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WEST ELK VOLCANIC FIELD GUNNISON AND DELTA COUNTIES, COLORADO

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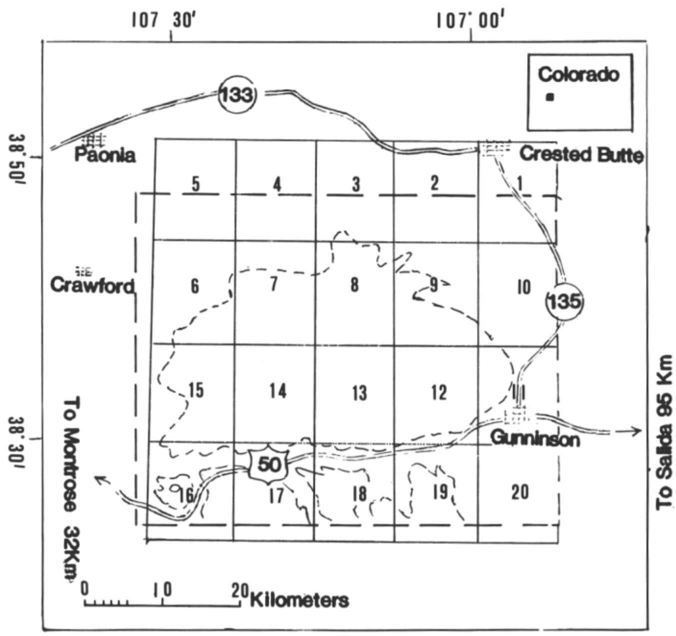
INTRODUCTION

The West Elk volcanic field covers about 1,600 km² in the southern part of the West Elk Mountains (fig. 1) and ranges in elevatior from about 2,100 m along the Gunnison River to 3,960 m at Wes Elk Peak. Tertiary volcanic deposits form a deeply dissected, south sloping volcanic plateau whose western and northern edge is ar imposing, almost continuous escarpment that culminates in the higher peaks of the Baldy Mountains. Most of the volcanic rock: were erupted locally from Oligocene intermediate-compositior volcanoes, which are related in time to the larger San Juan volcanic field south of the Gunnison River (Steven and Epis, 1968; Lipman and others, 1978).

The volcanic rocks have been eroded from the northern Dart o the map area (fig. 2), exposing a thick section of Mesozoic and Tertiary strata intruded by many Tertiary plutons. Reports and maps of the Hayden Survey (Peale, 1876; Hayden, 1881) remain excellent first references to this region. A geologic folio (Emmons and others, 1894) covers part of the volcanic field. The southern margin of the field has been recently mapped in detail by Hedlund and Olson (1973, 1974), Hedlund (1974), and Hansen (1971). A wilderness study by Gaskil I and others (1977) covers the northern part of the area. Perhaps the best general discussion of the geology is in Hansen (1965).



QUADRANGLE NAMES

1. Crested Butte
2. Mount Axtell
3. Anthracite Range
4. West Beckwith Peak
5. Minnesota Pass
6. Mount Guero
7. Big Soap Park
8. West Elk Peak
9. Squirrel Creek
10. Flat Top
11. Gunnison
12. McIntosh Mtn.
13. West Elk Peak SW
14. Little Soap Park
15. Lazy F Ranch
16. Currecanti Needle
17. Sapinero
18. Carpenter Ridge
19. Big Mesa
20. Iris NW

Figure 1. Index map showing area of the West Elk volcanic field (dashed lines), and 7½-minute U.S. Geological Survey quadrangle map coverage.

Most of the volcanic field lies within Gunnison National Forest. Oak brush and scattered stands of pine and fir predominate to elevations of about 2,600 m. Spruce, fir, and aspen are the dominant forest communities at higher elevations. About 6 percent of the area is above timberline. Erosion has removed all but scattered remnants of the West Elk volcanic field east of the map area, has exposed many of the intrusive structures, and has cut canyons many hundreds of meters deep into the volcanic pile. Glaciation has sculptured the higher peaks and valleys.

STRUCTURE AND GEOLOGIC HISTORY

The West Elk volcanic field is near the crest of the late Paleozoic Uncompahgre highland (Hansen, 1965) and on the flank of a later Laramide structure, the Gunnison uplift (Kelley, 1955). The Gunnison uplift is bounded on the south by the Cimarron fault, which displaced Mesozoic strata 800 m or more down to the south in Laramide time (Olson and others, 1968; Hansen, 1971). The rise of the Uncompahgre highland resulted in removal of the Paleozoic strata from this area and the gradual reduction of the highland to a peneplain eroded across Precambrian crystalline rocks (the Uncompahgran unconformity of Hansen, 1971). During Late Jurassic and Cretaceous time, about 2,200 m of continental and marine sedimentary rocks accumulated on the beveled Uncompahgran surface. Near the end of the Cretaceous and during Paleocene time, the Gunnison uplift (the area of the present Gunnison River valley) and the Sawatch Range rose to form a horseshoe-shaped upland that shed alluvial debris (Wasatch and younger strata) north and west into the Piceance basin. By early Oligocene time, erosion had greatly reduced the Sawatch Range and had cut a relatively smooth surface across the Gunnison uplift. The tilted edges of Mesozoic and Tertiary strata on the north flank of the uplift were beveled, reexposing Precambrian basement rocks along the crest (Hansen, 1965, p. 21, fig. 7). Thus, two or more major unconformities underlie the West Elk volcanic field.

In early-middle Oligocene time, granodiorite plutons were emplaced in the Elk Range, Ruby Range, and the West Elk Mountains.

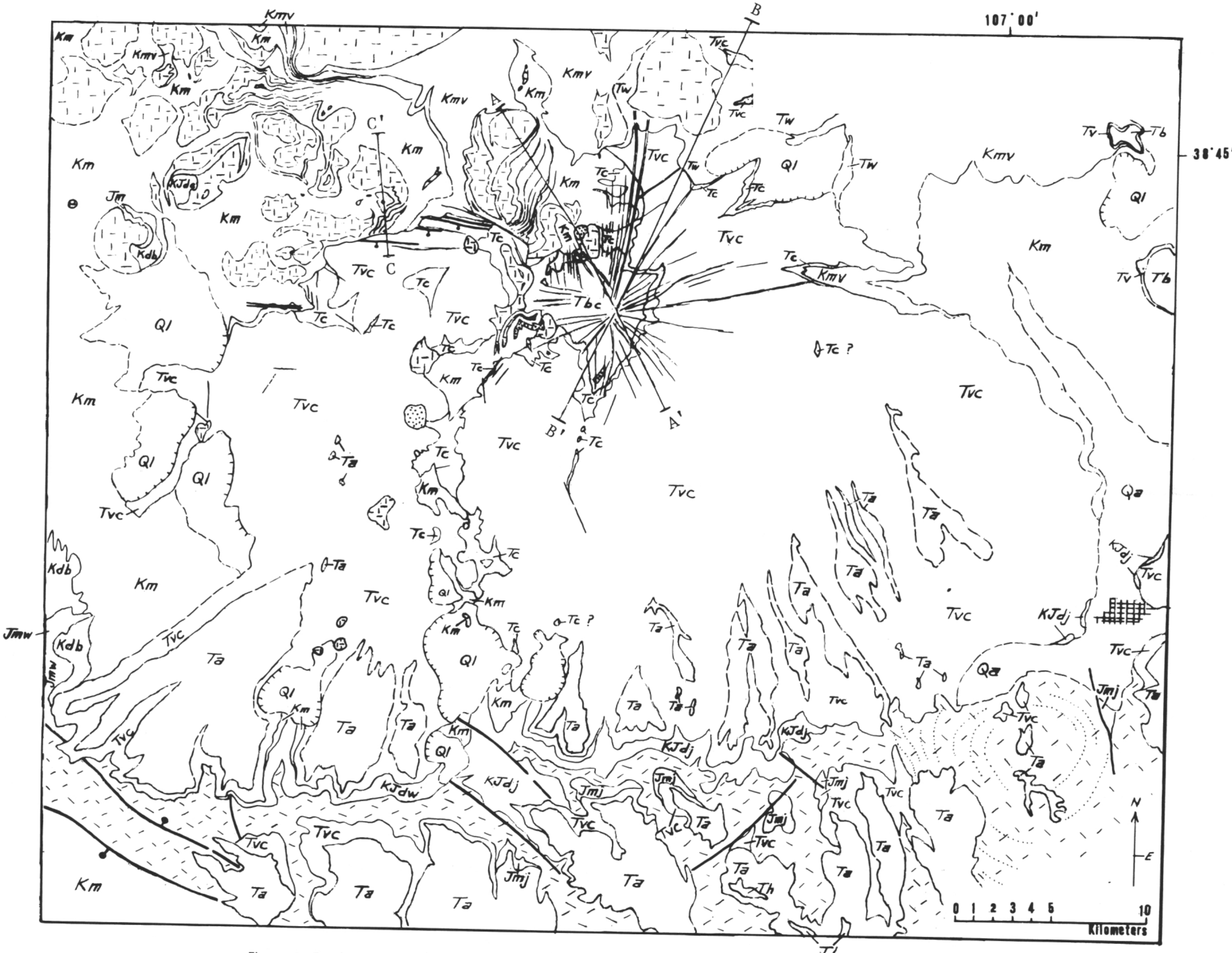


Figure 2. Geologic sketch map of the West Elk volcanic field and vicinity, Gunnison County, Colorado.

Explanation: Figures 2, 3, and 4. (West Elk volcanic field)

Ql — Quaternary landslides, and associated debris and earthflows

Miocene rocks:

- Th -Hinsdale Formation south of the Gunnison River
- Tb -Basalt flows on Red Mountain and Flat Top mesa
- Tv -Volcanic conglomeratic sandstones, rhyolite tuffs, and boulder gravels
- -Rhyolite intrusions in West Elk volcanic field(?), or in adjacent areas

unconformity

Oligocene rocks:

- Ta - Ash-flow tuff formations, undivided

unconformity

West Elk Breccia:

- Tvc -Volcaniclastic facies. f= lava flows
- -Granodioritic intrusive rocks. Includes hornblende granodiorite and dacitic rocks, and perhaps(?) the rhyolitic intrusives of uncertain age in the West Elk volcanic field
- Tc -Chaotic facies
- Tbc -Basal cone facies
- Tu -Volcanic rocks of Oligocene age, undivided

unconformity

-Hornblende granodioritic intrusive rocks. Includes rhyolitic sills, and might include the rhyolitic plutons exposed in the West Elk volcanic field

unconformity

Tw — Eocene and Paleocene(?) Wasatch Formation

unconformity

Cretaceous rocks:

- Kmv -Mesaverde Formation
- Km -Mancos Shale
- Kdb -Dakota Sandstone and Burro Canyon Formations, undivided

Cretaceous and Jurassic rocks:

- KJde -Dakota Sandstone, Morrison and Entrada(?) Formations
- KJdj -Dakota, ± Burro Canyon and Morrison and Junction Creek Sandstone Member of Wanakah Formation
- KJdw -Dakota Sandstone and Wanakah Formations, undivided

Jurassic rocks:

- Jm -Morrison Formation
- Jmj -Morrison Formation and Junction Creek Sandstone Member of Wanakah Formation
- Jmw -Morrison and Wanakah Formations, undivided

unconformity

P€ — Proterozoic rocks

Contact, dashed where approximately located, querried where doubtful

Sedimentary formations

Volcaniclastic layered deposits

Lava flows

Generalized attitude of layered rocks

Fault, bar and ball on downthrown side

Dikes

Kmv Kmv

Inferred southern edge of beveled Mesaverde strata under the West Elk volcanic field

Km Km

Inferred southern edge of beveled Mancos Shale under the West Elk volcanic field

Dry hole drilled for oil

Landslide scarp

Prospect

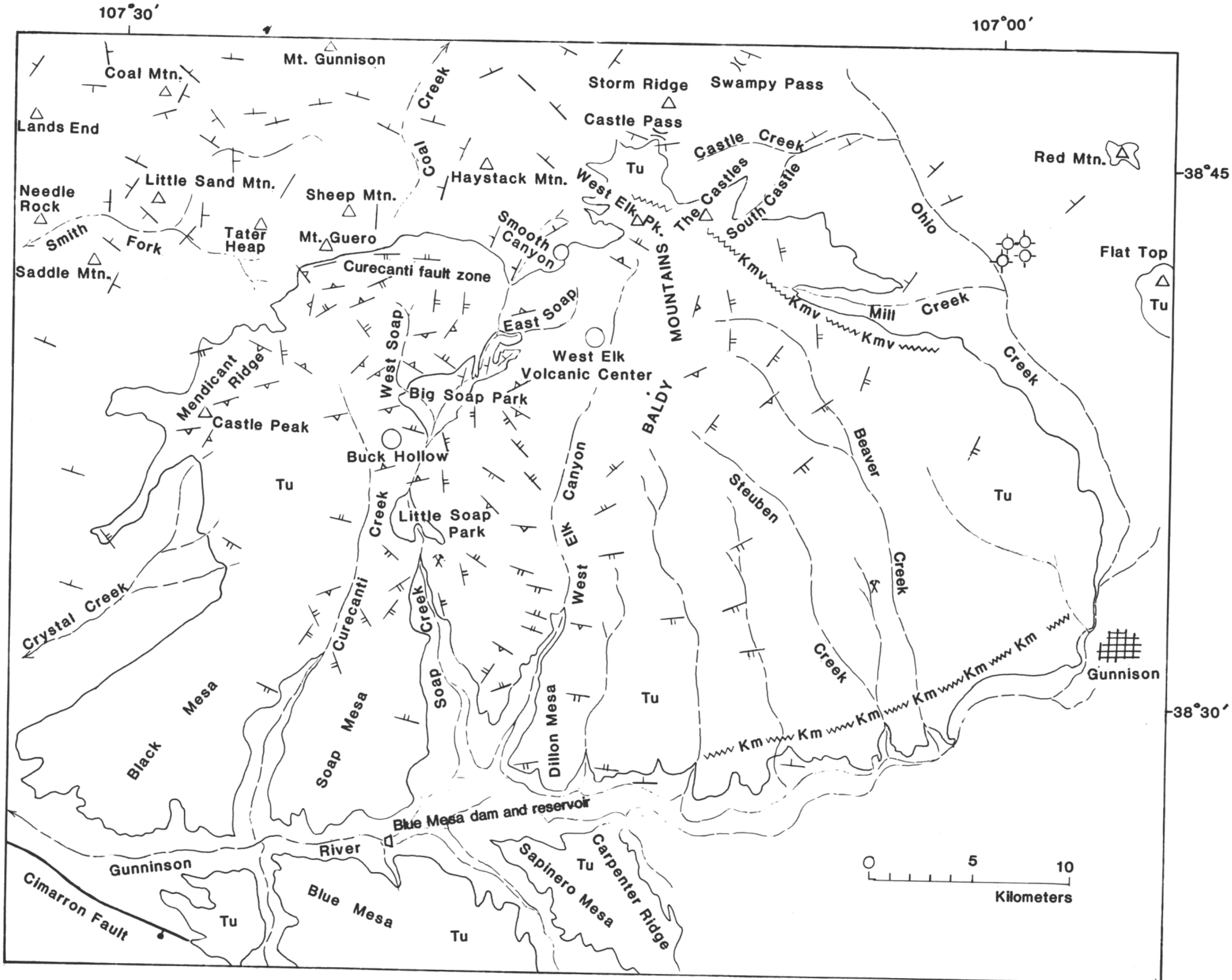


Figure 3. Map showing location of geographic features mentioned in text, and general attitude of layered rock units in the West Elk volcanic field and vicinity, Gunnison County, Colorado.

Many of these plutons probably vented, but volcanic ejecta are preserved only in the southern part of the West Elk Mountains and adjacent areas where they form the West Elk Breccia. The West Elk Breccia was erupted from numerous fissures and composite volcanoes in the area. Episodic volcanism is indicated by interbedded tuffs and gravel, and by numerous unconformities in the volcanic deposits. Potassium-argon dates in this region suggest that the West Elk Breccia and the associated granodiorite plutons are about 29-34 m.y. old (Lipman and others, 1969; Obradovich and others, 1969; Lipman and others, 1978). The southern part of the volcanic field is overlain by Oligocene ashflow tuffs erupted from the San Juan volcanic field.

The volcanic field is transected, in part, by the southwest-trending Ruby Range intrusive zone and the westerly trending Curecanti fault zone (Gableman and Boyer, 1960). These structures seem to intersect in the vicinity of the West Elk volcanic center (fig. 3). Both fracture zones are intruded by dikes that cut rocks of the West Elk volcanic field. The Ruby Range fractures seem to have been conduits for both the Storm Ridge laccolith and the West Elk volcanic center and its radial dike swarm. The Curecanti zone may be several kilometers wide, is adjacent to numerous laccolithic structures, and possibly reflects subsidence due to ejection of volcanic material.

Figures 2, 3 and 4 illustrate some of the major structural features in the West Elk Mountain region. The most conspicuous structures and rock bodies are the laccolithic mountains. Some nearly bell-shaped laccoliths have steep to nearly vertical contacts (fig. 5). Most are asymmetrical wedges having gently to steeply dipping strata overlying one or more sides, and ruptured, steeply upturned strata along the steeper face. Field relations indicate that some were fed by dikes and others by vertical pipe-like conduits. Some may be "cedar-tree structures" intruding different stratigraphic horizons (Corry, 1976). Both the roofs and floors of the laccoliths

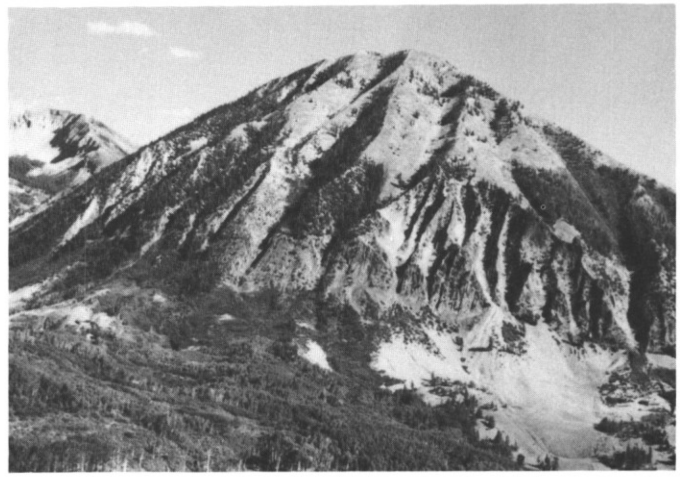


Figure 5. Tater Heap laccolith showing steeply dipping flatirons of indurated Mancos Shale along northwestern perimeter of the intrusion. The laccolith is composed of hornblende granodiorite.

locally transect the sedimentary strata. The igneous contacts corn monly follow bedding planes for a distance, but intrude along joints, fractures, folds, or bedding irregularities to higher horizons. For example, the roof of the Marcellina laccolith, north of the map area, transects more than 300 m of upper Mesaverde strata in a horizontal distance of 3.2 km. Positioning and cross-cutting relationships suggest that some laccolithic bodies were emplaced after deformation of the strata had started. Details of individual laccoliths are discussed in Peale (1877) and Cross (1894).

Laccoliths intercalated with myriad sills intrude all the sedimentary formations, and some seem to intrude the volcanics of the West Elk field. At least two laccoliths (Saddle and Little Sand Mountains) intrude Jurassic strata at or near the Precambrian contact,

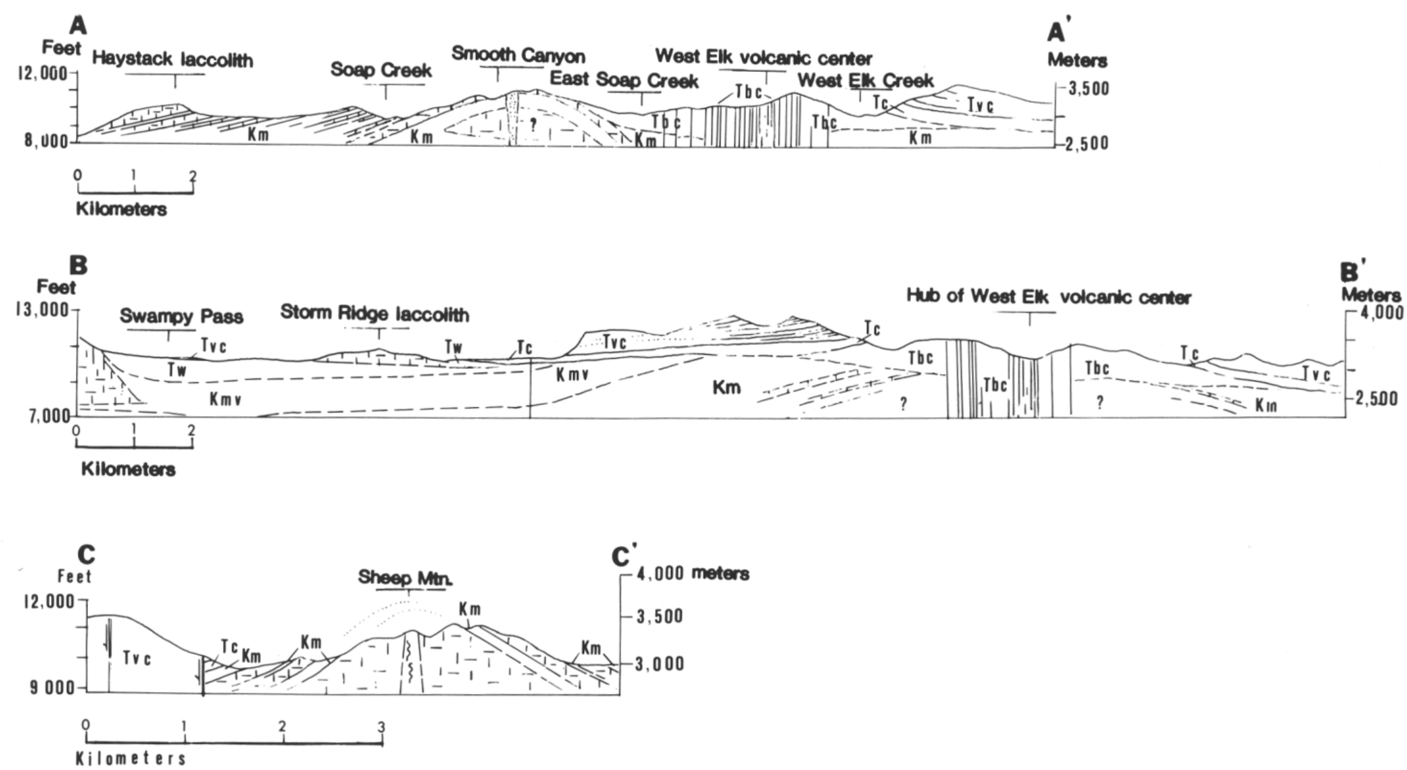


Figure 4. Cross sections through the West Elk volcanic center and Sheep Mountain (see Fig. 2 for locations).

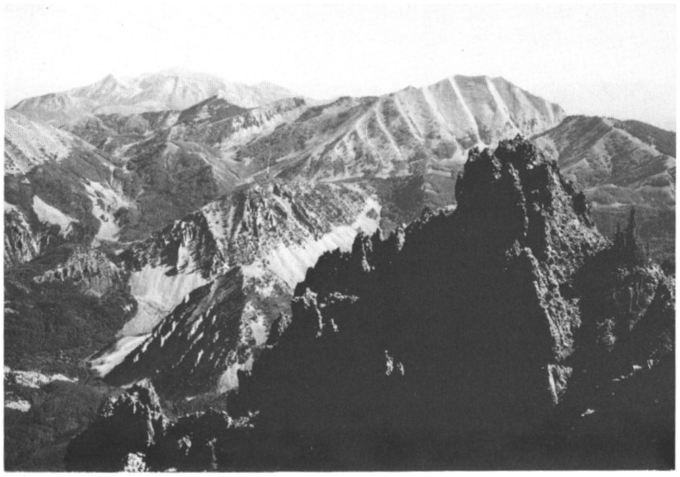


Figure 6. Laccoliths intruding Mancos Shale. Mount Guero (right), Mount Gunnison on the horizon. View northeast from Mendicant Ridge at the northwestern edge of the West Elk volcanic field.

but most of the laccoliths are emplaced in the Mancos Shale. The largest intrude the Mesaverde and Wasatch Formations. Many are more than a thousand meters thick. The largest, Mount Gunnison (fig. 6), is exposed over an area of about 42 km^2 and has relief of nearly 1,830 m. Most of the laccoliths thin into sills on one or more sides. They commonly are surrounded by numerous sills and smaller laccolithic bodies. In general, only a thin zone of baked or indurated strata, a few meters thick, overlies the roof and flanks, but locally, the sedimentary rocks in contact with laccoliths are metamorphosed to hornfels, quartzite, and anthracite. In contrast, the small hypabyssal stocks of the Ruby Range are surrounded by broad metamorphic aureoles, 0.8 km or more wide, that grade outward from metasomatized and silicified metasedimentary rocks to slightly baked shales.

The laccoliths consist of granodiorite porphyries that contain phenocrysts of plagioclase, hornblende, biotite, augite, or hypersthene. Some contain a few rounded phenocrysts of quartz and a few large phenocrysts of potassium feldspar. Most of the laccoliths north and east of the map area characteristically contain large phenocrysts of quartz and potassium feldspar.

The most unusual structural feature shown on Figures 2, 3, and 4 is the volcanic dome and radial dike swarm of the West Elk volcanic center. The dome consists of intrusive and basal extrusive rocks at the core of the major eruptive center in the area. The apex of the dome, at the hub of the dike swarm, probably overlies a buried stock similar to those exposed in the adjacent Ruby Range (Cross, 1894; Godwin and Gaskill, 1964; Kramer, 1972).

Several hornblende granodiorite bodies intrude Mancos Shale and may intrude the volcanic pile along Soap, West Soap, and Curecanti Creeks (figs. 2, 3). These intrusives are very similar in composition and texture to most of the laccoliths and sills along the northwest margin of the volcanic field. Several are associated with dikes of the same composition. Some are sills in the Mancos Shale; others are discordant or laccolithic bodies that have spread out at or near the base of the volcanics. Stocks or laccoliths of hornblende granodiorite northeast of Big Soap Park and at the head of East Soap Creek and Smooth Canyon (fig. 3) intrude Mancos Shale and may be older than the West Elk volcanics. The body near Big Soap Park is locally argillized and contains xenoliths of Precambrian rock. The body at the head of Smooth Canyon overlies Mancos Shale and is brecciated. An altered, brecciated, grano diorite intrusion and associated dikes intrude tuff breccias south of Castle Peak on Mendicant Ridge (fig. 3). The intrusion contains large phenocrysts of hornblende (as much as 1 cm in length); it appears to be a very near surface vent for the tuff breccias.

Sheep Mountain, at the head of Coal Creek and North Smith Fork, is a distinctive symmetrical laccolith or stock surrounded by thick sills and laccoliths in the upper part of folded Mancos Shale (fig. 4). The central pluton consists of an inner, unaltered core of vertically flow-banded porphyry surrounded by altered and mineralized porphyritic granodiorite. The upper part of the pluton is argillized to light gray or white and is stained reddish brown to yellowish orange by oxidized disseminated pyrite.

The cluster of laccoliths and sills in the northwestern part of the area causes a broad magnetic high (J. G. Rosenbaum, *in* Gaskill and others, 1977) that trends north-northeast across Coal Mountain. A body of intrusive porphyry exposed on the north flank of Coal Mountain has domed and hornfelsed overlying Mancos Shale. Both the upper part of the intrusion and the overlying shale are pyritized.

Several rhyolitic plutons are exposed in the area. One is a plug-like body of argillized felsite at the head of Smooth Canyon (fig. 4). A yellowish-gray, slightly pyritized body of rhyolite is exposed in volcaniclastic breccias at Buck Hollow. This rhyolite contains traces of molybdenum and other metals. Another body of rhyolite intrudes Mancos Shale and core rocks of the West Elk center in West Elk Canyon.

The age of these rhyolites is not known. They may be the source of a biotite-rich, crystal pumice tuff that locally overlies basal lava flows of the chaotic facies of the West Elk Breccia in Mill and South Castle Creek canyons; or the rhyolites may be of Miocene age and correlate with the Hinsdale Formation.

STRATIGRAPHY

Table 1 summarizes the stratigraphic sequence. Precambrian rocks underlie the Tertiary volcanics along the Gunnison River and the southern perimeter of the volcanic field (Hunter, 1925; Olson and others, 1968; Hedlund and Olson, 1973, 1974; Hedlund, 1974). Elsewhere, Jurassic, Cretaceous, and Tertiary sedimentary rocks underlie the volcanics. The Jurassic Entrada Sandstone overlaps the Uncompahgran Precambrian surface west of the volcanic field (Hansen, 1965) and may extend northeastward under the northern part of the field. The Wanakah Formation thins eastward over the Entrada and Precambrian surface before wedging out in the vicinity of the Blue Mesa Dam (Hansen, 1965). The Junction Creek Member of the Wanakah Sandstone and the succeeding Morrison Formation, Burro Canyon Formation, and Dakota Sandstone overlay the Uncompahgran surface, but have been removed locally by prevolcanic erosion along the Gunnison River. Thick Mancos Shale underlies all but the southern margin of the volcanic field where it has been largely removed by pre-volcanic erosion. The Mesaverde Formation underlies a small area of volcanic rocks along the northern edge of the field east of Coal Creek and locally overlies the west flank of Coal Mountain. The Tertiary Wasatch Formation underlies volcanic rocks in the Castle and Pass Creek drainage basins and at Castle and Swampy Passes. Unconsolidated deposits of Quaternary age in the area include extensive talus aprons, active rock streams, and minor glacial, alluvial, and lacustrine deposits. Widespread landslides and associated mud and debris flows cover many square kilometers along the western and northeastern edge of the volcanic field, along the lower parts of Soap and West Elk Creeks, and the upper reaches of the Black Canyon.

Table 1. Generalized stratigraphic section in the West Elk volcanic field and vicinity, Gunnison County, Colorado

Age		Stratigraphic units		Description	Approximate maximum thickness in meters
Tertiary	Miocene	Hinsdale Formation and rhyolite intrusions(?)		Basalt flows, basaltic tuff, volcanic sandstones and conglomerates, rhyolitic pumice tuff, and boulder gravels	150
Tertiary	Oligocene	Carpenter Ridge Tuff		A sequence of latitic welded and non-welded ash-flow tuffs with interbedded discontinuous gravel, and tuffaceous gravel deposits	70
		Fish Canyon Tuff			120
		Sapinero Mesa Tuff			160
		Dillon Mesa Tuff			55
		Blue Mesa Tuff			75
		West Elk Breccia	Volcaniclastic facies	Rhyodacite Granodiorite-dacite Rhyolite(?) Andesite Diorite See text for description of volcanic rocks	550
			Chaotic facies		400
			Basal cone facies		600
	Eocene and Paleocene(?)	Wasatch Formation		Variegated sandstone, siltstone, shale, mudstone, conglomeratic sandstone, and conglomerate	390
Late Cretaceous		Mesaverde Formation	Ohio Creek Member	Feldspathic, conglomeratic sandstone, sandstone, siltstone, shale, and minor carbonaceous shale	670
			Undifferentiated unit, Paonia Shale Mbr., and Bowie Shale Mbr.	Sandstone, siltstone, shale, carbonaceous shale and coal	
			Rollins Sandstone Mbr.	Basal regressive marine sandstone	30
		Mancos Shale	upper member	Mostly gray, laminated, silty, marine shale. Transitional zone at top includes thin beds of sandy limestone, and carbonaceous shale. Several thin to massive sandstone beds in upper half of formation	1,300
			Niobrara Member	Includes a basal limestone unit equivalent to the Fort Hayes Mbr. of the Niobrara Fm. of eastern Colorado, overlain by a limy shale unit equivalent to the Smokey Hill Mbr. of the Niobrara Fm. of eastern Colorado	
			Juan Lopez Member	Calcareous shale and calcareous sandstone	
			lower member	Interbedded shale, siltstone, sandstone, and limestone of Benton age	
Late(?) Cretaceous		Dakota Sandstone		Thin- to thick-bedded quartzose sandstone, carbonaceous shale and silty sandstone. Generally a thin chert and quartz pebble conglomerate at base	60
Early Cretaceous		Burro Canyon Formation		Sandstone, shale, and conglomeratic sandstone	
Late Jurassic		Morrison Formation		Varicolored claystone, sandstone, siltstone. Locally contains limestone and pebble conglomerate	130
		Wanakah Formation	Junction Creek Sandstone Member	Fine-grained, friable, eolian sandstone	54
		Wanakah Formation		Silty mudstone, gypsiferous sandstone and mudstone, cherty and silty limestone	45
		Entrada Sandstone		Fine to very coarse-grained, medium- to thick-bedded quartz sandstone with a few shale partings. Locally conglomeratic at base	0–(?)
Proterozoic Y and X				Crystalline metamorphic and plutonic rocks	

VOLCANIC AND ASSOCIATED IGNEOUS ROCKS

> "The hills west of Ohio Creek are composed mainly of breccia ... eroded in the most fantastic fashion. The breccia is stratified, and there are huge castle-like forms, abrupt walls, spires, and towers."
>
> Peale (1876, p. 168, 169)

The volcanic formations in the West Elk field include the Oligocene West Elk Breccia (Emmons and others, 1894), Oligocene ash-flow tuffs (Olson and others, 1968), and patches of the Miocene Hinsdale Formation (Larsen and Cross, 1956; Olson and others, 1968). The Hinsdale consists of basalt flows and interbedded fluvial and pyroclastic materials.

West Elk Breccia

Most of the volcanic rocks are included in a single formation, the West Elk Breccia. This formation was derived in large part from the West Elk volcanic center, a deeply eroded, composite strato-volcano in the north-central part of the West Elk volcanic field. Other volcanic vents are indicated by fiypabassal intrusions, extrusive domes, and local accumulations of steeply dipping, near-vent breccias south and west of the West Elk volcanic center. Eroded remnants of the West Elk Breccia are as thick as about 1,200 m. They overlie an eroded surface of Mesozoic and Tertiary strata, and locally overlie Precambrian rocks along the Gunnison River. Volcanic activity in the area is inferred to have begun with extrusion of lava domes (?), explosion breccias, and lava flows that formed part of a basal cone facies. Initial outflow aprons surrounding the basal cone facies are largely altered lava flows and tuff breccias. The greater part of the formation, however, consists of coarse, fragmental, layered breccia and a heterogeneous mélange of tuff breccia that was erupted explosively from intermediate-composition volcanoes. The formation also includes numerous andesitic to rhyodacitic lava flows, volcanic sands and conglomerates, minor ash layers, and discontinuous gravel deposits. In the northern part of the volcanic field, these deposits were widely intruded by porphyritic feeder dikes of several generations at various eruptive levels. The youngest and least altered dikes extend to the eroded top of the formation. Some of the dikes are wider than 100 m, longer than 9.7 km, and are exposed over a vertical range of more than 900 m. The West Elk Breccia has been tentatively subdivided into three facies.

Basal cone facies

The oldest and most altered volcanic rocks in the area form a basal cone unit (Tbc, fig. 2) of porphyritic, massive and brecciated, dark-gray, brown, grayish-green, red, and purple rocks of basaltic andesite, microgranular diorite, and quartz diorite (SiO_2 = 55-58 percent). This central intrusive-extrusive complex extends from West Elk Creek on the east to about Soap Creek on the west. It appears to locally underlie arched Mancos strata along the northwestern perimeter of the West Elk center. Some of these core rocks may represent lava domes and explosion breccias. The diorites probably are intrusive. The facies is widely propylitized, oxidized, locally pyritized, silicified, and laced with early mafic and later intermediate dikes. It forms a domal pile of core rocks at the West Elk volcanic center that is more than 600 m thick, although greatly reduced by erosion. There is little evidence of extrusive fabric in these core rocks.

The general symmetry of the core rocks at the West Elk center indicates that the sedimentary strata were initially domed by the dioritic magma. The granodiorite bodies along the western edge of the center intrude basal lava flows and tuff breccias, and perhaps the core rocks. They probably moved upward through narrow conduits and spread outward by lifting the near-surface strata and basal volcanics.

Chaotic facies

Altered extrusive rocks (Tc, fig. 2), associated with the initial eruptions at the West Elk center, overlie the core rocks (Tbc) and folded Mancos Shale on the periphery of the center (figs. 2, 4). These basal volcanics appear to underlie all of the northern part of the volcanic field, and are locally exposed elsewhere in the area. They extend outward over the pre-volcanic surface and form a mélange of propylitized and silicified lava flows, flow breccias, and tuff breccias that were locally fed by distinctive, dense, greenish-gray and brown siliceous dikes and dikes of intrusive breccia. These dikes are truncated at the top of the chaotic facies by an erosional surface.

Chaotic facies form a domal pile more than 400 m thick at the northwest edge of the volcanic field. Similar exposures on the northwest side of Little Soap Park are about 360 m thick. These and other exposures of pervasively altered chaotic facies intruded by igneous bodies, are shown on Figures 2 and 3 along lower Soap and West Soap Creeks and elsewhere, and seem to represent secondary eruptive centers. Where the base can be seen, or inferred, the basal extrusive rocks overlie Mancos Shale, except in a few places along the northern edge of the field, where they overlie Mesaverde and Wasatch strata.

Volcaniclastic facies

The volcaniclastic facies of the West Elk Breccia consists generally of gently dipping, crudely layered tuff breccias, local ash beds, laharic breccias, lava flows, minor tuffaceous conglomerate and epiclastic deposits. The breccias generally show large-scale stratification due to alternation of coarse, blocky, and fine-grained breccia. The volcanic fragments are generally angular and poorly sorted, and some are as much as 3 m across. The breccia beds generally dip away from the volcanic centers and are more steeply

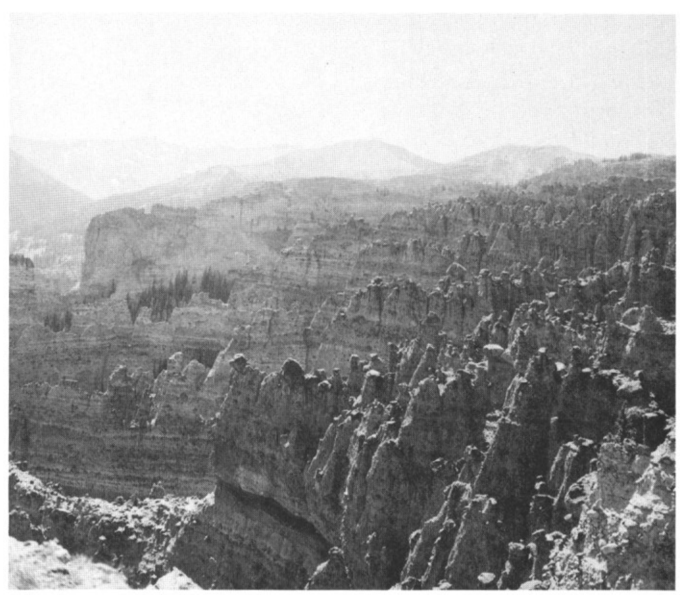


Figure 7. Hoodoos in volcaniclastic facies of the West Elk Breccia. View west from north ridge of Mill Creek canyon. West Elk Peak in distance, Castle View Peak on right.

inclined near vents. Most of the volcaniclastic material in the southern and southeastern part of the field seem to represent a sequence of volcanic mudflows or laharic breccias (Van Houten, 1957; Olson and others, 1968; Hedlund and Olson, 1973, 1974; Hedlund, 1974).

Tuff and tuffaceous conglomerate (as much as 100 m or more thick) are interbedded with, or overlie, the laharic breccias locally in the southern part of the field and may represent air-fall tuff reworked by streams. The conglomerates contain well-rounded cobbles and boulders of Precambrian rocks, quartzite, hypabyssal porphyries, and volcanic rocks (Hedlund and Olson, 1973; Hansen, 1971).

The volcaniclastic facies has a maximum thickness of more than 500 m and contains the largest volume of volcanic material in the West Elk volcanic field. The facies overlaps basal cone extrusive (chaotic) facies near volcanic centers, but extends many kilometers to the south and southeast beyond the limits of the chaotic facies. Lava flows in the volcaniclastic facies diminish in number and thickness outward from the West Elk volcanic center, whereas the proportion of laharic and epiclastic material increases outward. The volcaniclastic rocks are petrographically similar to the flows and breccias in the basal cone unit. Locally in the southwestern part of the field (on Black Mesa), this unit contains welded and nonwelded ash-flow tuffs, as much as 60 m thick (Hansen, 1971). Along the Gunnison River, discontinuous gravel deposits containing pebbles and cobbles of Precambrian and Mesozoic rocks overlie an irregular, channeled surface eroded on underlying Mesozoic strata and Precambrian basement rocks.

The volcaniclastic facies thins southward, away from the West Elk center. The facies is locally absent, or as much as 200 m thick along the Gunnison River, where it locally overlies Mancos Shale, the Dakota and Burro Canyon Formations, Junction Creek Sandstone Member of the Wanakah Formation, and Precambrian rocks. Thick deposits of West Elk volcaniclastic material are present 9 or more kilometers south of the Gunnison River in the Carpenter Ridge quadrangle (Hedlund and Olson, 1973).

North and east of the West Elk volcanic center, the volcaniclastic facies can be subdivided into four or more mappable units separated by conspicuous unconformities. Each unit seems to represent a discrete eruptive interval represented by many individual or gradational volcaniclastic layers, consisting of alternating fine fragmental and coarse blocky tuff breccias, thin ash beds, lapilli tuffs, and many sharp depositional breaks and minor erosional disconformities. Most of the volcaniclastic layers are tuff breccias containing angular to subrounded clasts in a crystal-fragment matrix of the same color and composition. Individual layers and units are dominantly composed of one rock type.

A distinctive basal unit of the volcaniclastic facies, about 90 m thick, locally overlies basal lava flows of the chaotic facies along South Castle Creek and Mill Creek. It is composed of greenish-gray and yellowish-brown sands, pumice tuff, and thin lava flows. The unit may represent nonwelded ash-flow tuffs, pyroclastic breccia flows, and base-surge material (fig. 8; Table 2).

Some exotic pebbles and boulders of Precambrian granite; Paleozoic sandstone, limestone, quartzite, marble, and chert; Tertiary hypabyssal porphyries, and densely welded, eutaxitic crystal tuff are present in channel-fill deposits cut in chaotic facies in the South Castle Creek and Mill Creek valleys; they are mixed with ash and tuffaceous debris overlying Wasatch beds at the base of the volcaniclastic facies on Castle Pass. The exotic pebbles and boulders were probably derived from the Elk Range northeast of the area.

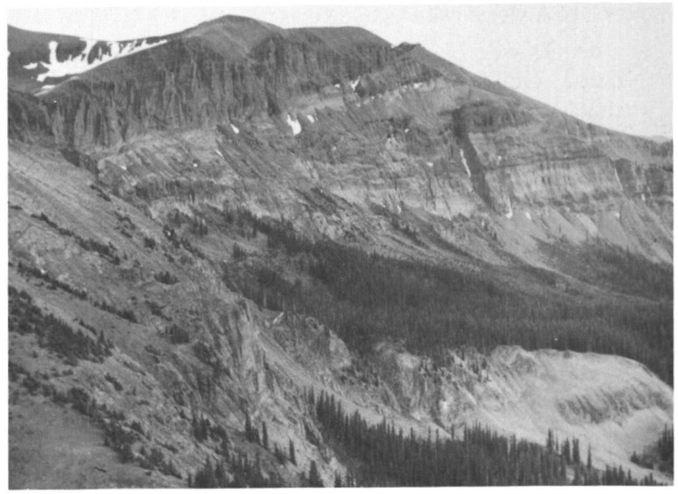


Figure 8. Angular unconformity in volcaniclastic facies of the West Elk Breccia at the head of Soap Creek and Soap Basin. Volcaniclastic layers and lava flows dip northeasterly away from the West Elk volcanic center. Large dacite dike in foreground intrudes the volcanic rocks. View south. West Elk Peak on the far left.

ASH-FLOW FORMATIONS

Following the eruption of the West Elk Breccia, and after erosion had planed the West Elk surface, a sequence of rhyolitic to quartz latite ash-flow tuffs of late Oligocene age blanketed the southern part of the area and the surrounding region (Olson and others, 1968; Steven and Lipman, 1976). These tuffs erupted from calderas in the San Juan Mountains. They generally thin northward, accompanied by a diminution in the degree of welding (Olson and

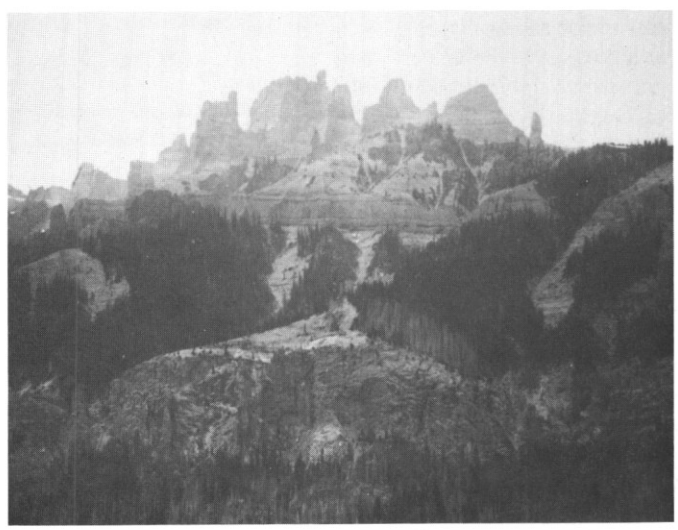


Figure 9. The Castles, erosional remnants of the West Elk Breccia along the northeast edge of the West Elk volcanic field. Cliff at base (chaotic facies) consists of varicolored and pervasively altered, silicified lava flows cut by feeder dikes. Light-colored beds of friable volcanic sandstones (base surge material?) interbedded with lapilli tuff (nonwelded ash-flow tuff?), lenses of conglomerate (or pyroclastic breccia flows?), and a few thin, brecciated lava flows overlie an erosional surface at top of the chaotic facies. The Castles are composed of layered crystal-tuff breccias. View west from South Castle Creek valley. Photo by W. T. Lee (1912, plate 12B) from a glass-plate negative.

Table 2. Measured section of tuffaceous, sandy beds in the basal part of the volcaniclastic facies, NW¼ Section 19, T. 15 S., R. 87 W., South Castle Creek valley.

Thickness in meters	Unit
30.0	1. Tuff breccias and tuffaceous conglomerates(?), or pyroclastic flow breccias: light brown, yellowish, and bluish-green tuff breccias, altered lapilli pumice tuffs, and interbedded, channeled, tuffaceous sands and conglomerates(?)
10.0	2. Brecciated lava flow: reddened zone at base
20.0	3. Interbedded tuffaceous, conglomeratic sandstone and crystal lapilli tuff: channeled or wind-furrowed(?) sandstone like unit 4, with andesitic pebbles, cobbles, and boulders in coarse-grained, discontinuous layers, and yellowish to greenish-gray tuff
9.2–16.0	4. Tuffaceous sandstone and conglomerate(?), yellowish-brown and greenish-gray, friable, well-sorted, fine to coarse-grained, with irregular layers of sub-rounded to sub-angular andesitic fragments that may represent pyroclastic material
5.7	5. Interbedded lava and tuff breccia: dark-gray to red and green brecciated lava(?) flows, and yellowish to greenish-gray, altered tuff breccias
1.9	6. Crystal pumice tuff, light-greenish-gray, yellowish and bluish-green, biotite- and sanidine(?)-rich, contains some heulandite
5.0	7. Tuffaceous sandstone: similar to unit 10, light-greenish-gray, yellowish and brownish-green, friable, sorted, angular-grained; slope mostly covered
9.0	8. Crystal pumice tuff: light-greenish-gray and white, fine- to coarse-grained andesitic fragments, highly altered
0.6	9. Lapilli crystal tuff: similar to unit 11, altered, contains small andesitic and vitrophyric fragments, and Precambrian granite(?) fragments
4.5	10. Tuffaceous sandstone: pinkish-brown and bluish-green, friable, well-sorted, very fine- to fine-grained, with altered biotite and sanidine(?); slope mostly covered
0.6	11. Crystal, nonwelded, pumice ash-flow(?) tuff: white to pinkish-brown and light-bluish-gray with euhedral crystals of biotite, sanidine(?), hornblende, and quartz. Pumice locally altered to montmorillonite

Base of section (unit 11) overlies basal lava flows of the chaotic facies

others, 1968). They form resistant, jointed, vertical cliffs capping the mesas and tributary divides along the Gunnison River. Typically, they "grade upward from a discontinuous nonweld base through a black or dark-brown vitrophyric zone, then a densely welded to partly welded devitrified zone, to a poorly welded to nonwelded top" (Olson and others, 1968, p. 9, 11-13). According to Olson and others (1968), boulder gravel a few meters thick underlies each ash flow, and interlayers with the Carpenter Ridge Tuff. Well-rounded pebbles, cobbles, and boulders were derived from the Morrison, Dakota, and Burro Canyon Formations, and from Precambrian rocks presumed to have come from the Sawatch Range. The ash-flows have been divided into five formations briefly summarized, from oldest to youngest, as follows (Olson and others, 1968; Hansen, 1971; Hedlund and Olson, 1973, 1974):

Blue Mesa Tuff

The Blue Mesa Tuff forms nearly continuous outcrops along both sides of the Gunnison River from Black Mesa eastward to Dillon Mesa. It consists mostly of densely welded and devitrified tuff (as much as 75 m thick), overlain by several meters of soft, nonwelded air-fall(?) and water-laid tuff. It was probably erupted from the Lost Lake caldera (Lipman, 1976; Steven and Lipman, 1976).

Dillon Mesa Tuff

The Dillon Mesa Tuff consists typically of nonwelded to moderately welded pumiceous tuff (as much as 24 m thick) and discontinuous thin beds of pumice tuff breccia (as much as 12 m thick). Locally, about 15 m of gravel, mostly derived from the West Elk Mountains, forms the basal part of the formation. The tuff was derived from the Uncompahgre caldera (Lake City area, San Juan volcanic field) about 28 million years ago (Lipman, 1976; Steven and Lipman, 1976).

Sapinero Mesa Tuff

The Sapinero Mesa Tuff is persistent and widespread, and overlies Dillon Mesa and Blue Mesa Tuffs, and older rocks in this area. The formation includes thin, discontinuous gravel deposits, and a conspicuous black vitrophyre at the base (commonly 3-15 m thick); nonwelded crystal pumice tuff (usually less than 6 m thick); and discontinuous welded tuff (as much as 60 m thick). It was derived from the San Juan and Uncompahgre calderas (Lake City and Silverton areas) about 28 million years ago (Lipman, 1976; Steven and Lipman, 1976).

Fish Canyon Tuff

The Fish Canyon Tuff is the most widespread and distinctive ash flow in the region (Olson and others, 1968). It consists largely of slightly to densely welded crystal-rich tuff that grades upward and laterally into nonwelded tuff. The unit is commonly 90-120 m thick along the Gunnison River. It was derived from the La Garita caldera (central San Juan volcanic field) and has been dated at 27.8 million years (Olson and others, 1968; Lipman, 1976; Steven and Lipman, 1976).

Carpenter Ridge Tuff

The Carpenter Ridge Tuff includes two or more ash flows, some water-laid tuff, and tuffaceous gravel (Olson and others, 1968). Most of the formation is devitrified, densely welded tuff. It is preserved only locally, but where present, it ranges from about 60 to 90 m in thickness. The formation was derived from the Bachelor caldera (Creede area, San Juan volcanic field) and has been dated at 27.5 million years (Lipman, 1976; Steven and Lipman, 1976).

Hinsdale Formation

The Hinsdale Formation is preserved in isolated knobs of basaltic lava and boulder gravel, 1 to 8 km south of the Gunnison River. It rests on a surface of low relief eroded across Oligocene volcanic and older rocks (Olson and others, 1968; Hedlund and Olson, 1973). According to Lipman and others (1978), late basaltic and rhyolitic rocks of the Hinsdale Formation range from 5 to 26.8 million years in the San Juan Mountains. The nearest dated deposit, on Cannibal Plateau, is about 18.5 million years old (Lipman and Mehnert, 1975, p. 132). Similar deposits on Grand Mesa have been dated at 8 to 23 million years (Larsen and others, 1975).

A thick Hinsdale sequence (about 50 to 70 or more meters thick) of unconsolidated boulder gravel and interbedded tuff, volcanic conglomerate sandstone and interbedded rhyolite pumice tuff underlies basaltic tuff and 12 or more basaltic lava flows on Red Mountain and Flat Top mesas about 7 to 12 km northeast of the West Elk volcanic field (fig. 2). These units overlie an erosional surface, or channels cut in Mesaverde and Mancos strata. The gravels contain well-rounded pebbles, cobbles, and small boulders derived from all or most of the sedimentary and igneous rocks exposed in the adjacent Elk Mountains. The lava flows appear to have had a nearby source to the northwest, probably along northwest-trending fissures. The rhyolite tuffs were probably erupted from one or more of the felsite and rhyolite plugs in the Elk Mountains. The lava flows have been dated at 9.7-10.9 million years by C. S. Robinson (C. S. Robinson and Associates, Lakewood, Colorado).

ECONOMIC GEOLOGY

One or more coal beds near the base of the Mesaverde Formation underlie parts of the northern and northeastern edge of the volcanic field (Lee, 1912) and a small area on the west side of Coal Mountain.

No metal production has been reported. Small vein deposits of manganese oxide were prospected in the late 1800's, along the forks of Steuben Creek and in Soap Creek Canyon (fig. 3). They occur in tuff breccia and overlying welded ash-flow tuff (Penrose, 1890; Harder, 1910; Muilenburg, 1919; Jones, 1921; Gaskill and others, 1977).

Base- and precious-metal anomalies in altered rocks associated with Tertiary intrusives, in and adjacent to the volcanic field, are discussed in Gaskill and others (1977). Anomalous values of zinc, copper, lead, silver, gold molybdenum, tin, mercury, sulfur, arsenic, boron, cobalt, antimony, fluorine, barite, vanadium and other elements are mainly concentrated on Sheep Mountain and in the area of the West Elk volcanic center. Areas of solfataric alteration occur along upper West Soap Creek and elsewhere in the area.

No oil or gas exploration has been reported in the near vicinity of the volcanic pile. Several dry holes in the Ohio Creek valley tested Mancos, Dakota, and Morrison strata, resulting in uneconomic showings of oil (fig. 3). The sedimentary section in the southern part of the West Elk Mountains is relatively thin and is intruded at most horizons by a mélange of igneous rocks.

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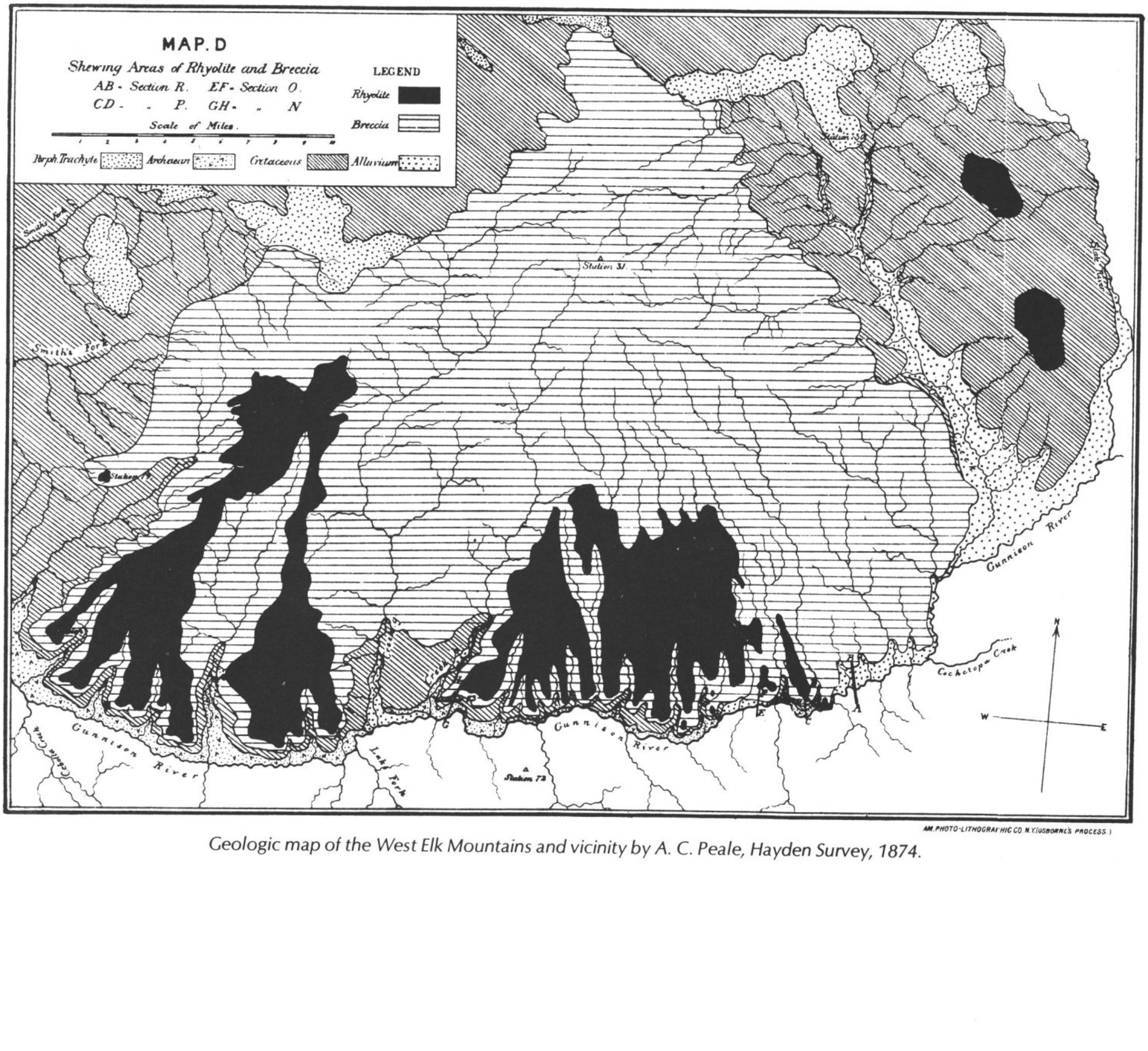

Geologic map of the West Elk Mountains and vicinity by A. C. Peale, Hayden Survey, 1874.