerate (Haley, 1983a, b, 1986).

The Red Butte Conglomerate can be divided broadly into two lithofacies: (1) a conglomerate-dominated facies, which characterizes the Red Butte in its type area (fig. 4*A*) and over most of its outcrop area, and (2) an interbedded sandstone-conglomerate facies, which is restricted to the exposures at Chute Canyon in its reference section (fig. 4*B*) (the informal Chute Canyon sandstone of Ryder and Scholten, 1973).

The Conglomerate Facies

The conglomerate facies consists of two subfacies: (1) a matrix-supported conglomerate subfacies, and (2) a stratified clast-supported conglomerate subfacies. The first is approximately equivalent to the "Gm facies" of Miall (1977, 1978) and many other workers (see Miall, ed., 1978; Koster and Steel, eds., 1984). The second is identical to the "Gms facies" of Miall (1978). Both these subfacies contain sandstone as a minor component.

Matrix-supported conglomerates are very poorly sorted, and the framework clasts are supported by a muddy matrix. Although these conglomerates comprise a volumetrically small percentage of the total conglomerate facies, their presence is significant (fig. 10). Lenses and beds of matrix-supported conglomerate may range in thickness from one-third of a meter to more than 2 meters. Framework clasts range in size from pebbles to large boulders. Internally, these beds and lenses are disorganized and show neither grading,

Figure 7. Poorly sorted, matrix-supported conglomerate interpreted as being of debris flow origin. Note small boulder of recycled limestone conglomerate to right of pencil. Pencil is about 13 centimeters long.

preferred orientation, nor layering. Figure 10 illustrates a particularly large coarse lens of matrix-supported conglomerate. We interpret the matrix-supported conglomerates as products of deposition by debris flow. Coarse debris flows on modern alluvial fans generally occur as lobes and levees. The flat bottom and convex top of the lens in figure 10 is typical of a cross section through a lobe or levee.

Clast-supported conglomerates are of two types: (1) Well-sorted, flat-bedded conglomerates are characterized by a vertical alternation of clast sizes in discontinuous thin beds 2–10 cm thick (fig. 11). Pebble-cobble alternations and large and small pebble alternations are most typical. A preferred orientation of clasts parallel to both bedding and imbrication is common. Coarse and fine pebble alternations are similar to the products of shallow sheetflow described by Bull (1972, 1977). (2) Poorly sorted conglomerates (fig. 8) are generally coarser and commonly contain clasts as large as boulders. These conglomerates commonly show imbrication but are not internally bedded. This type of conglomerate typically occurs in discontinuous lens-shaped bodies. Conglomerates such as these are generally interpreted as longitudinal bar deposits, although some may result from the washing and winnowing of debris-flow deposits. That debris flows were more important than the large amount of clast-supported material records is indicated by the common occurrence of "outsized" boulders. These unusually large boulders (as much as 2 m in diameter) sit conspicuously in a host conglomerate of much smaller material. These large boulders may occur singly or in clusters (fig. 6). Outsized boulders are common in alluvial fans (fig. 12) and are probably the surviving record of reworked debris flows.

Clast-supported conglomerates commonly fill deeply incised channels that have vertical walls and flat bottoms. Channel depths of a meter or more are common. Figure 10 illustrates the lower part of a particularly large channel at least 6 m deep. Incised channels such as these are abundant in the proximal and medial parts of alluvial fans.

Interbedded Sandstone-Conglomerate Facies

The interbedded sandstone-conglomerate facies present at Chute Canyon contains two subfacies—sandstone and conglomerate—in roughly equal proportions (fig. 4). The conglomerate subfacies is similar to the conglomerate facies except that the matrix-supported conglomerates are rare and thinner (0.7 m was the

Figure 8. Poorly sorted, clast-supported conglomerate interpreted as longitudinal bar deposits. Note west-dipping imbrication. Well-rounded clasts are Belt quartzite. Lower part of hammer handle at lower right is about 15 centimeters long. View is to the north.

thickest observed), and the largest boulders are less than one-half meter across. Conglomerate-filled, flat-bottomed, incised channels are also present. These channels are locally quite conspicuous because they are commonly incised into sandstone. They reach a maximum depth of about 2 m.

The sandstone subfacies is composed of tabular thin beds of poorly sorted, very coarse grained to fine-grained sandstone interbedded with siltstones. Some of the coarsest sandstones are pebbly. Bioturbation is abundant and sedimentary structures are preserved mainly in the coarser beds. Discontinuous horizontal or low-angle stratification is the most common layering style preserved. Small-scale scours are abundant and some are floored by pebbles. Current lineations are the primary bedding-plane feature. Ripple cross-lamination is rarely preserved, but wispy lamination in some of the bio-turbated sandstones suggests that, at the time of deposition, ripples were originally more common than the record now suggests.

The interbedded siltstones range in thickness from seams about a centimeter thick to interbeds one-half meter thick. These siltstones range from red or gray to black.

Conspicuously absent from the interbedded sandstone-conglomerate facies is the large-scale cross-bedding characteristic of braided streams (Boothroyd and Nummedal, 1978; Miall, 1977, 1978; Boothroyd and Ashley, 1975; Bluck, 1974; Smith, 1974; Rust, 1972; Williams and Rust, 1969; Doeglas, 1962). This is a striking and important difference between the Red Butte Conglomerate and sandy facies of the Lima Conglomerate in which large-scale cross-bedding is abundant (Haley, 1983a,b). The flat- and ripple-cross-lamination and current lineations in the sandstones of the Red Butte Conglomerate are characteristic of shallow flow. Roots and burrows caused widespread disruption of sedimentary structures in the sandstone, suggesting punctuated aggradation. The interbedded sandstone-conglomerate facies probably records deposition on alluvial fans, much like the conglomerate facies, but at a more distal location as suggested by the smaller clast size, the shallower channels, and the thinner, and rare, debris-flow deposits.

Comparison with the Lima Conglomerate

An inventory of depositional features of the Lima Conglomerate is beyond the scope of this paper. The

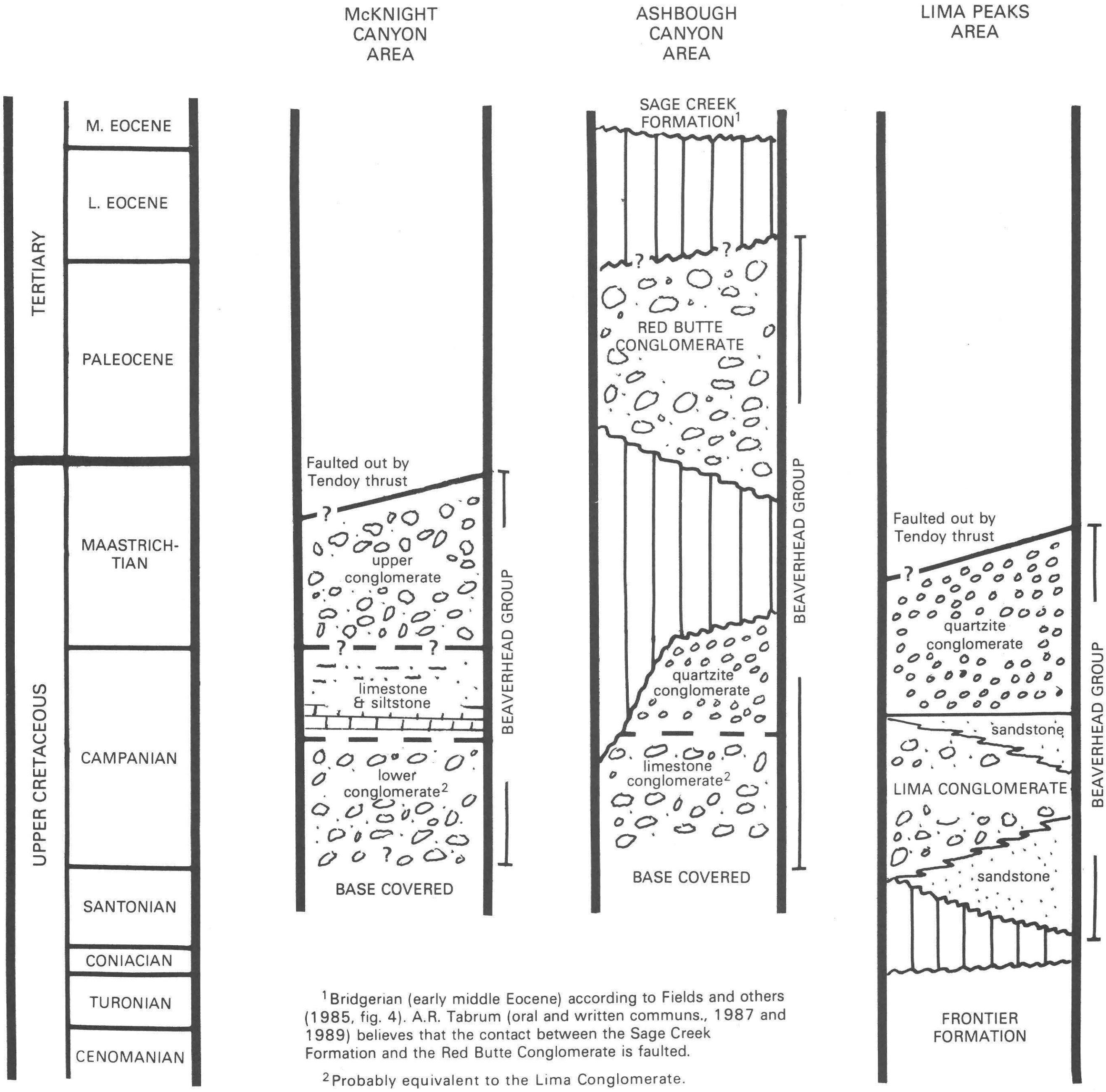


Figure 9. Stratigraphic relationships of the various formal and informal units within the Beaverhead Group. Because we lack biostratigraphic or isotopic evidence of the age of the Red Butte Conglomerate, we must query the age of this unit, although we believe the indirect evidence pointing to an early Tertiary age for most of the Red Butte Conglomerate to be strong. A.R. Tabrum (oral and written communs., 1987 and 1989) believes that the contact between the Sage Creek Formation and the Red Butte Conglomerate is faulted.

reader is referred to Haley (1986) for a detailed description of the sedimentology of the Lima Conglomerate ("Antone Peak Formation" in that work). However, for the purpose of comparison, a few of the important differences between the Lima and Red Butte Conglomerates are listed next:

1. The Red Butte Conglomerate contains debris flows characterized by matrix support, very poor sorting, and no organized fabric. The Lima Conglomerate lacks this lithology and appears to be entirely fluvial.

2. The deeply incised channels so abundant in the Red Butte and characteristic of alluvial fans are absent in the Lima Conglomerate.

3. Horizontally stratified, thinly bedded pebble and pebble-cobble conglomerates (fig. 11) dominate the water-laid conglomerates in the Red Butte. Horizontally

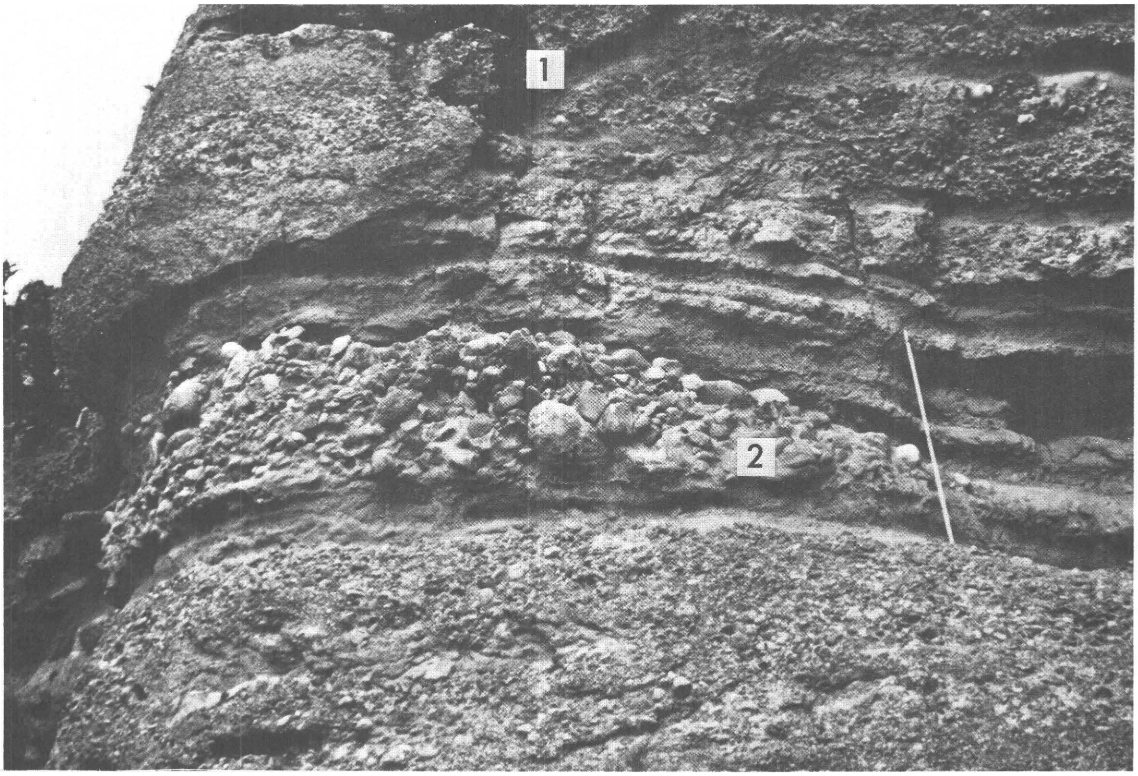


Figure 10. Outcrop of the Red Butte Conglomerate near Spring Gulch shows two large-scale features of the conglomerate facies: (1) large, deeply incised channel filled with clast-supported conglomerate, and (2) bouldery lens of matrix-supported conglomerate. The flat bottom and convex top of lens represent a cross-sectional view through a debris-flow lobe or levee. Jacob's staff is 1.8 meters long.

stratified sandstones also predominate. Thick, coarser, longitudinal bar deposits completely dominate the conglomerates in the Lima Conglomerate. Pebble conglomerates and sandstones typically are cross-stratified, and cross-bed sets are as much as a meter thick.

DISCUSSION

The Red Butte Conglomerate is significant because it is the first recognized conglomerate derived from the frontal-most thrust sheets in the Lima region. As such, the Red Butte is important in refining the deformation history of southwestern Montana. The recognition of the contrast in depositional environments between the Red Butte and the Lima Conglomerate suggests either a relationship between the type of source area (foreland uplift or thrust belt) and dominant depositional processes (braided stream or ephemeral flood and debris flow) or a change in climate in uppermost Cretaceous or Paleocene time.

Uplift History of Southwestern Montana

As we have discussed, the Red Butte Conglomerate cannot be dated directly. However, based on mapped relationships and clast composition, the stratigraphic position of the formation relative to other units in the Beaverhead Group can be deduced. The Red Butte Conglomerate is probably the youngest deposit in the Beaverhead Group of the study area (fig. 1). The inclusion of McKnight limestone clasts and recycled Belt quartzite clasts combined with the unconformable relationship between the Red Butte Conglomerate and older limestone and quartzite conglomerates requires that the Red Butte Conglomerate be the youngest Beaverhead conglomerate north of Lima. The areal and temporal relationships between the Red Butte Conglomerate, older Beaverhead units, and the Tertiary Sage Creek Formation were described in an earlier section and are summarized in figure 9. Linking these conglomerates with their uplift events results in the following refined uplift history for the Lima region:

1. Uplift and erosion of the Blacktail-Snowcrest uplift and deposition of the Lima Conglomerate from Coniacian to middle Campanian time (dates from Nichols and others, 1985).

2. Uplift and erosion of western thrust sheets shedding Proterozoic Belt quartzite detritus east into the Lima area, resulting in extensive deposits of quartzite conglomerates in the Lima Peaks and Ashbough Canyon areas. The western source area is required because the

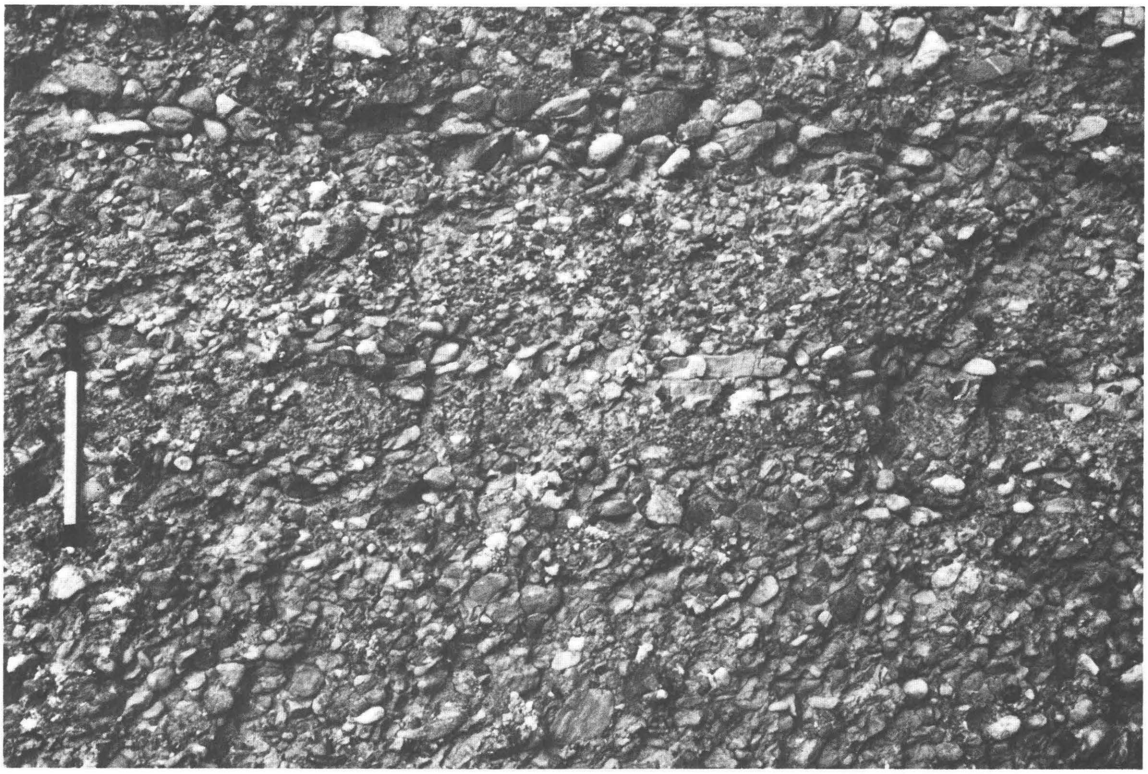


Figure 11. Thin-bedded, pebble-cobble conglomerate interpreted as the deposits of shallow sheet flood. Pen is 12 centimeters long.

Belt Supergroup is absent in the Blacktail-Snowcrest uplift and is present only to the west of the Lima area (Ryder and Scholten, 1973).

3. An overall foreland progression of thrust faulting in the thrust belt (Perry and Sando, 1983) resulted in the following events: first, widespread deposition of the quartzite conglomerates, then deposition of the upper limestone conglomerates of the McKnight Canyon area (Haley, 1986; and fig. 8), and, finally, uplift along the Tendoy thrust accompanied by deformation and erosion of older Beaverhead conglomerates and deposition of the Red Butte Conglomerate. This final phase ended by Eocene time.

Changing Depositional Processes in the Beaverhead Group

What controlled the profound difference in depositional style between the Lima Conglomerate and the Red Butte Conglomerate is an intriguing question. Three possible controls are (1) change in climate, (2) different slopes in the source terranes, and (3) the type of rocks eroded from the source terrane.

DeCelles and others (1987) and Graham and others (1986) suggested that source lithology primarily controlled depositional processes in the Sphinx Conglomerate, a Cretaceous synorogenic deposit derived from the Madison-Gravelly uplift, 80 km to the east of our study area. According to their model, depositional processes changed from debris flow to braided stream as gradual unroofing of the source area increased the amount of limestone available for transport and deposition at the expense of shale. Whereas source lithology can clearly exert some control on the depositing medium and, therefore, on the depositional processes, we believe that this hypothesis does not adequately explain the differences between the Lima and Red Butte Conglomerates. Except for recycled Beaverhead conglomerate clasts (less than 10 percent of the Red Butte clast assemblage) and the recycled quartzite clasts in the Red Butte Conglomerate, clast compositions of the two formations are similarly dominated by Paleozoic and early Mesozoic limestones. This similarity in clast composition suggests that the same formations were eroding during deposition of the Lima and Red Butte Conglomerates such that source-rock type is not a control.

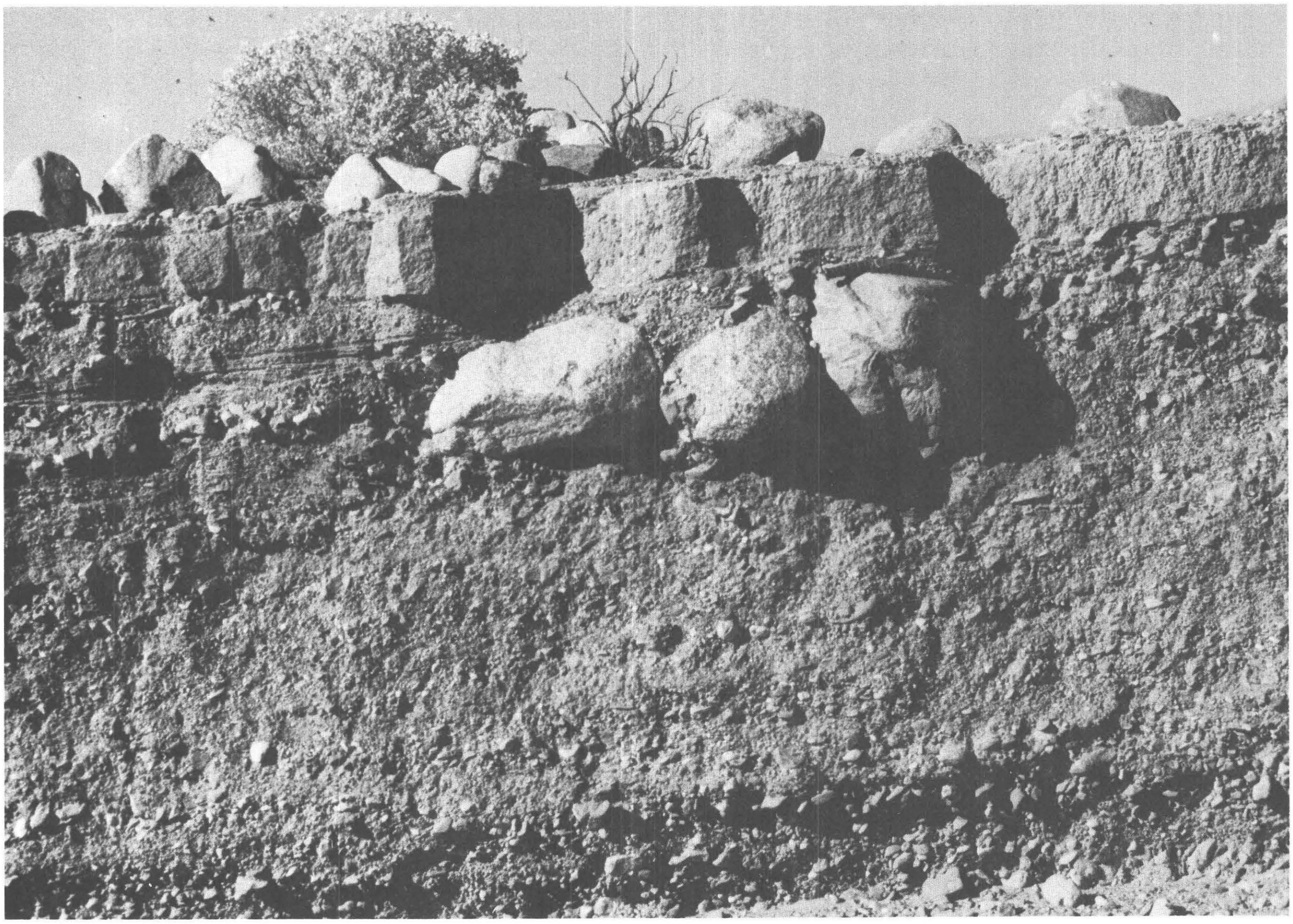


Figure 12. Three outsized boulders in stratified gravel in channel cut in Cottonwood Canyon alluvial fan, Death Valley, Calif. Compare with similar examples from the Beaverhead Group shown in figure 6. Channel wall is about 2 meters high. (Photograph courtesy of Dr. J. Smoot, U.S. Geological Survey, Denver, Colorado).

Influence of climate on depositional processes of the Beaverhead Group is difficult to assess due to lack of independent climatic indicators in the various deposits. Debris-flow-dominated fans seem to be most common in arid regions, an observation possibly due to abundant studies in arid regions and the relative neglect of other areas (Winder, 1965). Braided-stream fans, on the other hand, have been suggested as a model for fans in humid regions (Collinson, 1970; Boothroyd and Nummedal, 1978). It is tempting to suggest, therefore, that the Lima Conglomerate was deposited during a time of high rainfall and that the climate changed to more arid conditions in the Maastrichtian or Paleocene during deposition of the Red Butte Conglomerate.

Haley (1983a,b, 1986) has pointed out the relationship between the type of source area and type of resultant deposit (foreland uplift yielding braided-stream-dominated fans versus thrust belt yielding debris-flow- and ephemeral-flood-dominated fans) and suggested that uplift style dictates the type of deposit. Perry and others (1983) showed that the Blacktail-Snowcrest uplift was likely due to basement-involved thrusting on the northwest-dipping nonemergent sub-Snowcrest Range thrust along the southeastern margin of this uplift. Fairly low expected slopes on the margins of such an uplift are consistent with the predominance of low-angle fan deposits of the Lima Conglomerate. The emergent thrusts of the frontal thrust belt, on the other hand, likely resulted in steeper escarpments. Bull (1964) noted the direct relationship between slope of the trunk stream of fans and slope of fans themselves; the steeper the source streams, the steeper the fans. Fan slope can strongly influence depositional style (Ryder, 1971). Debris-flow-dominated fans described by Hooke (1967) had apex slopes of about 10°. The braided stream fans described by Boothroyd and Ashley (1975), on the other hand, had apex slopes of less than a degree.

We can only speculate at this time as to which of these factors—climate change or deformation style—caused a switch in depositional style or whether it was some combination of the two. Only more careful study of many synorogenic deposits, modern and ancient, from all types of source terranes can provide enough data to answer such questions.

REFERENCES CITED

Achuff, J.M., 1981, Folding and faulting in the northern Blacktail Range, Beaverhead County, Montana: Missoula, Mont., University of Montana Master's thesis, 64 p.

Bluck, B.J., 1974, Structure and directional properties of some alley sandur deposits in southern Iceland: Sedimentology, v. 21, p. 533–554.

Boothroyd, J.C., and Ashley, G.M., 1975, Process, bar morphology, and sedimentary structures on braided outwash fans, northeastern Gulf of Alaska, *in* Jopling, A.V. and McDonald, B.C., eds., Glaciofluvial and glaciolacustrine sedimentation: Society of Economic Paleontologists and Mineralogists Special Publication 23, p. 193–222.

Boothroyd, J.C., and Nummedal, K., 1978, Proglacial braided outwash—A model for humid alluvial fan deposits, *in* Miall, A.D., ed., Fluvial sedimentology: Canadian Society of Petroleum Geologists Memoir 5, p. 641–668.

Bull, W.B., 1964, Geomorphology of segmented alluvial fans in western Fresno County, California: U.S. Geological Survey Professional Paper 352–E, p. 89–129.

______ 1972, Recognition of alluvial fan deposits in the stratigraphic record, *in* Rigby, J.K., and Hamblin, W.K., eds., Recognition of ancient sedimentary environments: Society of Economic Paleontologists and Mineralogists Special Publication 16, p. 63–83.

______ 1977, The alluvial fan environment: Progress in Physical Geography, v. 1, p. 222–270.

Collinson, J.D., 1970, Bedforms on the Tana River, Norway: Geografiska Annaler, v. 52A, p. 31–56.

DeCelles, P.G., Tolson, R.B., Graham, S.A., Smith, G.A., Ingersall, R.V.. White, J., Schmidt, C.J., Rice, R., Moxon, I., Lemke, L., Handschy, J.W., Follo, M.F., Edwards, D.P., Cavassa, W., Caldwell, M., and Bargar, E., 1987, Laramide thrust-generated alluvial fan sedimentation, Sphinx Conglomerate, southwestern Montana: American Association of Petroleum Geologists Bulletin, v. 67, p. 725–743.

Doeglas, D.J., 1962, The structure of sedimentary deposits of braided rivers: Sedimentology, v. 1, p. 167–190.

Dyman, T.S., Perry, W.J., Jr., Nichols, D.J., Davis, L.E., and Haley, J.C., 1989, Stratigraphy, petrology, and provenance of the Cenomanian to Turonian Frontier Formation near Lima, southwest Montana, *in* French, D.E., and Grabb, R.F., Geologic resources of Montana: Montana Geological Society 1989 Field Conference Guidebook, p. 103–114.

Fields, R.W., Rasmussen, D.L., Tabrum, A.R., and Nichols, R., 1985, Cenozoic rocks of the intermontane basins of western Montana and eastern Idaho—A summary, *in* Flores, R.M., and Kaplan, S.S., Cenozoic paleogeography of the west-central United States: Denver, Colo., Rocky Mountain Section, Society of Economic Paleontologists and Mineralogists, Rocky Mountain Paleogeography Symposium 3, p. 9–36.

Graham, S.A, Tolson, R.B., DeCelles, P.G., Ingersall, R.V., Bargar, E., Caldwell, M., Cavassa, W., Edwards, D.P., Follo, M.F., Handschy, J.W., Lemke, L., Moxon, I., Rice, R., Smith, G.A., and White, J., 1986, Provenance modelling as a technique for analyzing source terrane evolution and controls on foreland sedimentation, *in* Allen, P.A. and Homewood, P., eds., Foreland basins: International Association of Sedimentologists Special Publication 8, p. 425–436.

Haley, J.C., 1983a, Depositional processes in the Beaverhead Formation, southwestern Montana-northwestern Idaho, and their tectonic significance [abs.]: American Association of Petroleum Geologists Bulletin, v. 67, p. 1340.

______ 1983b, Sedimentology of a synorogenic deposit; The Beaverhead Formation of Montana and Idaho: Geological Society of America Abstracts with Programs, v. 15, p. 589.

______ 1986, Upper Cretaceous (Beaverhead) synorogenic sediments of the Montana-Idaho thrust belt and adjacent foreland; Relationships between sedimentation and tectonism: Baltimore, Md., The Johns Hopkins University unpublished Ph.D. dissertation, 542 p.

Harlan, S.S., Geissman, J.W., Lageson, D.R., and Snee, L.W., 1988, Paleomagnetic and isotopic dating of thrust-belt deformation along the eastern edge of the Helena salient, northern Crazy Mountains basin, Montana: Geological Society of America Bulletin, v. 100, p. 492–499.

Hooke, R. Le B., 1967, Processes on arid-region alluvial fans: Journal of Geology, v. 75, p. 438–460.

Johnson, P.P., 1981, Geology of the Red Rock fault and adjacent Red Rock valley, Beaverhead County, Montana: Missoula, Mont., University of Montana, M.S. thesis, 88 p.

Koster, E.H., and Steel, R.J., eds., 1984, Sedimentology of gravels and conglomerates: Canadian Society of Petroleum Geologists Memoir 10, 441 p.

Lowell, W.R., and Klepper, M.R., 1953, Beaverhead Formation—A Laramide deposit in Beaverhead County, Montana: Geological Society of America Bulletin, v. 64, p. 235–244.

Miall, A.D., 1977, A review of the braided-river depositional environment: Earth-Science Reviews, v, 13, p. 1–62.

______ 1978, Lithofacies types and vertical profile models in braided river deposits—A summary, *in* Miall, A.D., ed., Fluvial sedimentology: Canadian Society of Petroleum Geologists Memoir 5, p. 597–604.

Miall, A.D., ed., 1978, Fluvial sedimentology: Canadian Society of Petroleum Geologists Memoir 5, 859 p.

Nichols, D.J., Perry, W.J., Jr., and Haley, J.C., 1985, Reinterpretation of the palynology and age of Laramide syntectonic deposits, southwestern Montana, and revision of the Beaverhead Group: Geology, v. 13, p. 149–153.

Pecora, W.C., 1981, Bedrock geology of the Blacktail Mountains, southwestern Montana: Middletown, Conn., Wesleyan University Master's thesis, 203 p.

Perry, W.J., Jr., Haley, J.C., Nichols, D.J., Hammons, P.M., and Ponton, J.D., 1988, Interactions of Rocky Mountain foreland and Cordilleran thrust belt in Lima region, southwest Montana, *in* Schmidt, C.J., and Perry, W.J., Jr., eds., Interaction of the Rocky Mountain foreland and Cordilleran thrust belt: Geological Society of America Memoir 171, p. 267–290.

Perry, W.J., Jr., and Sando, W.J., 1983, Sequence of deformation of Cordilleran thrust belt in Lima, Montana region, *in* Powers, R.B., ed., Geologic studies of the Cordilleran thrust belt—1982: Denver, Colo., Rocky Mountain Association of Geologists, p. 137–144.

Perry, W.J., Jr., Wardlaw, B.R., Bostick, N.H., and Maughan, E.K., 1983, Structure, burial history and petroleum potential of frontal thrust belt and adjacent foreland, southwest Montana: American Association of Petroleum Geologists Bulletin, v. 67, p. 725–743.

Rust, B.R., 1972, Structure and process in a braided river: Sedimentology, v. 18, p. 221–245.

Ryder, J.M., 1971, The stratigraphy and morphology of paraglacial alluvial fans in south-central British Columbia: Canadian Journal of Earth Sciences, v. 8, p. 279–298.

Ryder, R.T., 1968, The Beaverhead Formation—A late Cretaceous-Paleocene syntectonic deposit in southwestern Montana and east-central Idaho: University Park, Pa., Pennsylvania State University unpublished Ph.D. dissertation, 143 p.

Ryder, R.T., and Scholten, R., 1973, Syntectonic conglomerates in southwestern Montana; their nature, origin and tectonic significance: Geological Society of America Bulletin, v. 84, p. 773–796.

Scholten, R., Keenmon, K.A., and Kupsch, W.O., 1955, Geology of the Lima region, southwestern Montana and adjacent Idaho: Geological Society of America Bulletin, v. 66, p. 345–404.

Smith, N.D., 1974, Sedimentology and bar formation in the upper Kicking Horse River, a braided outwash stream: Journal of Sedimentary Petrology, v. 82, p. 205–224.

Tanner, W.F., 1963, Crushed pebble conglomerate of southwestern Montana: Journal of Geology, v. 71, p. 637–641.

——— 1964, Crushed pebble conglomerate—A reply: Journal of Geology, v. 72, p. 489–492.

Williams, N.S., and Bartley, J.M., 1988, Geometry and sequence of thrusting, McKnight and Kelmback Canyons, Tendoy Range, southwestern Montana, *in* Schmidt, C.J., and Perry, W.J., Jr., eds., Interaction of the Rocky Mountain foreland and Cordilleran thrust belt: Geological Society of America Memoir 171, p. 307–318.

Williams, P.F., and Rust, B.R., 1969, The sedimentology of a braided river: Journal of Sedimentary Petrology, v. 39, p. 649–679.

Wilson, M.D., 1970, Upper Cretaceous-Paleocene synorogenic conglomerates of southwestern Montana: American Association of Petroleum Geologists Bulletin, v. 54, p. 1843–1867.

Winder, C.G., 1965, Alluvial cone construction by alpine mudflow in humid temperate region: Canadian Journal of Earth Science, v. 2, p. 270–277.

☆U.S. GOVERNMENT PRINTING OFFICE: 1991-573-049/26021

SELECTED SERIES OF U.S. GEOLOGICAL SURVEY PUBLICATIONS

Periodicals

Earthquakes & Volcanoes (issued bimonthly).
Preliminary Determination of Epicenters (issued monthly).

Technical Books and Reports

Professional Papers are mainly comprehensive scientific reports of wide and lasting interest and importance to professional scientists and engineers. Included are reports on the results of resource studies and of topographic, hydrologic, and geologic investigations. They also include collections of related papers addressing different aspects of a single scientific topic.

Bulletins contain significant data and interpretations that are of lasting scientific interest but are generally more limited in scope or geographic coverage than Professional Papers. They include the results of resource studies and of geologic and topographic investigations; as well as collections of short papers related to a specific topic.

Water-Supply Papers are comprehensive reports that present significant interpretive results of hydrologic investigations of wide interest to professional geologists, hydrologists, and engineers. The series covers investigations in all phases of hydrology, including hydrogeology, availability of water, quality of water, and use of water.

Circulars present administrative information or important scientific information of wide popular interest in a format designed for distribution at no cost to the public. Information is usually of short-term interest.

Water-Resources Investigations Reports are papers of an interpretive nature made available to the public outside the formal USGS publications series. Copies are reproduced on request unlike formal USGS publications, and they are also available for public inspection at depositories indicated in USGS catalogs.

Open-File Reports include unpublished manuscript reports, maps, and other material that are made available for public consultation at depositories. They are a nonpermanent form of publication that may be cited in other publications as sources of information.

Maps

Geologic Quadrangle Maps are multicolor geologic maps on topographic bases in 7 1/2- or 15-minute quadrangle formats (scales mainly 1:24,000 or 1:62,500) showing bedrock, surficial, or engineering geology. Maps generally include brief texts; some maps include structure and columnar sections only.

Geophysical Investigations Maps are on topographic or planimetric bases at various scales; they show results of surveys using geophysical techniques, such as gravity, magnetic, seismic, or radioactivity, which reflect subsurface structures that are of economic or geologic significance. Many maps include correlations with the geology.

Miscellaneous Investigations Series Maps are on planimetric or topographic bases of regular and irregular areas at various scales; they present a wide variety of format and subject matter. The series also includes 7 1/2-minute quadrangle photogeologic maps on planimetric bases which show geology as interpreted from aerial photographs. Series also includes maps of Mars and the Moon.

Coal Investigations Maps are geologic maps on topographic or planimetric bases at various scales showing bedrock or surficial geology, stratigraphy, and structural relations in certain coal-resource areas.

Oil and Gas Investigations Charts show stratigraphic information for certain oil and gas fields and other areas having petroleum potential.

Miscellaneous Field Studies Maps are multicolor or black-and-white maps on topographic or planimetric bases on quadrangle or irregular areas at various scales. Pre-1971 maps show bedrock geology in relation to specific mining or mineral-deposit problems; post-1971 maps are primarily black-and-white maps on various subjects such as environmental studies or wilderness mineral investigations.

Hydrologic Investigations Atlases are multicolored or black-and-white maps on topographic or planimetric bases presenting a wide range of geohydrologic data of both regular and irregular areas; principal scale is 1:24,000 and regional studies are at 1:250,000 scale or smaller.

Catalogs

Permanent catalogs, as well as some others, giving comprehensive listings of U.S. Geological Survey publications are available under the conditions indicated below from the U.S. Geological Survey, Books and Open-File Reports Section, Federal Center, Box 25425, Denver, CO 80225. (See latest Price and Availability List.)

"Publications of the Geological Survey, 1879-1961" may be purchased by mail and over the counter in paperback book form and as a set of microfiche.

"Publications of the Geological Survey, 1962-1970" may be purchased by mail and over the counter in paperback book form and as a set of microfiche.

"Publications of the U.S. Geological Survey, 1971-1981" may be purchased by mail and over the counter in paperback book form (two volumes, publications listing and index) and as a set of microfiche.

Supplements for 1982, 1983, 1984, 1985, 1986, and for subsequent years since the last permanent catalog may be purchased by mail and over the counter in paperback book form.

State catalogs, "List of U.S. Geological Survey Geologic and Water-Supply Reports and Maps For (State)," may be purchased by mail and over the counter in paperback booklet form only

"Price and Availability List of U.S. Geological Survey Publications," issued annually, is available free of charge in paperback booklet form only.

Selected copies of a monthly catalog "New Publications of the U.S. Geological Survey" available free of charge by mail or may be obtained over the counter in paperback booklet form only. Those wishing a free subscription to the monthly catalog "New Publications of the U.S. Geological Survey" should write to the U.S. Geological Survey, 582 National Center, Reston, VA 22092.

Note.--Prices of Government publications listed in older catalogs, announcements, and publications may be incorrect. Therefore, the prices charged may differ from the prices in catalogs, announcements, and publications.