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Evolution of the Upper Colorado River as Interpreted from ERTS-1 Imagery

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EVOLUTION OF THE UPPER COLORADO RIVER AS INTERPRETED FROM ERTS-1 MSS IMAGERY*

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ABSTRACT

Manual interpretation of ERTS-1 MSS imagery provides a synoptic basis for recognition of anomalous drainage patterns in arid regions in west-central Colorado. These patterns suggest that numerous diversions of the Colorado River System across the Uncompahgre Plateau occurred in pre-Pleistocene time. Certain topographic characteristics, common to a series of stream channels traversing the plateau, indicate that many present-day valleys were formerly occupied by a through-flowing major stream.

Geomorphic inference, based on channel characteristics, regional structure, and physiographic relationships as interpreted from ERTS-1 imagery, suggests that prior to the San Juan Mountain and West Elk Mountain volcanic episodes, the Colorado River System flowed southward along the approximate western edge of the present mountains. Orogenic uplift combined with aggradation of volcanic sediments and flows initiated a sequence of westward diversions by blockage of the former southward flowing stream. The Colorado then migrated across the surface of the Uncompahgre region through a series of lithologically and joint controlled captures.

This process appears to have been repeated at several places until the master stream reached present Unaweep Canyon. Structural evidence suggests that uplift of the Uncompahgre Plateau commenced at this time. The subsequent history of diversion and capture of the Colorado River and its tributaries occurred as outlined in the literature.

The synoptic view provided by ERTS-1 MSS imagery demonstrates how a new perspective of the evolution of surface features may be obtained. This new perspective in a regional framework improves our understanding of geologic processes and our mapping capabilities of many important surface features.

INTRODUCTION

While performing machine analysis on ERTS-1 data obtained over a portion of the LARS San Juan Test Site (Mroczynski et al, 1973), our attention was attracted by the apparent anomalous character of certain stream channels developed on the nearby Uncompahgre Plateau. Compared with the major high order streams (Colorado, Gunnison, San Miguel, and Dolores Rivers) (Fig. 1) within the region portrayed on ERTS-1 frame 1066-17251, September 27, 1973, many drainage channels occupied by low order perennial and ephemeral streams flowing on the northeastward dipping slope of the uplifted Uncompahgre Plateau exhibit three apparently anomalous characteristics:

1. Valleys occupied by some of the ephemeral streams are more extensively developed than those cut by the major rivers.

2. The dip slope valleys commonly possess high level meander scars uncharacteristic of streams with a regimen and gradient comparable to their present day occupants; and

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3. These valleys possess apparently correlative components on both sides of the present drainage divide at the crest of the Uncompahgre Plateau, a divide created by uplift along a series of faults bounding the plateau's southwest side.

Analysis of ERTS-1 imagery was paramount in leading to recognition of these anomalous patterns. The synoptic view given by ERTS-1 MSS sensors provides a basis for regional pattern recognition and comparison never before possible. Texture and tone analysis enables comparison in the horizontal plane, whereas shadow pattern analysis permits comparison in the vertical plane (e.g. the depth of valleys). However, to even partly utilize the exceptional capabilities of ERTS-1 technology as an aid in manual interpretation, it is necessary to approach any analysis with an attitude founded in synopsis before any synthesis of distantly sensed patterns can be accomplished.

INITIAL HYPOTHESIS

The observed, apparent anomalous patterns of stream channels call for explanation. In responding to this call we devised a general two part working hypothesis, as follows:

1) Anomalous surface patterns seen on ERTS-1 imagery are an effect of erosion produced by an ancient, high order, southwestward through-flowing stream; and
2) The numerous "channel scars" represent time-dependent surface locations of a single master stream.

The feasibility of such a historical occurrence was determined by comparison of the hypothesis with the existing theory of Colorado River history. Clarence Dutton (1882) verbosely and beautifully described the central Colorado Plateau region, emphasizing the unending work of erosive processes in reducing the level of the land during the "Great Denudation". He also noted and illustrated an abandoned north-south trending major valley at DeMott Park on the Kaibab Plateau. This valley is perpendicular to and predates the Grand Canyon in northern Arizona. Cater (1966) and Lohman (1961) are the most recent in a series of writers extending back to Henry Gannett (1882) and the Hayden Survey (Peale, 1877) to recognize that Unaweep Canyon cuts through the Uncompahgre Plateau as an abandoned channel of a major river. Blackwelder (1934) and Longwell (1946) discussed the origin and history of the Lower Colorado River and concurred that its present course represents a major change in regional drainage patterns since late Tertiary time. Hunt (1965) dates the canyon cutting as late Tertiary and Quaternary, introducing the term "anteposition" as a synthesis of superposition and antecedence to explain the process of entrenchment along parts of the Colorado River System. Thus, in general, we found existing theory of the Colorado Plateau's Tertiary erosional history compatible with our working hypothesis.

Emboldened by absence of any immediately evident contraindications from the literature, we extended the initial hypothesis to begin an accounting for geologic process. Williams (1964) and Lohman (1965) provided structural and stratigraphic tools necessary to proceed with a more detailed explanation (Figs. 2 and 3). The result of our extended thinking was submitted in preliminary abstract to this symposium as follows: A southward through-flowing Tertiary drainage system in southwestern Colorado was blocked by extrusion of the Oligocene (Steven, et al. 1967) San Juan and West Elk Mountain volcanic lahars, ash deposits, and flows. Contiguous with the volcanic activity to the east, a westward dipping structural slope formed in the Uncompahgre region, possibly owing to doming around the volcanic center. Resistant preCambrian crystalline rocks acted as an impeding level of erosion for the master stream. Any downstream westward tributary, being downdip, could thus cut to the same topographic level as the master stream and remain in softer Mesozoic rocks which overlie the preCambrian in the area of the

Paleozoic Uncompahgre highland. The tributary, being able to cut more quickly than the master stream retarded by the preCambrian, could capture the waters of the master channel. This progressive process of downstream tributary capture was repeated at several places including Roubideau, Escalante, and Dominguez Canyons (Fig. 4) until the master stream reached Unaweep Canyon. At this point in time the Uncompahgre Plateau began to rise and the master stream became antecedent, entrenching itself into the preCambrian rocks at Unaweep Canyon. Subsequent evolution of the Colorado River system occurred as outlined by Cater (1966) and Lohman (1961).

FIELD RECONNAISSANCE

To seriously consider any validity of the initial hypothesis, the time had come to leave our library armchairs and visit the Uncompahgre to look at the "immutable" historical evidence, as recorded in surface deposits and landforms. Objectives of the field work were:

1) To search for old river gravels at or near the present divide between the San Miguel-Dolores drainage basin and the Uncompahgre-Gunnison-Colorado drainage basin (i.e. along the crest of the Uncompahgre Plateau).

2) To seek high level erosion scars that could represent surfaces graded to or correlative with the level of a major ancient, throughflowing stream; and

3) To collect ground based photography for future use in the development or modification of the initial working hypothesis.

The results of the field reconnaissance were quite encouraging. Old river gravels occur at several of the hypothesized ancient channel locations. On the Uncompahgre Plateau, well-rounded pebbles, cobbles, and boulders were found in a multistory valley 2 miles northeast of Divide Road along Colorado Highway 90 in the vicinity of Silesca Ranger Station at elevations 500 to 1,500 feet above Dry Creek (Figs. 5 and 6). The rounded gravels included many varieties of all major rock types; intrusive and extrusive igneous, metamorphic, and sedimentary. The only rock type within reach of the present drainage is sedimentary. Volcanics, granites, and metamorphic rocks at Silesca must have been carried to their present location by a major river no longer serving the drainage requirements of southwestern Colorado. Similar gravel deposits occur also at Glade Park and Unaweep Canyon at the northwestern end of the Uncompahgre Plateau, along Crystal Creek north of the Black Canyon of the Gunnison, and near Gould Reservoir on Fruitland Mesa. All these deposits were found within areas previously interpreted from the ERTS-1 imagery as probable ancient channel locations.

High level surfaces, interpreted from their field characteristics as erosion scars of a major river, were also found in their appropriate geographic positions. However, the scars were not cut on the preCambrian as originally hypothesized. The preCambrian surface, as realized from field observations, could not be a resistant level to impede downcutting of a major throughflowing stream on the Uncompahgre Plateau. Headward eroding box canyon nickpoints, along the present ephemeral and perennial streams flowing down the plateau dip slope, are defined by layers of resistant sandstones within the Mesozoic System. The recent canyons are cut to the preCambrian but do not extend across the present divide at the crest of the plateau. The high level surfaces, as well as their coincident nickpoints on the present tributary streams, are located stratigraphically on the most resistant sandstone in the uppermost part of the section as locally exposed. These surfaces do cross the divide.

No single individual geologic unit defines the high level surface throughout the Uncompahgre region. The surface drops stratigraphically from east to west, being successively cut on: the Cretaceous Dakota Sandstone at Silesca along Dry Creek, with the Mancos Shale forming the old "valley walls"; the Triassic Kayenta Sandstone in the headwaters of Dominguez Creek just east of Unaweep Canyon, with the Jurassic Morrison Formation forming old "valley walls"; and the Triassic Chinle Formation in Glade Park, in the headwater region of the Little Dolores River.

A correlative high level surface occurs south of the divide along the present course of the Dolores River between its confluence with the San Miguel River and Gateway. This surface is 1,200 to 1,800 feet above the present river, possesses meander scars of larger magnitude than those on the present river, and cuts across beds of varying resistance where the river crosses a broad, gentle syncline 10-15 miles west of the Uravan milling plant. If Cater (1966) is correct in correlation of latest Unaweep Canyon erosion by a major stream (i.e. the floor of the present canyon) with the erosion surface 100-200 feet above the present Dolores River at Gateway, then the high level surface along the Dolores is correlative with pre-Unaweep entrenchment erosion levels (Fig. 7). The meander scars and stratigraphic cross-cutting characteristics of this high bench indicate a graded surface produced by river erosion along a regional master throughflowing stream. The direction of flow in this old river may have been opposite to the present flow direction, but for the purpose of the present argument the establishment of an ancient major stream at the location of the present Dolores River is sufficient.

Other field observations germane to the discussion were obtained during field reconnaissance. Distinct, high level abandoned valleys are present in the Casto Reservoir area (Fig. 8) on the Uncompahgre Plateau and along Grizzly Gulch (Fig. 9) and Crystal Creek north of the Black Canyon on the Gunnison. A valley-in-valley form within the preCambrian gorge of Unaweep Canyon (Fig. 10) indicates antecedent entrenchment during multiepisodic uplift of the region. Windgap notches (Fig. 11, 12) cutting across the crest of the Uncompahgre Plateau and connecting the headwaters of Dry Creek-Horsefly Creek, and Roubideau Creek-Tabeguache Creek drainages are reminiscent of the classical windgaps of the Appalachian folded belt. We infer that all these surface characteristics are evidence from which the Tertiary drainage of the Uncompahgre region may begin to be reconstructed.

MODIFIED HYPOTHESIS

Two possible explanations can be invoked to explain the stratigraphic drop from east to west of the described high level erosion surface on the Uncompahgre Plateau.

1. Each drop represents a nickpoint supported by a resistant sandstone unit, and developed on a westward flowing drainage system (i.e. all levels were present on the same system at a given instant of time). In this case, the master drainage system of the area flowed parallel to the axis of the present Uncompahgre Plateau and was graded to a regional base level somewhere west of the present Colorado River.

2. Each level represents a time dependent stratigraphic location of a westward migrating, southward flowing river system. The levels are time dependent in that as time progressed the regional base level was cut deeper into the section simultaneously with westward diversion of the master stream. In this event, the levels do not represent nickpoints that migrated headward from a static, regional base level to the west, but rather a series of actual ancient regional base levels progressively defined by a laterally migrating master stream.

All facts being equal, the Law of Parsimony demands that we choose the first alternative for explanation of the Colorado River's ancestral drainage; however, we choose the second. As seen from ERTS-1, almost all streams in the area, flowing on preCambrian to Tertiary rocks, follow one of three master joint sets: 1) NE-SW, 2) NW-SE, and 3) E-W (Fig. 13).

Present high order streams conform almost entirely to the NE-SW and NW-SE sets. Many intermediate order streams such as Tabeguache and Horsefly Creeks follow the E-W joint set. From drainage patterns as shown on ERTS-1 imagery, we infer that the master joint system is inherited from the preCambrian basement rocks, with two master sets, NE-SW and NW-SE, determining the course for any major stream that has flowed in the area since preCambrian time.

The high level surface along the Dolores River places a major stream in this area preceding the entrenchment of Unaweep Canyon. If this ancient river course represents the master stream at that time, and if the headwaters of the drainage system were, as today, in volcanic mountains to the northeast (both seem reasonable assumptions), then the master stream must have occupied the NE-SW joint set along much of its course between the San Juan-West Elk Mountain source area and the high level Dolores River erosion surface. This joint set is well developed across the surface of the Uncompahgre Plateau. Abundant gravels of dispersed origin (volcanics, granites, quartzites, and sedimentaries) located near the Silesca Ranger Station in a high level valley indicate a major throughflowing stream once was at this topographic level (9,000+ feet). Windgaps, cut across the crest of the Uncompahgre Plateau, suggest that a major river flowed perpendicular or oblique to the axis of the present uplift at some earlier time. The weight of the evidence requires abandonment of the nickpoint hypothesis and adoption of the alternative. Thus, an ancestor of the Colorado River flowed southward across the Uncompahgre Plateau along the NE-SW master joint set.

EVOLUTIONARY SEQUENCE

Projection to a sequential series of events is highly inferential and based only on general geomorphic and structural processes and certain assumptions concerning the regional geologic history of the region. The assumptions are 1) a westward sloping structural surface with very low dip away from the San Juan-West Elk region existed during the time of the migration, 2) the Uncompahgre region was tectonically stable until uplift of the plateau was initiated, 3) slow epirogenic uplift and/or slow regional base level lowering occurred during the migration interval, 4) migration of the master stream post-dates the San Juan-West Elk Mountain volcanic episodes and predates the laccolithic intrusion of the La Sal Mountains, and 5) an outlet or depositional basin through or into which the master stream flowed existed somewhere to the south. With these assumptions in mind, we can now outline our current interpretation of the evolution of the ancestral Colorado River in southwestern Colorado (see Figs. 4 and 14 for the following discussion).

Prior to the San Juan-West Elk Mountain volcanic outpourings, the master stream of the region flowed southward along the approximate location of the present western edge of these mountains. Surficial aggradation by volcanic debris blocked the southward flow of this ancient stream and diverted its waters through a newly formed channel to the west, at the approximate location of the present town of Ridgway, Colorado. This river flowed upon the Cretaceous Dakota Sandstone. A tributary, downdip from the master stream, was flowing in the NE-SW joint set along the general trend of present Dry Creek. This downstream tributary easily cut to the same level as the master stream, while remaining in the easily erodible Mancos Shale. When northward tributary erosion reached the present Grand-Uncompahgre Valley area, its headward migration turned eastward and followed the NW-SE joint set, the flow direction of the stream at this point being down the structural slope. Eventually, headward migration produced intersection with the master stream, causing downstream tributary capture of the master stream's waters. This process of joint-controlled, downstream tributary capture was repeated at Roubideau, Escalante, Dominguez, and Unaweep Canyons, and possibly Glade Park. In the Dominguez Canyon area, the Triassic Kayenta Sandstone was the resistant layer impeding downcutting of the master stream, with the downdip tributary cutting headward in soft Morrison shales and siltstones. By the time the master stream reached Glade Park, the Kayenta had been breached and sandstone units in the Chinle acted as the retardant to downcutting. While the master stream was in Glade Park, intrusion of the La Sal Mountains laccolith began. A subsurface portion of this intrusion uplifted Glade Park, forcing the stream to reestablish its course on the preCambrian surface at Unaweep Canyon. The stream exhumed a slightly stripped preCambrian surface at this location before new tectonic forces initiated uplift of the present Uncompahgre Plateau (Fig. 15). During early stages of this uplift downcutting by the master stream kept pace with pulses of uplift, causing valley-in-valley forms to be cut in the preCambrian rocks of Unaweep Canyon as antecedent entrenchment proceeded (Fig. 10). Eventually the forces of uplift dominated, and the master stream was forced out of Unaweep Canyon by capture around the western end of the plateau, bringing the Colorado River to its present position.

Uplift of the plateau continued, raising the floor of Unaweep Canyon 2,000± feet above the present major stream levels and causing entrenchment of the present Colorado River across the northwest end of the plateau. This hypothetical sequence of events is intuitive and inferential, but is employable as a useful working model in a reconstruction of actual events comprising the Tertiary evolution of the Colorado River system.

REGIONAL RIVER DEPOSITS AND CHANNEL SCARS

Upon return from field reconnaissance of the Uncompahgre, we perused the literature for any mention of old river deposits or abandoned channels in adjacent areas. Yeend (1969) describes a high level, north-south trending abandoned valley containing old river gravels of igneous and metamorphic materials. This valley, which predates Quaternary glaciation, is located atop Grand Mesa across Grand Valley from the Uncompahgre Plateau. Yeend also states that 3,000 feet of downcutting occurred between the time of abandonment of this valley and the earliest evidences of Pleistocene erosion and deposition. This high level valley on Grand Mesa could represent a northern extension of the drainage system that migrated across the Uncompahgre Plateau. The 3,000 feet of erosion between recognizable Pliocene and Pleistocene erosion surfaces would then correlate with the 1,800 foot difference between the high level Dolores River surface and the Quaternary benches 200 feet above the present Dolores River. The Dolores River is downstream on the ancient profile from Grand Mesa, which accounts for the difference in vertical erosion at the two localities during the same time interval (Fig. 7).

A surficial deposit of questionable origin "rests upon an erosion surface, most of which has been carried away by streams since...earliest Pleistocene", and whose distribution is "suggestive of a valley system quite different from that of the present day" (Atwood, 1916, p. 15). This deposit, called the "Cerro Till", was mapped by Atwood and Mather (1932) in a line extending from the Black Canyon of the Gunnison to Horsefly Peak on the Uncompahgre Plateau, and is along the alignment of one of our hypothesized channels of the ancient Colorado River. Dickinson (1965) challenges the origin of the "Cerro Till" at its type locality on Cerro Summit, maintaining that the deposits are landslide material. Could the elusive Cerro Till be, in part, fluvial deposits of a pre-Pleistocene Colorado River?

Southward from the Uncompahgre Plateau are other old surficial deposits of questionable origin, resting 2,000 feet above the Animas River. Bridgetimber Mountain southwest of Durango, Colorado is covered with sorted gravels of volcanic, intrusive, and pre-Cambrian metamorphic rocks. This gravel, the Bridgetimber Gravel, was considered by Atwood and Mather (1932) to represent deposits of a Pliocene river system flowing southward from the San Juan region. Richmond (1965) reconsidered this deposit as Nebraskan glacial outwash, but is unconvincing in establishing a glacial event to coincide with the gravel deposits. Do these gravels represent the southern extension of a river that crossed the Uncompahgre?

Thus, both north and south of the Uncompahgre region, gravels of supposed Pliocene to early Pleistocene age have been described. The old channel on Grand Mesa pre-dates the earliest glaciation. Inversion of topography at Bridgetimber Mountain places a major stream to the south in a previous erosional epoch. Midway, numerous channel scars transgress the Uncompahgre Plateau. We here posit that all these river marks are evidence of a Pliocene drainage system which, as has been described, underwent complex changes during its transition from the ancient drainage system to the fluvial network now draining southwestern Colorado.

CONCLUSIONS CONCERNING ERTS INTERPRETATIONS

We have outlined essentially in case history format a hypothesis to explain the distribution of certain land forms, and to account for the genesis of geomorphically anomalous surface patterns as recognized from analysis of ERTS-1 imagery.

Utilization of ERTS-1 imagery toward these ends has provided some clues as to the possible uses and misuses of products derived from satellite technology. On the positive side, ERTS provides the synoptic view necessary to collate hitherto seemingly unrelated surface patterns. The anomalous patterns, which led us to recognize the problems of Tertiary drainage evolution in the region, appear anomalous only if viewed from the ERTS-1 perspective. Patterns displayed on the horizontal plane are most obvious and least subject to misinterpretation. However, given the unfamiliar scale and resolution of ERTS-1 imagery, many tonal and textural variations may be randomly distributed, but subjectively forced into "patterns" which exist only in the interpreter's mind, rather than being actual distinct patterns of tone and texture of the surface represented on MSS imagery. By analogy, a perfectly random distribution of dots on a piece of paper can be subjectively organized into any pattern of the viewer's choosing. When analyzing subtle tone and texture variations, care must be taken not to assign patterns to random distributions.

In the vertical plane, the difficulty in interpreting quantitatively accurate variations is obvious. Shadow pattern analysis is useful but limited in this respect. From 560 miles altitude, differences in distances parallel to the line of sight are extremely difficult to recognize. Stereoscopic quality of ERTS-1 image pairs is poor owing in part to geographic distortions inherent in the imagery. Geographical correction decreases image quality, also impairing stereoscopic analysis. As an example of misuse of imagery, our initial interpretation of the preCambrian as the impeding level of fluvial erosion across the Uncompahgre Plateau was based on faulty vertical dimension analysis. Interpretation of regional patterns from ERTS-1 imagery should be accepted with caution, especially until the new perspective becomes familiar.

To derive meaningful pattern recognition procedures for use in conjunction with ERTS and Skylab imagery, patterns recognized on the imagery should be used to plan and direct adequate observations in the field, on larger, more familiar scale remote sensing imagery such as conventional aerial photography, and on compiled maps of the study area. Nothing definitive can be stated nor conclusions drawn based solely on interpretation of ERTS-1 data, but with ERTS-directed field observations, a basis for regional pattern recognition can be obtained. The surface characteristics of repetitive patterns seen on the imagery must be defined and evaluated in the field. Interpretation of similar patterns may then be extended to the imagery. Only with caution can we proceed to develop working hypotheses or synthesize regional patterns into a cohesive historical framework.

APPLICATIONS CONSIDERATIONS

We cannot predict precisely how basic landform studies of arid regions, such as presented herein, will find application. However, it is reasonable to expect that better understanding of regional surface landform patterns and geomorphic processes will be used in the future search for water and mineral resources, and solution of engineering and land use problems in arid zones.

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LEGEND FOR FIGURE 1

RIVERS

1) Colorado River
2) Gunnison River
3) Uncompahgre River
4) San Miguel River
5) Dolores River
6) Mancos River
7) Animas River
8) San Juan River
9) Chinle Creek

MOUNTAINS

10) West Elk Mountains
11) La Sal Mountains (laccolith)
12) San Juan Mountains
13) Abajo Mountains (laccolith)
14) La Plata Mountains (laccol.)
15) El Late (Ute) Mountains (laccolith)
16) Carrizo Mountains (laccol.)
17) Shiprock (volcanic neck)

PLATEAUS AND MESAS

18) Uncompahgre Plateau
19) Battlement Mesa (volcanic flow)
20) Grand Mesa (volcanic flow)
21) Mesa Verde
22) Monument Uplift

STRUCTURAL VALLEYS

23) Sinbad Valley (anticlinal graben)
24) Castle Valley (anticline)
25) Paradox Valley (anticlinal graben)
26) Spanish Valley (anticlinal graben)
27) Lisbon Valley (anticline)
28) Gypsum Valley (anticlinal graben)

LINEARS

29) Roan Cliffs
30) Book Cliffs
31) Comb Ridge
32) Black Canyon of the Gunnison
33) Unaweep Canyon (abandoned Colorado River Channel)

MUNICIPALITIES

County Seats in Colorado

34) Grand Junction (Mesa Co.)
35) Delta (Delta Co.)
36) Montrose (Montrose Co.)
37) Ouray (Ouray Co.)
38) Telluride (San Miguel Co.)
39) Silverton (San Juan Co.)
40) Dove Creek (Dolores Co.)
41) Cortez (Montezuma Co.)
42) Durango (La Plata Co.)

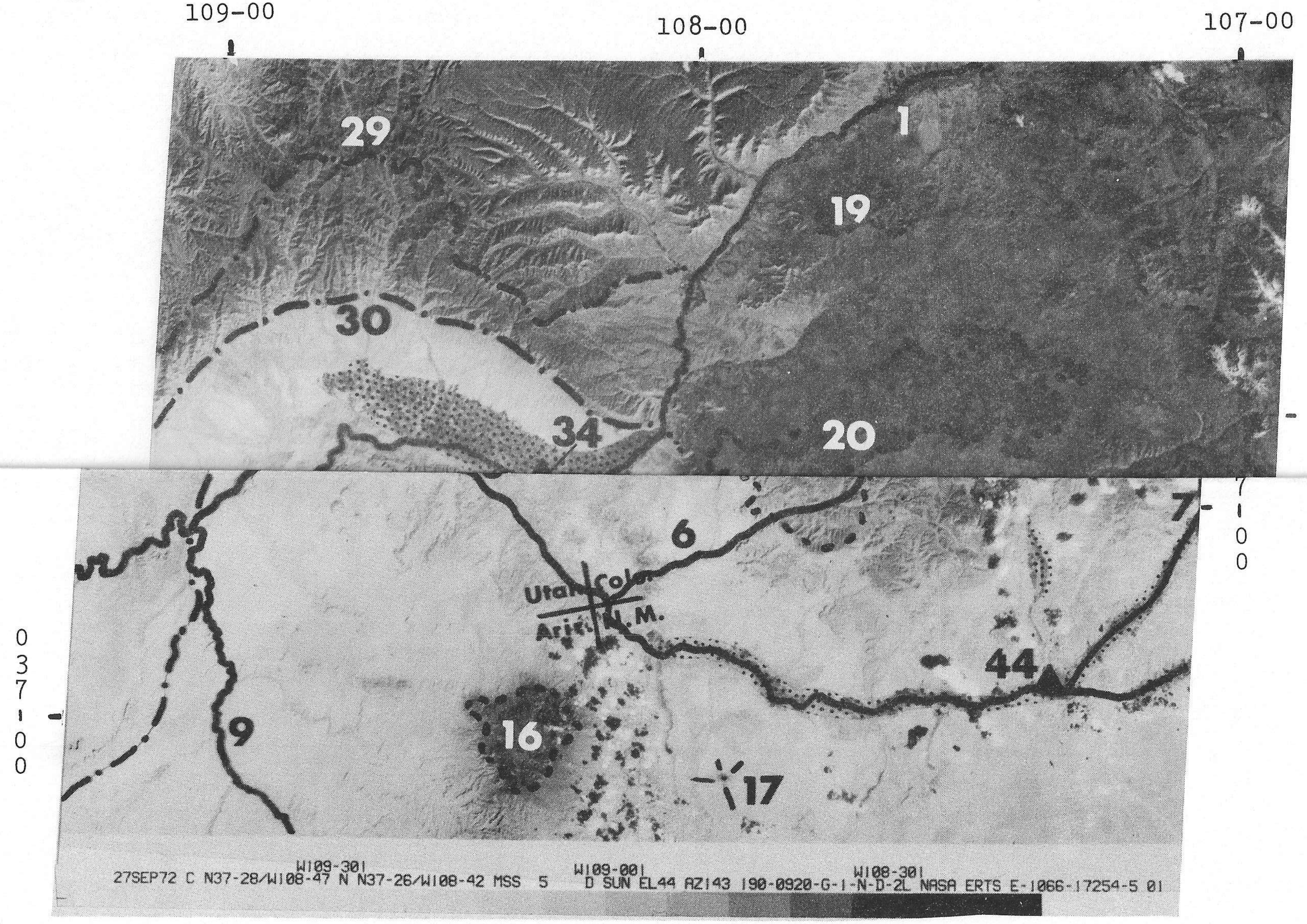
Outside Colorado

43) Moab, Utah
44) Farmington, New Mexico

LAND USE

!!!!! Crop Land

////// Pasture Land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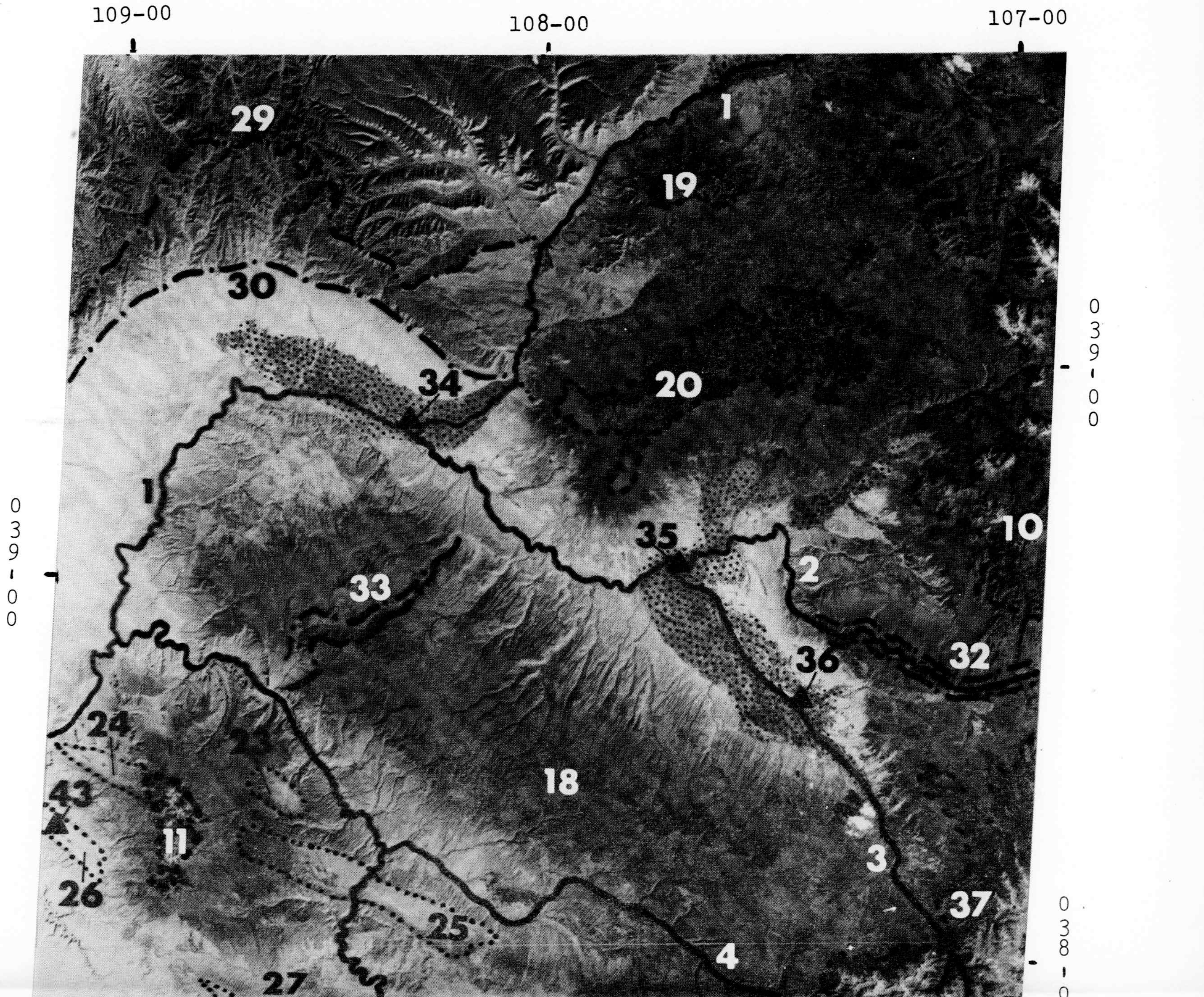

Fig. 1. General physiograp
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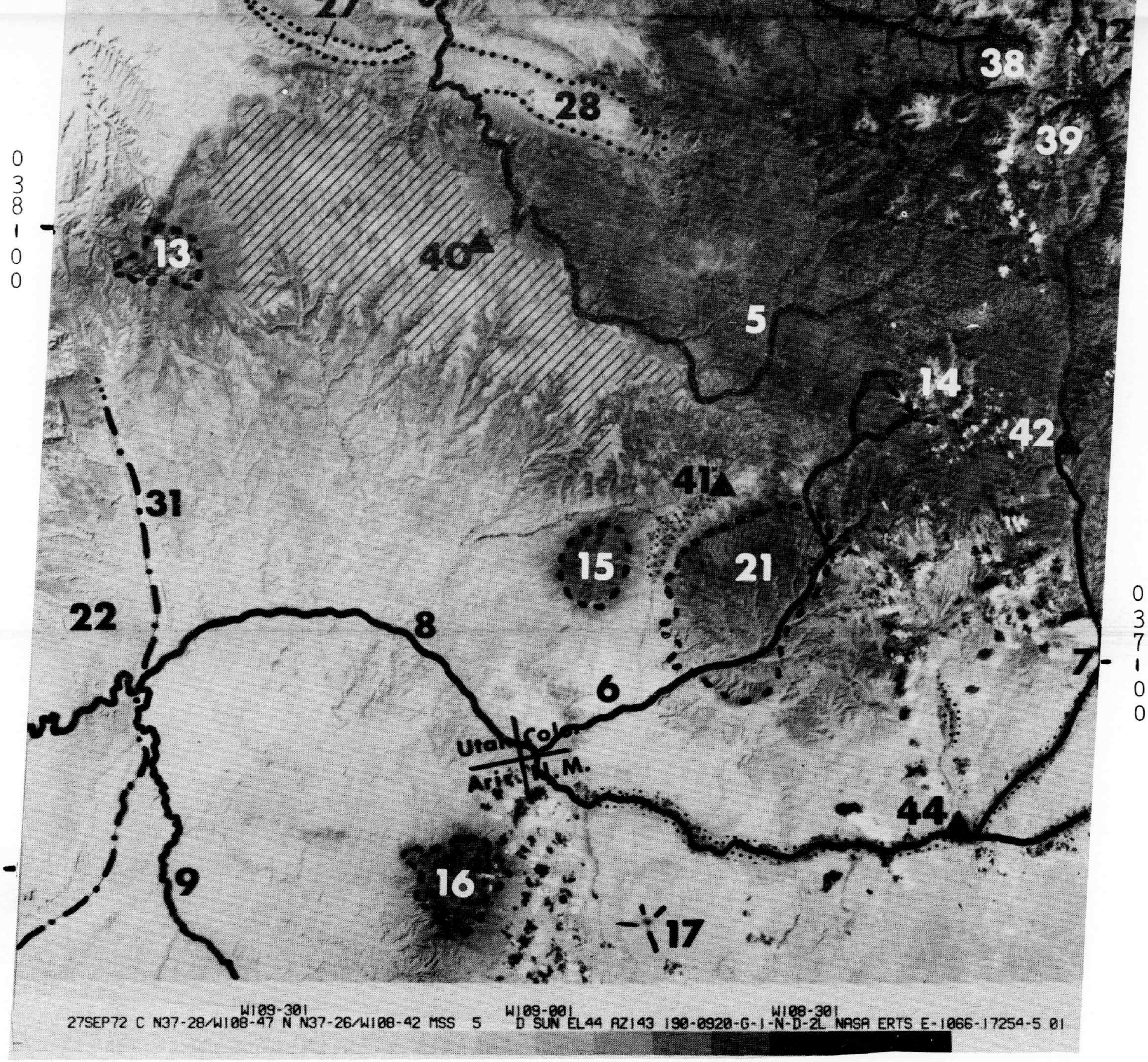
Uncompahgre Platea
middle portion and



aphic and land use features of southwest-
nually interpreted from ERTS-1 Frames
half) and 1066-17254 (bottom half). The
eau region trends NW-SE across the upper
nd is marked as (18).

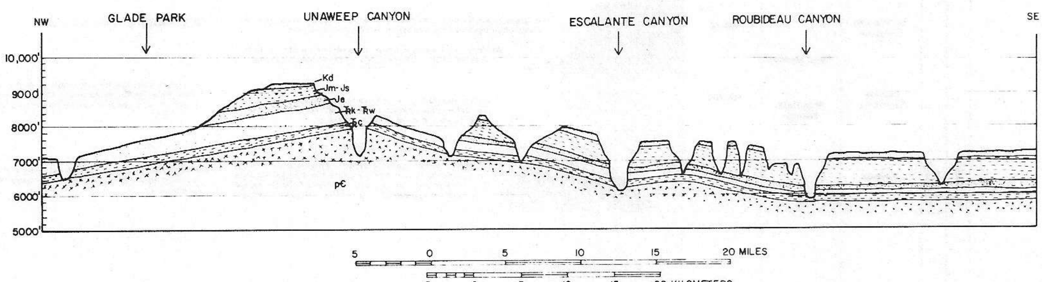


Fig. 2. Geologic cross-section subparallel to axis of the Uncompahgre Plateau.

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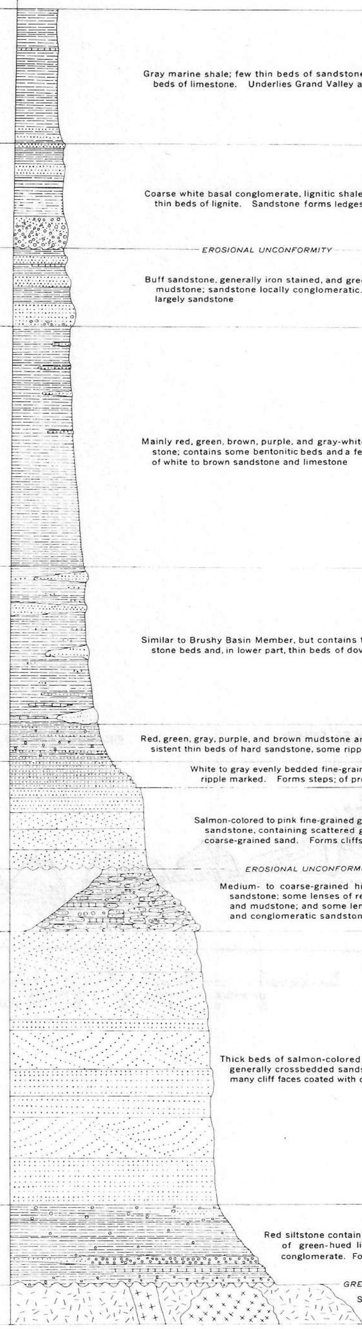
PROFESSIONAL PAPER 451
PLATE 2



SYSTEM	SERIES	FORMATION	MEMBER	THICKNESS (FEET)	CHARACTER	WATER SUPPLY
Cretaceous	Upper Cretaceous	Mancos Shale		Top not exposed	Gray marine shale; few thin beds of sandstone near base; few thin beds of limestone. Underlies Grand Valley and forms Book Cliffs	Weathered zone contains meager amounts of highly mineralized water; generally not used as source of water; water generally unconfined
		Dakota Sandstone		150±	Coarse white basal conglomerate, lignitic shale, buff sandstone, and thin beds of lignite. Sandstone forms ledges and cliffs	Yield small supplies of water to a few wells; water generally is salty; locally contain pockets of natural gas; water generally under low artesian head
					EROSIONAL UNCONFORMITY	
	Lower Cretaceous	Burro Canyon Formation		50-120	Buff sandstone, generally iron stained, and green-hued siltstone and mudstone; sandstone locally conglomeratic. Forms cliffs where largely sandstone	
Jurassic	Upper Jurassic	Morrison Formation	Brushy Basin Member	260-340	Mainly red, green, brown, purple, and gray-white siltstone and mudstone; contains some bentonitic beds and a few thin beds or lenses of white to brown sandstone and limestone	Yields no water to wells in this area, but some sandstones contain water locally
			Salt Wash Member	190-312	Similar to Brushy Basin Member, but contains thick lenticular sandstone beds and, in lower part, thin beds of dove-gray limestone	One or more sandstone lenses in lower part yield small supplies of soft water to a few wells; water under moderate artesian head
		Summerville Formation		40-60	Red, green, gray, purple, and brown mudstone and siltstone, and persistent thin beds of hard sandstone, some ripple marked	Yields no water to wells in this area
		Entrada Sandstone	Moab Member	60-200	White to gray evenly bedded fine-grained sandstone, some ripple marked. Forms steps; of probable Curtis age	Yield small supplies of soft water to many wells in area; water under moderate to high artesian head except in local areas of concentrated development
			Slick Rock Member		Salmon-colored to pink fine-grained generally crossbedded sandstone, containing scattered grains of medium- to coarse-grained sand. Forms cliffs	
					EROSIONAL UNCONFORMITY	
Triassic(?)	Upper Triassic (?)	Kayenta Formation		0-127	Medium- to coarse-grained highly lenticular hard sandstone; some lenses of red or purple siltstone and mudstone; and some lenses of conglomerate and conglomeratic sandstone. Forms benches	No wells end in this formation but may yield small amount to wells drilled into underlying Wingate sandstone
Triassic	Upper Triassic	Wingate Sandstone		215-370	Thick beds of salmon-colored to buff fine-grained generally crossbedded sandstone. Forms cliffs; many cliff faces coated with desert varnish	Yield small supplies of soft water to several wells that obtain water also from Entrada Sandstone; therefore, contribution from Wingate alone generally not known. Water under moderate to high artesian head
		Chinle Formation		80-120	Red siltstone containing a few thin lenses of green-hued limestone or limestone conglomerate. Forms slopes	Yields no water to wells in this area
					GREAT UNCONFORMITY	
Precambrian complex				Base not exposed	Schist, gneiss, granite, and pegmatite dikes	Weathered zone supplies water to a few small springs in canyons

GENERALIZED SECTION OF ROCK FORMATIONS IN THE GRAND JUNCTION AREA, COLORADO, EXCLUDING QUATERNARY DEPOSITS

721-906 O - 65 (In pocket)

Fig. 3. Stratigraphic section of the Uncompahgre region. From Lohman (1965).

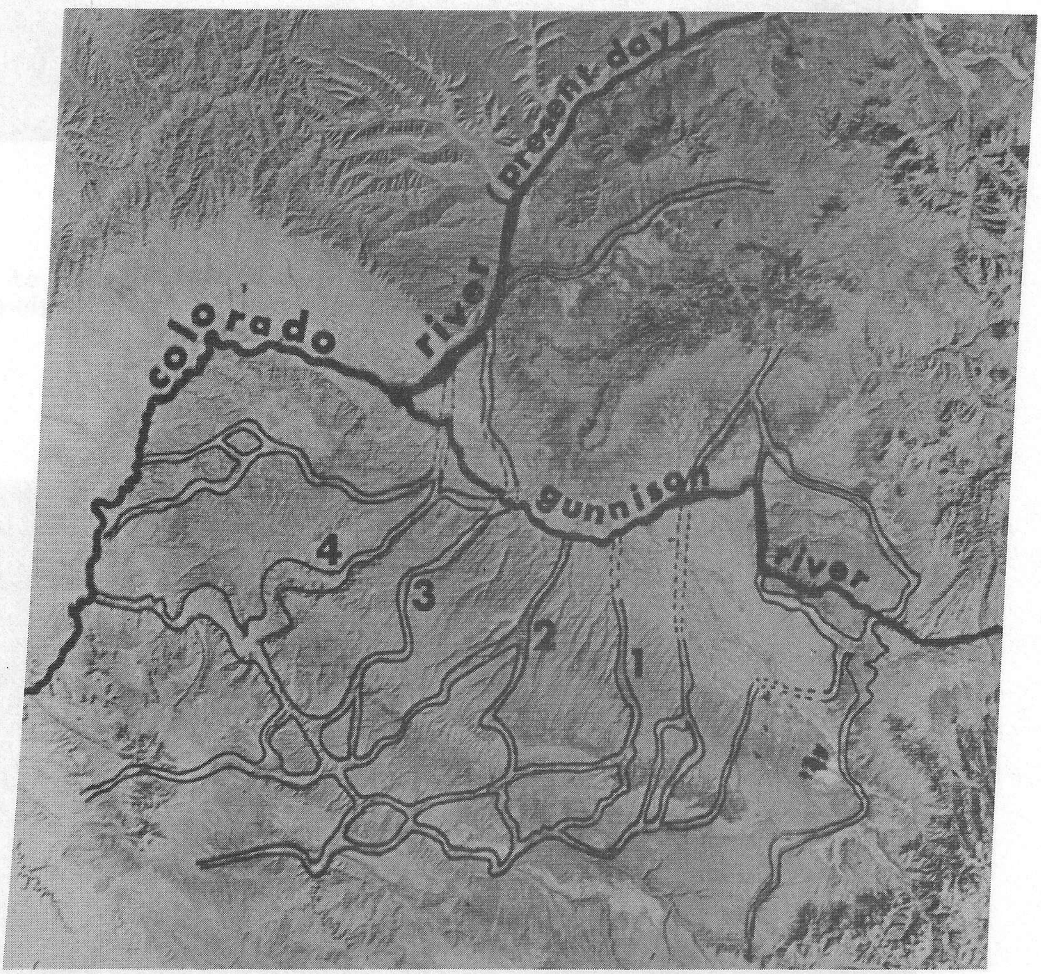


Fig. 4. Drainage diversion channels of westward migrating Tertiary Colorado River system: 1 = Roubideau Canyon, 2 = Escalante Canyon, 3 = Big Dominguez Canyon, 4 = Unaweep Canyon, Present Colorado and Gunnison rivers shown by heavy, solid lines. Details are superposed on ERTS-1 Frame 1066-17251, channel 7.

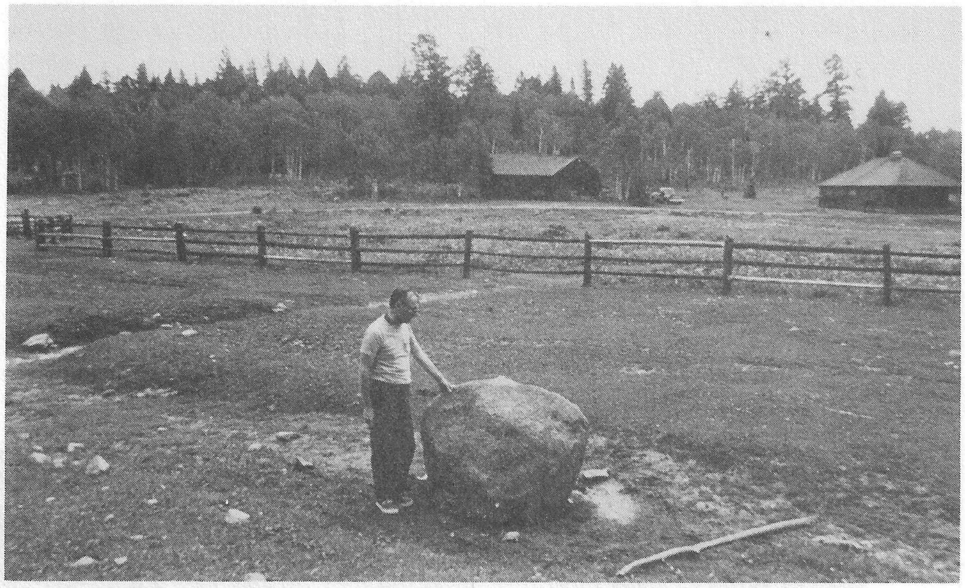


Fig. 5. Large, subrounded rhyolite boulder 30 yards south of entrance to Silesca Ranger Station on Colorado Highway 90; elevation 9,000 feet.

Fig. 6. Stream-rounded pebbles, cobbles, and boulders on west side of Colorado Highway 90, 5 miles north of Silesca Ranger Station. Quartzite and granite cobbles manually placed atop the volcanic boulder in center of picture. Elevation 7,500 feet.

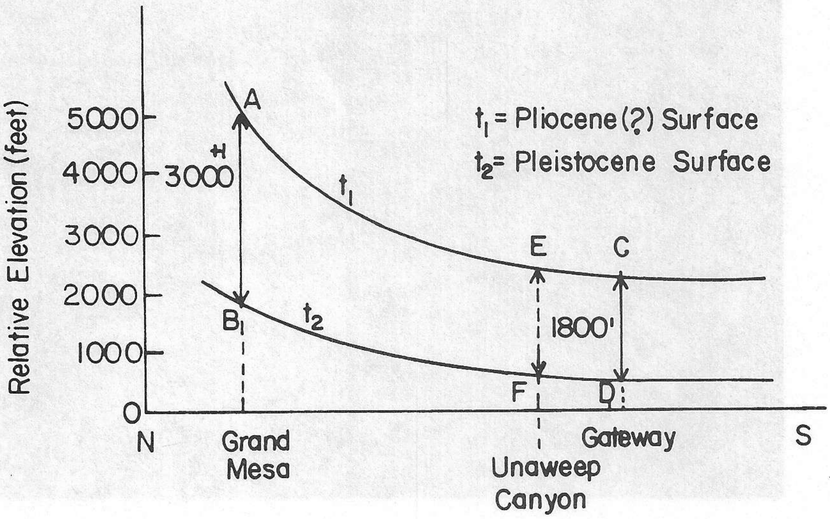


Figure 7A.

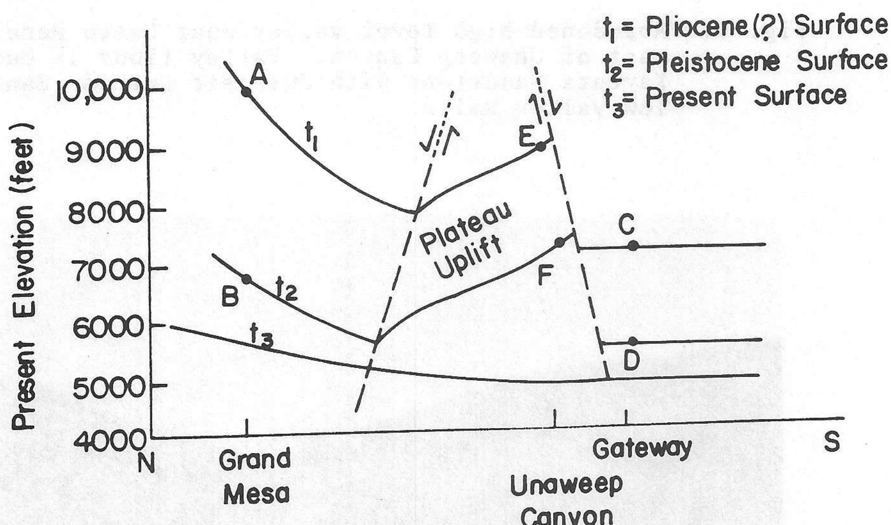


Figure 7B.

Fig. 7. Generalized graded profiles of ancient and modern Colorado River systems at times t_1, t_2, and t_3. Time t_1 represents pre-Unaweep Canyon entrenchment surface, t_2 the post-Unaweep entrenchment surface, and t_3 the present north-south profile of Colorado River. A = high level abandoned valley on Grand Mesa, B = highest alluviated bench (pediment ?) along the flank of Grand Mesa, C = high level surface along Dolores River, D = low level bench 100 to 200 feet above present Dolores River, E = stripped Kayenta surface along Unaweep Canyon, F = floor of Unaweep Canyon. Arrows represent amount of vertical erosion in Grand Mesa, Unaweep, and Gateway areas during time interval $t_1 - t_2$. Fig. 7A restores profiles to their pre-Uncompahgre uplift relations. Fig. 7B shows relationships of the three surfaces as they now exist.

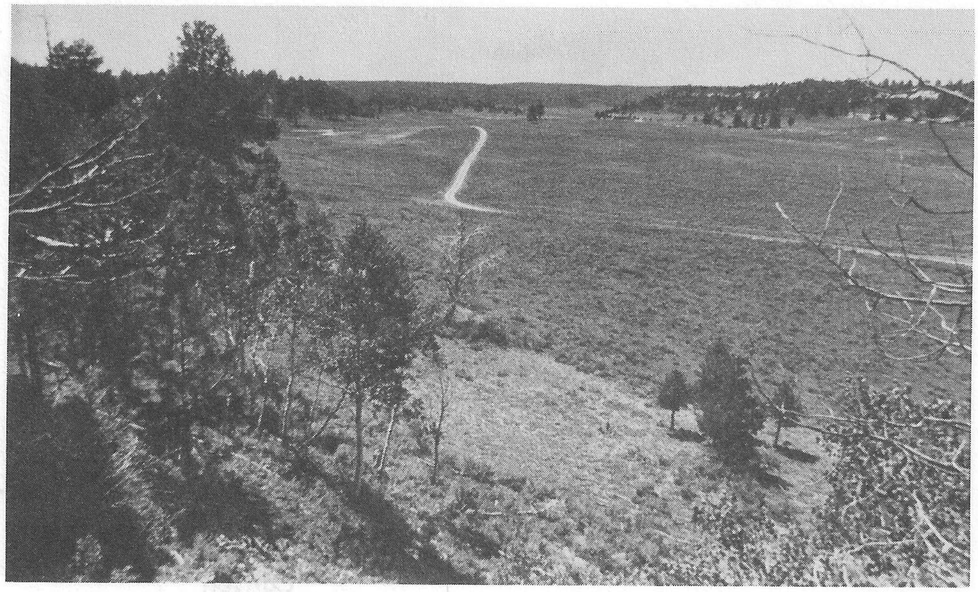


Fig. 8. Abandoned high level valley near Casto Reservoir, 5 miles east of Unaweep Canyon. Valley floor is cut on Triassic Kayenta Sandstone with Jurassic Entrada Sandstone forming low valley walls.

Fig. 9. Grizzly Gulch, looking south towards Black Canyon of the Gunnison River. Present stream is underfit. Line of hills on horizon is across Black Canyon, which drops 2,000 feet and runs normal to line of sight 1.5 miles distant from point of photography.

Fig. 10. Valley-in-valley form cut in preCambrian rocks of Unaweep Canyon.

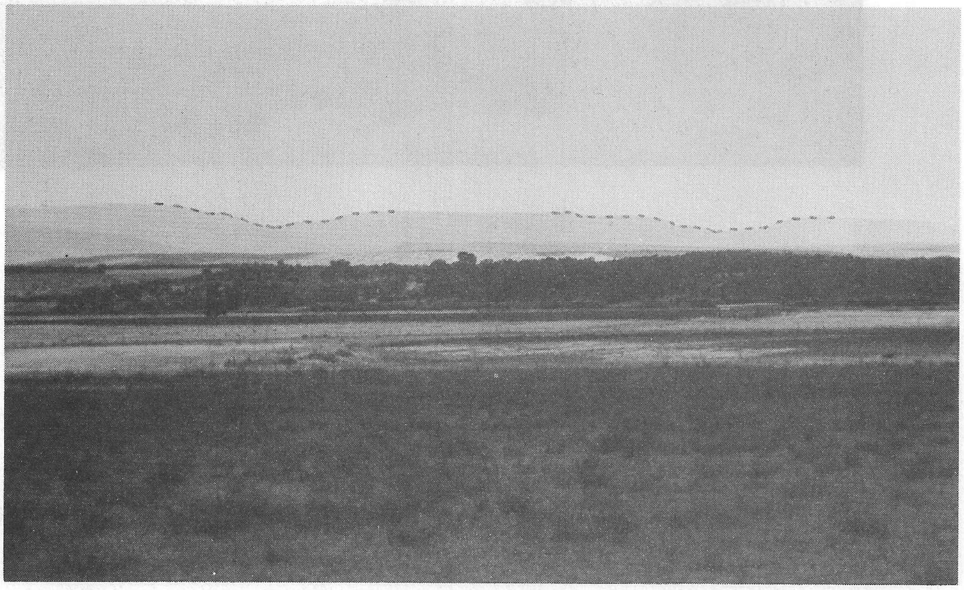


Fig. 11. Windgap notches cut into crest of the Uncompahgre Plateau. Left notch connects headwaters of Roubideau Creek and Tabeguache Creek. Right notch connects Deep Creek and Horsefly Creek.

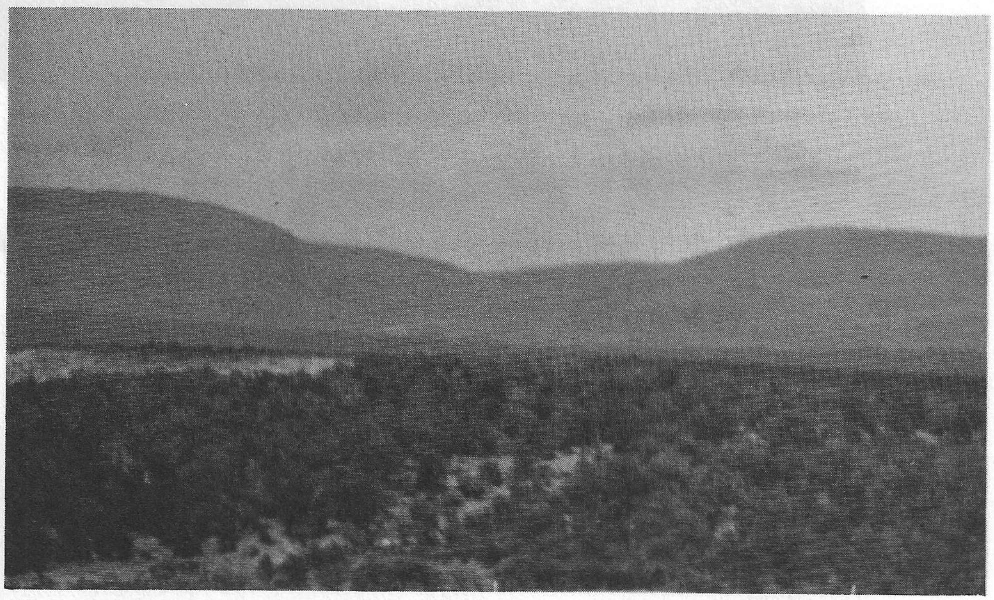


Fig. 12. Telephoto view of windgap, showing valley-in-valley characteristics.

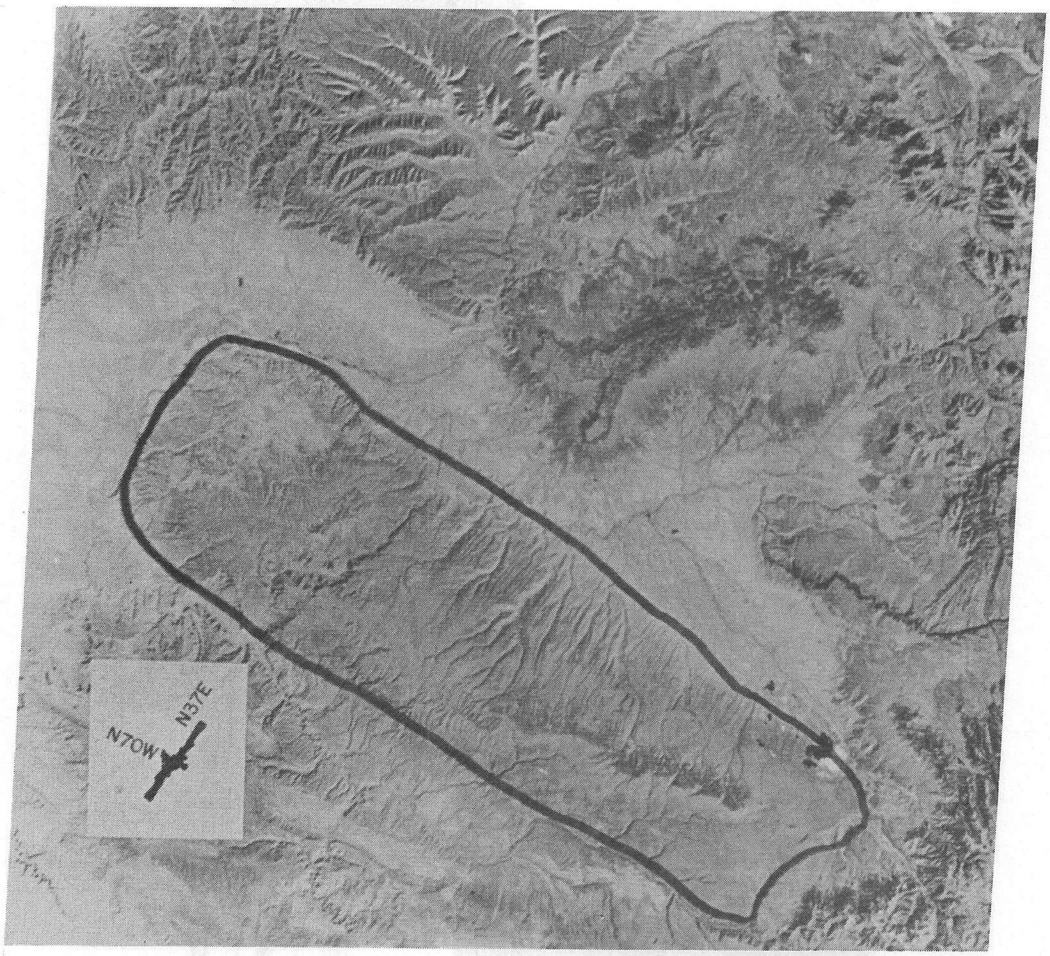


Fig. 13. ERTS-1 Frame 1066-17251, channel 6, showing joint control of drainage system. Rose diagram of regional jointing from Badgley (1962), compiled from air photo analysis of outlined portion of the Uncompahgre Plateau.

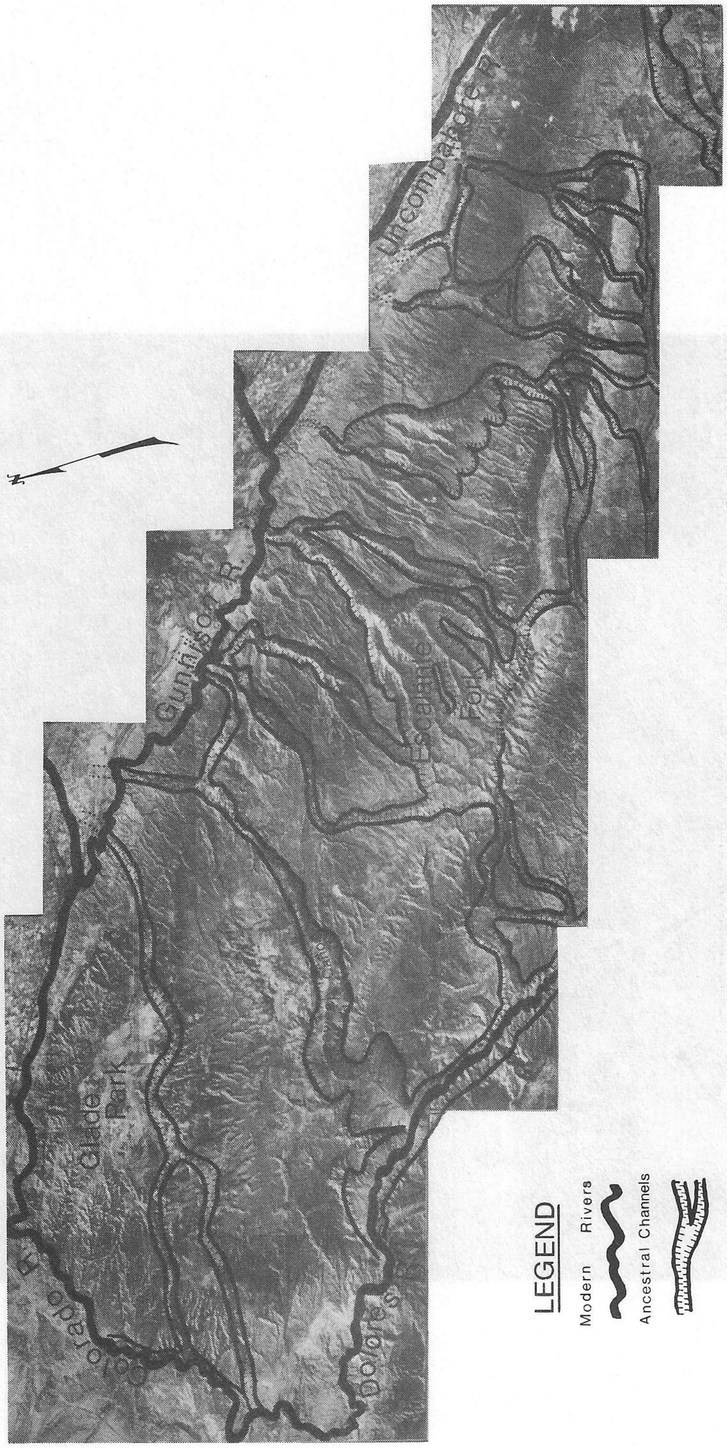


Fig. 14. Enlargement of ERTS-1 Frame 1066-17251 showing the Uncompahgre Plateau. Enlargement obtained through use of LARS/Purdue LARSYS program DISPLAY and digital display television screen. Each ERTS-1 data element is represented by four gray scale picture elements on the video screen. The town of Ridgway is just off picture to the right. The first diversion channel described in text is the lower left hand corner of the picture.

Fig. 15. Unaweep Canyon, looking west from point along secondary road leading out of canyon to Divide Road on the Uncompahgre Plateau. The stripped preCambrian surface is in the immediate foreground and along the top of cliffs to the right. Cutting of the sharp canyon walls in preCambrian rocks occurred during entrenchment coincident with uplift of the plateau. West Creek is the present underfit stream flowing in the canyon. Colorado 141 is the highway.