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Tertiary Igneous Rocks and Laramide Structure and Stratigraphy of the Spanish Peaks Region, South-Central Colorado:

Road Log and Descriptions from Walsenberg to La Veta (First Day) and La Veta to Aguilar (Second Day)

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TERTIARY IGNEOUS ROCKS AND LARAMIDE STRUCTURE AND STRATIGRAPHY OF THE SPANISH PEAKS REGION, SOUTH-CENTRAL COLORADO: ROAD LOG AND DESCRIPTIONS FROM WALSENBURG TO LA VETA (FIRST DAY) AND LA VETA TO AGUILAR (SECOND DAY)

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INTRODUCTION

The Spanish Peaks are located in the western part of the Raton basin in south-central Colorado, southwest of Walsenburg (Figure 1). The two peaks, West Spanish Peak (WSP, 13,626 feet) and East Spanish Peak (ESP, 12,683 feet), are located on the upland part of the far western edge of the Great Plains physiographic region. East of Spanish Peaks, a deeply dissected plateau extends into the Great Plains.

The Raton basin, an asymmetric structure of Laramide age, underlies and surrounds the Spanish Peaks. The basin extends north from Ute Park, New Mexico, to Huerfano Park, Colorado. The juncture of steeply dipping western and gently dipping eastern limbs of the Raton basin forms the basin axis, known locally as the La Veta syncline (Johnson and Stephens, 1954a; Johnson, 1969). The La Veta syncline extends north-northwest into Huerfano Park, between the Sangre de Cristo and Wet Mountains. Immediately north of the town of La Veta, the Del Carbon syncline, a shallower and more symmetrical feature (Johnson, 1969), forms a second basin axis that extends northeastward around the subsurface southern extension of the Wet Mountains arch. The Apishapa and Las Animas arches (not shown) form the eastern structural boundary of the Raton basin.

The Sangre de Cristo thrust system forms the western border of the Raton basin (Figure 1). The thrust system extends nearly the entire length of the Sangre de Cristo Mountains (including the Culebra Range) in New Mexico and Colorado, a distance of about 180 miles (mi). Laramide reverse faults also form the southern and eastern structural boundaries of the Wet Mountains.

Normal faults are not common in the region around the Spanish Peaks, but they are characteristic of the Rio Grande rift to the west and northwest. In southern Colorado, the rift consists of the San Luis Valley graben, the Sangre de Cristo horst (north of Ft. Garland), and the Wet Mountain Valley (north of Huerfano Park) (Tweto, 1979). West of the Culebra Range near Ft. Garland, the Culebra reentrant of the San Luis Valley graben was intensely faulted during Rio Grande rifting (Wallace, 1995).

Laramide orogeny

The record of the Laramide orogeny in southern Colorado is well preserved west of the Spanish Peaks. The Culebra Range segment of the Sangre de Cristo Mountains, located west of the Spanish Peaks, contains part of the Sangre de Cristo thrust system. The style of Laramide deformation in the Culebra Range and the synorogenic sedimentary record in the western Raton basin have been documented by newly published mapping (Lindsey, 1995a; 1995b; 1996; Wallace and Lindsey, 1996). The eastern foothills of the range merge with the dissected uplands that surround the Spanish Peaks, and these together expose one of the most complete sections of Upper Cretaceous through Eocene Laramide synorogenic sedimentary rocks in the Raton basin. The resistance to erosion of the igneous intrusions and the metamorphic aureole of the Spanish Peaks accounts for preservation of the section. At stops 6, 7, 11, and 12 on the trip, participants will be introduced to the Laramide structure of the Culebra Range and the synorogenic sediments of the Raton basin around the Spanish Peaks.

The Laramide structure of the Culebra Range is interpreted to be a series of tilted basement blocks bounded by high-angle thrust and reverse faults. The frontal thrust of the Sangre de Cristo Mountains and the Wagon Mesa thrust are dominant structures in the northern part of the Culebra Range. The Culebra thrust, which transposed Precambrian over Paleozoic rocks, is the dominant structure in the central part of the range. North and east of the Culebra thrust, sedimentary rocks are interpreted to overlie west-tiltedbasement blocks bounded by high-angle thrust and reverse faults; these faults typically dip 40-60° westward. In the Pennsylvanian and Permian sedimentary rocks that cover the tilted blocks, major east-facing anticlines overlie, occur adjacent to, and occur along strike

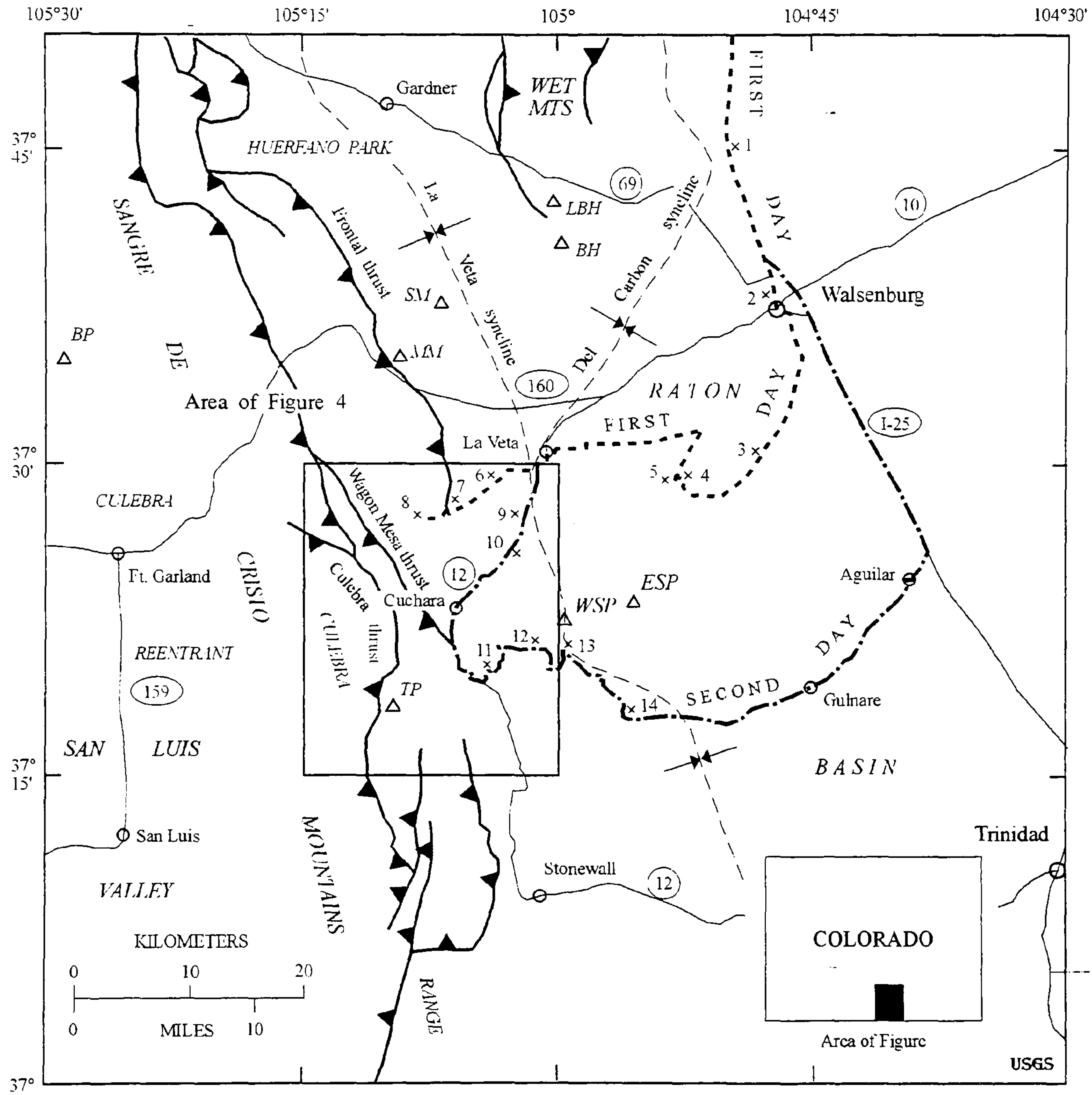

Figure 1.--Field trip route and structural setting of the Raton basin in southern Colorado (modified from Johnson, 1969). Geographic features on map: *BP*, Blanca Peak, *BH*, Black Hills; *ESP*, East Spanish Peak; *LBH*, Little Black Hills, *MM*, Mt. Mestas (Baldy); *SM*, Silver (Dike) Mountain; *TP*, Trinchera Peak; and *WSP*, West Spanish Peak.

from thrusts and reverse faults; these anticlines are interpreted to be fault-propagation folds. Cover rocks between thrusts and accompanying anticlines have been folded into broad, east-facing synclines. In synclines having steeply dipping west limbs, the backlimb may contain out-of-syncline backthrusts.

Around the Spanish Peaks, the stratigraphic record of the Laramide orogeny consists of the Late Cretaceous Vermejo Formation, the Paleocene and Late Cretaceous Raton and Poison Canyon Formations, and the Eocene Cuchara Formation. Three features in these formations document episodes of Laramide tectonism: 1) the first appearance of abundant feldspar detritus derived from Pennsylvanian-Permian sedimentary rocks or from Precambrian rocks, 2) the appearance of conglomerate containing Precambrian clasts, and 3) major unconformities. The earliest evidence of uplift and erosion of a highland is the appearance of abundant feldspar in the Late Cretaceous Vermejo Formation. Above the Vermejo, unconformities overlain by conglomerate indicate other episodes of highland erosion during late Cretaceous (Raton) and Eocene (Cuchara) time. Eocene alluvial-fan conglomerates in the Cuchara Formation probably represent erosion of the Culebra fault block.

Igneous rocks

Several authors (Lipman and others, 1972; Christiansen and Lipman, 1972; Mutschler and others, 1988) have identified three general episodes of Laramide and younger magmatic activity in Colorado and related them to tectonic stresses. The earliest resulted from stresses associated with the Laramide deformation of the Rocky Mountains from latest Cretaceous to Eocene times (72-42 Ma). The second episode, the late Eocene and Oligocene (40-26 Ma) "ignimbrite flareup," resulted from a period of tectonic quiescence and initiation of regional extension. The latest episode, Cenozoic (25-0 Ma) bimodal (basalt and rhyolite) magmatism, was associated with the initiation and propagation northward of the Rio Grande rift in Colorado. Magmatism in the Spanish Peaks area was mostly related to the last episode. During these magmatic episodes regional stresses changed from compressional to extensional. This transition influenced both the character and extent of magmatic activity in south-central Colorado and northern New Mexico.

The Spanish Peaks region is dominated by numerous igneous intrusive features consisting of stocks, dikes, laccoliths, plugs, and sole injections (Figure 2). The East and West Spanish Peaks, Silver Mountain, and North, Middle, and South White Peaks are the major stocks. This area is a world-renowned location for well-developed and exposed dike systems. The dikes vary from 3 to 100 feet (ft) in thickness and are exposed for distances of up to 12 mi. The dikes are divided into three distinct groups: radial, subparallel, and independent dikes (Johnson, 1968). Of the two sets of radial dikes, the most prominent set, which includes more than 500 dikes, is focused on West Spanish Peak (WSP). None of these are in direct contact with the stock of WSP. A smaller set of radial dikes is focused on Silver Mountain, located about 22 mi north of WSP. Both of the radial dike sets are centered around points close to the axis of the La Veta syncline. The subparallel dikes strike N80°E and are present throughout the Raton basin from south of Trinidad to just south of the Wet Mountains on the north. The subparallel dikes are also the longest dikes in the area; several extend up to 17 mi. The third group of dikes are oriented independently of the other two dike sets.

The Spanish Peaks intrusions were emplaced during late Oligocene to early Miocene time (Armstrong, 1969; Stormer, 1972; Smith, 1975; 1978) and are roughly contemporaneous with the initiation of the Rio Grande rift on the west side of the Sangre de Cristo Mountains in southern Colorado (Tweto, 1979). Until the work of Penn and others (1992) and Penn (1994), absolute age data for the area were minimal and inconsistent, leading to controversial conclusions regarding the intrusive history. High-precision $^{40}Ar/^{39}Ar$ age data (Figure 3) indicate the following sequence of intrusion in the Spanish Peaks region: 1) the Silver Mountain, Black Hills, and Little Black Hills intrusive complex; 2) an early phase of subparallel camptonite and basalt dikes; 3) WSP monzonite; 4) ESP granodiorite porphyry (inner stock) and granite porphyry (outer stock); 5) WSP syenite porphyry radial dikes; 6) White Peaks microgranite; and 7) a late phase of subparallel minette dikes north and northwest of ESP.

Overview of Petrology

The rocks of the Spanish Peaks region span the range from mafic to silicic (45 - >66 percent SiO_2) compositions. In several instances, silicic rocks are in close proximity to or in direct contact with mafic rocks, for example at Devil's Stairway (stop 10) a radial granodiorite dike is situated within a few tens of feet from a radial lamprophyre dike. These relationships signify a complex petrogenetic history.

Most of the rocks of the Spanish Peaks region are holocrystalline and porphyritic-aphanitic, with as much as 70 percent of the rock composed of groundmass. Local spherulites indicate that some of these rocks were formerly hypocrystalline and subsequently devitrified. Textures range from trachytic to glomeroporphyritic. Either hornblende or biotite is the dominant mafic phase in the radial dikes, whereas clinopyroxene and biotite are the dominant mafic phases in the subparallel dikes. The groundmass of the porphyritic rocks is composed mostly of feldspars, clinopyroxene, opaques (iron-titanium minerals), and occasional glass.

The most common rock compositions are monzonite and syenite porphyries. These compositions generally form the radial dikes proximal to WSP and Silver Mountain, the Silver Mountain stock, and the Black Hills laccolith. The silicic rocks generally are concentrated near ESP and WSP. More mafic rocks are prevalent farther from the two peaks. The ESP stocks and some radial dikes are granite and granodiorite. Basaltic rocks most commonly form sills, dikes, and plugs distal to the two peaks.

Fresh samples of the Spanish Peaks rocks are rare.

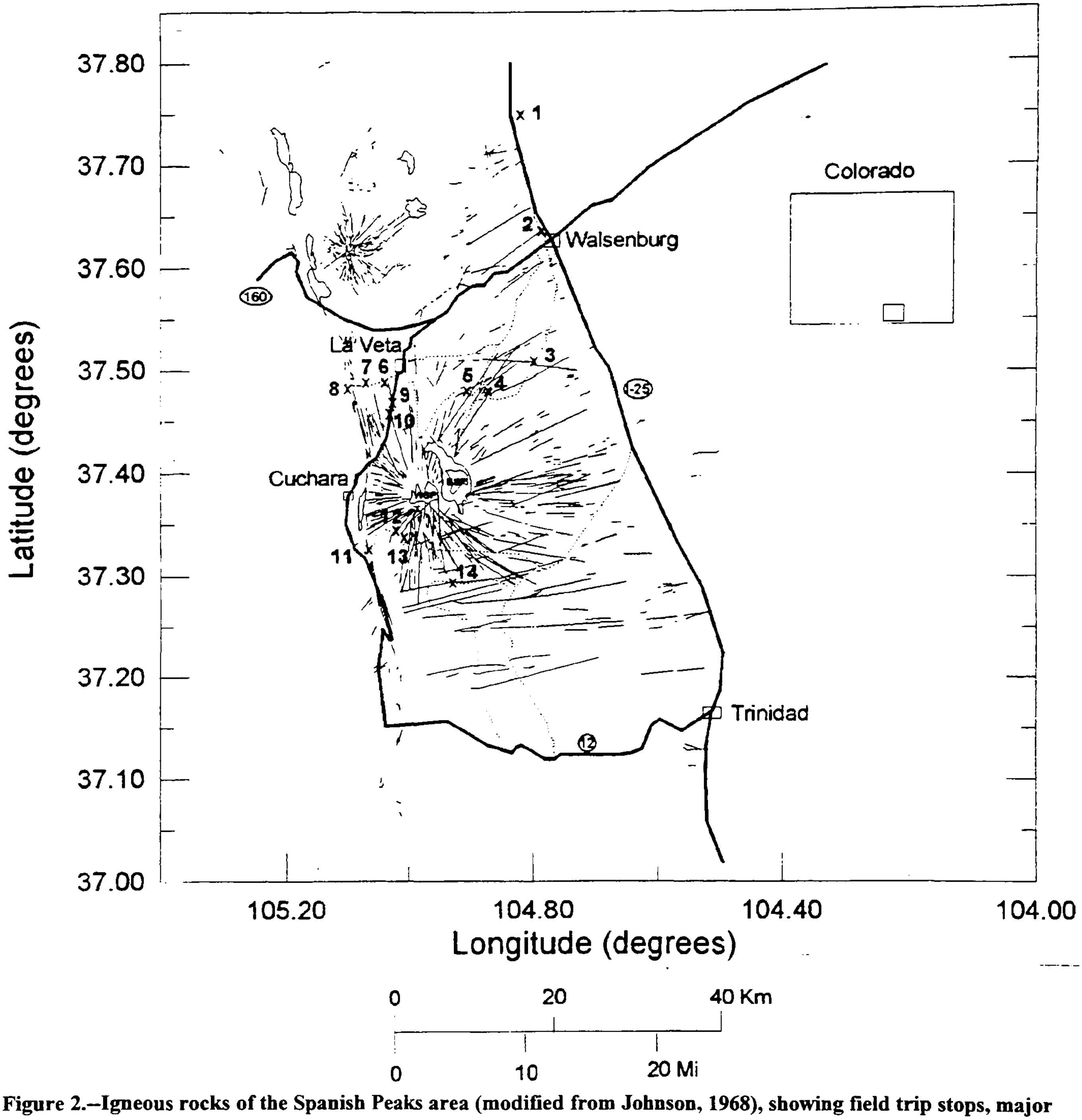

Figure 2.--Igneous rocks of the Spanish Peaks area (modified from Johnson, 1968), showing field trip stops, major highways (heavy lines), and secondary roads (dotted lines).

The felsic rocks are the most intensely altered; feldspars are almost entirely altered to fine-grained clays and micas (sericite). Carbonate resulting from alteration or weathering of intermediate to felsic rocks is abundant, and some of the mafic rocks have amygdules that contain carbonate and quartz cores. Epidote is found in the groundmass of many samples.

Biotite is present in almost all of the intrusions in the Spanish Peaks region. Green and brown hornblende occurs both in radial dikes and subparallel dikes. Many of the hornblende phenocrysts have very fine-grained inclusions of apatite and zircon. Hornblende and biotite rarely are present in the same rock. Titanaugite is found in most intrusions, often forming stellate clusters with individual crystals exhibiting hourglass zonation, as in the camptonite of the Bear Creek dike. Apishapa Crag east of Aquilar ntains striking coarse-grained, partially embayed, ıenocrysts of titanaugite that exhibit well-developed ıcillatory zonation, contact twinning, and fine- to ıedium-grained inclusions of olivine. Orthopyroxene is ːlatively rare. Olivine is present only in the most mafic ɔcks and usually is only slightly altered to iddingsite. ːoarse-grained plagioclase (An_{24-36}) and potassium feldspar ɔccur in the radial dikes. Rapakivi and anti-rapakivi ːextures, which suggest complex P_{H2O} conditions during crystallization (Bowen and Tuttle, 1950), are present in the stocks of ESP and WSP.

Mafic enclaves ranging in size up to 30 centimeters (cm) (Johnson, 1968; Jahn and others, 1979) occur in plugs, stocks, laccoliths, and dikes. Pleochroic green and brown hornblende with fine-grained inclusions of apatite and zircon is the major constituent of the enclaves. Plagioclase (An_{30}), clinopyroxene, olivine, biotite, and iron-titanium oxide minerals are also present in the enclaves. Many of the enclaves are embayed or have iron-titanium oxide rims.

Fluorite, not previously reported at the Spanish Peaks, is present in most rocks that contain hornblende and/or olivine. It may have resulted from scavenging of hornblende or iddingsite for Ca^{2+} by fluorine. Calcite frequently occurs as a minor phase in a number of samples, sometimes as fine-grained, euhedral crystals, but typically as fine-grained anhedral masses. The dominant occurrence of calcite is as an alteration product in the groundmass, but it occasionally fills amygdules.

The inner stock of ESP contains numerous coarse-grained (5-6 mm) lithic inclusions. Lithic fragments in dikes range from a few millimeters to several centimeters (ESP and Silver Mountain). The presence of lithic inclusions can signify a number of processes, including wallrock assimilation, stoping, and syntexis.

Syenite and monzonite porphyries are found predominantly in radial dikes. Up to 70 percent of these rocks is groundmass, which is composed of fine-grained plagioclase and potassium feldspar laths, clinopyroxene, and iron-titanium oxide minerals. Quartz is rare. Feldspars are the coarsest and most abundant phenocryst phase; potassium feldspar is generally more abundant than plagioclase. The feldspars commonly are extensively altered to fine-grained masses of clay and mica. Neither orthopyroxene nor clinopyroxene comprise more than 3 percent of these rocks. Hornblende is common, some samples contain more than 25 percent hornblende. Biotite is present in most samples and comprises up to 10 percent of the rock. Apatite occurs infrequently. Chlorite and epidote commonly replace the groundmass.

The International Union of Geological Sciences (IUGS) classification of lamprophyres is based on textural and mineralogical characteristics (Streckeisen, 1979). Lamprophyres are mafic porphyritic rocks that contain mafic silicate phases only in a groundmass comprised of both felsic and mafic minerals. By definition, lamprophyres only form dikes (Streckeisen, 1979).

Lamprophyre dikes are found almost exclusively in subparallel orientations in the Spanish Peaks area. Lamprophyres in the area include both alkaline (camptonite) and calc-alkaline (minette) varieties. The camptonites are distinguished from minettes by their plagioclase and alkali feldspar abundances and the presence of hornblende and mica. In camptonite dikes, both hornblende and biotite are essential constituents and plagioclase content exceeds that of potassium feldspar. In minette dikes, biotite is the main hydrous phase and potassium feldspar is more abundant than plagioclase.

Minette dikes generally are restricted to the area northeast of ESP and WSP (Johnson, 1968). Walsen Crag, a composite dike, is the best-known and most-studied minette dike in the Spanish Peaks area (Knopf, 1936; Johnson, 1964; Jahn, 1973; Jahn and others, 1979). Three separate minette intrusions comprise Walsen Crag (Johnson, 1964).

Minette from Walsen Crag and another subparallel dike east of Walsenburg contain titanaugite (up to 27 percent) as the dominant phenocryst phase; biotite commonly makes up <12 percent. Rare orthoclase phenocrysts in minette at Walsen Crag may have resulted from the retention of volatiles during cooling at low pressure (Esperanca and Holloway, 1987).

Camptonite dikes are spatially more widespread than minette. One of the oldest samples (26.6 ± .12 Ma) collected and dated by Penn (1994) is a camptonite; it contains relict hornblende phenocrysts, titanaugite, and plagioclase > potassium feldspar. The hornblende phenocrysts are almost entirely altered to fluorite. Crelling's (1973) petrographic description indicates that the Bear Creek (also known as Small) dike, one of the major subparallel lamprophyre dikes northeast of ESP, is a camptonite. Crelling (1973) analyzed phenocrysts from the Bear Creek dike and determined that kaersutite and phlogopite are present, but only in the core of the dike. The far northeast extension of the Bear Creek dike is also a camptonite. The amphibole in the Bear Creek dike has also been mostly replaced by fluorite. Jahn and others (1979) described the Pictou Dike (north of Walsenburg) as camptonite, yet no hornblende was included in their petrographic description. Knopf (1936) described very minor amounts of hornblende in Pictou Dike. Titanaugite content is variable, ranging up to 50 percent (Jahn and others, 1979). Stellate clusters of titanaugite are present in several of the early subparallel dikes. Olivine is not common, but in some samples it is as much as 16 percent. As much as 12 percent mica (biotite and phlogopite) is present in some samples.

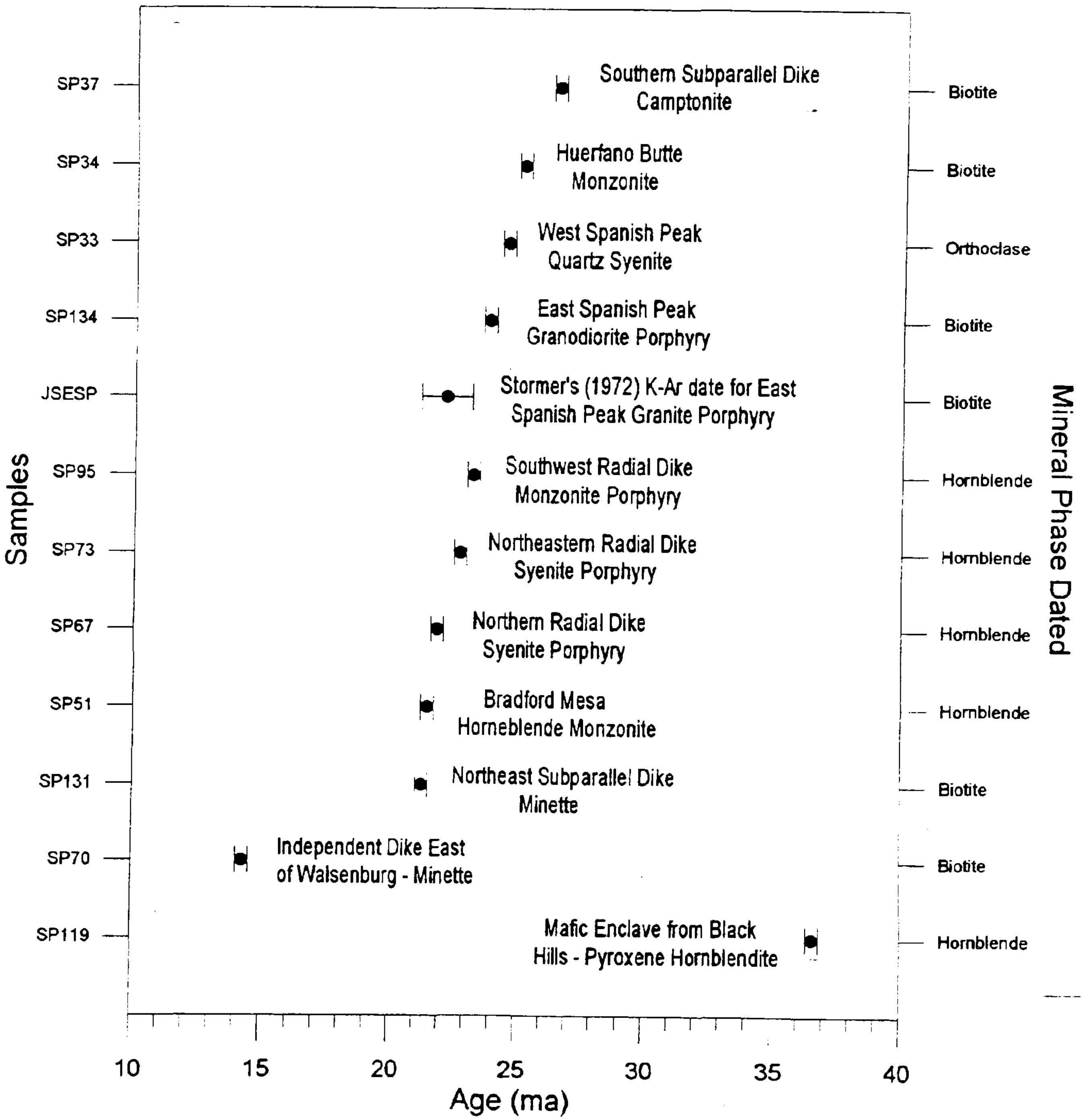

Figure 3.–$^{40}Ar/^{39}Ar$ dates (and one K-Ar date) of igneous rocks, Spanish Peaks area. Error bars indicate one sigma uncertainty.

ROAD LOG
First day

The road log begins (stop 1) on Interstate 25 (I-25) at Huerfano Butte, located 7 mi north of the Walsenburg north exit (Figure 1). In addition to work cited in the log and the foregoing discussion, many aspects of the geology of the Spanish Peaks region are also discussed in the Guidebook to the Raton basin (Rocky Mountain Association of Geologists, 1969).

(0 miles) STOP 1--Huerfano Butte is conspicuous on the east side of I-25 nine mi north of Walsenburg, CO. This conical feature rises approximately 100 ft above the surrounding plain. Metamorphism of the surrounding

Upper Cretaceous Pierre Shale to argillite extends radially >80 ft from the butte. Popular literature indicates that this feature is a volcanic edifice of some sort, but the medium- to fine-grain size of the alkali-gabbro and lack of volcanic deposits do not support the hypothesis that the rock exposed at Huerfano Butte is extrusive. More likely, Huerfano Butte is a hypabyssal plug.

When viewed from the south or the north the butte appears to be homogeneous. If possible, view the plug from I-25 while crossing the Huerfano River. Most noticeable are the notch at the summit and the distinct color differences. The north and south sides of the plug are comprised of a dark rock, in the middle is a lighter colored band of rock extending from the base to the top of the butte. Huerfano Butte is a biotite olivine alkali-gabbro plug bisected by a 30-ft thick east-trending biotite monzonite dike and a 15-ft thick east-trending alkali-lamprophyre dike. Cross-cutting relationships indicate that alkali-lamprophyre post-dates the monzonite. On the east side of the butte, about half-way up, fingers of alkali-lamprophyre intrude cooling joints in the monzonite.

The contrast of the felsic monzonite with the medium- to coarse-grained aegerine-augite and biotite lamprophyre and the fine-grained alkali-gabbro is quite striking. $^{40}Ar/^{39}Ar$ data for both the alkali-gabbro (25.2 ± 0.8 Ma) and monzonite (25.2 ± 0.18 Ma) yield late Oligocene ages, which are similar to dates from the alkaline intrusive rocks of the Spanish Peaks. The nearly identical dates and concordant isotopic spectra for both the monzonite and alkali-gabbro suggests that either they are about the same age, or the date of the alkali-gabbro was reset by the intrusion of the monzonite, or the later intrusion of the alkali-lamprophyre reset the date of both the alkali-gabbro and the monzonite.

(6.8 miles) Exit I-25, south on I-25 business route and follow route U.S. highway 160 to the north edge of Walsenburg.

(8.4 miles) STOP 2 --Walsen dike. This dike is one of the longer (12 mi) late subparallel dikes in this area. A sample from this location yielded an $^{40}Ar/^{39}Ar$ date of 21.8 ± 0.2 Ma. The Walsen dike is a minette (calc-alkaline lamprophyre). Evidence for multiple intrusions is readily apparent from the outcrop as earlier fractures were intruded by later magma. Johnson (1964) described this as a composite dike, composed of three separate injections of minette and soda-minette of different compositions. Notice the alteration of the Pierre Shale to hornfels, extending 10-15 ft outwards, along the dike's selvages. Vitrinite reflectance data for hornfels indicate that the shale adjacent to the dike attained temperatures as high as 500°C. (Bostick and Pawlewicz, 1984).

(8.9 miles)--City center, Walsenburg; junction of route 160 west; continue south at city center on I-25 business route.

(9.4 miles)--Turn right on Ideal Canyon Road. As we drive south, the cliffs on the right are Upper Cretaceous Trinidad Sandstone; coal beds in the overlying Vermejo and Raton Formations were mined for many years by the Colorado Fuel and Iron Company.

(12.1 miles)--Road turns right and crosses railroad tracks. More cliffs of Trinidad Sandstone ahead, on west side of road.

(17.7 miles) STOP 3--Big Dike, an independent dike, intersects the Ideal Canyon road; it is composed of latite with scattered fine- to medium-grained hornblende inclusions. Aerial photos and field evidence suggest that Big Dike post-dates the radial dikes. The composition of this dike is quite similar to that of the plug at Goemmer Butte southwest of La Veta (see stop 6). Also, the ridge line 650 ft to the southeast contains rocks of the same composition and is probably part of the same dike. On the south side of the Spanish Peaks, radial dikes are offset in a similar manner; at neither site are there indications of offset by faults. The dike pattern may represent a change from local to regional stress regimes during intrusion. Also visible to the southeast is a northeast-trending ridge held up by Small (Bear Creek) Dike, which intersects Big Dike at an oblique angle.

(19.7 miles)--Road crosses Small (Bear Creek) Dike. Crelling (1973) did an extensive study of this dike. Bear Creek dike strikes N80°E, is composed of camptonite (alkali-lamprophyre), and belongs to the early set of subparallel dikes. As with many lamprophyres found in the Spanish Peaks area, the Bear Creek dike is porphyritic aphanitic with fine- to medium-grained subhedral to euhedral, except for anhedral-olivine, phenocrysts in a light-brown groundmass. The primary phenocrysts are olivine and titanaugite. Fluorite replaces iddingsite after olivine in a number of samples. Titanaugite forms striking stellate clusters.

(20.3 miles)--Road junction; proceed straight (southwest).

(22.6 miles)--Road junction; proceed straight (west).

(23.5 miles) STOP 4 -- Dike intersection. Stop a little below the top of the ridge (a radial dike) to avoid congestion. The dike intersection is about 650 ft to the northeast. On the northeast side of the road, follow the southeast side of the gully and continue north-northeast to the top of the ridge. Follow the ridge to the east and to where the radial dike is cut by a late mafic subparallel dike. (24.2 miles)--Road turns sharply north-northeast.

(25.2 miles)--Junction, Huerfano County road in valley of Bear Creek; turn left (south).

(28.7 miles)--Radial syenite dike intersection with late mafic subparallel dike. Turn right off Bear Creek road to Andreatta Cattle Ranch; go one mile to intersection. Turn left and go 1/4 mi to ranch house for permission to enter. Backtrack to intersection. Continue through intersection to gate. Remember to close gate securely after passing through. Continue 1/4 mi on road through pasture to top of ridge. Stop on ridge.

STOP 5--Dike intersection on ridge. This intersection is probably the best example of the forces that operated during the later phases of dike intrusion in the Spanish Peaks area. From this location the dike intersection can be reached by two routes. The first, more strenuous, route involves walking southwest along the dike for about 1/3 mile. The easier approach is to walk in the pasture next to the irrigation ditch on the south side of the ridge until reaching a clump of trees and a small pond. From the trees turn northwest and walk up the ridge to the top of the dike. If you miss the intersection it is easy enough to find: just look for the place where another ridge intersects the ridge on which you are standing. The composition of this radial dike is typical of most of the felsic radial dikes in the Spanish Peaks area; the dike is composed of syenite porphyry with fine- to medium-grained phenocrysts of plagioclase, orthoclase, and minor amounts of biotite, pyroxene, and hornblende.

From the intersection look back southwest toward WSP. The curve in the radial dike as it intruded is believed to be a function of the varying stress regimes, i.e., the transition from the influence of WSP stock into the regional stress field. Turning and facing east-northeast, the radial dike can be followed to the east where it bifurcates. One branch of the dike continues curving to the east. The other branch deviates and continues eastward in a subparallel orientation. The radial dike may have propagated outward from somewhere below WSP and reached this transitional stress zone. The stress environment permitted syenitic magma to follow both radial and subparallel orientations. Examine the subparallel dike and follow its path as it approaches the radial dike. The subparallel dike propagated from west to east and encountered the radial dike directly in its path. With its primary route blocked, magma of the subparallel dike cut across the radial dike and continued in a southeasterly direction. The dike can be followed down the ridge to the west side of the pond below, across the pasture to the top of the next hill. Even further to the southeast, the mafic dike crops out on the ridge southeast of the main house of the Andreatta Cattle Company just north of Bear Creek Road.

Return to Bear Creek road and resume log mileage at 28.7 miles; turn left and proceed north past road at 25.2 miles. Outcrops of brown sandstone along west side of road are Paleocene and Upper Cretaceous Poison Canyon

(28.7 miles)--Junction with road to La Veta; turn left and proceed west on Huerfano County road to La Veta. Outcrops of brown sandstone are Poison Canyon Formation.

(30.6 miles)--Road crosses drainage divide (benchmark 7191 on Ritter Arroyo 7 1/2' quadrangle); Poison Canyon Formation. Geology from here to the Sangre de Cristo Mountains is shown on Vine's (1974) map.

(32.4 miles)--Cliffs on left (south) are Eocene Cuchara Formation, which overlies the Poison Canyon Formation. Contact is near base of cliffs.

(35.4 miles)--Road turns south 0.1 mile, then back west.

(36.6 miles)--Wahatoya Lake on left (south) side; dike intersection in Cuchara Formation.

(37.6 miles)--Village of La Veta; turn left on CO (state highway) 12 and drive south through business district; follow CO 12 markers; turn right, then left, at intersections. Highway 12 is known for its spectacular scenery and is also designated as the "Highway of Legends," marked by the state scenic byway sign.

(38.3 miles)--Right turn; proceed west past convenience store on right and Grandote golf course on left (south) side of CO 12; cross bridge over Cucharas River.

(38.9 miles)--Highway 12 turns left (south) at corner of golf course. The structure and stratigraphy for this part of the trip is shown in more detail on figure 4.

(39.4 miles) Junction of CO 12 and Indian Creek Road; weathered sign says "Goemmer Bros.;" turn right on gravel road and proceed west on alluvium of Cucharas River. Goemmer Butte is on the left at about 10 o'clock.

(40.0 miles) Road ascends to pediment; this pediment is the lowest level, widespread on the divide between East Indian Creek and the Cucharas River. See discussion of pediments at stop 6.

(40.9 miles) Pass road junction; road bears left (southwest) after junction.

(42.3 miles; 4.7 miles from La Veta town center) STOP 6-- Stop on the pediment surface before the road descends into the scrub timber along East Indian Creek. Refer to figure 2 for the location of igneous rocks and to figure 4 for Formation. sedimentary rocks and structural features.

The lower pediment surface and outcrops of the basal Cuchara Formation where it crosses the East Indian Creek road afford a panoramic view of high-level Quaternary pediments to the east, of dikes radiating from WSP, and of the plug at Goemmer Butte. Looking southwest, one can see bold sandstone outcrops of the Paleocene and Upper Cretaceous Poison Canyon Formation and the pine-covered ridge that is underlain by the basal conglomerate and sandstone member of the Paleocene and Upper Cretaceous Raton Formation. Coal mines on the back (west) side of the ridge produced low-grade bituminous coal from thin seams in the Upper Cretaceous Vermejo Formation (Johnson and Stephens, 1954b). Coalbed methane was produced briefly from a small field in the Vermejo Formation south and southwest of Goemmer Butte (drillholes shown on Figure 4; Rose and others, 1984).

Three levels of pediments are distinguished along the valleys of the Cucharas River and East Indian Creek (Lindsey, 1995b). The highest, located about 275 ft above stream level, may be equivalent to the San Miguel Creek Alluvium (San Miguel alluvium of Levings, 1951, and Pillmore and Scott, 1976). The highest level is visible on the skyline east of the Cucharas River and as remnants as high as 9,700 ft above sea level on the slopes of WSP. The intermediate level, located about 110-140 ft above stream level, may be equivalent to the Beshoar Alluvium (Levings, 1951; Pillmore and Scott, 1976). Remnants south of Goemmer Butte are visible from the stop. The lowest level, located about 30-70 ft above drainages, may be equivalent to the Barela Alluvium (Barilla alluvium of Levings, 1951, and Pillmore and Scott, 1976). It occurs at two levels adjacent to the valley floors of the Cucharas River and East Indian Creek, slightly above modern alluvium.

Numerous radial dikes are visible from this point. Gazing across the landscape from southeast to southwest, the radial nature of the dikes is apparent. The long tan dike extending outward from WSP is called the "Great Wall;" the dike is nearly 6.5 miles long. The Great Wall dike is nearly 100 feet high and 20-30 feet wide in places. On the east side of Goemmer Butte is another radial dike. This syenite porphyry dike is the youngest radial dike; its age, 21.9 ± 0.13 Ma, is only slightly greater than that of the Walsen Dike. While having a radial orientation, it is quite different from the majority of the radial dikes in that the dominant phenocryst phase is an acicular green-brown hornblende instead of plagioclase. The composition of the dike is more like that of the magmas of Silver Mountain to the north than to the composition of the WSP radial dikes. The $36.2 \pm .12$ Ma ($^{40}Ar/^{39}Ar$ date) for the Silver Mountain - Black Hills - Little Black Hills complex is much older than the dike east of Goemmer Butte, which suggests a different source for the Silver Mountain - Black Hills - Little Black Hills magma.

East and West Spanish Peaks dominate the landscape to the south. The two stocks are compositionally quite different. WSP consists of a fine- to medium-grained hypidiomorphic-granular quartz syenite. Numerous felsic dikes cross-cut WSP at its summit. ESP is the larger of the two stocks and has two slightly different compositions. The part of ESP exposed above 11,000 ft is a granodiorite porphyry. ESP rocks exposed below 11,000 ft are granite porphyry. The border between these two rock compositions is marked by a dark contact.

Goemmer Butte is a volcanic plug intruded into the Cuchara Formation. The plug is composed of dark latite with scattered medium- to coarse-grained hornblende-rich mafic inclusions. Goemmer Butte and Big Dike in Ideal Canyon are compositionally similar. Muller and Pollard (1977), and Muller (1986) identified the location of Goemmer Butte as a possible isotropic point in their stress model of the Spanish Peaks intrusive rocks. Goemmer Butte exhibits the only evidence in the immediate vicinity of the Spanish Peaks for magma venting to the surface. A crescent-shaped body of eruptive breccia (diatreme) is well-exposed on the south and west sides of the butte (Lindsey, 1995b). The breccia consists of fragments of Cuchara sandstone and lesser amounts of latitic volcanic rock and it is intruded by thin dikes of latite that extend from the plug.

The Eocene Cuchara Formation exposed here represents its lowermost part. The Cuchara typically is arkosic, conglomeratic, and crossbedded; beds are arranged in fining-up alluvial cycles. Overbank mudstones (not exposed here, but well exposed along CO 12 north of La Veta) range from drab brown to red. In the La Veta area, the Cuchara can be distinguished by the presence of prominent pebbles and cobbles in sandstone and by red mudstone; these are rare to absent in the underlying Poison Canyon Formation. From East Indian Creek south to a point east of the village of Cuchara, the base of the Cuchara Formation is marked by an interval of pebble and cobble conglomerate. Conglomerate clasts are mostly Early Proterozoic gneiss, vein or pegmatitic quartz, and sandstone from the Middle Pennsylvanian Madera Formation and the Pennsylvanian and Permian Sangre de Cristo Formation. Measurements of trough crossbedding in the Cuchara Formation show a westerly source.

The Poison Canyon Formation is well-exposed south of the road to the west. Bold outcrops of light-brown, cross-bedded sandstone are characteristic of the Poison Canyon. Crossbedding measurements show a westerly source, comparable to that of the Cuchara. The upper part of the Raton Formation forms valleys and depressions The lower Raton, which is well exposed on the pine- covered

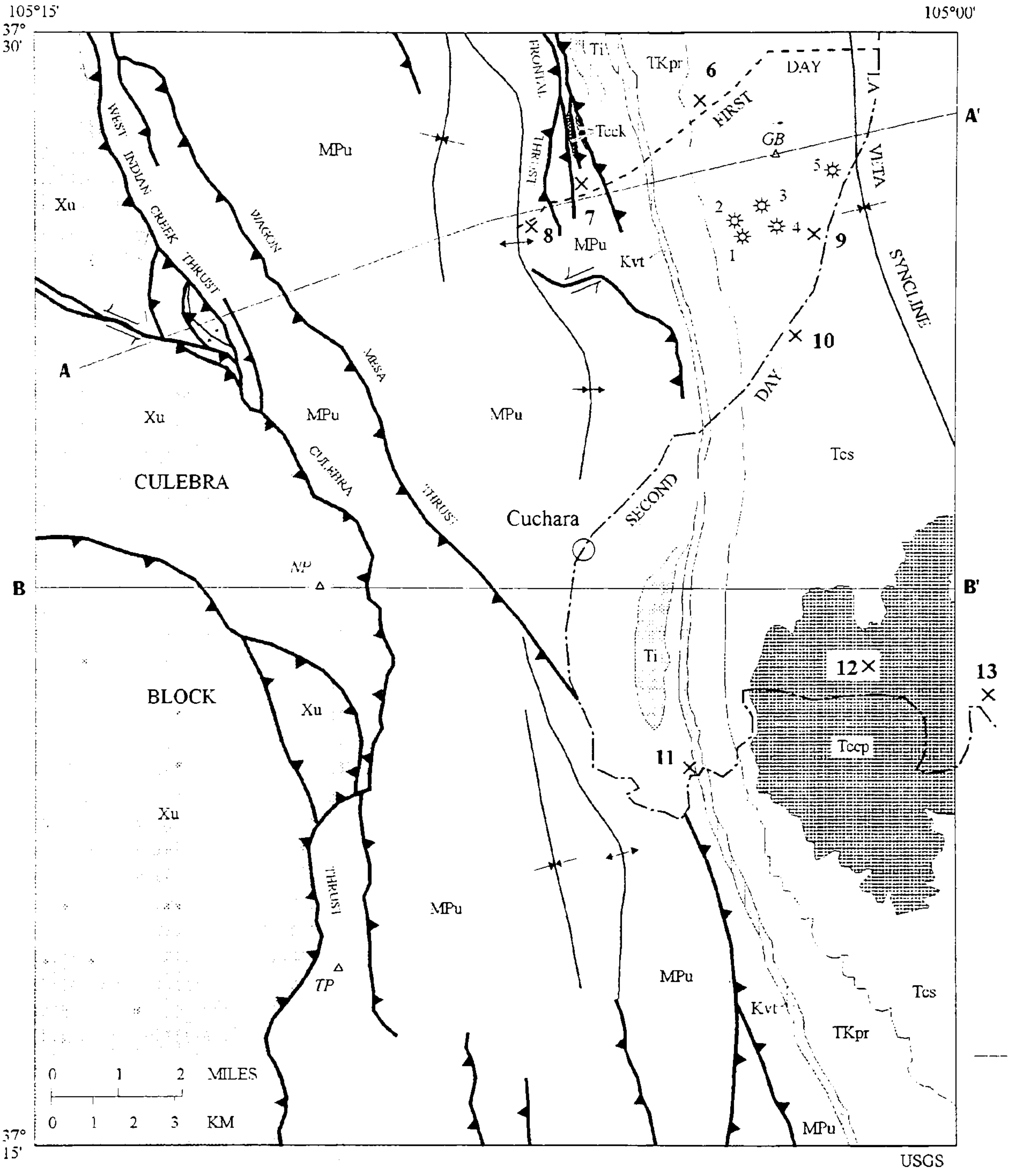

Figure 4.--Laramide structural features of the central Culebra Range, synorogenic formations of the western Raton basin, and major post-Laramide intrusions (generalized from Lindsey, 1995a; 1995b; 1996; and Wallace and Lindsey, 1996). Map symbols as follows: Ti, intrusive rhyolite and granite; Tccp, Cuchara Formation, conglomerate of Cordova Pass; Tcck, Cuchara Formation, conglomerate of Copper King Canyon; Tcs, Cuchara Formation, sandstone member; TKpr, Poison Canyon and Raton Formations undivided; Kvt, Vermejo Formation and Trinidad Sandstone undivided; MPu, Mesozoic and Paleozoic sedimentary rocks undivided; Xu, Early Proterozoic metamorphic rocks undivided. *GB*, Goemmer Butte; *NP*, Napoleon Peak; *TP*, Trinchera Peak. Drillholes as follows: 1, HBB No. 1 Goemmer; 2, HBB No. 2 Goemmer; 3, HBB No. 3 Goemmer; 4; HBB No. 4 Goemmer; 5 HBB No. 5 Goemmer. Field trip stops (X).

ridge to the southwest, consists of conglomerate and conglomeratic sandstone with abundant pebbles of gneiss, quartz, and feldspar derived from Early Proterozoic rocks. The conglomerate beds unconformably overlie the Vermejo Formation and evidently record an episode of erosion of a basement-cored Laramide highland during Late Cretaceous time. However, the presence of abundant feldspar in the underlying Vermejo Formation indicates even earlier erosion of the highland.

Proceed west on the Indian Creek Road.

(42.8 miles)--Bold outcrops of sandstone on left (south) side are Poison Canyon Formation.

(43.1 miles)--Strike valley on left (south) underlain by upper part of Raton Formation.

(43.3 miles)--Pine-covered ridge on left (south) underlain by lower conglomeratic sandstone of Raton Formation.

(43.5 miles)--Small road cut is an excellent exposure of Trinidad Sandstone; coal-bearing Vermejo to southeast on west-facing slopes.

(43.9 miles)--Pass large mafic dike on right (north) side of road; its composition plots in the trachyandesite field (total alkali-silica diagram, IUGS nomenclature as described by Le Bas and Streckeisen, 1991, and Le Bas and others, 1992) (Lindsey, 1995b). This dike is one of a swarm of mafic dikes and sills that strike nearly parallel to the mountain front and intrude Upper Cretaceous shale.

(44.6 miles; 7 miles from La Veta town center) STOP 7--The old Sulphur Springs resort on East Indian Creek is located near the southern end of the frontal thrust of the Sangre de Cristo Mountains, which will be discussed at this stop. The resort takes its name from springs that discharge hydrogen sulfide gas; several active springs can be observed on the north side of the creek at the base of the hogback.

The hogback and adjacent formations are located in the footwall of the frontal thrust of the Sangre de Cristo Mountains (Figures 4 and 5). The hogback consists of overturned (70° west) Lower Cretaceous Dakota Sandstone and Purgatoire Formation. East of the hogback, but away from the road, is a small outcrop of Upper Cretaceous Ft. Hays Limestone and Juana Lopez Member of the Upper Cretaceous Carlile Shale. The Juana Lopez Member is only 3-6 ft thick here. The remainder of the Cretaceous shale section (Upper Cretaceous Graneros Shale through Upper Cretaceous Pierre Shale) is very poorly exposed. The Codell Sandstone Member of the Carlile Shale is not exposed, and may be absent (see Pillmore and Eicher, 1976). West of the hogback, a small brush-covered ridge is underlain by Middle Jurassic Entrada Sandstone; the intervening Upper Jurassic Morrison Formation is not exposed.

The frontal thrust here consists of two splays. The easternmost splay, located approximately in the tree-covered valley west of the Entrada Sandstone, is probably the main thrust (Figure 5). Overturned (45-60° west) red sandstone of the Permian and Pennsylvanian Sangre de Cristo Formation, located in the cliffs west of the tree-covered valley, is overlain by an upper thrust splay, located near the top of the cliffs. Above the cliffs, the Sangre de Cristo Formation has been folded into the east-facing Price Canyon anticline. The west limb of the anticline dips about 10° west, but the east limb dips steeply east. If time permits, we will drive an additional 1.1 mi to stop 8 (optional) at the end of the maintained road and walk through the anticline axis

The frontal thrust is interpreted to dip moderately west at approximately 55° (Figure 5). Displacement, assuming a 13,000-ft thickness for the Sangre de Cristo Formation, is probably minimal at the southern end of the thrust. (Complete, unfaulted sections of the Sangre de Cristo Formation do not exist in the Culebra Range; the assumed thickness is the minimum value required to accommodate reverse offset on the frontal thrust). The dip of the frontal thrust probably flattens as displacement increases northward (Vine, 1974).

The hangingwall anticline, with its overturned forelimb (Figure 5), resembles fault-propagation folds described in the literature (e.g., Mitra, 1990) and is so interpreted. The splay-bounded slice of strongly overturned Sangre de Cristo Formation is part of the forelimb. Fault propagation took place almost entirely in the forelimb.

The frontal thrust extends north along the front of the mountains for many miles (Vine, 1974), but southward the thrust ends abruptly near a tear fault (Figure 4). Slickensides along the tear fault reveal evident strike-slip motion, which was required to separate vertical to overturned strata in the hangingwall of the frontal thrust from the simple monocline south of the tear fault. The hangingwall anticline, located behind the tear fault, passes from a tight east-verging fold into a simple monocline south of the tear fault. This abrupt change in structure along strike is interpreted to illustrate compartmentalization of strain, where compressive stress was transferred from the frontal thrust to the Culebra thrust to the south.

The frontal thrust also defines the structural margin of the Raton basin. At section *A-A'* (Figure 5), the basin margin is marked by a sharp flexure. Backthrusts in incompetent Upper Cretaceous shale can be mapped with confidence north of the line of section, where they also displace the younger Cuchara Formation (Lindsey, 1995b). Although some backthrusts may be rooted in shale, map relations demonstrate that others descend steeply into the alternating sandstone and shale beds of the Sangre de

Cristo Formation. In the configuration shown in Figure 5, the backthrusts in section *A-A'* are interpreted to intersect a blind thrust located beneath the frontal thrust. The presence of a blind thrust is based on an earlier seismic interpretation (Rose and others, 1984), which did not recognize the backthrusts mapped in shale at the surface. Possibly, these faults outline a triangular wedge of deformed sedimentary rocks in the footwall of the frontal thrust as shown section *A-A'*. The blind thrust is not necessary to balance the section, however, and a section

are overturned (45° west) in the footwall but are upright (70° east) in the hangingwall.

(45.3 miles)--Road crosses bridge over East Indian Creek. Immediately before the bridge, a gate on the south side of the road is immediately west of outcrops of red sandstone of the Sangre de Cristo Formation. Behind the gate (locked), a trail leads to abandoned uranium prospects on the east side of Price Canyon. The Vanadium Corporation of America drilled radioactive anomalies here in the 1950s.

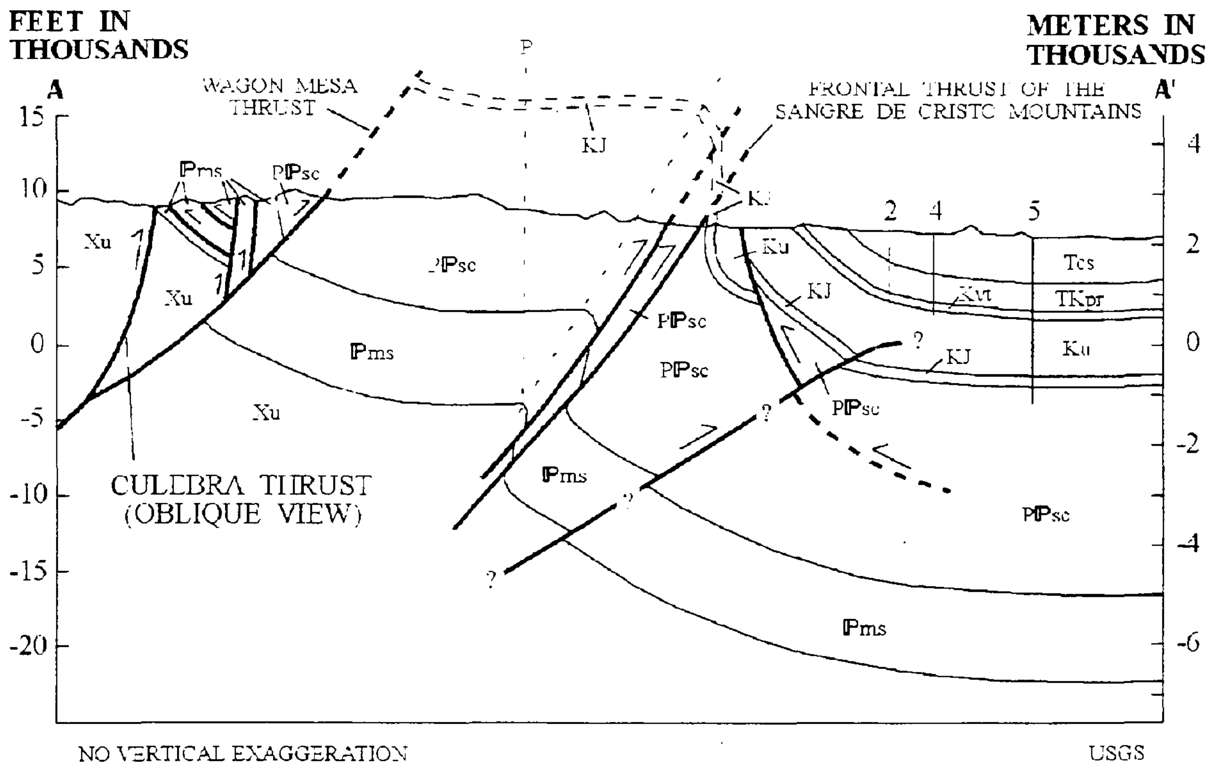

Figure 5.--Structural cross-section A-A' through the centralCulebra Range and western Raton basin. Symbols as follows: Tcs, Cuchara Formation, sandstone member; TKpr, Poison Canyon and Raton Formations undivided; Kvt, Vermejo Formation and Trinidad Sandstone undivided; Ku, Pierre Shale, Niobrara Formation, Carlile Shale, Greenhorn Formation, and Graneros Shale undivided; KJ, Dakota and Purgatoire Formations, Morrison Formation, and Entrada Sandstone undivided; Phsc, Sangre de Cristo Formation; hms, Minturn and Sandia Formations undivided; and Xu, Early Proterozoic metamorphic rocks undivided. Line of section shown on figure 4. Drillholes identified in caption, figure 4

could be drawn showing backthrusts extended into the basin without interruption (the preferred configuration for backthrusts in the southern part of Figure 4).

OPTIONAL: If time permits, drive to stop 8.

(45.2 miles)--Road crosses upper splay of frontal thrust of the Sangre de Cristo Mountains. The thrust splay is poorly exposed at road level, but strongly contrasting dips serve to fix its location. Bedding dips in outcrops along the road

The prospects were dug in gray (reduced) shale and siltstone beds, about 3-10 ft thick, of the Sangre de Cristo Formation. The geologic features of these mineral occurrences, and probably also their mineral and chemical characteristics, are essentially the same as those described elsewhere in the Sangre de Cristo Mountains (e.g., Tschanz and others, 1958; Lindsey and Clark, 1995). The trail also leads to some spectacular exposures of horizontal slickensides along a tear fault (Figure 4), where it crosses the ridge south of Kruger Mountain (see Lindsey, 1995b, for location).

(45.4 miles)--Jeep road to right leads to Linscott Mine; small incline shaft in copper-mineralized mafic dike and contact-metamorphosed sandstone of the Sangre de Cristo Formation.

(45.7 miles; 8.1 miles from La Veta town center) STOP 8 (OPTIONAL)--County road maintenance ends here, at the San Isabel National Forest boundary. Park vehicle and walk west about 200 ft on forest road to view the axis of the Price Canyon anticline in a small canyon cut by East Indian Creek. The east-facing asymmetry of the anticline is apparent. In the canyon, the Sangre de Cristo Formation consists of alternating beds of red sandstone, siltstone, and shale, arranged in fining-upward cycles of alluvial origin. Nodular calcareous horizons in shale and siltstone are probably paleosols. Measurements of trough crossbedding axes in gently dipping sandstone beds from here west into McCarty Park show an overall easterly paleocurrent direction.

Return to CO 12 and proceed to the night's accommodations (either La Veta or Cuchara).

Second day

The trip route will follow CO 12 south from La Veta through the Cucharas River valley to view examples of the radial dikes (stops 9 and 10), pass through the village of Cuchara, and proceed south through roadside exposures of the Sangre de Cristo Formation. The trip will exit CO 12 at Cucharas Pass and proceed east on Las Animas County roads, eventually linking back to I-25 at the town of Aguilar. Stop 11 provides an opportunity to complete discussion of Laramide structure and to view a major Miocene granite pluton from a distance. Stop 12, at Cordova (Apishipa) Pass, provides an introduction to Laramide synorogenic fanglomerates in the Cuchara Formation and a panoranic overview of the Cucharas River valley, including the radial dike system. The trip route then proceeds into the head of the Apishipa River valley to stop 13, to examine another radial dike and redbeds in the Cuchara Formation, and thereafter down the Apishipa River valley to the Spanish Peaks Ranch, where it leaves the Apishipa and crosses the divide to Jarosa Canyon. Stop 14, located immediately south of the junction with the Jarosa Canyon road, is a road-cut exposure of a major east-trending mafic dike. From stop 14, the trip proceeds east, rejoins the Apishipa River valley road, passes through the village of Gulnare, and proceeds to Aguilar.

(0 miles)--Begin trip mileage at intersection of Main Street and Ryus Avenue, La Veta. Proceed south on CO 12 as described for day 1; pass Grandote golf course at south end of town heading west and then south. Refer to figure 2 for dikes and to figure 4 for sedimentary rocks and structural features.

(1.8 miles)--Junction of route 12 and East Indian Creek Road.

(3 miles)--Gravel pit in alluvium, west side highway. Goemmer Butte on right at 2 o'clock.

(4.2 miles) STOP 9--Dike of Profile Rock (at "Three Bridges" on topographic map of Cuchara 7 1/2' quadrangle). Profile Rock was called granodiorite porphyry by Johnson (1968); however, two analyses plot in the rhyolite (granite) field of a total alkali-silica diagram (Le Bas and others, 1992). Compositionally, Profile Rock is atypical and probably more closely related to ESP than the radial dikes of WSP. Nonetheless it is spectacular!

Rising upwards of 100 ft above the surrounding terrain and ranging from 10 to 30 ft wide, Profile Rock is one of the prominent dikes along this section of CO 12. Perhaps the most interesting visible feature is how the country rock (Cuchara Formation) has been baked to almost black by the intrusion of the dike. As we continue southward look back at Profile Rock to see how weathering has left a profile of a face complete with a location where a hole has been eroded through the dike to form an eye.

(4.3 miles)--Highway crosses bridge over Cucharas River. Profile Rock at 11 o'clock. Continuing southward, numerous small dikes are exposed on the east side and to a lesser degree on the west side of the road. Notice the bleached Cuchara sandstone adhering to the sides of a number of dikes.

(6.4 miles) STOP 10--Dike of Devil's Stairway. Park on the turnout across the road from the dike. This is another spectacular example of a granite porphyry radial dike. Erosion has produced several horizontal surfaces that are offset like giant stairsteps. Here again, especially on the east side, are sections of bleached Cuchara sandstone adhering to the east side of the dike.

The dike intrudes typical conglomeratic sandstone of the Cuchara Formation. The Cuchara Formation here is comparable to that at stop 6. Dips of 20°-30° east are typical in Cuchara Formation from here west. One mile southwest of stop 10, the abrupt increase in dip from 35° east in the lowermost Cuchara Formation to 50° east in the uppermost Poison Canyon Formation is interpreted as evidence of an angular unconformity (Lindsey, 1995b). The unconformable contact between the Cuchara and Poison Canyon Formations was first noted by Johnson and others (1958). Northward, at East Indian Creek, angular discordance is slight or absent.

Thirty to forty yards east of Devil's Stairway are what looks like two small parallel felsic radial dikes with a depression between them. Actually, the two "dikes" are the more erosion-resistant remains of metamorphosed Cuchara Formation. The depression between the two "dikes" is a lamprophyre dike that was less resistant to erosion than the sandstone it altered during intrusion.

(7.7 miles)--Valley south of highway marks approximate position of unconformable base of Cuchara Formation; thin, ridge-forming pebble and cobble conglomerate at base to south; steeply dipping (50° east) sandstone beds of Poison Canyon Formation exposed west of valley.
(8.3 miles)--Bridge over Cucharas River; outcrops in riverbank on south side are Trinidad Sandstone.

(8.5 miles)--Barn on south side highway with mural advertising "Bright and Early Coffee." North Peak, part of a large pluton of granite porphyry, about due south.

(9.5 miles)--Route passes through hogback of Dakota Sandstone and Purgatoire Formation. Morrison Formation not exposed.

(9.6 miles)--Low ridge on right (north) side is underlain by Entrada Formation. A unit composed of interbedded quartzose sandstone, limestone, red cherty limestone, and gypsum--about 55 ft in total thickness and assigned to the Upper Jurassic Ralston Creek (?) Formation by Johnson (1962)--is partially exposed in the road cut here. A more complete section of Jurassic rocks is exposed 1.2 mi south of Cuchara.

(9.9 miles)--Outcrops of red sandstone on west side of highway are Sangre de Cristo Formation. Trip route will pass through Sangre de Cristo Formation from here almost to the summit of Cucharas Pass.

(11.5 miles)--Village of Cuchara, a popular summer vacation spot. Continue south on CO 12.

(12.1 miles)--U. S. Forest Service Spring Creek picnic area to right. Road cuts in Sangre de Cristo Formation.

(12.5 miles)--Small dike (part of the radial dike system) in road cut, west side of highway; wall rocks are Sangre de Cristo Formation.

(13.3 miles)--Highway crosses southernmost mapped extension of Wagon Mesa thrust, here represented by two splays.

(13.5 miles)--Road to Cuchara ski area; CO 12 proceeds through Sangre de Cristo Formation. West slope of Dakota hogback at 9 o'clock contains the most completely exposed section of Entrada, Ralston Creek (?), and lower Morrison Formations in the Spanish Peaks area. Mountain east of hogback is White Peak, composed of granite porphyry.

(15.1 miles)--Road to Blue Lake and Bear Lake Forest Service campgrounds, west side CO 12; Spanish Peaks Campground (private) east of highway; route makes hairpin curve; road cut ahead is near-vertical Sangre de Cristo Formation.

(17.3 miles)--Cucharas Pass, elevation 9941 ft; junction of CO 12 and Las Animas County road to Aguilar; turn left on the county road. About 200 ft north of the junction, the trip route passed over the trace of the Dakota hogback (not exposed at the highway). East of the junction, the road will pass over Upper Cretaceous Pierre Shale. If the road is wet, be careful. Proceed to stop 11.

(17.9 miles) STOP 11--Turnout at John T. Farley Memorial Wildflower Trail. The stop is located in upper part of the Pierre Shale; thin mafic sills in the road cut here are common in Upper Cretaceous shales. The top of the Pierre (and Trinidad Sandstone) is located around the bend in the road east of stop 11. The view north (refer to cross-section *B-B'*, shown in figure 6) is of granite porphyry of the White Peaks, which intrudes Pierre Shale. The valley of White Creek, west of the White Peaks, is located in Upper Cretaceous shales; the east side of the valley contains someof the best exposures of Pierre in the area. The hogback to the west is Dakota Sandstone and Purgatoire Formation. Trinchera Peak is directly west on the crest of the Culebra Range. Cirques on the east side of range were formed during Pinedale glaciation. Below treeline are Blue Lake and Bear Lake, dammed by Pinedale recessional moraines.

The light-colored granite porphyry, called "granite of White Peaks" by Johnson (1968), is a sill-like body that extends through North, Middle, and South White Peaks. Although Johnson (1961, 1968) considered the White Peaks intrusion to be a stock, the rootless sill shown on figure 6 is consistent with surface geologic relations (Lindsey, 1996). The porphyry is believed to post-date the intrusion of WSP, ESP, and the radial dikes primarily because it is not cross-cut by any radial dikes. Compositionally an alkali-feldspar microgranite porphyry, the White Peaks intrusion is unusual because it contains mafic enclaves (> 10 mm in diameter) composed of hornblende diorite. Mount Mestas (also known as Mt. Baldy), northwest of La Veta on the north side of US highway 160, is also an alkali-feldspar microgranite, but lacks mafic enclaves.

As plotted on a total alkali-silica diagram, the composition of one of the mafic sills in the road cut at this locality (no. 167, syenogabbro of Johnson, 1968) is basaltic

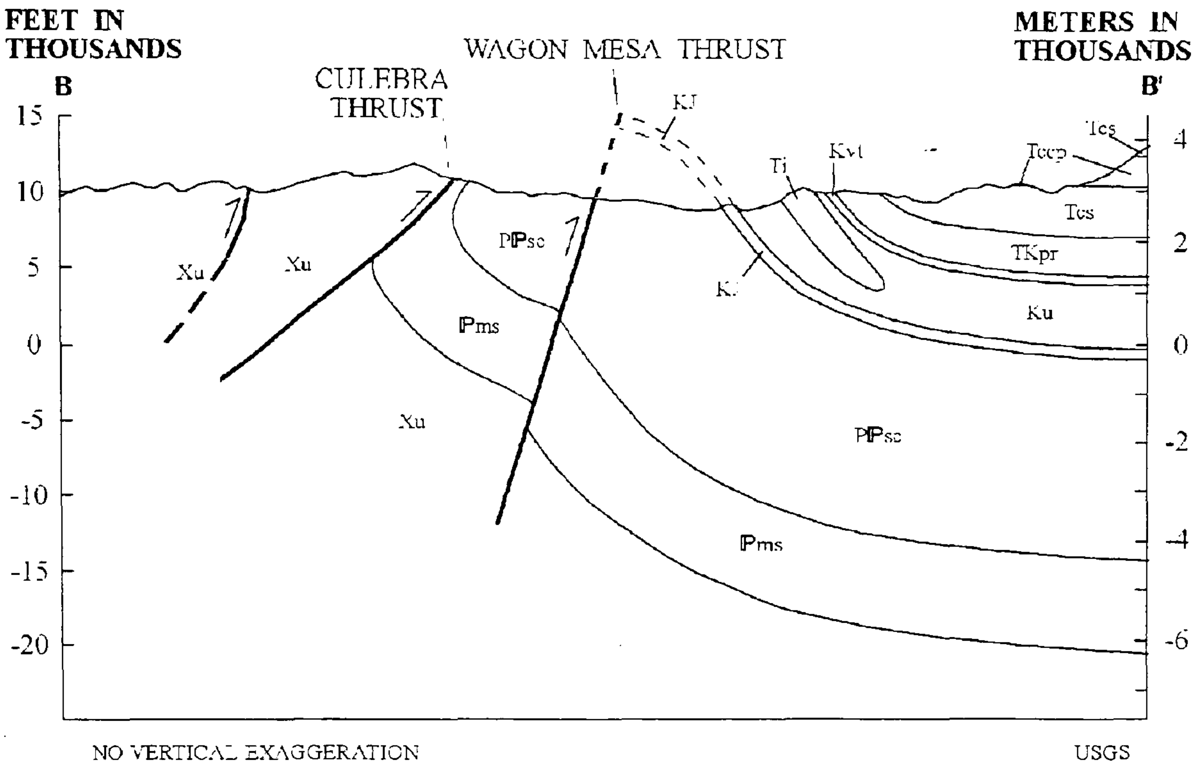

Figure 6.--Structural cross-section B-B' through the central Culebra Range and western Raton basin to West Spanish Peak. Symbols as follows: Ti, intrusive leucogranite (of White Peaks); Tccp, Cuchara Formation, conglomerate of Cordova Pass; Tcs, Cuchara Formation, sandstone member; TKpr, Poison Canyon and Raton Formations undivided; Kvt, Vermejo Formation and Trinidad Sandstone undivided; Ku, Pierre Shale, Niobrara Formation, Carlile Shale, Greenhorn Formation, and Graneros Shale undivided; KJ, Dakota and Purgatoire Formations, Morrison Formation, and Entrada Sandstone undivided; Phsc, Sangre de Cristo Formation; hms, Minturn and Sandia Formations undivided; and Xu, Early Proterozoic metamorphic rocks undivided. Line of section shown on figure 4.

andesite (Le Bas and others, 1992). Mafic sills resembling those in the road cut at stop 11 are abundant in Upper Cretaceous shale along CO 12 south of Cucharas Pass. Although time will not permit examining the sills south of the pass, excellent exposures of a swarm of mafic sills can be seen in a road cut at a sharp curve on CO 12 at North Lake, 7 mi south of Cucharas Pass. The sills there (at least 15 separate intrusions) are so thick and numerous that they form a hogback in the Pierre Shale on the east side of North Lake.

Although the geology of the Culebra Range is best examined by going to the crest of the range, time and two-wheel drive require that they be discussed from a distance, at this stop or the next one. First, locate Trinchera Peak, the most prominent peak on the western skyline. The Whiskey Creek Pass Limestone Member of the Middle Pennsylvanian Madera Formation (Brill, 1952) crops out on Trinchera Peak and its northern extension. Reexamination of fusulinids (D. A. Myers, 1994, written commun.; described in Lindsey, 1995a) confirm earlier assignments of a Desmoinesian age (Tischler, 1963) to all of the Madera except the lowermost part. The Sangre de Cristo Formation crops out from the high east slope of Trinchera Peak to the Cucharas River valley, east of CO 12. The Sangre de Cristo section is repeated by folding and faulting.

The Culebra thrust is exposed in the second pass north of Trinchera Peak. Early Proterozoic gneiss crops out along the crest of the range north of the pass. The pass is usually marked by a long snowbank that does not disappear until August. The Culebra thrust is the dominant Laramide compressional feature of the central Culebra Range. Exposed for more than 12 mi on either side of the crest of the range, the thrust dips 40°-55° west at the surface and brings Lower Proterozoic gneisses a minimum of 2 1/2 mi over Pennsylvanian and Permian sedimentary rocks of the footwall (Figures 4 and 6).

The Sangre de Cristo and underlying sedimentary formations east of Culebra thrust contain Laramide structures typical of the Culebra Range (Figure 4). A small backthrust, exposed along the east side of the crest of the Culebra Range, rises from a syncline in Sangre de Cristo

Formation. An anticline in Sangre de Cristo Formation in the eastern part of the range passes southward, and is interpreted to pass downward, into a thrust. The near-vertical beds of Sangre de Cristo Formation at the junction of CO 12 and the road to Blue Lakes are part of the steep forelimb of the anticline. East of the anticline, steeply dipping to vertical Dakota Sandstone and Purgatoire Formation are separated from moderately dipping Trinidad Sandstone and Vermejo Formation by Upper Cretaceous shales. South of Cucharas Pass, the interval of Upper Cretaceous shale contains backthrusts. Shale commonly occupies the structural hinge between the Culebra Range and the Raton basin.

(18.0 miles)--Enter Trinidad Sandstone (poorly exposed in road cuts) at second bend in road.

(18.1 miles)--Enter Vermejo Formation; traces of coal beds are found in road cuts.

(18.2 miles)--Enter base of Upper Cretaceous Raton Formation, marked by weathered pebbly sandstone in road cut.

(18.6 miles)--Enter Poison Canyon Formation where road crosses clearing and passes sign for real estate subdivision. Road becomes sandy and road cuts contain poorly exposed brown sandstone.

(19.1 miles)--Road crosses radial dike and enters Cuchara Formation. Loose cobbles on slopes above next curve are float from conglomerate of Cordova Pass.

(20.4 miles)--Road crosses two large radial dikes of gray porphyry (outcrops on right side); analysis of first dike (no. 150, syenodiorite of Johnson, 1968) indicates a trachyandesite composition (Le Bas and others, 1992).

(20.7 miles)--Hairpin curve; road crosses conglomerate beds near base of sandstone member, Cuchara Formation, then turns northeast, parallel to radial dikes of gray syenite porphyry. These dikes are typical of the radial dike system on Cordova Pass; an example will be examined at the next stop.

(21.1 miles)--Approximate base of conglomerate of Cordova Pass (Figure 4). The conglomerate of Cordova Pass is a tongue of alluvial fanglomerate within the Cuchara Formation. Along the road to Cordova Pass, large round to subround boulders and cobbles from the conglomerate of Cordova Pass are visible in road cuts.
(22.3 miles)--Road passes Peaks trailhead. This trail descends to the White Peaks.

(23.6 miles) STOP 12--Summit, Cordova Pass (formerly known as Apishipa Pass); elevation 11,248 ft. Restrooms on south side of road. The foot trail on the north side of the road leads to WSP; walk to overlook at elevation 11,412 ft, about 0.5 mi north of the road and about 500 ft northwest of the trail.

At the pass, large subround boulders and cobbles strewn on the surface are from the conglomerate of Cordova Pass; they consist mainly of Early Proterozoic gneiss, quartz (probably derived from pegmatite and quartz veins in Early Proterozoic gneiss), and red sandstone from the Sangre de Cristo Formation. Quartz cobbles commonly exhibit what appear to be layers of iron oxide minerals; some layered cobbles were cut into slabs and examined for evidence that they are actually quartzite, but only coarse vein quartz was found. Boulders of gneiss and red sandstone exceeding 1 m across are common locally, but quartz clasts seldom exceed 15-20 cm.

At the overlook, one can see the entire Cuchara valley, including the northwestern quarter of the radial dike system and formations along the mountain front. Trinchera Peak is on the skyline at S60°W and Napoleon Peak (composed of Early Proterozoic gneiss above the Culebra thrust) is at about N85°W. The mountains in the distance include, clockwise from about N60°W: the Mt. Blanca group, composed mostly of Early Proterozoic tonalite gneiss and metagabbro (Johnson and Bruce, 1991); the Crestone Peak group at N35°W in the far distance, composed of the Crestone Conglomerate Member of the Sangre de Cristo Formation (Lindsey and others, 1986); and Greenhorn Mountain at N5°W in the high part of the Wet Mountains, composed of Proterozoic rocks. In the middle distance at about N30°W is Mt. Mestas, a large pluton of microgranite porphyry; at N15°W is Silver (Dike) Mountain, an igneous center with a small radial dike system (Vine, 1974); and at about N5°E is Black Mountain, an igneous center immediately south of the Wet Mountains. West Spanish Peak looms immediately east of the overlook.

At the overlook, the conglomerate of Cordova Pass is well exposed in the north wall of a syenite porphyry dike of the radial system. The conglomerate here is preserved from erosion by hardening in the contact metamorphic zone adjacent to the dike. The nearly massive, but faintly stratified, conglomerate in the dike wall is composed mostly of cobbles and boulders in red sandstone matrix. A large boulder of augen gneiss, weathered from the conglomerate, lies nearby on the surface. The augen gneiss is typical of the leucocratic augen gneiss exposed in the Culebra thrust block (Lindsey, 1995a) and is interpreted to have been derived from the Culebra block. Thus, the deposition of coarse fanglomerate in the Cuchara Formation is linked directly to exposure and erosion of the Culebra thrust block.

As mentioned previously, the conglomerate of Cordova Pass is a tongue within the Eocene Cuchara Formation. A reconstruction of facies parallel to the present structural strike of the Cuchara suggests that the remaining exposures represent the northern part of an alluvial fan (Figure 7). Only the proximal parts of the fan are represented by the conglomerate, which intertongues with sandstone and mudstone of the adjacent sandstone member of the Cuchara Formation on the slopes of WSP. This zone of intertonguing is marked by shallow channels filled with conglomerate and coarse sandstone and by overbank deposits of dark-red mudstone. In the metamorphic aureole of the igneous plug on WSP, the interbedded sandstone and mudstone have been metamorphosed to quartzite and slate (Budding and Lawrence, 1983), and the formerly red mudstone has a fine-grained, black appearance.

On West Spanish Peak, the upper 3,800 ft of the Cuchara Formation consist almost entirely of redbeds (and, in the upper part, former redbeds that have been subjected to contact metamorphism). From bottom to top, the redbeds consist of about 800 ft of the sandstone member of the Cuchara Formation, about 2,000 ft of conglomerate of Cordova Pass (interbedded conglomerate, sandstone and mudstone), and as much as 1,000 ft of metamorphosed sandstone, siltstone, and mudstone, also assigned to the Cuchara Formation. These redbeds originally were assigned to the Eocene Huerfano Formation by Hills (1901) and Johnson and others (1958), both of whom regarded the Huerfano and Cuchara as distinct formations. No continuity of the redbeds on WSP with the type Huerfano of Huerfano Park has ever been demonstrated, however, and considering the current interpretation of the conglomerate of Cordova Pass as a locally derived deposit, probably no continuity ever existed.

Since the work of Johnson, biostratigraphic studies suggest that the type Huerfano and the type Cuchara are probably lateral facies equivalents (Robinson, 1966). Robinson (1966, p. 11) recommended abandoning the name "Cuchara" in favor of "Huerfano" because the name "Huerfano" has precedence (compare Hills, 1888, and Hills, 1891). However, the name "Cuchara" has been used on all maps of the Spanish Peaks region since Hills (1901), including the regional maps published by the U. S. Geological Survey (Johnson and others, 1958; Johnson, 1969), and a more recent detailed map of part of the type area north of La Veta (Vine, 1974). Because of its continued long use in the Spanish Peaks region, the name "Cuchara" was retained and redescribed to include all Eocene rocks above the Poison Canyon Formation on new geologic maps of the Cuchara and Cucharas Pass quadrangles (Lindsey, 1995b; 1996). The Eocene redbeds of the Spanish Peaks region are regarded as a facies of the Cuchara Formation, including but not limited to the conglomerate of Cordova Pass. The relationship of the Spanish Peaks redbeds to the type Huerfano remains unknown. If the redbeds are, like most other redbeds, of diagenetic origin, then they have only local stratigraphic significance because color boundaries of diagenetic redbeds tend to cut across bedding.

Return by foot trail from overlook, drive east from Cordova Pass.

(24.1 miles)--Road crosses radial dike of syenite porphyry; analysis (no. 86, Johnson, 1968) indicates a trachyte composition (Le Bas and others, 1992).
(24.6 miles)--Overlook of the Apishipa River valley and radial dikes on south slopes of Spanish Peaks. A detailed

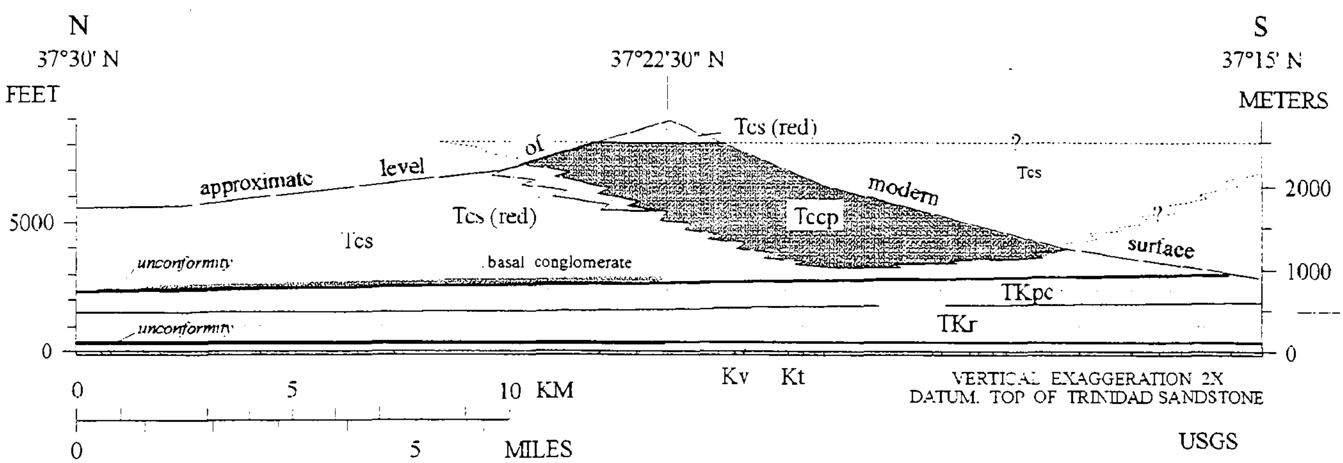

Figure 7.--Reconstruction of Laramide synorogenic formations along line of strike, northern to southern boundaries of figure 4. Symbols as follows: Tccp, Cuchara Formation, conglomerate of Cordova Pass; Tcs, Cuchara Formation, sandstone member; TKpc, Poison Canyon Formation; TKr, Raton Formation; Kv, Vermejo Formation; and Kt, Trinidad Sandstone.

study of these dikes by Smith (1978) concluded that they were intruded from a deep center immediately east of the summit of WSP. Representatives of the east-west dike system are also visible in the valley. The valley is underlain by Cuchara and Poison Canyon Formations.

(25.5 miles)--Hairpin curve to left.

(26.2 miles)--Road cuts on left are red sandstone and conglomerate of the conglomerate of Cordova Pass. Road crosses several radial dikes.

(26.4 miles)--Road turns sharply left (north).

(26.8 miles)--Road cuts reveal radial dikes intruding red sandstone and conglomerate of the conglomerate of Cordova Pass.

(27.1 miles)--Road turns sharply right (east) as it crosses Oliver Canyon. Refer to figures 1 and 2 for location and geologic features on remainder of trip.

(27.2 miles) STOP 13--Apishipa arch, constructed by the Civilian Conservation Corps; road passes through radial dike of porphyry. Red sandstone in road cut is in conglomerate of Cordova Pass. The slight west dip of bedding indicates the east limb of the La Veta syncline. The axial portion of the syncline is very broad, making the exact position of the axis difficult to locate.

(27.8 miles)--Road crosses the Apishipa River and turns sharply right (east).

(28.1 miles)--Road cut on left (north) in red sandstone and conglomerate, base of conglomerate of Cordova Pass. Conglomerate lens about 3 ft thick has boulders as much as 18 in. A radial dike about 4-5 ft thick cuts across conglomerate. Outcrops on the ridge above, accessible from the Apishipa trail (see below), consist of interbedded red sandstone and conglomerate of the transition zone between the conglomerate of Cordova Pass and the sandstone member of the Cuchara Formation. The transition zone here is comparable to that on the west slope of WSP; both represent the intertonguing of coarse proximal fan deposits with midfan alluvial deposits.

(28.3 miles)--Hairpin curve to right (south). Trailhead access north of road is to Apishipa trail, which connects northwestward to the West Spanish Peak trail and northeast to an abandoned section of the Wahatoya trail.

(28.4 miles)--Apishipa picnic area; road crosses Apishipa River and heads southeast, down Apishipa River valley.

(28.6 miles)--Road passes radial dike in cliffs of red conglomeratic sandstone, sandstone member of Cuchara Formation, right (south) side of road.

(28.8 miles)--Road passes radial dike in cliffs, right (south) side.

(30.2 miles)--Light-brown to cream-colored conglomeratic sandstone of Cuchara Formation in road cut, north side of road. The Cuchara here contains conglomerate-filled channels in sandstone. Bedding strikes S55°W, dips 6° northwest.

(30.6 miles)--Spanish Peaks Ranch; sign over road. Turn right (south) on Animas County road.

(31.4 miles)--Outcrops of conglomeratic sandstone, Cuchara Formation, east of road.

(31.7 miles)--Road passes between ranch buildings.

(32.5 miles)--Aspen Grove School. Cliffs on right (west) of light-brown conglomeratic sandstone are in the lowermost Cuchara Formation.

(32.8 miles)--Road crosses east-west mafic dike, turns left (east), and runs parallel to dike. Location of dike marked by wall of indurated sandstone north of road; dike intrudes Poison Canyon Formation.

(33.1 miles)--Road turns right (south) and passes outcrops of yellowish-brown sandstone of Poison Canyon Formation. Bold outcrops and yellowish-brown color are typical of the Poison Canyon.

(33.7 miles)--Junction with Jarosa Canyon road; bear left (southeast).

(33.8 miles) STOP 14--Road cut in east-west mafic dike at bend in road. Road turns east. This is an early subparallel dike which is discontinuously exposed for almost 20 miles. The subparallel dikes south of the Spanish Peaks are interpreted as older than the radial dike system (Smith, 1978); this relation is opposite that of the subparallel and radial dikes northeast of Spanish Peaks (Penn, 1994). The dike wallrock of conglomeratic sandstone is Poison Canyon Formation. The dark lenses in the Poison Canyon Formation are probably overbank deposits of siltstone; their dark color is attributed to metamorphism by heat from the dike.

North of the Spanish Peaks, two criteria have been used to distinguish the Cuchara Formation from the underlying Poison Canyon Formation: 1) the widespread presence of pebble and cobble conglomerate in the Cuchara

(Lindsey, 1995b), and 2) the reddish-brown color of mudstone in the Cuchara, in contrast to brown mudstones of the Poison Canyon Formation (Vine, 1974). The presence of abundant pebbles and cobbles in beds believed to be Poison Canyon Formation south of the Spanish Peaks makes use of the conglomerate criterion unreliable. Two miles west of stop 14, where the road enters Wet Canyon, a prominent interval of reddish-brown mudstone is interpreted to represent the lowermost part of the Cuchara Formation. Reddish-brown mudstone is also exposed in the banks of the Apishipa River about one mile east of the Spanish Peaks Ranch (mile 30.6). Conglomeratic sandstone ledges above the reddish-brown intervals at both localities can be projected approximately back to the level of the cliffs of conglomeratic sandstone at the Aspen Grove School (mile 32.5). These ledges and the underlying interval of reddish-brown mudstone are therefore interpreted to mark the lowermost part of the Cuchara Formation south of the Spanish Peaks.

(36.6 miles)--Road junction; main road turns right. Ledges of crossbedded yellowish-brown sandstone of Poison Canyon Formation in hills north of road.

(39.8 miles)--Road junction; bear left.

(42.9 miles)--Road junction at Apishipa River valley; rejoin county road from Spanish Peaks Ranch and proceed northeast toward Gulnare.

(44.7 miles)--Village of Gulnare.

(45.7 miles)--Contact of Poison Canyon with underlying Raton Formation. The Raton Formation is coal-bearing; the Poison Canyon is not.

(51.8 miles)--Trinidad Sandstone in road cuts; forms prominent cliffs nearby. The coal-bearing Vermejo and Raton Formations crop out on slopes above cliffs of Trinidad Sandstone. These formations are visible west of I-25 between Aguilar and Walsenburg.

(52.7 miles)--Town of Aguilar; route turns right.

(53.2 miles)--Junction; turn left (north); road divides immediately north of junction; take right fork and follow to I-25 north. Some 5 miles east of Aguilar a large hogback, held up by a dike, is visible. This is dike is called Apishapa Crag and is another porphyritic subparallel dike, although not a lamprophyre. Technically, by IUGS convention, it is a basalt, but a better name would be pyroxenite. This rock has coarse-grained zoned phenocrysts of orthopyroxene with fine- to medium-grained inclusions of olivine. Many of the pyroxene phenocrysts are partially resorbed.

(55.1 miles)--Road junction with I-25; turn north for return to Denver. End of log.

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