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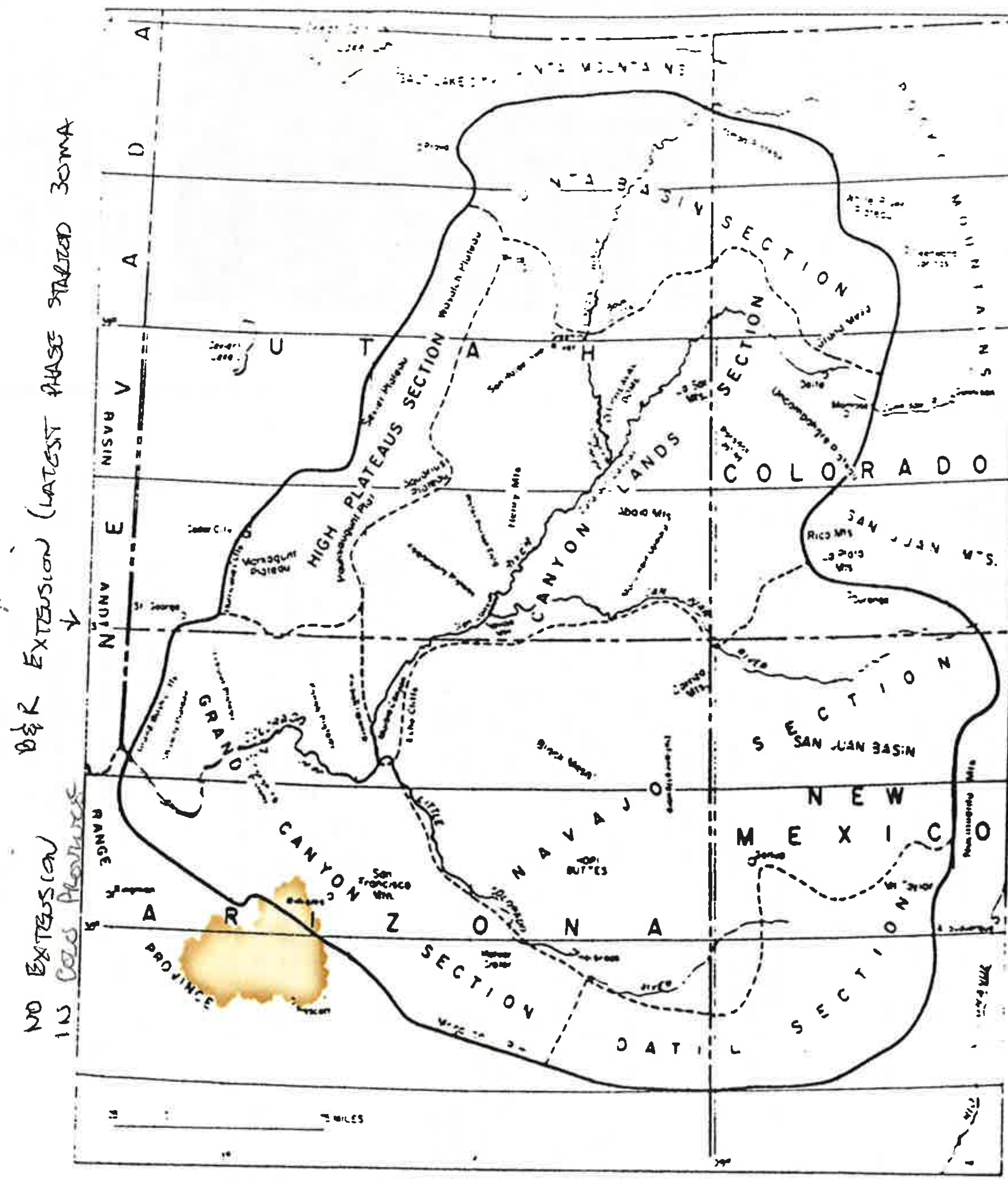
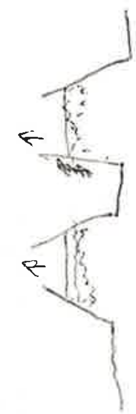
1995 FALL FIELD FROLIC

ZION, BRYCE CANYON, and CEDAR BREAKS

CSUN Geological Sciences Dept.





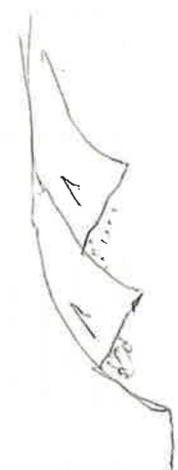


FIG. 22.3 Index map of Colorado Plateau province with sectional boundaries. (*After C. B. Hunt, U. S. Geol. Surv. Profess. Paper 279.*)

low seas. Beds of gypsum and casts of salt cubes preserved in the red beds indicate evaporation. Large reptiles, represented by tracks, and big amphibian skeletons in the stream deposits suggest warm climates. Stewart and others (1972a) present the latest analysis of the Moenkopi Formation and its environments.

Ammonoid and conodont (Sweet et al., 1971) faunas in the Thaynes Formation and in the limestone members of the Moenkopi, shown on Text-figure 35, Column 2, enable sure correlation of this part of Utah's Triassic rocks with middle-Early Triassic rocks in other parts of the world. Marine bivalves, snails, and brachiopods are, as usual, more obvious and abundant in Early Triassic limestones than are ammonoids but are not as distinctive in indicating time. Utah's Late Triassic rocks, lacking marine fossils, cannot be correlated intercontinentally with the same degree of precision.

Chinle Continental Deposits

Petrified Forest National Park in Arizona displays thousands of logs of the conifer *Auracaria* which came to rest as driftwood on Chinle river floodplains in Late Triassic time. Elsewhere fossil wood occurs in lesser quantities in most places where the Chinle Formation is present. In some instances the cellular tissues of the wood have been replaced by silica in exquisite detail. Silicification of the wood in the Chinle Formation was probably related to the bentonitic volcanic ash in the formation which provided a ready source of silica. The volcanoes which provided the ash were probably located in southern Arizona.

Although conifers are the most common plants preserved in the Chinle Formation, it also yields foliages of cycadeoids and ferns. Chinle plants resemble those of the Late Triassic Newark Group of New Jersey and those from the Keuper of Germany. Fossil animals from the Chinle include fresh-water bivalves, snails, ostracods, and fish as well as amphibians and reptiles. Most common among the reptiles was the river-dwelling phytosaur, which resembles modern crocodiles but has a slender snout. Other reptiles from the Chinle Formation include the small bipedal carnivore *Coelophysis,* and the dog-tooth therapsid *Placerias*.

Arrows on Text-figure 36b, adapted from McKee and others (1959), indicate direction of stream-sand and gravel transport during Chinle time. Gravels and sands which make up the Shinarump, Moss Back, Gartra, and Higham members in Utah were derived chiefly from the east and south. Stream channel systems represented by the Moss Back and Shinarump sands and gravels were the site of later localization of uranium mineralization. Stewart and others (1972) provide the latest information on the Chinle Formation.

Latest Triassic Sandstone

Although the Navajo Sandstone has been shown as Jurassic in most older reports, Lewis and other (1961) reassigned it to a "Late Triassic (?) and Jurassic" age, an assignment which has been accepted by most geologists now working in the area. Exactly where the Triassic-Jurassic boundary lies within the Navajo Sandstone has not been determined, but sparse reptile remains in the Kayenta and Navajo formations suggest a Late Triassic age for much of the Navajo.

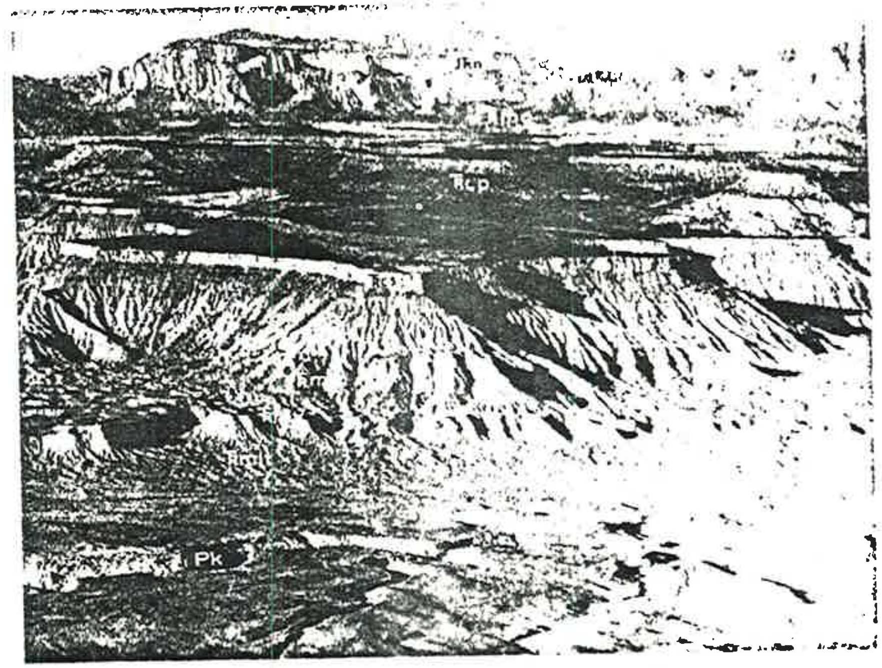
The Navajo, Kayenta, and Wingate Sandstones are separable over most of the Colorado Plateau because the cross-bedding of the intervening Kayenta Sandstone is on a smaller scale typical of streams, whereas that of the Navajo and

Wingate is on a large scale typical of sand dunes. In some places however, this Late Triassic–Early Jurassic sand pile is not obviously tripartate, and the collective term "Glen Canyon Group" is useful. Nugget may be the northern counterpart of the Glen Canyon Group; in a few instances, the name "Navajo" has been applied to undifferentiable Late Triassic–Early Jurassic sandstone, as shown on Text-figure 35, Column 3.

Separating the Navajo into Triassic and Jurassic parts for thickness maps has its problems. Consequently, on the included thickness maps the Navajo thicknesses are all shown on the Jurassic maps and the underlying sandstone units on the Triassic.

JURASSIC

Jurassic strata are among Utah's most scenic; they include the Navajo Sandstone that makes the great monoliths at Zion National Park, and that, along with the Kayenta and Wingate sandstones, makes the "reef" at Capitol Reef National Park; they also include the Entrada Sandstone that makes the arches at Arches



TEXT-FIGURE 37.—Triassic strata near Zion Park, Utah. U.S. Air Force ejection seat testing track shows atop Hurricane Mesa in left center of photo (see Chart 42 for stratigraphic succession). Permian Kaibab Limestone (Pk) exposed in gully in foreground. Labeled members of Triassic Moenkopi Formation include Timpoweap and "lower red" members undivided, Virgin Limestone(capping basal ledges), "middle red," Shnabkaib (light banded), and "upper red." Hurricane Mesa is capped by the resistant Shinarump Conglomerate Member of the Chinle Formation. The Petrified Forest Member of the Chinle Formation comprises the weak shaly beds above the Shinarump ledge. Moenave Formation sandstones, siltstones and shales from the ledge-slope topography beneath the Navajo-Kayenta line of cliffs in the background. (Oblique air photo courtesy of W. K. Hamblin)

National Park, and the Morrison Formation, which yields the bones at Dinosaur National Monument. Jurassic rocks are exposed over wide areas in eastern Utah, and their multicolored layers are an open text to the knowledgeable traveler and a scenic delight to all.

Relation of Jurassic Strata to Later Mesozoic Thrusting

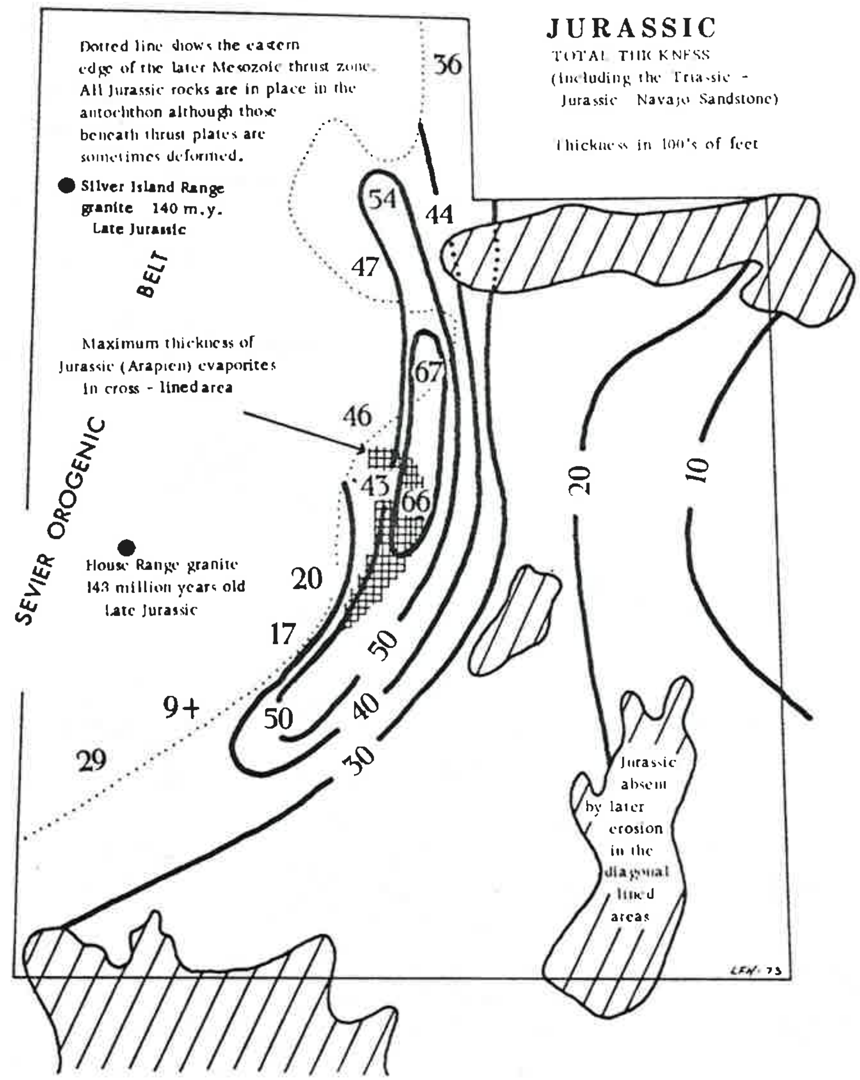
The Jurassic thickness map (Text-fig. 38) is the earliest map *not* shown on a palinspastic base. Jurassic rocks are the youngest rocks most commonly present beneath overthrust rocks along the later Mesozoic thrust zone, as shown on Text-figure 2. They have not been transported by the thrusting, and their extent to the west is concealed beneath the overthrust plates. All of the thickness figures west of the dotted line on Text-figure 38 are of Jurassic rocks (usually the Triassic-Jurassic Navajo Sandstone) beneath the thrust plate. The original western depositional limit of these rocks is concealed, but the rocks probably did not extend more than a few tens of miles west of their present exposures. No Jurassic sediments have been found in Utah west of the Sevier Geanticline where Triassic remnants occur (see Text-fig. 34), and the thickness figures on the east side of the Sevier Geanticline (Text-fig. 38) begin to show rapid westward thinning where they pass beneath the thrusts.

Jurassic Evaporites

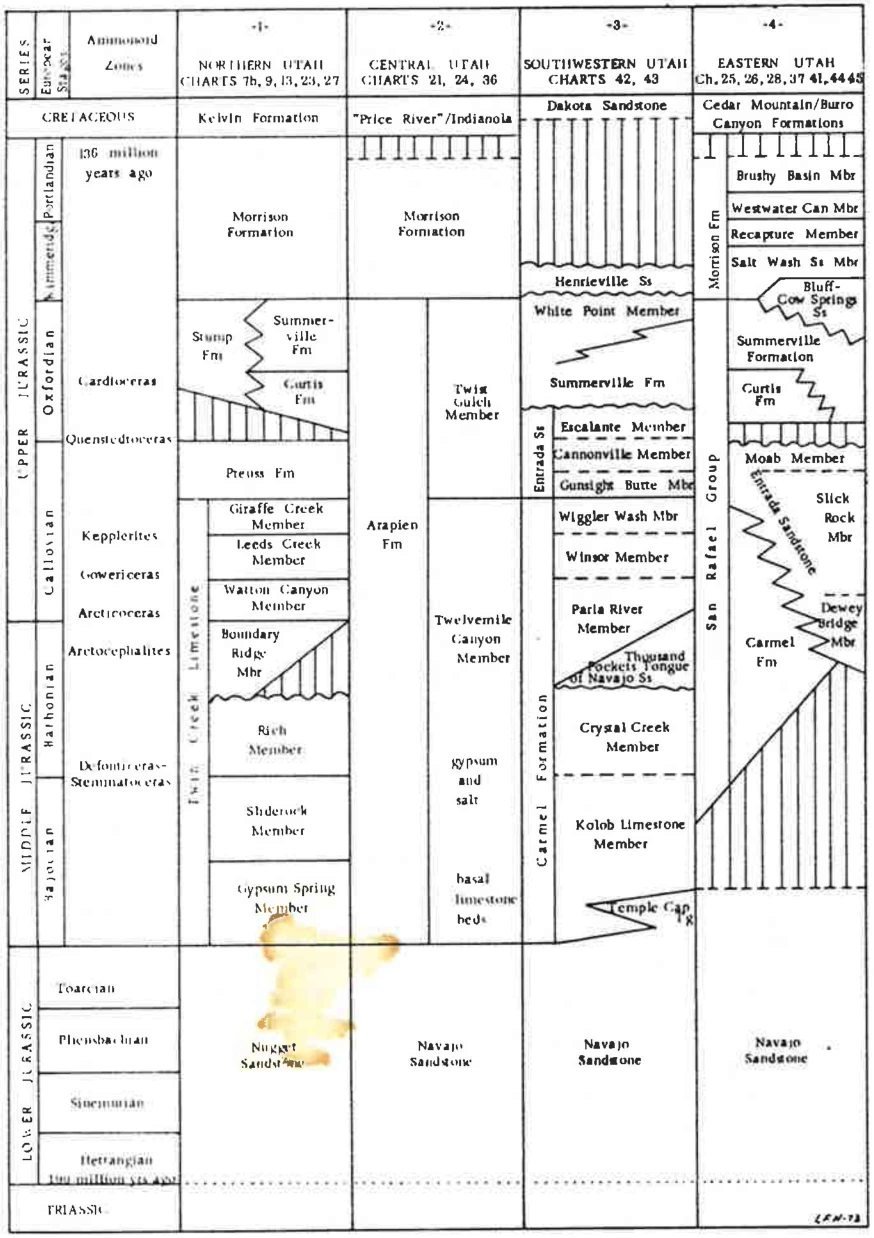
Thickest Jurassic sediments occur in an arcuate belt that extends from Devil's Slide east of Ogden southward to near Marysvale (south of Richfield). Maximum thickness nearly coincides with maximum occurrence of evaporites, as shown on Text-figure 38. Although thin beds and veinlets of gypsum are common in the Carmel and Summerville formations (Text-fig. 39) over much of southern and eastern Utah, commercial salt and gypsum of Jurassic age have been claimed only from the Arapien Shale in the area between Nephi and Richfield. Depositional thickness of Jurassic salt and gypsum in this area is not known because the plasticity of these evaporites has brought about considerable mobility and contortion of their enclosing shaly beds, but certainly several hundred feet of evaporites are indicated by available data. These evaporites may have had a key role in the development of many of the "tectonic" features in the Sanpete Valley area.

Jurassic Intrusion and Sevier Geanticline

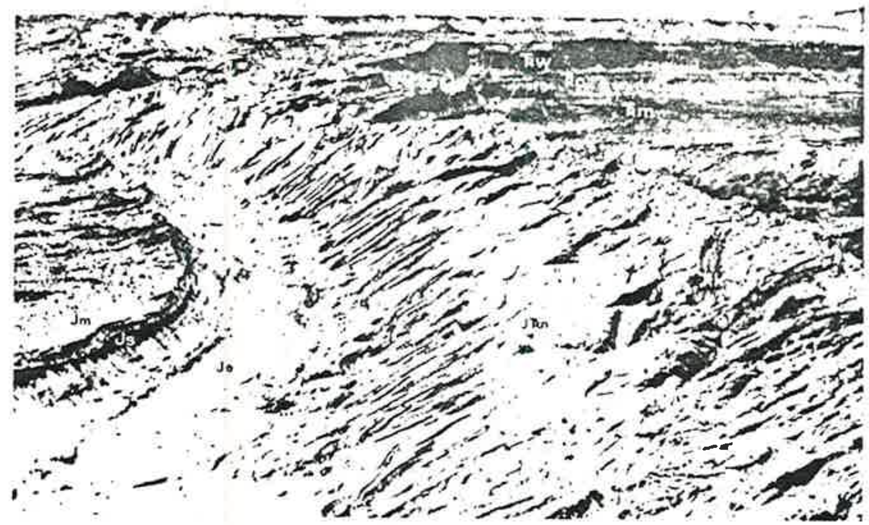
Radiometric dating of the Painter Spring Granite in the House Range of western Utah as Late Jurassic (Text-fig. 38, chart 31) reveals that tectonic activity was certainly under way in the Sevier Geanticline by this time. Stratigraphic data bearing on development of the Sevier Geanticline suggest that (1) the geanticline could not have existed in Early Triassic time, because Thaynes Limestone and equivalent beds probably covered the area, as indicated by remnants still present in western Utah and eastern Nevada, (2) Late Triassic conditions in western Utah are uncertain; streams which deposited the conglomerate members of the Chinle Formation were flowing northwestward, as indicated on Text-figure 36b, and while their ultimate destination to the west is not known, their direction is *towards*, rather than away from, the future site of the Sevier Geanticline, (3) cross-bedding and other primary structures in the Curtis Formation in the San Rafael Swell area record the earliest evidence of sediment transport to



TEXT-FIGURE 38.—Jurassic thickness map. Thickness figures from accompanying stratigraphic charts.



TEXT-FIGURE 39.—Jurassic correlation table (after Peterson, 1972).



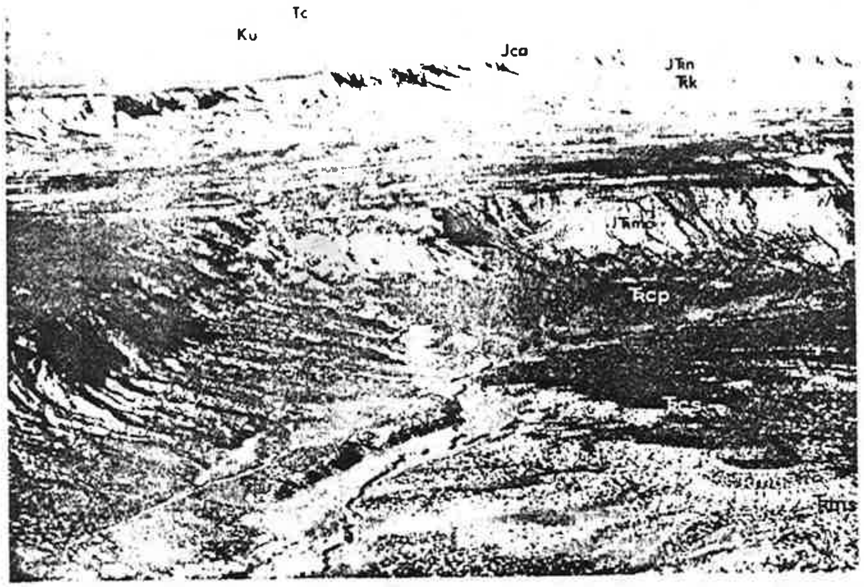
TEXT-FIGURE 40.—Jurassic strata on the south flank of the San Rafael Swell (see Chart 38). From the youngest beds on the left side of the picture the formations are Morrison (Jm), Summerville (Js), Curtis (Jc), Entrada (Je), Carmel (Jca), Navajo (Jtrn), Kayenta (Trk), Wingate (Trw), Chinle (Trc), and Moenkopi (Trm). The San Rafael Swell is believed to be a Laramide structure. (Photo courtesy of W. K. Hamblin)

the east *away from* the Sevier Geanticline (Stokes, 1972, p. 25), and (4) certain Morrison Formation gravels were surely derived from the Sevier Geanticline (Stokes, 1972, p. 23).

Thus, the Late Jurassic date of the House Range intrusive rock coincides with the date for initial rise of the Sevier Geanticline as inferred from the Upper Jurassic Curtis-Morrison sedimentary features. The Sevier Geanticline was on the rise by Late Jurassic time.

Lower Jurassic Sandstones

The Navajo Sandstone is world famous for its large-scale cross-bedding indicative of sand-dune origin. Where underlain by the smaller-scale water-laid cross-beds of the Kayenta, the Navajo is easily distinguished from older sandstone units. Where the Kayenta Formation is missing, the Navajo appears to merge downward with the Triassic Wingate Sandstone. The combined sandstones are called the Glen Canyon Group in southern and eastern Utah. The correlative Nugget Sandstone of northern Utah and Wyoming has water-laid features near the base and eolian cross-beds near the top. Upper Navajo sands interfinger



TEXT-FIGURE 41.—Giant Staircase east of Kanab, Utah. Oldest strata in foreground are Shnabkaib Member of Moenkopi Formation, overlain by "upper red" Moenkopi member. Low cuesta in foreground is developed on Shinarump Conglomerate Member of Chinle Formation and this is overlain by the nonresistant Petrified Forest Member. Vermillion Cliffs in photo center are held up by sandstones and siltstones of the Triassic Moenave Formation. White Cliffs in middle distance are capped by Triassic-Jurassic Navajo Sandstone, underlain by Kayenta Formation. Pink Cliffs near top of picture expose Early Tertiary lake and stream deposits of the Cedar Breaks—Canaan Peak formations. Between the White Cliffs and Pink Cliffs are the less resistant Jurassic and Cretaceous strata listed on Chart 43. (Oblique air photo courtesy of W. K. Hamblin)

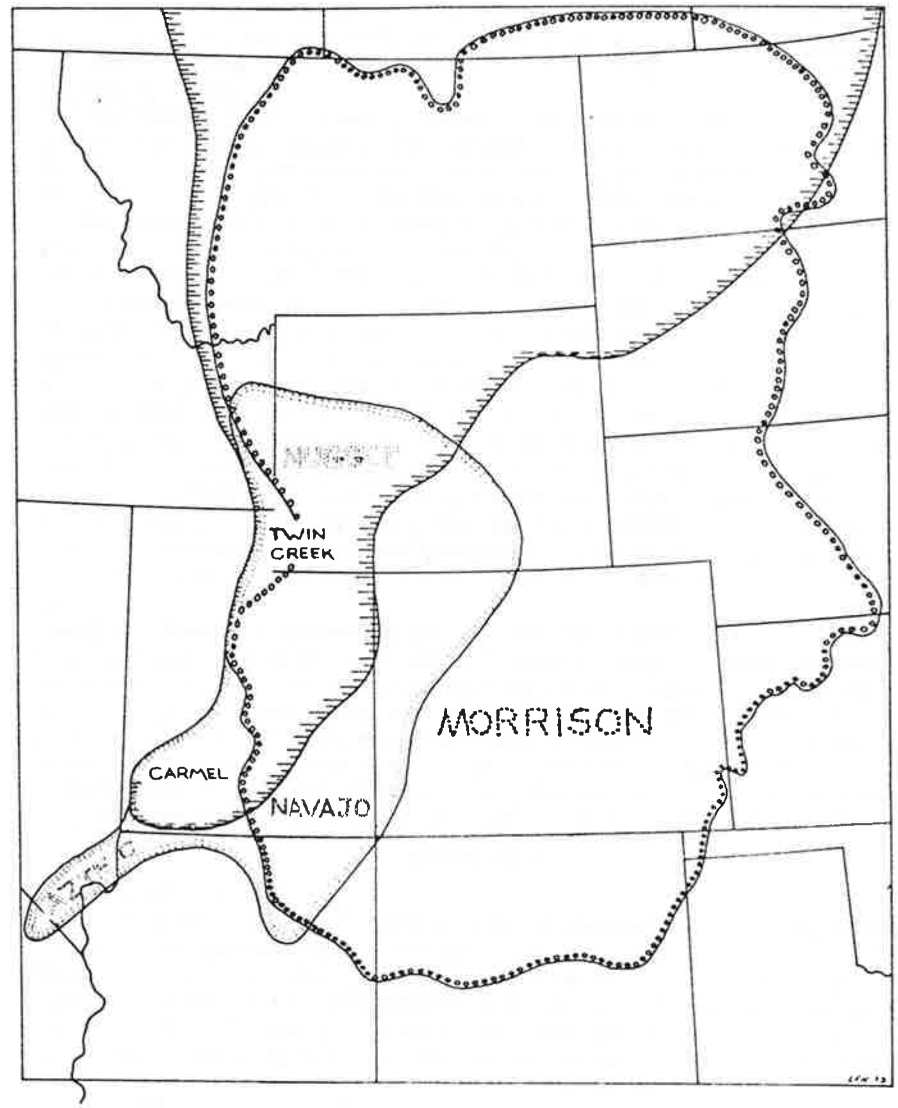
with marine beds of the Carmel Formation, as indicated on Text-figure 39, column 3.

This amazing Triassic-Lower Jurassic sand sheet covered all of eastern Utah and parts of adjacent states (Text-fig. 42). Dip directions of Navajo cross-beds indicate wind directions from the north or northwest.

Middle and Upper Jurassic Marine Invasions

Fossil-bearing limestones and shales of the Twin Creek and Carmel formations record a shallow seaway of Middle Jurassic time. As shown in Text-figure 42, the sea extended from Canada southward to Carmel Junction, near Zion Park. Basal Twin Creek-Arapien-Carmel limestones of Bajocian age (Text-fig. 39) are the most widespread marine Jurassic rocks in Utah; later Bathonian and Callovian strata include substantial evaporites and red beds indicating marginal marine conditions. By Entrada-Preuss time, marine conditions had retreated northward out of Utah.

Another Jurassic marine invasion, less extensive than the first, is documented by marine fossils in the Curtis Formation. These marine waters penetrated only



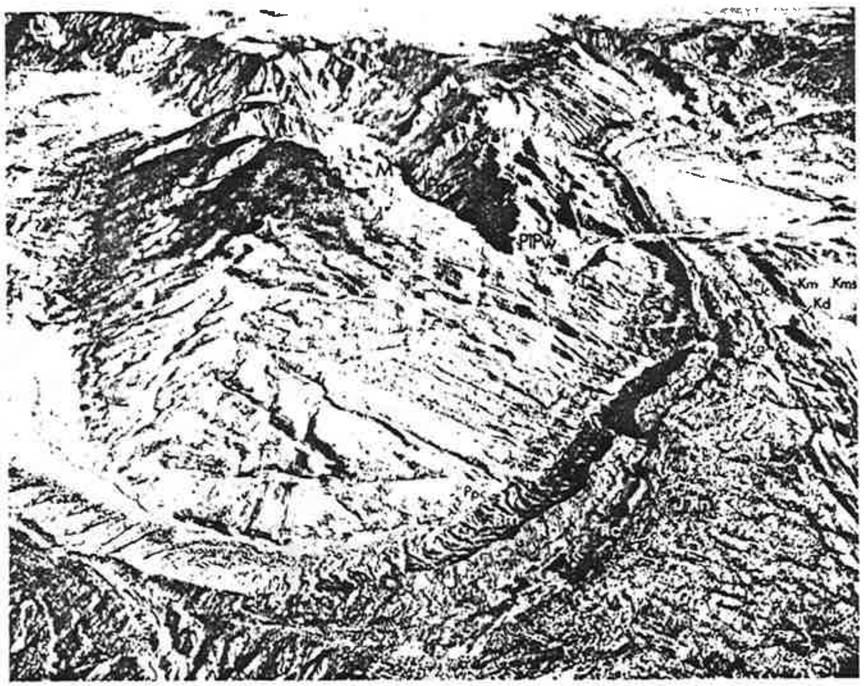
TEXT-FIGURE 42.—Extent of some famous formations: Triassic-Jurassic Navajo-Nugget-Aztec sandstone, Jurassic Carmel–Twin Creek marine strata, Upper Jurassic dinosaur-bearing Morrison Formation.

to the San Rafael Swell area of central Utah where the Curtis Formation interfingers with the marginal marine gypsiferous chocolate shales of the Summerville Formation. Peterson (1972) has traced the marine Jurassic invasions northward to the more continuously limy deposits in Wyoming and Montana.

Morrison Formation

Varicolored mudstones, interbedded stream channel sandstones and conglomerates, and lacustrine limestones comprise the distinctive lithologies of this unique formation. The Morrison has yielded most of the dinosaur bones of this region, chiefly from quarries at Como Bluff in Wyoming, Dinosaur National Monument in eastern Utah, and the Cleveland quarry south of Price. Bones occur both in claystones and in the sandstones and grits, and, although whole skeletons are rare, bone fragments are common enough throughout the formation to serve to identify it in most places.

Considering that the Morrison Formation is entirely continental in origin, it covers a surprisingly large area (Text-fig. 42) rather uniformly. Stokes (1944)



TEXT-FIGURE 43.—Split Mountain anticline, a Laramide fold subsidiary to the Uinta Mountain uplift. Arrow near center of right edge of picture points to visitor center building, Dinosaur National Monument (see Chart 14 for stratigraphy). Oldest beds exposed where Green River cuts the anticlinal axis are Mississippian (M). Successively higher formations labeled on the photo are Morgan Formation, Weber Sandstone, Park City Formation, Moenkopi Formation, Gartra Grit, Chinle Formation, Navajo Sandstone, Carmel Formation (Jca, thin, forms narrow strike-valley), Entrada Sandstone, Curtis Formation, Morrison Formation (Jm), Dakota Sandstone, Mowry Shale (Km), Frontier Sandstone, and Mancos Shale. (Photo by John S. Shelton)

suggests that Morrison sediments were deposited by intermittent shifting streams under posible semiarid conditions. Mudstones in the Morrison include much reworked volcanic ash. Discontinuous lacustrine limestones represent local lakes in low places on a Morrison plain.

Although some conglomerates, such as the Salt Wash, were probably derived from a source to the southwest in Arizona, many of the conglomerates in central Utah were certainly derived from the Sevier Orogenic Belt in western Utah. Stokes (1972, p. 26) and Crittenden (1963) have discussed the problem of distinguishing Morrison age conglomerates from the overlying Cretaceous conglomerates in central Utah from Sanpete Valley northward. In this regard, Pinnell's (1972) recent discovery of dinosaur bone fragments from Morrison conglomerate near Thistle, Utah, ties down the northwesternmost occurrence of known Morrison rocks in Utah.

CRETACEOUS

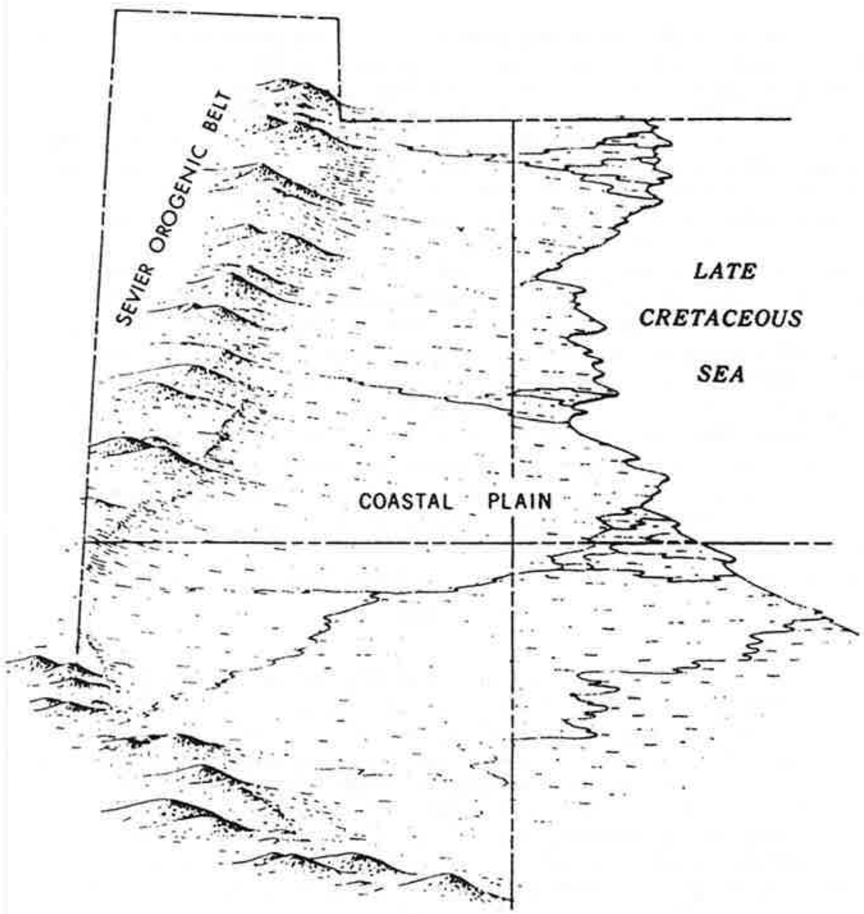
Cretaceous was the time of the last epicontinental sea in Utah. Unlike the Jurassic seaway of northern connection, the Cretaceous waters spread northwestward across the Texas coastal plain, finally covering all of eastern Utah by early Upper Cretaceous time. The westward spread of marine waters was limited by the Sevier Orogenic Belt, which had begun its rise in the late Jurassic; throughout later Cretaceous time this positive area continued to provide clastic material to eastern Utah to such an extent that the wedge of sands and muds ultimately forced the eastward withdrawal of the seas from Utah (Text-fig. 44, from Hunt, 1956).

Cretaceous deposition and accompanying subsidence was such that total thickness of Cretaceous strata more than doubled that of the Jurassic in the same area, as can be seen by comparing Text-figures 45 and 38. Cretaceous rocks, however, have been stripped away from much of eastern and southern Utah through erosion by the Colorado River and its tributaries in late Cenozoic time, but Text-figure 45 outlines the area where Cretaceous strata remain. Utah's most imposing lines of cliffs—the Book Cliffs, the eastern front of the Wasatch Plateau, and the Straight Cliffs—are all held up by resistant sandstones of the late Cretaceous Mesaverde Group. The underlying Mancos Shale forms the broad low areas that are now traversed somewhat unevenly by the major highways and railways.

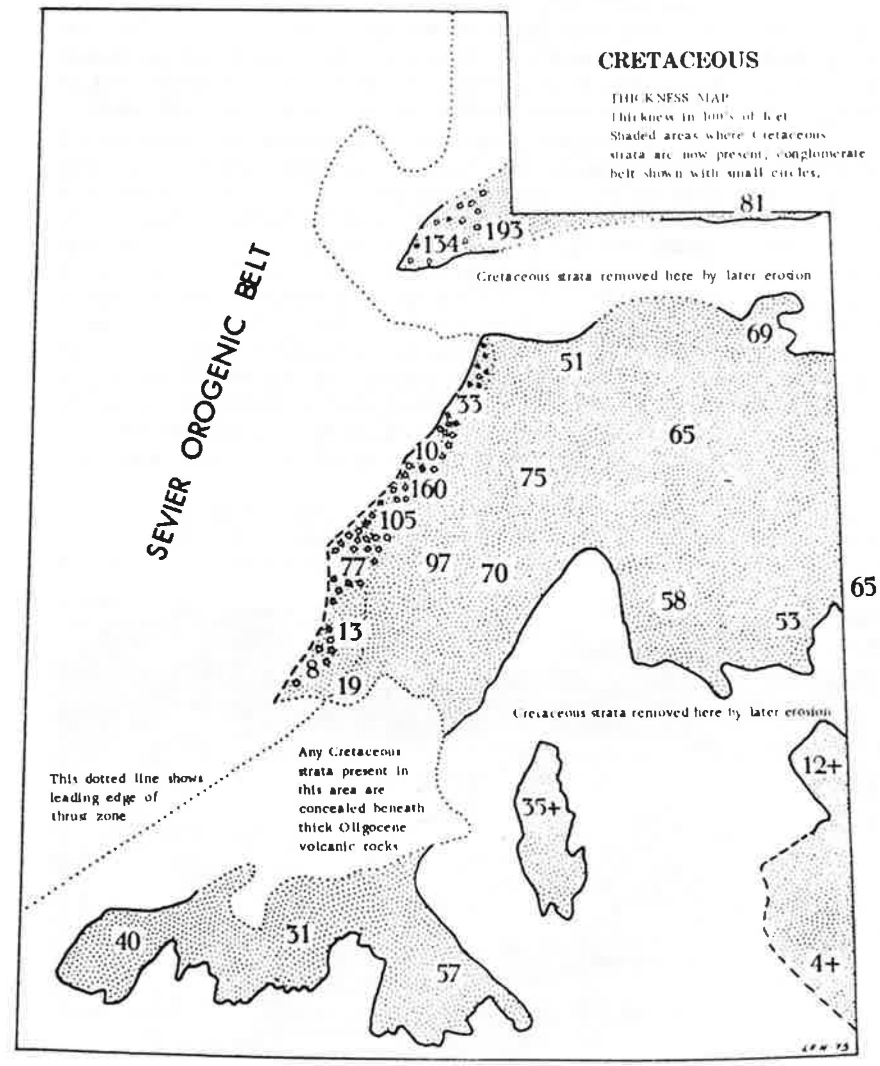
Cretaceous events can be read fairly directly from the correlation table (Text-fig. 46) and the cross section (Text-fig. 48) that covers the area shown in Columns 2, 3, 4, and 5 of the correlation table.

Immediately adjacent to the mountain front of the Sevier Orogenic Belt, deposition of stream-laid sands and gravels was probably continuous from Late Jurassic into Early Cretaceous time, as represented by the Kelvin and Lower Indianola formations. Dinosaur-bone-bearing Cedar Mountain and Burro Canyon sediments represent Lower Cretaceous river floodplain deposits similar to the underlying Morrison.

Earliest marine Cretaceous formations are the fish-scale bearing Aspen-Mowry Shale and the underlying Dakota Sandstone in the Utah-Wyoming corner. Sandstones called "Dakota" vary in age, as shown on the correlation table, because they are the basal deposit of a transgressing sea which spread across eastern Utah between late Early and early Late Cretaceous time (Lawyer, 1972). Although the Dakota itself does not usually contain diagnostic fossils, its age can be determined by macro- and micro-fossils (Lessard, 1972) in the overlying shale. The *Gryphaea newberryi* bivalves and associated microfossils, which are



TEXT-FIGURE 44.—Late Cretaceous paleogeographic map (from Hunt, 1956).



TEXT-FIGURE 45.—Cretaceous thickness and preserved extent map. Thickness figures from accompanying stratigraphic charts.

present in such countless numbers in Greenhorn age rocks, may be regarded as a "time line" that demonstrates this transgression very nicely: near Grand Junction *Gryphaea* occurs more than 50 feet above the base of the Mancos Shale; hence, the Dakota is somewhat older. At Green River *Gryphaea* is directly on the Dakota. Near Price the *Gryphaea* horizon is not present, presumably because the seas had not reached that far west by *Gryphaea* time.

Once marine waters had reached central Utah they regressed eastward and transgressed westward in an oscillating fashion during Mancos time: sandstones such as the Ferron and Emery tongues represent eastward regressions (the Ferron Sandstone has been the major natural gas horizon in the Wasatch Plateau), while intervening shale tongues of the Mancos represent westward transgressions. Late Cretaceous Mesaverde sandstones in Utah document a final regression of marine waters eastward. This final regression was also somewhat oscillatory, as indicated by the interfingering sandstone-shale relationships in Text-figure 48. These regressive sandstones are the rock record of complex fluvial, deltaic, and shallow marine interrelationships which have been studied in detail by many, notably Young (1955, 1966), Hale and Van de Graaff (1964), Hale (1969, 1972), Howard (1966), and Van de Graaff (1972).

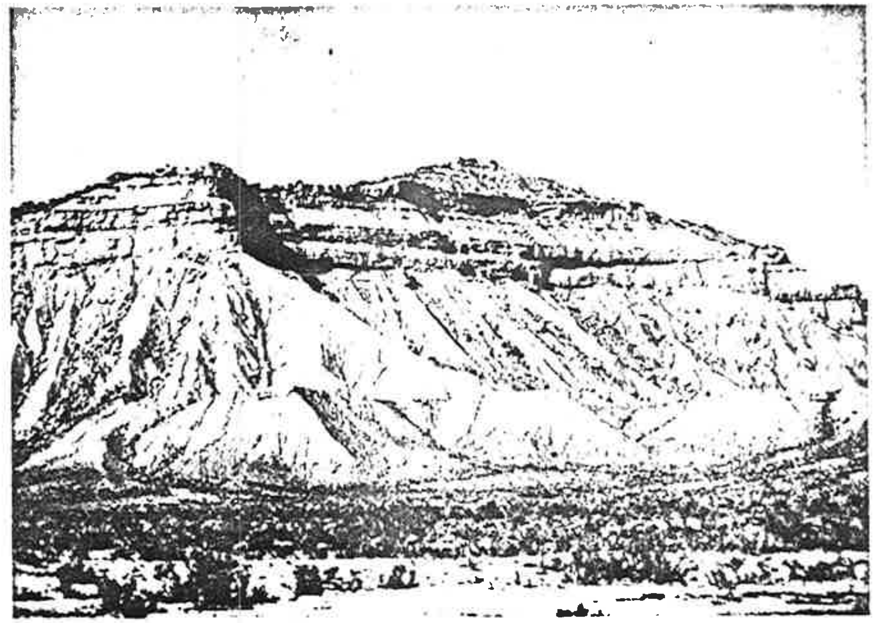
Cretaceous Coals

Bituminous coal has been mined from Cretaceous rocks in Utah since pioneer times, when early mining operations were conducted at Coalville, to supply Salt Lake Valley, and at Cedar City, in connection with the iron mines. Locus of coal mining shifted to Carbon County in the early 1900s, and more recently the coals of Kane and Garfield counties are being exploited for power generation.

Coal occurs at many horizons in Cretaceous strata as, indicated on the correlation table, Text-figure 46. Oldest coals are those at Coalville, of early Coloradoan age. Southern Utah coals occur in the Straight Cliffs Formation of late Coloradoan age. Carbon County coals are from the Blackhawk and higher units of Montanan age. Regardless of age, the coals are usually associated with sandstones and were deposited in coal swamps areas behind barrier beach sands along Cretaceous coastlines. Visualize, if you can, central Utah at sea level, with a broad, flat, marshy belt along the shoreline of the coastal plain. Dinosaurs roamed in the coal marshes, as indicated by thousands of their footprints left in coal beds. The proportion of different plants in the coal swamps is not well known, but conifers were abundant, and deciduous trees such as gum, maple, walnut, fig, and cottonwood were represented. Details on coal deposition in central Utah are summarized in Utah Geological and Mineralogical Survey Bulletin 80 (1966); those in the Kaiparowits area of south-central Utah are in Utah Geological Society Guidebook 19 (1965) and in several papers of the Special Studies series of the Utah Geological and Mineralogical Survey.

Cretaceous Tectonics

Three names have been coined to differentiate Mesozoic orogenic events in the western United States: Nevadan Orogeny, Sevier Orogeny, and Laramide Orogeny. Their time ranges, as interpreted by Armstrong (1968), are shown on Text-figure 49. The Nevadan Orogeny is evidenced chiefly by intrusive rocks in Nevada and California, although the Jurassic granite in the House Range of western Utah could be included. Intense metamorphism within the Sevier Oro-

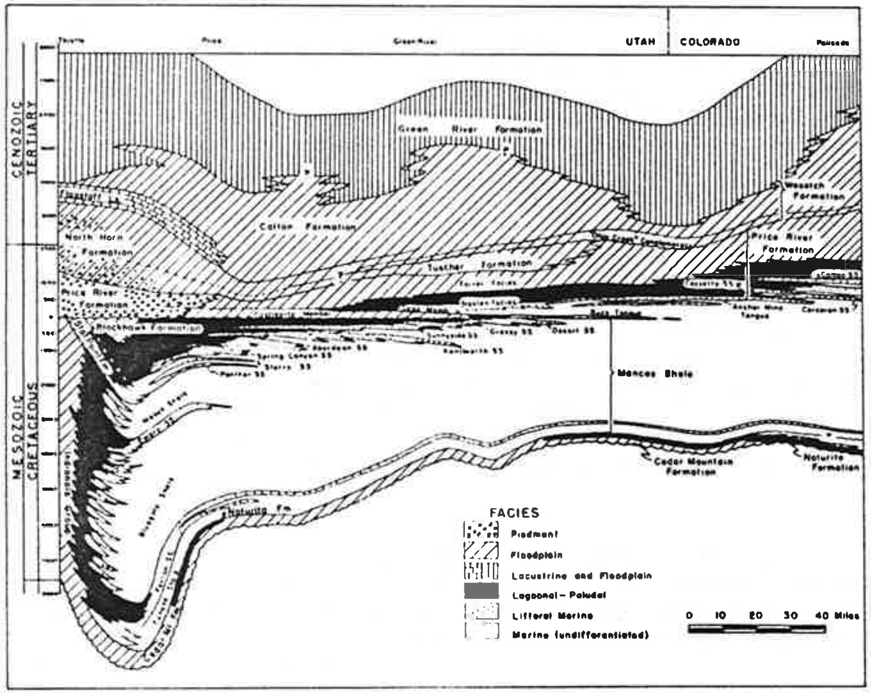


TEXT-FIGURE 47.—Book Cliffs at Prairie Creek near Utah-Colorado border. Lower, middle and upper sandstone tongues of Sego Member of Price River Formation, resting on Buck Tongue of Mancos Shale. (Photo courtesy of Robert G. Young)

genic Belt occurred in the Raft River Range of Utah and in the Kern Mountains and the Northern Snake Range just west of the Utah-Nevada border. Date of this metamorphism is post-Triassic, pre-Late Cretaceous (80 m.y.) according to Armstrong and Hansen (1966). Interpretation of radiometric dates for this metamorphism is complicated by the likelihood that these rocks were subsequently reheated by Cenozoic thermal events. The Sevier Orogeny is the name attached to events related to producing the tremendous Cretaceous clastic wedge. Specific dating of movements within the source area in western Utah is not possible beyond "post-Triassic to pre-Oligocene." (Triassic limestones are the youngest pre-orogenic rocks and Oligocene volcanics are the oldest post-orogenic rocks in western Utah) except by making inferences from the stratigraphy in eastern Utah. As discussed under the Jurassic, Late Jurassic sediments in eastern Utah are the oldest ones derived from the Sevier Orogenic Belt.

Both the Nevadan and Sevier orogenic events are included under Phase III of Text-figure 3. Utah moved into Phase IV of its history with the new patterns developed during the Latest Cretaceous to Eocene Laramide Orogeny. None of the orogenies named are single events; rather, they form a continuum in which the named orogenies overlap, as indicated in Text-figure 49.

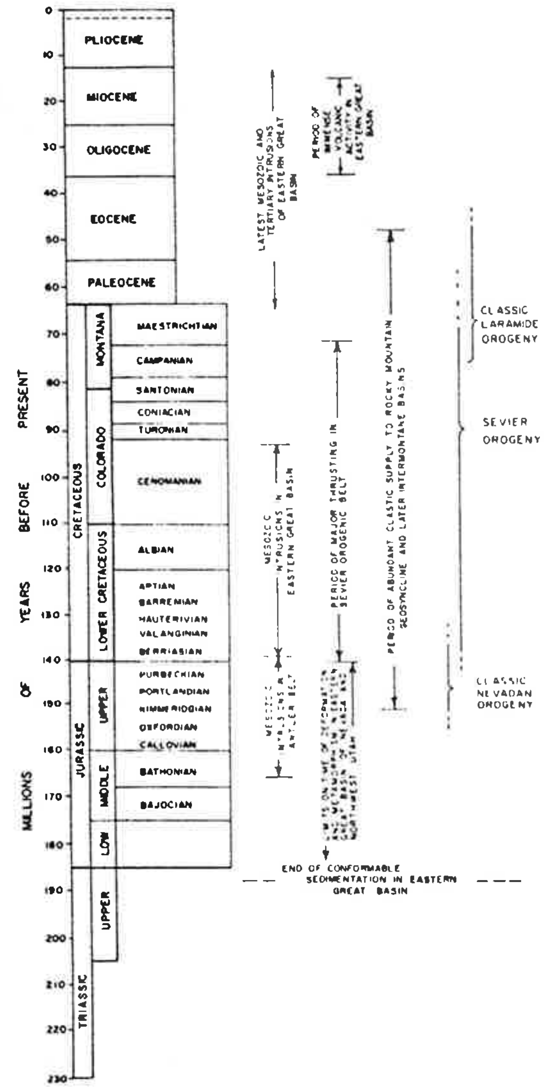
Geologic authors use "orogeny" in two different ways: some emphasize that a named orogeny includes everything orogenic that happens between certain specified time and space limits; others emphasize that a named orogeny is characterized by a certain structural style. Our discussion will follow the latter usage. Accordingly, the Sevier Orogeny is characterized by compressional folds and



TEXT-FIGURE 48.—Cretaceous–Early Tertiary strata exposed between Thistle, Utah, and Grand Junction, Colorado, emphasizing intertonguing relations between Mancos Shale and Mesaverde sandstones (from Young, 1966).

overthrusts along a belt that extends from Nevada to Alaska and that was active in its various parts between late Jurassic and early Tertiary time. The Laramide Orogeny, on the other hand, is characterized by vertical uplifts that formed the Rocky Mountains from New Mexico to Montana in latest Cretaceous and early Tertiary time.

Laramide events are clearly separate in the Rocky Mountains (including Utah's Uinta Mountains) where the great Laramide anticlinal uplifts have tilted latest Cretaceous and early Tertiary strata along their flanks. Sevier thrusting and folding events (of "Laramide-age") are known from several Utah areas along the interface between the Sevier orogenic belt, and its clastic wedge: (1)in the Canyon Range the Indianola conglomerates have been vertically tilted and overridden by the Canyon Range thrust, while in the adjacent Pavant Range, "Price River" conglomerates overlie the thrust (Burchfiel and Hickcox, 1972); (2) in Spanish Fork Canyon Indianola beds are nearly vertical, whereas "Price River-North Horn" conglomerates overlie them nearly horizontally (Hintze, 1962); (3) in the Wasatch Range east of Salt Lake City all strata up to and including the early Late Cretaceous Frontier Formation have been folded (Marsell and Threet, 1960) and are overlain by less-folded Echo Canyon Conglomerate of latest Cretaceous age; all older folded strata are covered by the essentially horizontal Wasatch Conglomerate of Eocene age (Crittenden, 1964); and (4) in the Idaho-Wyoming fold-and-thrust belt, Eardley (1967) argues, there was an east-



TEXT-FIGURE 49.—Dating of orogenic events in Utah and Nevada (from Armstrong 1968a).

ward migration of the locus of folding and thrusting throughout later Mesozoic and early Cenozoic time.

One of the greatest difficulties in all of this work is in identifying the ages of various conglomerates. Although the above summary may suggest that the problems have been resolved, development of some uncontestable means of showing the true ages of the conglomerates might modify our understanding. At present, rocks called "Price River" form the near-horizontal cover for the folded Indianola and earlier strata in central Utah, while in northern Utah the Eocene Wasatch Formation has a similar relationship to the latest Cretaceous Echo Canyon Conglomerate. Basinal deposits resulting from Laramide uplifts are discussed in the next chapter.

TERTIARY

Radiometric dating is revising our concept of Tertiary history by more accurately tying the European epoch and stage names shown on Text-figures 50 and 51 to the fossil mammal succession which had been the principal means of dating Tertiary rocks in western North America. In addition, the unfossiliferous volcanic suites, which are an important part of Utah's Cenozoic record, can be correlated now between volcanic centers by radiometric dating. An emerging coherent pattern can be related to the plate tectonic history of interaction between the North American and Pacific plates as summarized in a later chapter.

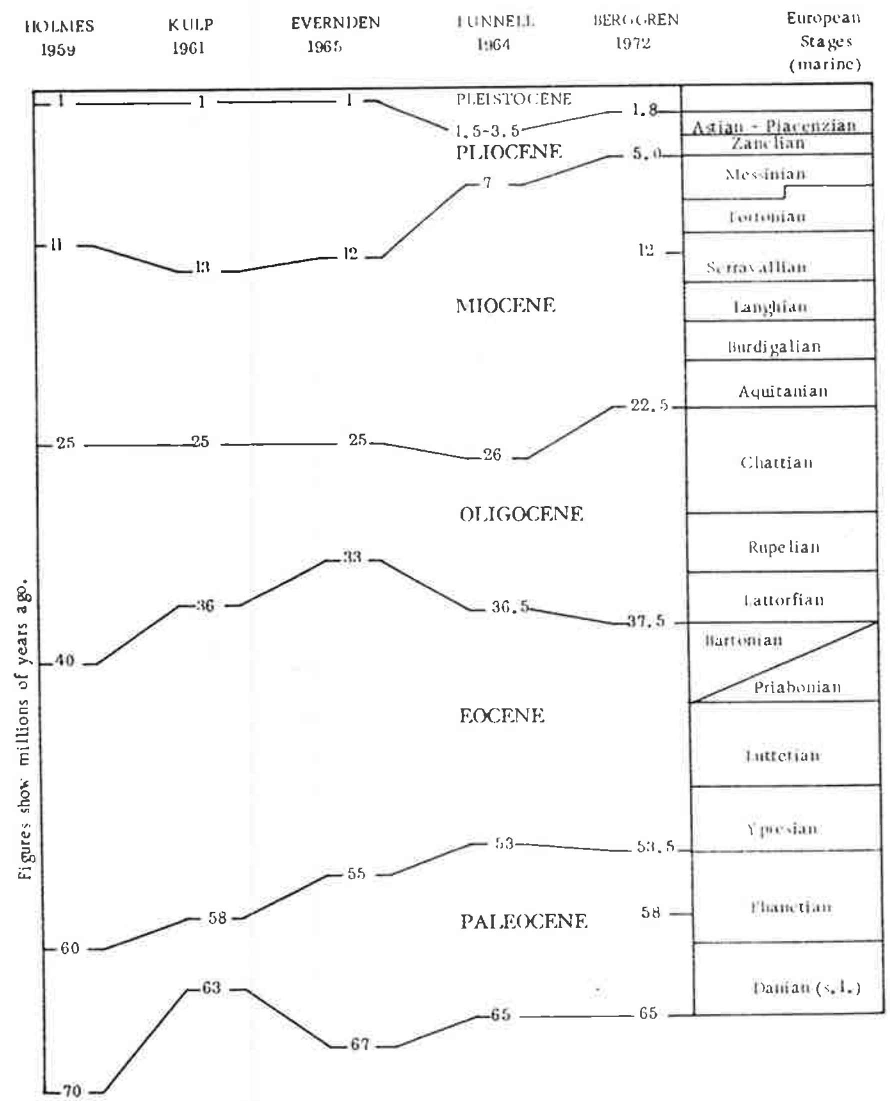
Cenozoic events fall into the last three phases of Utah's history (Text-fig. 3): Phase IV, of Latest Cretaceous through Eocene age, embodies the Laramide Orogeny and the attendant sedimentation in northern Utah and in the Uinta Basin; Phase V, of Oligocene age, is a period of explosive volcanism in western Utah and of laccolithic intrusion in eastern Utah; Phase VI, of Miocene to Recent age, is the time when the Utah landscape with which we are familiar came into being as a result of uplift of the entire western United States and extensional block faulting which formed the Great Basin of western Utah.

Phase IV

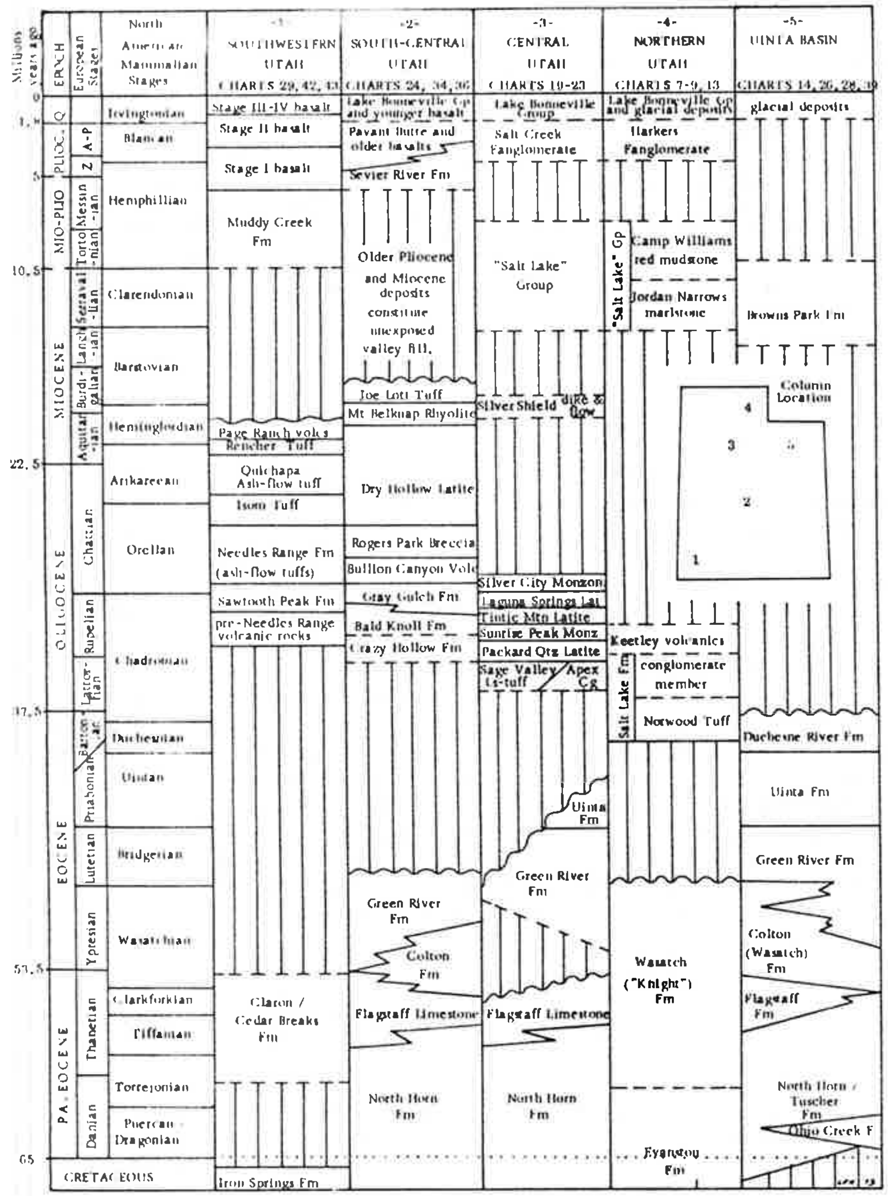
The Uinta Mountain anticline is the largest Laramide structure in Utah. Dating of this uplift is done by noting that the Late Cretaceous rocks are uptilted along the flanks of the fold and are overlain with angular unconformity by early Tertiary strata. On the north flank of the Uintas, near Flaming Gorge, the Paleocene Fort Union Formation angularly overlies the Late Cretaceous Ericson Sandstone; on the south flank of the Uintas, near Dinosaur Monument, Late Cretaceous Mesaverde Sandstone is angularly overlain by the Wasatch Formation. In southeastern Utah three asymmetrical upwarps shown on Text-figure 40, are considered by Hunt (1956) to be of Laramide age despite the lack of Tertiary cover rocks in that area. Eardley (1969) attempted to recognize Laramide structures in western Utah where late Cenozoic block faulting complicates their identification.

Basins adjacent to Laramide uplifts were filled with erosional debris from the uplifts; coarsest debris is the Wasatch (Knight) Conglomerate of northern Utah, which grades into finer-grained material eastward in Wyoming; thickest are the deposits filling the Uinta Basin where Paleocene-Eocene strata attained a maximum of more than 13,000 feet (Chart 28).

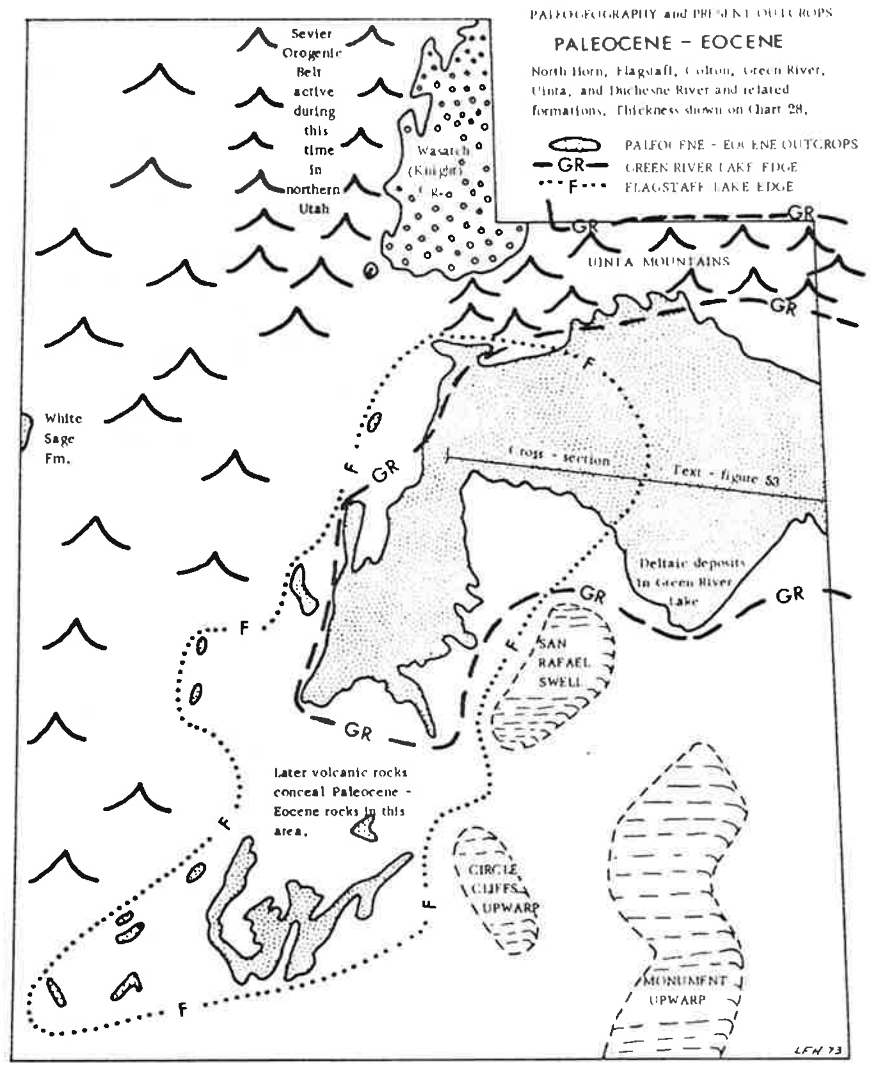
Two large lakes left extensive freshwater deposits in Utah, as shown on Text-figure 52. The older, Paleocene, Lake Flagstaff left algal "bird's eye"



TEXT-FIGURE 50.—Cenozoic radiometric time scales (after Berggren, 1972). Difference of time placement of boundaries is largely a matter of whether authors used European marine invertebrates or North American continental mammals to define epochs.



TEXT-FIGURE 51.—Cenozoic correlation table for Utah.



TEXT-FIGURE 52.—Paleocene-Eocene paleogeography and preserved extent map. Inferred original extents of Flagstaff and Green River lakes are outlined.

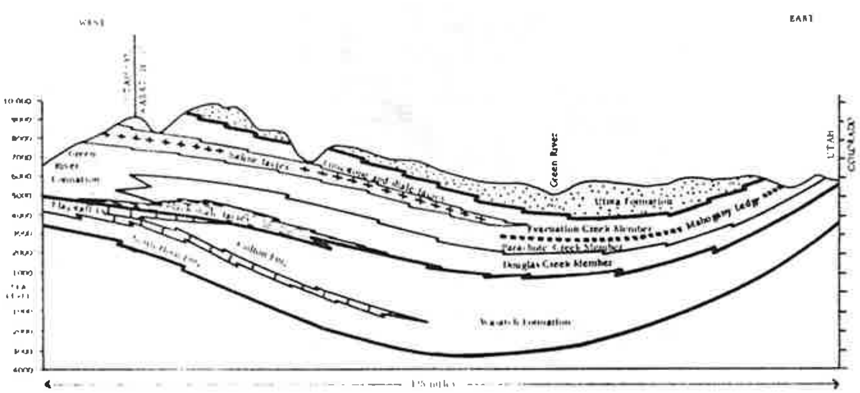
limestone in the Southern Wasatch Mountains and the multihued marly mudstones at Richfield and Bryce Canyon and Cedar Breaks. The younger Eocene Lake Green River deposits do not extend as far south as do those of Lake Flagstaff; instead, they wrap around the east end of the Uinta Mountains and form a basin both north and south of the Uintas. The "Mahogany Ledge" shown on the right side of Text-figure 53 is an oil-shale resource of substantial proportions. Green River oil shales from the Mahogany and other, similar, beds will undoubtedly attain commercial production as other oil reserves are depleted.

In the later part of Phase IV the Uinta Mountains became worn down enough that the Duchesne River Formation could extend up onto the south flank, overlapping the earlier Tertiary basin-fill.

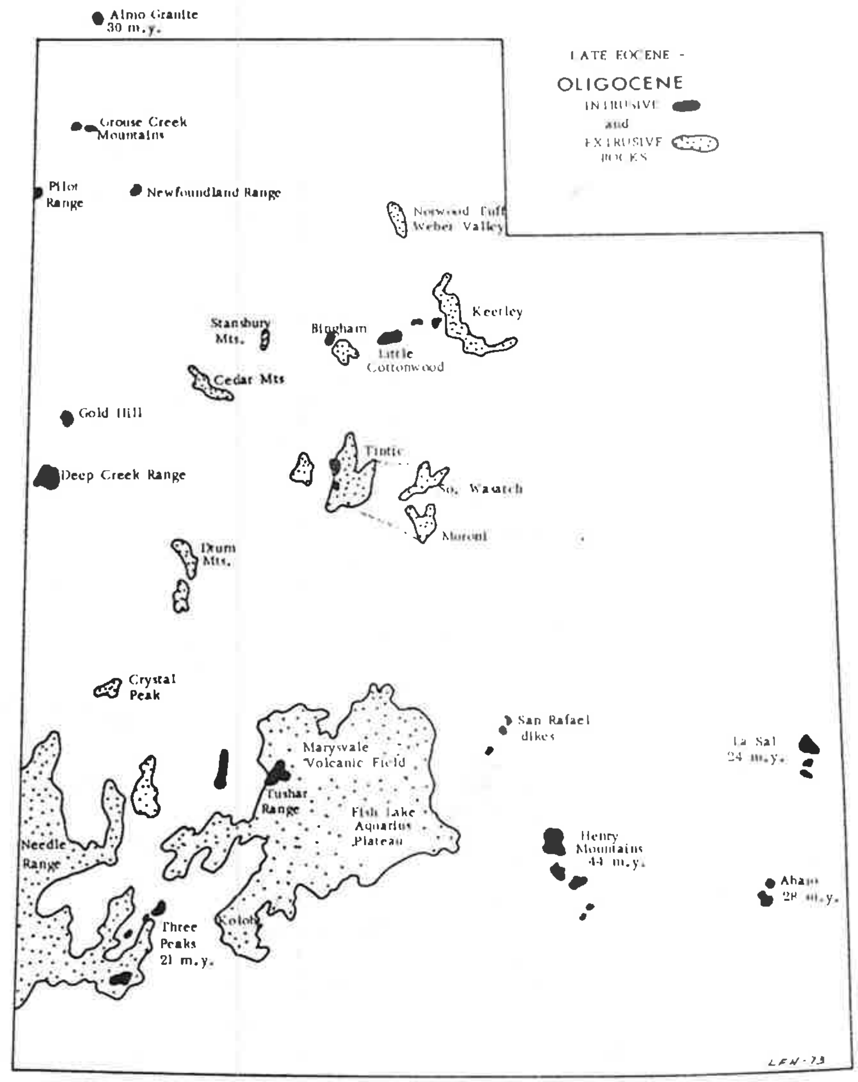
Phase V

For some 150 million years, during Jurassic through early Tertiary, western Utah served as a source area (Sevier Orogenic Belt), and therefore it contains no depositional record itself. Abruptly, in Oligocene time, this situation changed: volcanic centers developed at Bingham, Tintic, Crystal Peak, Marysvale, and in the Needle Range; and eruptions from them covered much of western Utah with volcanic rocks, including many ash-flow tuffs (sometimes referred to as "ignimbrites" or "welded tuffs.") The present exposures are shown on Text-figure 54. In addition, data from wells show that many thousands of square miles of these rocks are buried by valley fill in western Utah.

Quartz-rich rocks such as the rhyolite at Crystal Peak and the Packard Quartz Latite in the Tintic district were among the early (33 m.y.) volcanic deposits. Unusual landslide deposits associated with the rhyolite at Crystal Peak bespeak earthshaking events connected with this explosive volcanism (Hintze, 1972). The most widespread single Tertiary volcanic unit is the Needles Range ash-flow tuff, which spread its distinctive sheet over more than 13,000 square miles in southwestern Utah and eastern Nevada approximately 29 million years ago. Abundant phenocrysts of plagioclase, biotite, and amphi-



TEXT-FIGURE 53.—Cross section of Paleocene-Eocene strata through the Uinta Basin from Thistle to the Roan Cliffs along the Utah-Colorado border north of Mack, Colorado (after McDonald, 1972).



TEXT-FIGURE 54.—Distribution of Late Eocene and Oligocene igneous rocks in Utah.