Laramide Faulting and Orogeny on the North Flank of the Uinta Mountains in Eastern Daggett County, Utah

by

W.R. HANSEN
U.S. GEOLOGICAL SURVEY
DENVER FEDERAL CENTER
DENVER, COLORADO
AND
M.G. BONILLA
U.S. GEOLOGICAL SURVEY
MENLO PARK, CALIFORNIA

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ABSTRACT

An early orogeny, far greater in intensity than any subsequent disturbance, occurred in the eastern Uinta Mountain area after deposition of the Red Creek quartzite in pre-Cambrian time. A long period of subsidence then ensued, bebinning with deposition of the Uinta Mountain group in the newly formed Uinta trough and lasting until Late Cretaceous time. Although subsidence was interrupted now and then by gentle uplift and erosion, significant movements did not recur until the Laramide orogeny. Laramide movements in this area may be divided into three separate phases, the first and third of which culminated in thrust faulting. The first phase began with deep-seated southerly stresses that elevated the Uinta arch on the site of the old Uinta trough. Stresses from a westerly direction then produced minor flanking folds -- anticlinal noses and their synclinal counterparts -- approximately normal in trend to the main structure. It is suggested that the Uinta arch moved eastward relative to the Green River Basin, setting up shear couples that ultimately produced the present pattern of thrust faulting. Rupture on the Uinta fault occurred before Tertiary time and was accompanied by a strong strike-slip

component of movement in which the mountainward or upthrown block moved east relative to the basinward block. Quiescence in early Tertiary time was followed by strong uplift, the second phase of the orogeny, during deposition of the Wasatch formation. Further quiescence was then terminated by renewed thrusting in post-Eocene time, the third phase of the orogeny, when rupture occurred on the Henrys Fork fault and renewed movement occurred on the Uinta fault.

Normal faults are abundant in the pre-Cambrian rocks south of the Uinta fault but are rare in the younger rocks north of it. Dating of movements on most of these is uncertain. Some faults appear to be of pre-Cambrian age; others certainly moved during the post-Miocene collapse of the east end of the Uinta Mountains.

INTRODUCTION

Geologic mapping was started in August of 1951 in the area bordering the upper Green River in Utah, between the town of Manila on the west and the Browns Park area on the east, as a part of the U.S. Geological Survey's program for studying areas containing sites of proposed heavy construction. Ashley dam site in Red Canyon is near the center of the area: a dam there would create a long fiordlike lake extending nearly to Green River, Wyoming. A second lake, inundating parts of Browns Park, will be created if the proposed Echo Park dam on the south flank of the Uinta Mountains is built.

The area considered in this report (pl. 1) is bounded on the north by the Utah-Wyoming state line, on the east by the Utah-Colorado state line, on the south by latitude 40°52'30", and on the west by longtitude 109°45'. Detailed maps are being prepared for publication by the U.S. Geological Survey. Although this area has been visited in the past by many geologists, little detailed mapping has been done prior to the present investigation.

A thick section of stratified rocks, ranging in age from pre-Cambrian to Recent, underlies the area. Except for the intense pre-Cambrian orogeny that followed deposition of the Red Creek quartzite, the history of the area prior to the Laramide orogeny was one of quiescence -- long periods of slow subsidence and aggradation interrupted intermittently by gentle uplift and erosion. The stratigraphy is summarized in figure 1. A fuller discussion of the stratigraphy than that which follows will appear in a forthcoming paper on the Flaming Gorge quadrangle (Hansen, in preparation).

STRATIGRAPHY

Pre-Cambrian. — The oldest rocks in the section, the Red Creek quartzite of pre-Cambrian age, crop out mostly in an area east of the top of Goslin Mountain between the Uinta fault on the north and Browns Park on the south; a few small areas of Red Creek quartzite are upfaulted west of Goslin Mountain along the Uinta fault. The Red Creek quartzite attained a high grade of metamorphism before deposition of the overlying Uinta Mountain group. In most places it is massive and completely recrystallized. Much of the bedding has been obliterated, and in many places bedding attitudes cannot be reliably determined. The rock contains considerable quartz-mica schist, staurolite - garnet - quartz-mica schist, and garnet-hornblende schist; locally it is feldspathic and gneissic. Contacts between various lithologic types commonly are indefinite, although many amphibolite masses possess sharp discordant contacts and are regarded as metamorphosed dike rocks.

The Uinta Mountain group of later pre-Cambrian age is more widely exposed than any other unit. It consists chiefly of massive to cross-bedded red siliceous sandstone and quartzite with lesser amounts of varicolored shale and argillite. Conglomerates, some very coarse, occur in considerable thickness on the northwest slope of Goslin Mountain, near the top of the Uinta Mountain group just south of Clay Basin, and in lesser quantities elsewhere. Most if not

STRATIGRAPHIC SUMMARY

Period	Correlative Units: Central Wasatch Mountains	Correlative Units: Rock Springs Uplift	Daggett County, Utah	Thickness (Feet): Flaming Gorge	Thickness (Feet): Clay Basin
Tertiary			Browns Park*		
		Bishop			
		Green River	Green River*		
	Knight				
	Fowkes	Wasatch	Wasatch*	2,000 +	2,000 +
	Almy				
		"Post Laramie"	Ft. Union(?)	2,000 ±	1,000 ±
Cretaceous	Henefer of Eardley (1944)	Lance			
		Lewis			
		Almond			
		Ericson	Ericson	290	800
		Rock Springs	Rock Springs	1,090	100
		Blair	Blair	360	
		Baxter	Hilliard	6,300	6,400 ±
	Frontier	Frontier	Frontier	190	117
	Aspen	Aspen	Mowry	200	240
	Kelvin	Dakota			
		Fuson(?)	Dakota(?)	250 - 300	135
		Lakota(?)			
Jurassic		Morrison	Morrison	940	600
	Stump	Curtis	Curtis	146	177
	Preuss	Entrada	Entrada	245	100
	Twin Creek	Carmel	Carmel	325	108
	Nugget	Nugget	Navajo	815	778
Triassic	Ankareh	Jelm	Chinle	280	228
	So-called Suicide Member	Basal	Shinarump	20 - 90	25
	Thaynes				
	Woodside	Chugwater	Moenkopi	725	895
		Dinwoody	Dinwoody(?)	530	
Permian	Park City	Phosphoria	Park City	328	325
Pennsylvanian	Weber	Tensleep or Weber	Weber	956	330 +
	Morgan	Amsden or Morgan	Morgan	930	No penetration below Weber
Mississippian and Older Paleozoic Rocks	Humbug	No penetration below Amsden	Unnamed shale	Not determined	
			Humbug		
	Deseret		Deseret		
	Several units without correlatives in eastern Daggett County		Fault contact		
Pre-Cambrian	Big Cottonwood Series		Uinta Mountain Group	15,000 ±	
	Older Pre-Cambrian rocks		Red Creek Quartzite	Not determined	

* Incomplete sections

** R. D. Murphey Well 6-W (W. W. Skeeters, personal communication)

Figure 1.

all of the conglomerate was derived from a source in the Red Creek quartzite; the basal contact of the group, where exposed, is overlain in most places by such conglomerate. At all other places in the area the Uinta Mountain group is bounded by faults, except in Browns Park where it is overlain unconformably by the Browns Park formation, and in parts of Red Canyon, where it is overlain by patches of well-lithified fanglomerate of probably Pliocene age (not shown on the map).

Mississippian.—The oldest Paleozoic rocks in the area are Mississippian in age. These rocks crop out in a normal sequence only in the extreme western part of the area, although a few limestone slices within the Uinta fault may be of Mississippian age. In the western part of the area the exposed Mississippian rocks are assigned to three units, in ascending order, the Deseret limestone; the Humbug formation of interbedded limestone, red to gray sandstone, and brown quartzite; and an unnamed unit of red and black shale, possibly correlative with the Manning Canyon shale. This in turn is overlain by the Morgan formation of Pennsylvanian age.

Pennsylvanian.—Pennsylvanian rocks of the area include the Morgan formation and the overlying Weber sandstone. The Morgan formation is a threefold unit comprising a lower limestone sequence; a middle red-bed sequence of shale, siltstone, limestone, and sandstone; and an upper sequence of interbedded limestone and sandstone. The upper sequence grades westward and upward into the Weber sandstone; McMinn (1948, p. 20) has shown that the limestone beds thin and wedge out toward the west and that the sandstone beds merge into and become part of the Weber sandstone. The top of the uppermost limestone bed is arbitrarily considered to be the top of the Morgan formation.

The overlying Weber sandstone forms massive cliffs and rugged canyons south of Manila and Flaming Gorge in the western part of the area. (See pl. 2.) It is a uniformly fine-

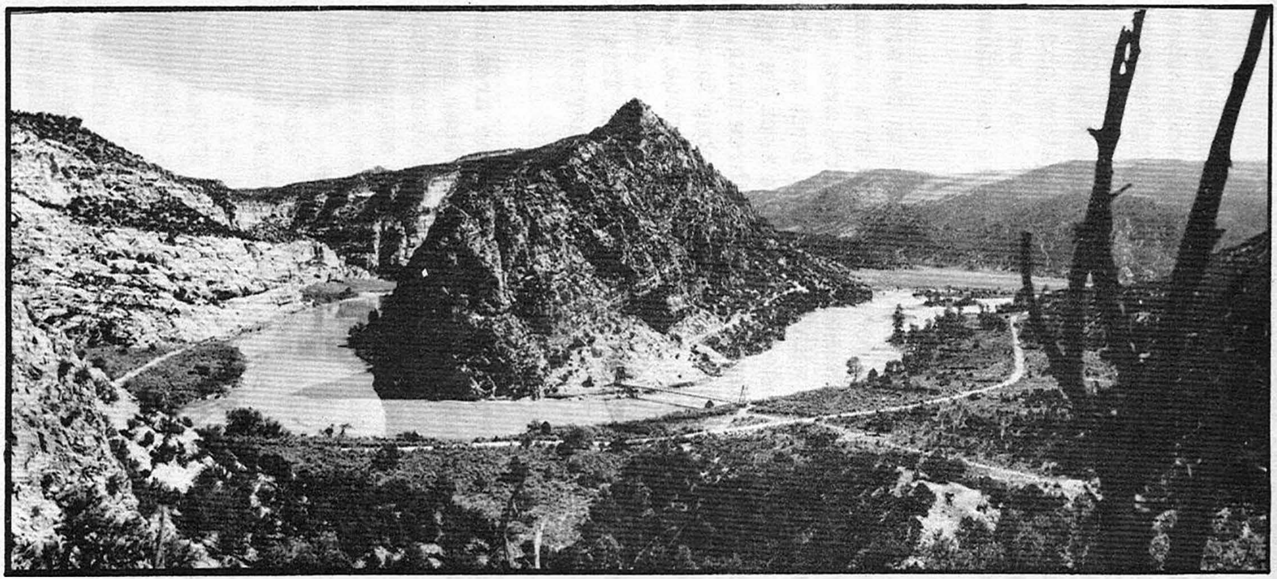

Plate 2. View northeast along Uinta fault from Hideout Canyon. The Uinta fault passes from center of picture, in foreground, to right of sharp ridge and through low saddle beyond. Note overturning (in Morgan formation) in sharp ridge adjacent to fault, and gentle dips (in Weber and Park City formations) to left away from fault. Kingfisher Canyon of the Green River is carved in Weber sandstone at left; Uinta Mountain group forms Bear Mountain at right.

grained mostly calcareous massive to highly cross-bedded cream-colored sandstone.

Permian.—The Park City formation of Permian age is roughly coextensive with the Weber sandstone, on which it rests with a sharp, probably disconformable contact. It forms prominent flatirons and dip slopes south of Manila and Flaming Gorge, and its basal beds commonly form a cap rock on the Weber cliffs. It is divisible into three contrasting members: a lower member, doubtfully Permian, of gray limestone, dolomite, and sandstone; a middle member of phosphatic shale, mudstone, limestone, and dolomite; and an upper member of gray cherty limestone, gray dolomite, and brownish sandstone. Red siltstone is exposed discontinuously about midway in the upper member. Overlying the Park City formation with a sharp lithologic break is the Dinwoody (?) formation of Triassic age.

Triassic.—Triassic rocks of the area comprise four formations, in ascending order, the Dinwoody (?), the Moenkopi, the Shinarump, and the Chinle. The gray shales of the Dinwoody (?) formation contrast markedly with the red beds of the overlying Moenkopi formation. However, the boundary between the two is gradational and is arbitrarily placed at the color change from predominantly gray beds below to predominantly red beds above. In the exposed section in the western part of the area the boundary appears to be at about the same horizon everywhere, but in the subsurface section at Clay Basin red beds occur in significant proportions throughout the combined Dinwoody (?) - Moenkopi interval, although the lowermost 170 feet is chiefly green or greenish gray. The Moenkopi formation is overlain unconformably by the Shinarump conglomerate.

In this area the Shinarump is more properly a gritty or pebbly sandstone than a true conglomerate. Its contact with the underlying Moenkopi formation has considerable relief, especially where the Shinarump fills channels scoured in the upper part of the Moenkopi by pre-Shinarump erosion.

Upward the Shinarump grades transitionally into the Chinle formation, although the contact is generally fairly sharp. The Chinle formation likewise appears to grade upward into the Navajo sandstone, of Jurassic (?) age, without any break in sedimentation, even though the contact is sharp and well defined.

Jurassic.—Impressive cliffs of Navajo sandstone form a nearly continuous barrier from Flaming Gorge west to the limit of the area. The Navajo is composed chiefly of very pale gray almost uniformly fine-grained, highly cross-bedded eolian sandstone. Its Jurassic age has never been conclusively established, and a possible Triassic age is suggested by the apparently conformable basal contact. The Carmel formation of the San Rafael group rests disconformably on the Navajo sandstone.

The San Rafael group of this area, comprising the Carmel formation, the Entrada sandstone, and the Curtis formation, strongly resembles the Sundance formation of central Wyoming; and a direct correlation between Carmel and lower Sundance, Entrada and the red zone of the Sundance, and Curtis and upper Sundance seems probable. Although the group as a whole thins appreciably from Flaming Gorge to Clay Basin, the Curtis formation is thinner at Flaming Gorge than at Clay Basin. Also, the bright red color of much of the Entrada sandstone west of Flaming Gorge is lacking at Clay Basin, where the formation is light gray. A sharp lithologic break at the top of the Curtis formation marks a change from the marine and onshore environments, under which most of the San Rafael group was deposited, to the flood plain environment, under which the overlying Morrison formation was deposited.

The Morrison formation consists chiefly of variegated red, gray, and greenish shales and lesser but considerable amounts of coarse-grained sandstone and pebble conglomerate. Conglomerate is most abundant in the lower part of the section; in places the basal beds are conglomerate. The formation is overlain and channeled by the Dakota (?) formation of Early Cretaceous age.

Cretaceous.—The Dakota (?) formation is divisible into three units, a lower and an upper sandstone separated by carbonaceous shales. The lower sandstone varies appreciably in thickness and in places is nonexistent. The upper sandstone, which commonly fills shallow channels in the top of the shale unit, is overlain by the distinctive Mowry shale, also of Early Cretaceous age.

Dark gray siliceous shale, weathering silvery gray, and containing abundant fish scales readily identifies the Mowry shale even in small exposures. The Mowry also contains porcellanite beds as well as considerable bentonite in thin seams and in beds as thick as three feet. The boundary between the Mowry shale and the overlying Frontier formation is placed at the change from siliceous shale below to dark gray clay shale above.

The Frontier formation of Late Cretaceous age is divisible into two units, a shale unit below and a sandstone unit above. Both units vary somewhat in thickness and lithology -- the shale contains appreciable amounts of sandstone and nodular limestone, and the sandstone contains more or less shale. The formation grades upward into the Hilliard shale; the boundary is placed arbitrarily at the change from predominant sandstone below to predominant shale above.

The soft Hilliard shale underlies Lucerne Valley, Antelope Flat, and Clay Basin. It is partly equivalent to the Baxter shale of the Rock Springs uplift and to the Mancos shale of Moffat County, Colorado. It is chiefly drab, dark gray calcareous shale; weathered outcrops are mostly light gray to light yellowish gray. It contains considerable thinly bedded sandstone, however, and local beds of nodular limestone. Upward it intertongues with the Mesaverde group in a manner that is very well displayed in the cliffs north of Antelope Flat.

At the west end of Antelope Flat, north of Flaming Gorge, the Mesaverde group is divisible into the Blair, Rock Springs, and Ericson formations. Toward the east, however, the Blair formation intertongues with the upper part of the Hilliard shale and at the east end of Antelope Flat is entirely replaced by Hilliard shale. The Rock Springs formation similarly intertongues with the Hilliard toward the east, and at Clay Basin only the uppermost massive sandstone bed persists, although a few thinner-bedded sandstones occur in the shales below. The sandstones of the Blair and Rock Springs formations are shoreward deposits of a regressive seaway which lay to the southeast at the time of their deposition; the Hilliard shale is an off-shore deposit. Coal beds and "punky" shales in the Rock Springs formation north of Flaming Gorge are marsh deposits that accumulated marginal to the seaway as it withdrew toward the southeast. By the time that deposition of the Ericson sandstone began, the seaway had withdrawn entirely from the area, and flood-plain conditions prevailed. The relationship of the Baxter shale to the Mesaverde group in the Rock Springs uplift, which parallels the relationship of the Hilliard to the Mesaverde group in this area, is well described by Hale (1950, p. 55).

The Ericson sandstone is the youngest pre-Laramide formation in the area, and an interval of strong deformation, followed by deep erosion, intervened between the time of its deposition and that of the next younger unit, the Fort Union (?) formation.

Tertiary.—The name Fort Union (?) formation is assigned to a thick sequence of drab gray to pale yellowish gray compact silts, friable lenticular sandstones, and pebble conglomerates overlying the Ericson sandstone and underlying the Wasatch formation. The Fort Union (?) formation rests on the Ericson sandstone with an unconformity that varies from near concordance to great angularity. On the north side of Goslin Mountain, and also just east of Clay Basin, moderately dipping Fort Union (?) beds rest directly on overturned Ericson sandstone (pl. 3A), and the unconformity has a local relief of 40 feet or more. Low hogbacks of Ericson sandstone were buried beneath Fort Union (?)

sediments.

The lithology of the Fort Union (?) formation and that of the lower part of the overlying Wasatch formation do not, however, indicate any nearby lofty source; hence it seems likely that erosion kept pace with uplift. It should be pointed out, however, that probably none of the formations exposed by erosion during Fort Union (?) time, that is, the Morrison and younger formations, is of suitable lithology to act as a source for deposits coarser than those found in the Fort Union (?) formation. These deposits consist of bedded silts, variously grained sandstones, and fine conglomerates. Pebbles of recognizably local derivation in the Fort Union (?) formation include abundant shale chips from the Mowry shale and what probably are gastroliths from the Morrison and petrified wood fragments from the Dakota (?) formations.

About midway in the Wasatch section, however, coarse orogenic deposits appear; these deposits suggest a nearby source higher than the present Uinta Mountains. Boulders 3 to 4 feet in diameter are common, including materials derived from most of the resistant Paleozoic and Mesozoic formations in the area; one limestone boulder of Paleozoic age, probably Mississippian, measured 11 feet across and must have been transported at least 8 miles. The boulder beds (pl. 3B) occur as lenses or channel-fillings in finer grained conglomerate and sandstone; some of the channels had vertical sides. All of these features suggest torrential discharge and deposition, and a very strong relief seems necessary to explain transport of such coarse material so far. Certainly no similar material is being carried off the Uintas at the present time, or was in the recent past.

During Wasatch time the eastern part of the range was eroded to its pre-Cambrian core, for the Wasatch formation nearby contains abundant quartzite pebbles derived from the Uinta Mountain group. In the western part of the area no pre-Cambrian material has been definitely recognized in the Wasatch.

Toward the top of the Wasatch formation finer grained sediments again predominate, ultimately interfingering with

Plate 3 A. Unconformity between Ericson sandstone and Fort Union (?) formation. Ericson sandstone, below, dips 85° to left and is overturned.

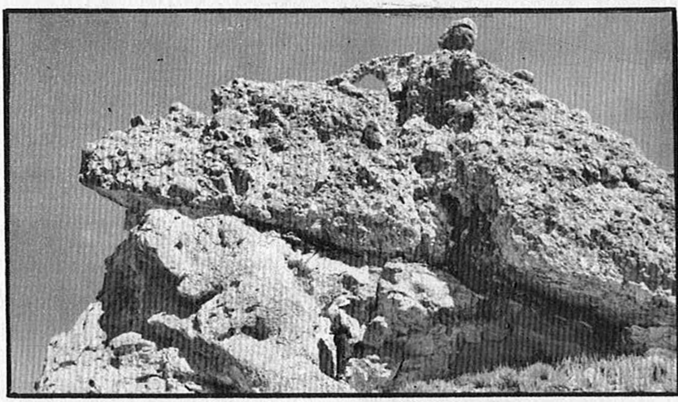

Plate 3 B. Orogenic deposits in Wasatch formation northeast of Manila. Contact dipping to right below coarse conglomerate is side of filled channel, originally near vertical. True bedding is overturned and dips steeply toward front of photograph.

and giving way to the lacustrine limestones of the Green River formation. The Green River formation crops out only in the extreme northwest corner of the area.

The youngest formation shown on the map, the Browns Park formation of Miocene age, crops out only in Browns Park; small gravel deposits tentatively correlated with it occur in a few other areas. It consists mostly of soft, friable water-laid sediments of volcanic origin -- bedded tuffs, ash, and pumice -- but it contains abundant friable sandstone and considerable conglomeratic material derived from the nearby pre-Cambrian rocks.

STRUCTURE

The present Uinta Mountains mark the site of a long-enduring depositional trough that persisted from pre-Cambrian time until the Laramide revolution. This trough is generally regarded as an east-trending arm of the larger and deeper north-trending Wasatch trough, which once lay to the west. The rather anomalous easterly trend of the Uinta anticline, as contrasted with the northerly trends of most other major Rocky Mountain folds, has been well known since the time of Powell, King, and Hayden. Its position and orientation were perhaps controlled and largely localized by the Uinta trough, as noted by Forrester (1937, p. 655); a prism of sediments, which thinned to the north and to the south, provided an area of release for stresses that accumulated in Late Cretaceous time and produced the Uinta anticline.

The Manila-Browns Park area is mostly on the north limb of this anticline and on the south margin of the Green River Basin. The crest of the anticline, trending somewhat north of east, enters Browns Park a short distance south of the area; east of there it is concealed for several miles beneath the Browns Park formation. Near the Colorado State line it turns southeastward in a broad arc. On the north limb of the fold the large Uinta fault extends the length of the area, separating pre-Cambrian rocks on the south or upthrown block from the younger strata on the north; the trend of the fault is similarly arcuate and roughly parallel to the axis of the anticline.

Flanking folds

Several minor folds flank the main anticline, modifying the homoclinal structure of the north limb of the anticline on the upthrown as well as on the downthrown side of the Uinta fault (see pl. 1). Only two of these folds, the Red Canyon anticline in pre-Cambrian rocks near Greendale and the gas-producing Clay Basin anticline, have closure. The remainder are asymmetrical anticlinal noses and their synlinal counterparts. Of these, all have certain features in common: the axes of all trend northward, chiefly northwestward or roughly normal to the trend of the main Uinta fold; the westerly limb of each nose is broad and gentle; the easterly limb is steep or overturned. The larger folds are truncated, either on the north or on the south, by the Uinta fault. Clearly a westerly component of compressive stress is indicated, a component that is further expressed in the faulting. Thus it appears that the uplift of the Uinta Mountains was more complicated than is generally believed. Simple domical uplift forced by batholithic intrusion or other deep-seated forces is inadequate to explain (1) the cross-axial character of the flanking folds, (2) the asymmetry of these folds, (3) the asymmetry of the Uinta anticline itself, which is much steeper on the north than on the south limb, and (4) the compressive stresses responsible for the large-scale thrust faulting.

Flanking noses north of the Uinta fault have been described by Curtis (1950, p. 96). Offset complements of these noses appear in the pre-Cambrian rocks of the Uinta Mountain group south of the fault. Just west of the area mapped, beyond the western termination of the Uinta fault as redefined by the authors (Hansen and Bonilla, 1953), the Lodgepole Creek nose extends south into the Uinta Mountain group without offset. The prominent Linwood nose, which is truncated on the south by the Uinta fault, is complemented in the pre-Cambrian rocks by the Red Canyon anticline. The Spring Creek nose, a very broad asymmetrical warp, is complemented by the Dutch John nose. Similarly offset synclinal troughs complement one another on opposite sides of the fault. Horizontal displacements of complementary fold axes increase eastward proportionately with an increase eastward in throw on the Uinta fault. The asymmetry of these folds, together with their horizontal displacement, is rather compelling evidence of westerly stress prior to faulting and of strong strike-slip movement on the Uinta fault.

Thrust faults

Uinta fault.—The Uinta fault (pl. 2) arises near the west boundary of the area. From there it trends sinuously north of east the entire length of the area, increasing in size and complexity toward the Utah-Colorado State line, beyond which it turns southeastward. The maximum stratigraphic throw, east of Clay Basin where the Wasatch formation is in contact with Red Creek quartzite, probably exceeds 30,000 feet. The fault zone itself increases greatly in width and thickness from west to east; near Flaming Gorge it is probably no more than 100 feet across; southeast and east of Clay Basin it has a mean width of about 1,000 feet, and locally it exceeds 3,000 feet. Owing to the southerly dip of the fault, however, the actual thickness of the fault zone may not greatly exceed 800 feet; its 3,000-foot width especially appears to be due to a local flattening of the foot wall. Although the actual plane of either wall has not been observed, the dip of the fault appears to range from about 45° to vertical, and 60° to 70° appears to be approximately the mean.

Clayey gouge, typically either black or red but commonly a mottled mixture of both, is a prominent constituent of the fault zone. A small sample of black gouge collected from the northwest side of Goslin Mountain yielded a trace of straw-yellow greasy petroleum in the laboratory. Locally the zone is mostly breccia; breccia fragments torn from most of the competent formations involved in the faulting

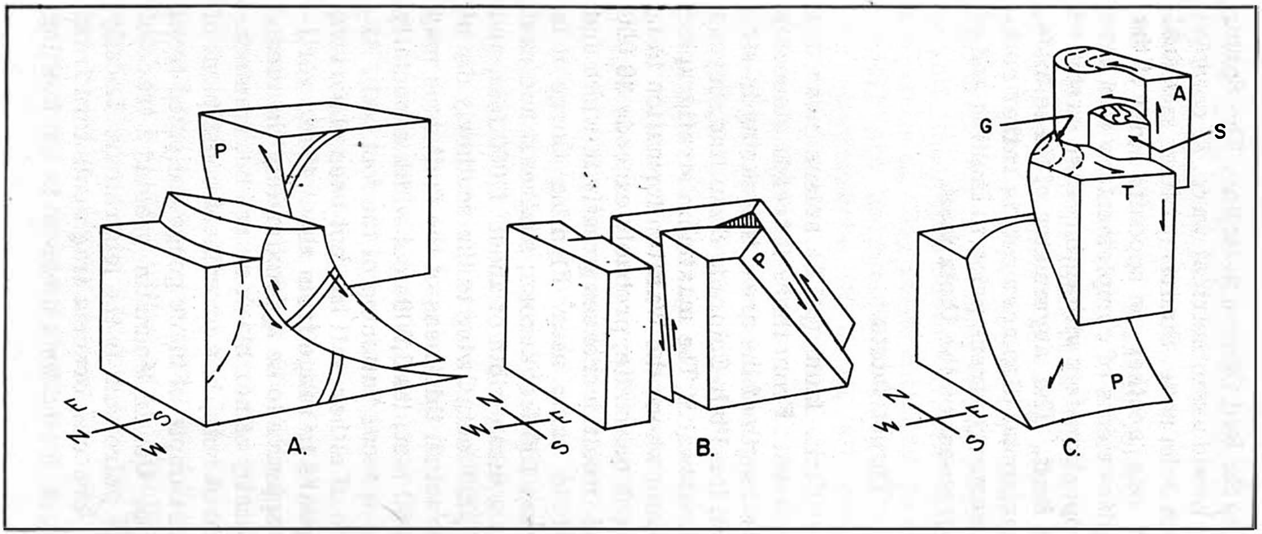

Fig. 2. Schematic block diagrams illustrating three types of fault movement. Effects of distortion and crushing are not shown. In each diagram, P is plane of Uinta fault.

A. Slice west of Dowd Mountain. Flattening of dip in slice caused by rotational movement about horizontal axis parallel to strike of fault. A slice northwest of Goslin Mountain shows similar relationships.

B. "Scissors" fault near mouth of Hideout Canyon. Reverse habit at west end and normal habit at east end caused by rotational movement about horizontal axis normal to strike of fault. Diagram is "exploded" to show movement in west part of fault.

C. Goslin fault (G). Sigmoid folding in slice, S, caused by horizontal component of drag. Note also drag in block T, toward observer, and in block A, away from observer.

are common throughout. These range in size from small blocks to great masses. Indeed, the larger masses, mostly limestone of Paleozoic age are best regarded as slices rather than breccia fragments. (See fig. 2A.) One such slice north of Dutch John Bench is about 3 miles long and 500 feet wide. A smaller but more conspicuous slice west of Goslin Mountain is about 4,000 feet long and forms a prominent butte at the head of Antelope Flat. Still other slice-like blocks, including one 6 miles west of Goslin Mountain, are of Red Creek quartzite.

Blocks of Red Creek quartzite wedged in the fault between younger rocks in both walls pose a difficult problem. Two alternate hypotheses are offered: first, that these represent blocks faulted into contact with the Uinta Mountain group in pre-Cambrian time, later to be brought against still younger rocks by the Uinta fault; and second, that the original throw on the Uinta fault was much greater than now, that Red Creek quartzite was brought up originally against post-Cambrian rocks over a much wider area than now, and that late reverse movement on the fault -- accompanying collapse of the east end of the range (Sears, 1924, p. 287-298, and Bradley, 1936, p. 185) -- left blocks of Red Creek quartzite between the foot wall and the collapsed hanging wall. For reasons presented under the heading Normal faults the first hypothesis is favored.

A zone of strong deformation, chiefly sharp overturning but also minor faulting and shattering, extends well back -- in places a mile or more -- from the walls of the fault proper. Overturning is more pronounced in the downthrown block, faulting more common in the upthrown block, a condition that may be due in part to the relatively great competence of the pre-Cambrian rocks as compared with the younger formations. The width of the overturned belt varies widely; it is greatest adjacent to northward projecting salients of the fault and least adjacent to intervening reentrants. Several high-angle faults that join the Uinta fault from the south at angles approaching normal are regarded as tears caused by differential movement within the upthrust block.

The Uinta fault appears to be of the "stretch thrust" type as defined by Billings (1942, p. 172); overturning along the fault appears to be due more to folding prior to faulting than to drag after the initial rupture. It seems improbable that mere frictional drag would be adequate to tilt and overturn rocks, competent and incompetent alike, as far distant as a mile or more from the fault plane.

Where Tertiary rocks are involved in the faulting (just west and east of Clay Basin) they display very little deformation despite their low competence and despite strong overturning in the immediately underlying Cretaceous rocks. It appears, therefore, that at least two distinct periods of thrusting have occurred on the Uinta fault, that the first and greatest movement followed sharp overturning and rupture before Tertiary time, and that the second movement, in Tertiary time and along the already established thrust plane, simply sheared the Tertiary rocks without first flexing them or subsequently dragging them.

Henrys Fork fault.—A considerable part of the Henrys Fork fault is west of the area mapped. Enough of the fault is within the area, however, to permit reasonable inferences regarding its nature and origin. Except for its smaller size, it is similar structurally to the Uinta fault in most respects: strata on both walls are generally but not universally overturned; the fault contains slices of conglomeratic material derived from the Wasatch formation; a strike-slip component of movement seems probable.

At Manila, Hilliard shale on the upthrown or hanging wall is against the Wasatch formation on the foot wall. However, the stratigraphic throw cannot be accurately adjudged, owing to some uncertainty as to how great a thickness of pre-Wasatch strata has been cut out by faulting and how much has been removed by pre-Wasatch erosion. In any event, parts of both the Wasatch and the Hilliard formation have been faulted out, as well as probably the entire Fort Union (?) formation and perhaps part of the Mesaverde group, which however, may also have been removed by erosion. The throw is probably of the order of 4,000 feet and may be considerably more. Two miles or so west of the area the entire Wasatch formation is faulted out and the Green River formation is against Hilliard shale.

Like the Uinta fault, the Henrys Fork fault appears to be a stretch thrust. Evidence of pre-Tertiary rupture, however, is lacking, and strong overturning in the Wasatch formation in a narrow zone adjacent to the fault suggests that initial rupture occurred after the Wasatch formation was deposited, probably after Eocene time.

The Henrys Fork fault appears to terminate in three branches west of the Green River. The southernmost of these branches may possibly extend eastward across the river, but it does not join the Uinta fault as some maps have shown. Rather, it passes into a flexure indicated by overturning just east of Flaming Gorge.

Other thrust faults.—South of Manila in the vicinity of Sheep Creek are two small southward-dipping thrust faults. The more westerly of these involves Jurassic and Cretaceous rocks; the more easterly involves Triassic and Jurassic rocks. At no place do these faults appear to exceed 400 feet in throw. Both have decidedly concave upward profiles, hence have a rotational movement about horizontal axes parallel to their strikes. Drag and overturning is confined to a narrow zone near the fault planes. These faults very likely formed contemporaneously with the Uinta fault and as a result of the same stresses, although compelling evidence is lacking. It seems entirely possible that they served to dissipate stresses that must have accumulated in the western part of the area, near the terminations of the Uinta fault and the Crest fault yet farther west. If this possibility is true, shear in that area was distributed among several small thrusts rather than along a single large one.

Another fault of considerable interest in the same general area, possibly a gravity fault but partly of reverse habit, joins the Uinta fault near the mouth of Hideout Canyon. A so-called scissors fault, it is upthrown on the north side at its east end, on the south side toward its west end. (See fig. 2 B.) Its dip, where observable, is 60° - 70°S. A possible explanation for its peculiar habit assumes that the fault originated as a thrust contemporaneous with or slightly antecedent to the Uinta fault but that the foot wall was dragged differentially upward by the Uinta fault, reversing the original movement at the east end of the fault.

Other small faults, mostly thrusts, branch at intervals from the Uinta fault. Essentially these are but minor ramifications of the Uinta fault itself, although several in the eastern part of the area have not yet been fully studied, and their relationships are not yet fully understood.

Normal faults

Normal faults are abundant in the pre-Cambrian rocks on the south side of the Uinta fault, as a glance at the map (pl. 1) shows, but are exceedingly rare in the younger rocks north of the Uinta fault. A single sizable normal fault, here called the South Valley fault, offsets post-Cambrian strata in the western part of the area. It has a maximum vertical displacement of about 300 feet, a length of about 5 miles. Several smaller normal faults occur on the Spring Creek nose; a few still smaller ones here and there are not shown on the map. But in the area of pre-Cambrian outcrop, normal faults both large and small are numerous from Bear Mountain east to the boundary of the area. The size of many of these is conjectural, owing to a general lack of reliable key beds, but displacements of 300 feet or more appear to be common.

Either or both of two factors may be largely responsible for the great variance between the number of faults in the two areas. First, most of the faults may be of pre-Cambrian age -- a supposition without much valid support, although many small faults confined to the Red Creek quartzite (some not shown on map) must reflect pre-Cambrian movements prior to deposition of the Uinta Mountain group. Second, because the mountainward block of the Uinta fault was the more active element in the Laramide deformation, it probably was subject to greater stress during the compressive phase of the deformation and during tensional relief and collapse after deformation. Sears (1924, p. 287-298) and Bradley (1936 p. 185) have shown clearly that large-scale gravity faulting accompanied collapse of the east end of the Uinta arch after the Browns Park formation was deposited in Miocene time; many of the small normal faults in areas north and west of Browns Park may well have resulted from this collapse. Faulting in Red Canyon east of Bear Mountain appears to be associated with collapse of the Red Canyon anticline; at any rate the net result of this faulting was a slight lowering of the crestal part of the fold relative to its limbs.

On the other hand, if an attempt is made to explain the presence of blocks of Red Creek quartzite along the Uinta fault west of Goslin Mountain by reverse movement on this fault in post-Miocene time, a collapse of far greater magnitude would be required in that area than is indicated by other facts. Just south of the area in question, between the west end of Bear Mountain and the east end of Dutch John Bench, the Miocene erosion surface exhibited by the nearly level top of Bear Mountain has an average eastward gradient of about 100 feet per mile, and part of this gradient certainly is original. The surface extends westward far beyond the termination of the Uinta fault with the same order of gradient. On Dutch John Bench the surface also has a northward slope of about 80 feet in 1-1/2 miles; this figure probably represents the northward component of tilt due to collapse in that area. A much steeper tilt, especially eastward and probably also northward, would be necessary to expose the Red Creek quartzite blocks by collapse of the Uinta Mountain group south of them. The net slip between the two must amount to several thousand feet. These blocks, then, seem best explained by pre-Cambrian faulting, fortuitously exposed by much later uplift along the Uinta fault; if so, other faults in the same general vicinity also may logically be of pre-Cambrian age.

Farther east, on Goslin Mountain, a large high-angle fault, here called the Goslin fault, also probably is of pre-Cambrian age but may have had subsequent movement during the Laramide revolution. The Goslin fault (pl. 1 and fig. 2C) brings Red Creek quartzite and basal beds of the Uinta Mountain group in the northeast wall or upthrown block against younger beds of the Uinta Mountain group in the southwest wall or downthrown block; a displacement of several thousand feet is probable. Although the fault plane is not exposed, near-vertical sheeting parallel to the trend of the fault suggests that the fault itself also is near vertical. A strong horizontal component of movement is indicated by drag structures along the fault, especially in the downthrown block; that block moved southeast relative to the upthrown block, and within the fault, a large slice of quartzite from the Uinta Mountain group was dragged into vertically plunging sigmoid folds, which are concave southward on the west side of the slice and concave northward on the east side. Whether or not vertical and horizontal components of movement occurred simultaneously is not known. The southeast movement of the downthrown block, as indicated by drag structures, suggests a resolution of westerly stress, hence, possibly Laramide movements contemporaneous with movements on the Uinta fault. It also seems possible that late vertical reverse movements occurred during post-Miocene collapse of the east end of the range.

TECTONIC HISTORY

Pre-Laramide deformation

Intense pre-Cambrian orogeny, far exceeding in magnitude any subsequent disturbance, is indicated by the highly deformed character of the Red Creek quartzite. This orogeny took place before deposition of the Uinta Mountain group in later pre-Cambrian time, as indicated by the strong deformation and high metamorphic grade of the Red Creek quartzite versus the relatively weak deformation and low metamorphic grade of the Uinta Mountain group, and by a pronounced angular unconformity between the two units. The Red Creek quartzite was deformed in at least two distinct episodes; bodies of igneous rock intruded into and cutting across previously folded structures are themselves folded, faulted, and foliated.

After uplift and degradation of the Red Creek quartzite, a long period of relative quiescence and subsidence ensued. During this time, approximately 15,000 feet of sediments, the Uinta Mountain group, was deposited. By far the greater part of this group, as pointed out, is monotonously uniform coarse-grained sandstone and quartzite. Variations in texture, nevertheless, are wide -- from shale to coarse conglomerate -- and together with considerable local channeling indicate fluctuating conditions of deposition. Most of the conglomerates are derived entirely from the Red Creek quartzite; some are hundreds of feet thick and contain abundant cobbles and boulders, which suggest a high and nearby source, and hence, tectonic activity in nearby areas. The direction from which the sediments came in this part of the Uinta Mountains appears to have been northeast, for that is the direction indicated by foreset bedding and by facies changes between shales, sandstones, and conglomerates.

Sometime after deposition of the Uinta Mountain group, gentle uplift, a long period of erosion and apparently block faulting followed. This probably was in pre-Cambrian time, although it may have been at any time prior to Mississippian. (The oldest post-Uinta Mountain group rocks of the area are Mississippian in age.) It is of interest that Huddle and McCann (1947) and Kinney and Rominger (1947) noted post-Cambrian pre-Mississippian deformation in widely separated areas on the south flank of the range. The lack of Cambrian rocks in unfaulted areas adjacent to the Manila-Browns Park area, despite their probable occurrence in other areas nearby,* suggests post-Cambrian pre-Mississippian uplift and

* Cambrian rocks have been recognized tentatively in Sols and Birch Creek canyons a few miles west of the area.

erosion on the north flank as well.

The period that followed, preceding the Laramide revolution, was a long span of gentle subsidence and trough filling again interrupted from time to time by gentle uplift and erosion. Erosion intervals occur at several places in the section; sharp lithologic breaks at several other places in the section suggest but do not prove unconformities. Wide lithologic variations, however, indicate fluctuating depositional environments ranging from marine offshore to continental flood plains. The interval including and following Early Cretaceous time was one of more or less continuous subsidence, interrupted and terminated by the Laramide revolution.

Laramide revolution

In the area mapped the Laramide revolution is divisible into three separate phases, the first and third of which culminated in thrust faulting.

First phase.—The onset of the Laramide revolution in the Manila-Browns Park area has not been exactly dated. The youngest pre-Laramide formation in the area is the Ericson sandstone of the Mesaverde group. It is overlain by the Fort Union (?) formation with an unconformity that varies from near concordance to great angularity. The occurrence of younger pre-Laramide rocks -- the Almond, Lewis, and Lance formations -- in the nearby Rock Springs uplift (Hale, 1950, p. 55) suggests that these units may have been deposited in the Manila-Browns Park area but have since been removed by pre-Tertiary erosion. The best that can be said, however, is that uplift began no earlier than late Montana time and no later than pre-Tertiary time.

This uplift was of major proportions and appears to have evolved in two separate episodes, during which the resolution of stresses changed from south to southwest or west. In the first episode, deep-seated southerly stresses probably produced the initial Uinta arch together with such flanking folds as the Clay Basin anticline and the Red Canyon anticline. These stresses may have extended as far west as the central Wasatch Mountain area, where east-trending folds apparently represent extensions of the Uinta Mountain structure, as pointed out by Forrester (1937, p. 650), and where southerly stress preceded strong compressive stresses from the west (Eardley, 1944, p. 865, and Curtis, 1950, p. 99).

The second episode of this deformation was brought on by compressive stresses from the west and culiminated in rupture along the Uinta fault. These movements began before stress from the south died out; a northeasterly resultant would arise as a resolution of two such directed stresses -- such a resultant is suggested by the arcuate patterns of the Uinta Mountain axis and the Uinta fault. It also seems probable that the Uinta arch, once formed, would resist strongly any internal deformation due to stresses of subsequent westerly origin, and, although admittedly speculative, it is suggested that the Uinta arch moved eastward relative to the Green River Basin to the north, setting up shear couples that ultimately produced the Uinta fault, the Henrys Fork fault, the minor thrusts of the area, and possibly also the Crest fault and the North Flank fault west of the mapped area. Before rupture occurred, however, the north-plunging noses and synclines were folded and in part overturned, the Linwood nose being a modification of the earlier formed Red Canyon anticline.

Whatever the actual mechanics of the first uplift, it is clear that the uplift was strong and that deep erosion preceded deposition of the earliest Tertiary beds. Despite strong uplift and deep dissection, however, the height of the range at this time probably was not great; judging from the lithology of the Fort Union (?) formation and the lower part of the Wasatch formation, erosion kept pace with uplift. By Fort Union (?) time, erosion had penetrated at least 8,500 feet, and possibly considerably deeper, into the pre-Tertiary cover of the range. By Wasatch time the range was eroded to its pre-Cambrian core in the eastern part of the area where the Uinta Mountain group became exposed.

Second phase. —During Wasatch time the range again began to rise. Coarse orogenic deposits about midway in the Wasatch section suggest a nearby source higher than the present Uintas. As uplift died out, rate of erosion again overtook and surpassed rate of rise; during deposition of the Green River formation in the basin to the north the height of the range must again have been greatly reduced.

Third phase. —Shearing stresses again built up, probably at the end of Eocene time after deposition of the Bridger formation -- certainly after deposition of the Green River formation, because Green River strata are involved in the thrusting that ensued. At this time renewed movement took place on the Uinta fault, and the Henrys Fork fault was formed. Before thrusting occurred, additional warping modified the flanking folds by flexing the Tertiary as well as the older strata. The rupture that followed marked the culmination of the third phase of the orogeny. Intermittent uplift, however, apparently continued until after early Oligocene time; although evidence of such movement is lacking in this area, Huddle, Mapel, and McCann (1951) and Untermann and Untermann (in Kay and Garwood, 1953, p. 9) reported such movements in the Moon Lake and Vernal areas respectively on the south flank of the range. By Miocene time, perhaps earlier, Red Creek quartzite was exposed south of Clay Basin; cobbles originating from Red Creek quartzite are abundant in the Bishop conglomerate of probable Miocene age on Little Mountain in Wyoming just north of Clay Basin.

Post-Miocene collapse

Collapse of the east end of the range is described in detail by Sears (1924, p. 286-298) and by Bradley (1936, p. 185). In brief, large-scale gravity movements occurred on the Uinta and other faults on the north flank of the range and on the Yampa fault on the south flank, dropping the crestal part of the anticline relative to both limbs in a graben-type displacement. Movement on the Uinta fault was a gravitative reversal of the earlier Laramide movements, thus diminishing the net slip on the fault while at the same time tilting and displacing the Miocene Gilbert Peak and Bear Mountain erosion surfaces. Collapse diminished rapidly toward the west, but its effects are evident as far west as Bear Mountain, where faulting on the Red Canyon anticline is attributed to this disturbance.

Dutch John Bench was also probably tilted to the northward at this time. If so, the Green River must have established and entrenched itself in Red Canyon prior to collapse, because the bench slopes north away from the river, and unless previously entrenched, the river would have shifted its course a mile or so north in the direction of tilt to the then lowest part of the old valley.

The most notable effects of collapse, however, are found in the vicinity of Browns Park, where the crest of the Uinta arch was greatly depressed and where the Browns Park formation and the Uinta Mountain group were sharply dragged by faulting along the north side of Browns Park valley. Except for gentle but considerable Quaternary uplift, intermittent and on a regional scale, the structural history of the range in this area was completed.

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REFERENCES CITED

Billings, M.P., 1942, Structural geology: New York, Prentice-Hall, Inc. 473 p.

Bradley, W.H., 1936, Geomorphology of the north flank of the Uinta Mountains: U.S. Geol. Survey Prof. Paper 185-I, p. 163-199.

Curtis, B.F., 1950, Structure of the north flank of the Uinta Mountains: Wyoming Geol. Assoc. Fifth Ann. Field Conf. Guidebook, p. 93-102, Casper, Wyoming.

Eardley, A.J., 1944, Geology of the north-central Wasatch Mountains, Utah: Geol. Soc. America Bull., v. 55, p. 819-894.

Forrester, J.D., 1937, Structure of the Uinta Mountains: Geol. Soc. America Bull., v. 48, 631-666

Hale, L.B., 1950, Stratigraphy of the Upper Cretaceous Montana group in Rock Springs uplift, Sweetwater County, Wyoming: Wyoming Geol. Assoc., Fifth Ann. Field Conf. Guidebook, p. 49-58, Casper, Wyoming.

Hansen, W.R., in preparation, Geology of the Flaming Gorge quadrangle: U.S. Geol. Survey Geol. Quad. Map Series.

__________, and Bonilla, M.G., 1953, The western termination of the Uinta fault in Daggett County, Utah:* Geol. Soc. America Proc., 1953, p. 64.

Huddle, J.W., and McCann, F.T., 1947, Geologic Map of Duchesne River area, Wasatch and Duchesne Counties, Utah: U.S. Geol. Survey Oil and Gas Inv., Preliminary Map no. 75.

__________, Mapel, W.J., and McCann, F.T., 1951, Geology of the Moon Lake area, Duschesne County, Utah: U.S. Geol. Survey Oil and Gas Inv. Map OM115.

Kay, J.L., and Garwood, Vaughn, 1953, Soc. Vertebrate Paleontology: Fifth Ann. Field Conf. Guidebook, 33 p., Utah Field House of Natural History, Vernal, Utah.

Kinney, D.M., and Rominger, J.F., 1947, Geology of the Whiterocks River, Ashley Creek area, Uinta County,

---

* Abstract

Utah: U.S. Geol. Survey Oil and Gas Inv., Preliminary map 82.

McMinn, P.M., 1948, Pennsylvanian stratigraphy in Daggett County, Utah: Unpublished Masters Thesis, Univ. of Wisconsin, 45 p.

Sears, J.D., 1924, Relations of the Browns Park formation and the Bishop Conglomerate, and their role in origin of Green and Yampa Rivers: Geol. Soc. America Bull, v. 35, p. 279-304.