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Depositional Environments of Codell–Juana Lopez Sandstones and Regional Structure and Stratigraphy of Canon City and Huerfano Areas and Northern Raton Basin, South–Central Colorado

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DEPOSITIONAL ENVIRONMENTS AND HYDROCARBON POTENTIAL OF CODELL-JUANA LOPEZ SANDSTONES (UPPER CRETACEOUS), CAÑON CITY, HUERFANO, AND NORTHERN RATON BASINS, SOUTH-CENTRAL COLORADO, U.S.A.

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ABSTRACT

The Codell and Juana Lopez Members of the Carlile Shale (Upper Cretaceous - Middle to Late Turonian) occur at the surface and in the subsurface of the Denver, Cañon City, and northern Raton Basins, Colorado. Comprising a widespread inner neritic to supratidal marine sequence, these strata represent the waning regressive phase of the Greenhorn Regressive Hemicyclothem, which furnishes a model for eustatically generated cyclic sedimentation in Cretaceous epicontinental seas.

Outcrop and core studies indicate the thicker, underlying Codell Member consists mainly of fine-grained sandstones and silty shales; whereas, the thinner, overlying Juana Lopez Member contains phosphoritic calcarenites with abundant vertebrate fragments, as well as lenticular biosparites.

Subsurface Codell sandstones in the Denver Basin are well developed in the southern part of the Basin; are missing in a broad northeast-trending zone in the medial portion of the Basin; thicken northeastward, but eventually pinch out against the southeast flank of the Hartville Uplift in Wyoming.

Codell deposits in the Denver Basin represent three lithofacies/paleoenvironments: 1) sheetlike, marine (shoreline) bars or shelf sandstones, 2) bioturbated, reworked shelf sandstones which often occur together with thin, irregular, coarse-grained, conglomeratic shelf sandstones, and 3) marine (?) sandstones occupying large scour depressions (valleys?) eroded into underlying Fairport or Greenhorn strata.

Type one (nomenclature of Weimer and Sonnenberg,1983b) Codell rocks display well-preserved porosity and permeability, but have not yet proven productive of hydrocarbons. This facies occurs only in the southern portion of the Basin, and was deposited on a marine shelf or as offshore bars. The Codell may reach thicknesses in excess of 40 ft (12.19 m) in this area. This Guidebook will address the southern extension of this facies onto the Apishapa Uplift in Pueblo and Huerfano Counties, Colorado.

Type two Codell materials comprise the 1983 major oil and gas play in Colorado and occur in a broad NE-SW trending swath that extends from southwestern Nebraska to as far south as Douglas County, Colorado. Codell core porosities and permeabilities are low (less than 12% and 1.0 md), apparently because of bioturbation and growth of authigenic clay minerals (smectite, illite and chlorite). This facies of the Codell usually averages 10 ft (3 m) or less in thickness.

Type three Codell is concentrated along the southeast flank of the Hartville Uplift in southeastern Wyoming (Kennedy, 1983, Fig. 12, p. 21) and may exceed 100 ft (30.5 m) in thickness. These brackish-water, intertidal sandstones were apparently deposited as fill in local valleys eroded into the Fairport Shale. Most of the sandstones are fine-grained, parallel to ripple-laminated, and very rarely burrowed. Type one Codell exists locally in this area, and might provide superior, if limited, reservoirs. Codell thicknesses maximize here, reaching 100 ft (30.5 m) just south of the Hartville Uplift; however, despite widespread oil shows, actual production has been minimal. Post-depositional authigenic clay minerals have drastically reduced porosity in this facies.

Subsurface Codell sandstones average 15-20 ft (4.5-6.1 m) in thickness, and produce oil and gas from the bioturbated relict shelf sandstones in the west-central portion of the Basin. Drilling depths in the Basin range from 4003-8002 ft (1220-2439 m). Net pays range from 3-25 ft (0.9-7.6 m). Porosities range from 8-24% with permeabilities usually less than 0.5 md. Wells may initially produce from 64-262 BOPD; initial gas flows range from 270-750 MCFD. Codell oil is yellowish and has generally high (48°-54°) API gravities.

Juana Lopez rocks in the subsurface of the Denver Basin are generally too thin (less than 10ft/3m/) to resolve on standard scale electric logs (1"=100'). As far as known, no commercial hydrocarbons have yet been produced from this interval, although where fracture production occurs at the top of the Codell, the Juana Lopez and the overlying Fort Hays Limestone form a commingled reservoir that produces dark green 38°-40° API gravity oil. Surface Codell and Juana Lopez strata (R6 - Late Middle Turonian/87.75 mybp/) in the Cañon City-Raton-Huerfano Basins make up a nearshore marine system which was deposited in a series of barrier islands, lagoon fills, tidal deltas, and offshore bars. Codell thicknesses are variable, but average 20 ft (6 m). Drilling depths in this area are significantly more shallow, probably less than 4000 ft (1219 m). Three areally significant Codell paleoenvironments occur: 1) barrier island, 2) lagoonal, and 3) offshore bar. Fort Hays limestones, which overlie Codell-Juana Lopez rocks, represent maximum marine transgression and eustatic sea level rise. These rocks belong to the Niobrara Transgressive Hemicyclothem (Fisher *et al.*, 1985).

Codell production began in 1955 when the Soda Lake field was discovered just southeast of Morrison, Colorado. Initial wells exceeded 100 BOPD, but the field was abandoned after producing only 15,275 BO (Kennedy, 1983). During the 1960s and early 1970s, the Codell was occasionally tested and perforated in conjunction with Niobrara, Sussex, and Shannon completions; however, it was only tested if other primary targets were non-economic.

Five distinctive lithofacies/paleoenvironments occur in the Juana Lopez: 1) a calcarenite or limey sandstone (tidal flat), 2) a sandstone with limonitized borings (offshore bar complex), 3) a shaley to massive sandstone sequence (subaerial beach/dune?), 4) a sandy limestone or biosparite (lagoonal/bay molluscan biostromes), and 5) a sandy shale (offshore bar sequence). These deposits accumulated along a northeastward trending coast which prograded south-eastward in response to a gradual sea level drop. Oil production from Juana Lopez rocks is so far limited. The few wells that do produce make ~12 BOPD initially. Gas production has been confined to carbon dioxide flows of 50 MCFD.

Petrographic and scanning electron microscopy study reveals the following diagenetic sequence in the Codell Sandstone: 1) modification by authigenic, syntaxial quartz overgrowths, 2) chert cementation, 3) dissolution episodes causing corrosion of quartz, chert, and feldspar, 4) porosity development, 5) calcite cementation, 6) late stage limonitization, 7) dehydration of limonite to hematite, and 8) oil and/or gas generation, migration, and emplacement.

Diagenetic changes in the Juana Lopez Member involve: 1) minor dolomitization, 2) precipitation of calcite rim cement, 3) limonitization, 4) fracturing and microporosity development and 5) oil and/or gas generation, migration, and emplacement.

INTRODUCTION

The Codell and Juana Lopez Members of the Carlile Shale (Upper Cretaceous) crop out on the flanks and occur also in the subsurface of the Denver, Cañon City, Huerfano, and northern Raton Basins, Colorado (Fig. 1). These rocks make up a widespread nearshore to supratidal marine sequence and represent the last phase of the Greenhorn Regressive Hemicyclothem (Glenister and Kauffman, 1985).

The Greenhorn Cyclothem furnishes a model for eustatically-generated, cyclic sedimentation in Cretaceous epicontinental settings. The upper portion of this cycle, the Greenhorn Regressive Hemicyclothem includes (in ascending order): the upper Bridge Creek Limestone Member, Greenhorn Formation, the Fairport Shale, Blue Hill Shale, and the Codell Sandstone Member of the Carlile Shale. The Codell, and the thin overlying Juana Lopez (Fig. 2), record final shoaling of the Greenhorn Regressive Hemicyclothem prior to eustatic rise, transgression, and burial by pelagic carbonates of the Fort Hays Limestone Member of the Niobrara Formation.

In 1980, as the price of hydrocarbons escalated, renewed interest in old Codell production occurred, and the Codell became a new exploration target for hydrocarbons in the northern Denver Basin (Carraway, 1990).

Carraway (1990) pointed out that the Martin Exploration Management Corporation #1 Ertl (Sec 17, T1N, R69W, Boulder County), drilled in 1979, provided the impetus for the Codell play in the Denver Basin. Codell and 'J' sandstones were commingled with initial production of 1.6 MMCFGPD, 250 B of condensate/day, and 47 BWPD. A little more than a year later, Toltek Drilling and Centennial Petroleum drilled a joint venture, the #1 Futhey (Sec 26, T1N, R69W, Boulder County). Initial Codell production, following acidization and fracture treatment, was 262 B of 52 gravity condensate/day and 1.3 MMCFGPD. At this time, the Codell play was limited to the faulted western flank of the Denver Basin. Energy Minerals Corporation and Energy Oil drilled and completed Codell wells in or near the Wattenberg Field area in 1981. This extended the Codell play eastward towards the axis of the Basin.

These wells indicated that Codell hydrocarbon reserves existed in a large area of the Basin in northeastern Colorado. Concomitantly, the diminution of new exploration targets in the Basin, along with the Natural Gas Policy Act of 1978, and the subsequent de-control of oil in 1981, escalated prices to the extent that the Codell became an economic target (Kennedy, 1983).

Despite falling oil/condensate prices and shrinking markets for Codell gas, exploration proceeded into 1983

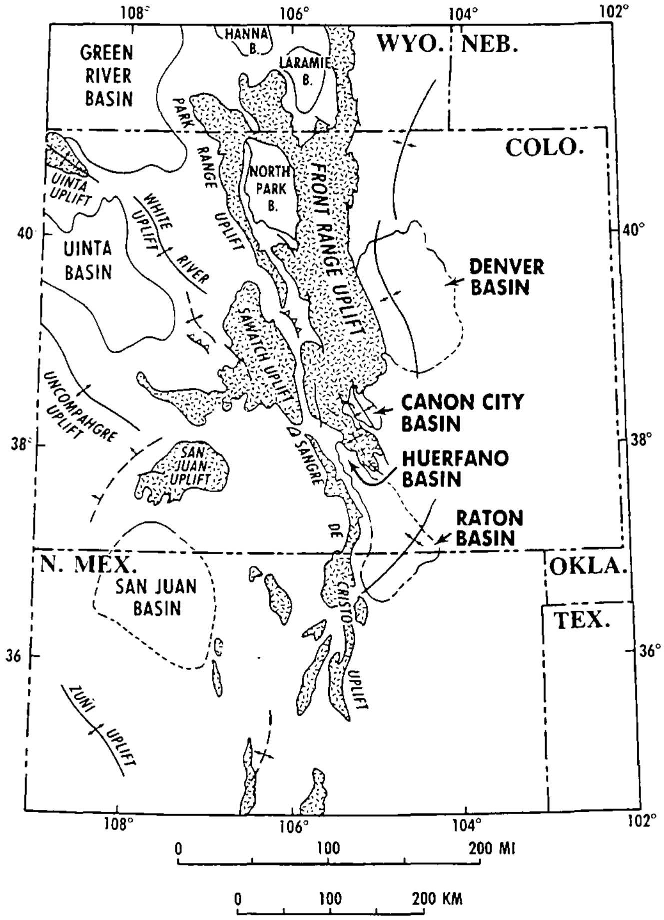


Fig. 1. Location map, Denver (D-J/Denver-Julesburg/), Cañon City, Huerfano and Raton Basins, Colorado and New Mexico, U.S.A. Modified from King (1959).

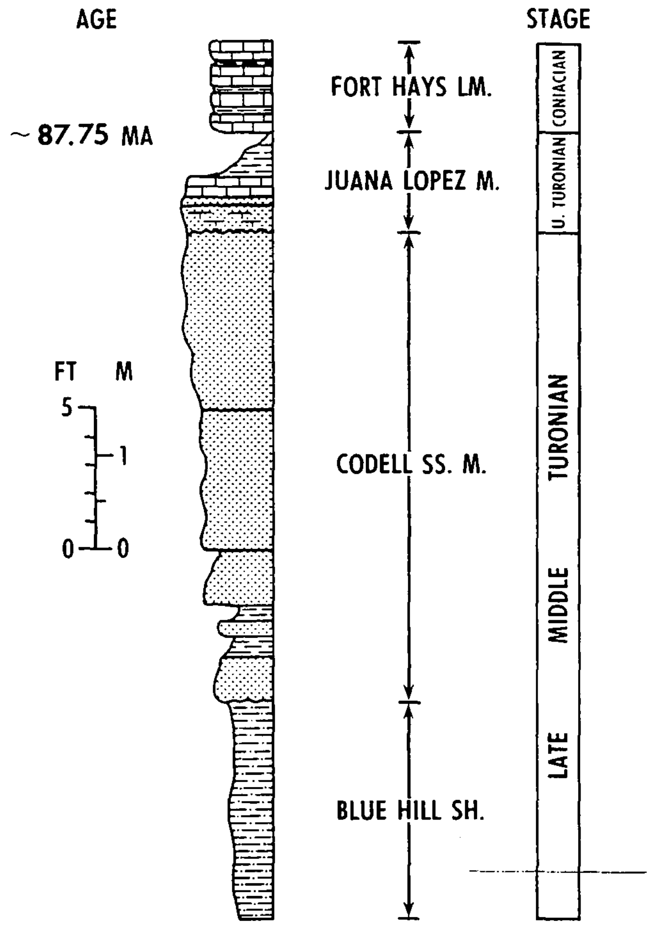


Fig. 2. Generalized lithostratigraphy and ages of Codell Sandstone and Juana Lopez Members of the Carlile Shale (Upper Cretaceous), south-central Colorado, U.S.A. From Krutak (1991).

and 1984. For example, Weimer and Sonnenberg (1983a,b) demonstrated that Codell sandstones in the Energy Oil #1 Grant Arens (Sec. 22, T4N, R65W) flowed 750 MCFD and 80 BOPD from perforations at 7094-7108 ft (2163-2167 m). Another well, the Machii-Ross #1 Barclay Crisman (Sec. 20, T3N, R66W) flowed 270 MCFD and 64 BOPD from perforations at 7390-7404 ft (2253-2257 m). Annual decline curves for these wells indicated rapid depletion - as much as 80% for oil and 68% for gas in the #1 Grant Arens. Whether or not such declines will prove basinwide, or extend southward into the Cañon City, Huerfano, or Raton Basins, remains to be seen. In 1984 and 1985 operators became more cautious when pipeline companies began to deny hook-ups for new Codell gas. When oil prices crashed in 1985 and early 1986 to $10-$12/BO (Goddard and Bourgeois, 1994), Codell exploration ceased. During 1986 and 1987, drilling was restricted to in-field development. Wright and Fields (1988) showed that Codell exploration and production would be marginally economic when prices increase and stabilize around $20-$24/BO.

Nonetheless, the Codell remains an excellent example of a secondary or tertiary target objective. The Cretaceous section in the Rocky Mountain region is well known for its thin, relatively "tight" sandstones (e.g. 'D', 'J', and Hygiene units). Commingled production from the Codell and either of these units, or later up-hole completions, may increase the return on investments and provide additional oil and gas reserves to the state of Colorado.

Codell sandstones are very well exposed in outcrop, and provide an ideal field laboratory for observation and study of a sequence of shallow marine siliciclastics and carbonates that have significant economic potential.

This Guidebook describes the inferred depositional environments, hydrocarbon potential, and diagenetic history (through petrographic analysis) of the Codell-Juana Lopez sequence - a sequence that provides a model coarsening-upward facies succession that reflects the final phases of basin filling and epeiric regression during eustatic sea level fall. It analyzes the distribution and facies of the Codell-Juana Lopez in the under-explored Cañon City, eastern Huerfano, and northern Raton Basins and compares these rocks with their hydrocarbon-bearing equivalents in the Denver Basin to the north.

REGIONAL STRATIGRAPHY

Codell Sandstone Member

Bass (1926, p.28) named the Codell Sandstone Member for exposures in the Saline Valley about 5 mi (8 km) southwest of Codell, Ellis County, Kansas. At the type locality it consists of about 20 ft (6 m) of very fine-grained sandstone overlying the Blue Hill Shale Member of the Carlile Shale. Dane *et al.* (1936) traced the Codell westward to the region of the type Carlile near Pueblo, Colorado. Dane *et al.* (1936, p. 217) stated the Codell contained an intermittent "hard grey to brown, rusty, brown-weathering, bituminous limestone" at the top of the Carlile. Kauffman and Pope (1961) dated the Codell as Late Middle Turonian and assigned an Upper Turonian age to the thin brown limestone and shale (now known as the Juana Lopez) which lies disconformably above the Codell and below the limestones of the Fort Hays Member of the basal Niobrara Formation. Kauffman *et al*, (1977, p. 133) placed the Codell in the upper part of the *Prionocyclus hyatti* (Stanton) - *Inoceramus costellatus* (Woods) - *I. howelli* (White) assemblage zone. Kauffman and Pope recognized that the faunal break between the sandstone and the thin limestone indicates an hiatus of at least two faunal zones. This hiatus is even more conspicuous eastward where Hattin (1975) recorded up to five missing faunal zones between the Fort Hays and the top of the Carlile Shale in northeastern Nebraska.

Krutak (1970) made a detailed facies analysis of the Codell in southern Colorado. He divided the unit into a "basal sequence" of sandstones and shales and an "upper sequence" of calcarenites and biosparites rich in fossil material. The thin carbonate or calcarenitic "upper sequence" of Krutak is lithologically identical to and laterally equivalent to part of the Juana Lopez. Later, Krutak (1989, 1991) re-examined the Codell and its lithofacies.

Lowman (1977, Fig. 25) presented regional lithofacies patterns during *Prionocyclus hyatti* range zone time (= Codell Sandstone deposition). Her paleocurrent work indicated SSE directed currents during this time span. She also demonstrated lithofacies patterns during *P. wyomingensis* range zone time (= Juana Lopez deposition - Lowman, *op. cit.*, Fig. 26). Offshore current directions similar to those of the Codell prevailed during Juana Lopez time.

Merewether *et al.* (*in* Pinel, 1983a, Figs. 1 and 2) documented the general map distribution and lithofacies of Turonian units laterally equivalent to the Codell Sandstone Member of the Carlile Shale in the Middle Rocky Mountains.

Glenister and Kauffman (1985) measured a "high resolution" stratigraphic section of the Codell Sandstone Member and the Juana Lopez at Liberty Point, Rock Canyon Anticline, immediately west of Pueblo, Colorado. Their section, which serves as a "type" for the Western Interior Basin, defines lithostratigraphic units down to a few millimeters and includes geochemical analyses (organic carbon and carbonate carbon percentages) as well as biostratigraphic details.

Juana Lopez Member

Rankin (1944) introduced the Juana Lopez for an exposure northwest of Cerrillos, Santa Fe County, New

Mexico. Dane *et al.* (1966) found in it or just above it, a previously unrecognized monzonite sill. They established a new reference section about 50 mi (80 km) northwest of the type section near La Ventana, Sandoval County, New Mexico. Here, the Juana Lopez is 107 ft (32.6 m) thick and is mostly black shale with a few thin beds of fine-grained calcarenite. Rankin called the unit a "sandstone" rather than a calcarenite sequence interbedded with biosparite, but noted that the unit was widespread throughout the San Juan Basin and extended into southwestern Colorado. Elsewhere in the San Juan Basin (Hook and Cobban, 1980), the member contains very thin to slabby-bedded, dense, hard, grayish to orange-brown calcarenites consisting almost entirely of prisms and shell fragments of *Inoceramus* (so-called "Inoceramite") with rarer fish bones, phosphate pellets and granules, and oyster shell debris. Calcarenites comprise ~ 5-10% of the member where fully developed; the remainder consists of thinly laminated calcareous to ripple-laminated calcarenite lenses. In thick sections on the flanks of the San Juan Basin, Dane *et al.* (1966) collected *Prionocyclus macomberi* Meek, *P. wyomingensis wyomingensis* Meek, *P. wyomingensis elegans* Haas, *Inoceramus dimidius* White, *Lopha lugubris* (Conrad), *Scaphites warreni* Meek and Hayden, *S. ferronensis* Cobban, and *S. whitfieldensis* Cobban. The assemblage indicates an early Late Turonian age.

CODELL-JUANA LOPEZ DATA BASE

Lithofacies analysis and paleoenvironmental interpretations that follow are based on 96 complete measured surface sections, including the 39 of Krutak (1970) as well as selected key sections of the 57 described by McLane (1982, 1983). Figures 3 and 4 illustrate the locations of these sections. Exact locations of Krutak's sections are in Appendix I. See Mclane (1982) for specific locations of his 57 measured sections.

Petrographic conclusions and diagenetic histories are derived from modal analyses of 84 thin sections (300 grain counts) made by Reisser (1976) - 43 from the Codell Sandstone, 41 from the Juana Lopez. Photomicrographs of thin sections that are not illustrated in this Guidebook are available in Reisser (1976).

LOGISTICAL OVERVIEW

This field seminar is an overview of the Codell and Juana Lopez depositional systems. It encompasses an area of extensive surface outcrop in southern Colorado east of the Front Ranges in El Paso, Teller, Fremont, Pueblo, Custer, and Huerfano Counties (Fig. 3).

On the field excursion, we will study and sample a few of the 39 complete stratigraphic sections measured by Krutak (1970) as well as selected key sections of the 57 described by Mclane (1982, 1983).

If desired, you may purchase a duplicate set of 35 mm slides illustrating the petrographic details of these potential reservoir rocks. A set of field photographs, including aerials, will also be available for your perusal and/or purchase.

Finally, we will examine the structure and tectonics of the two important Basins containing these rocks. These Basins - the Cañon City/Raton - were affected by severe Laramide folding and faulting, and also display spectacular Cenozoic intrusions (Fig. 5). They also contain large reserves of coal concentrated in the Vermejo Formation (Figs. 6-9).

We will begin this field seminar in the Colorado Springs area on the north, proceed southwestward into the Cañon City Basin and Florence area, and work our way westward up the Arkansas River. Returning to Florence, we will move southward towards Beulah, Colorado City, and Rye and thence south and west towards Gardner. The field conference will terminate at Badito, near Farisita, Colorado. Appendix I gives the detailed location of the 39 sections measured by Krutak (1970). Appendix II is a detailed, day-by-day roadlog and guide to the geology of the area we will traverse.

COLORADO SPRINGS AREA

Krutak (1970) measured thin (6.0-14.5 ft/1.8-4.4 m/), very pale orange, fine-grained to medium-grained, calcareous sandstones in the Codell of the Colorado Springs area (sections 25-27, Fig. 10). McLane (1982, sections 1-4) described these sandstones as laminated, burrowed, and rippled. He interpreted them as tidal deposits which accumulated near the western edge of the Codell coastal complex. McLane (1983) also measured a thin Codell section at Glen Eyrie (SE, NE, NW, Sec 27, T13S, R67W). This section is near the northern extent of the Codell, since Codell rocks disappear a few miles north of this outcrop, apparently as a result of pre-Juana Lopez erosion (see McLane, 1983, Fig. 4.). Sand-shale ratios of this interval (Fig. 11) indicate this region is sand-rich. Reisser (1976, Appendix II, p.84) showed the bulk of Codell rocks here are quartz arenites cemented by a combination of quartz, chert, calcite, and in one rare instance (Krutak's sample 26.1), hematite.

Krutak (1970, Fig. 9, p. 196, sections 25-27) measured less than 1 ft (0.3 m) of podded, phosphoritic Juana Lopez calcarenites and biosparites overlying the Codell in the Colorado Springs area. He interpreted these as localized coquinoid thanatocoenoses of molluscan fragments entombed in intertidal flats that were alternately exposed and inundated by tidal fluctuations during late Carlile time. McLane (1983, Fig. 6) indicated the Juana Lopez at Glen

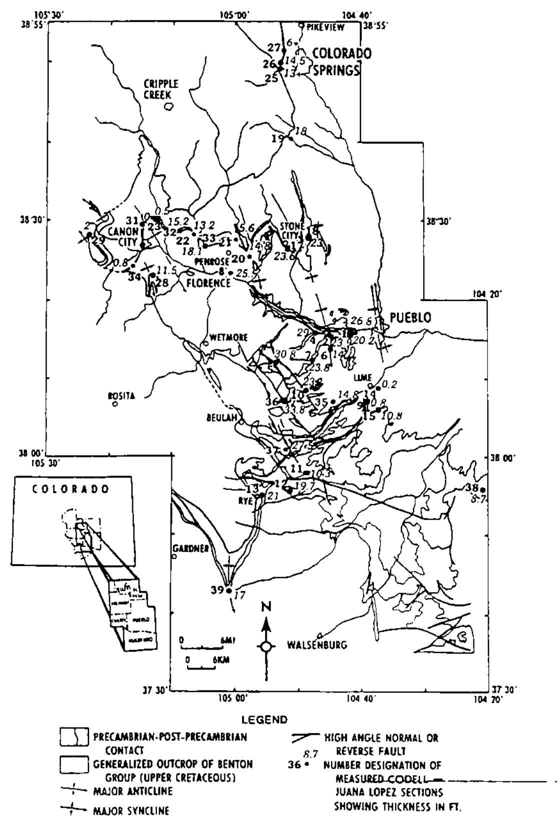


Fig. 3. Location map of Codell-Juana Lopez measured surface sections in south-central Colorado, U.S.A. From Krutak (1991).

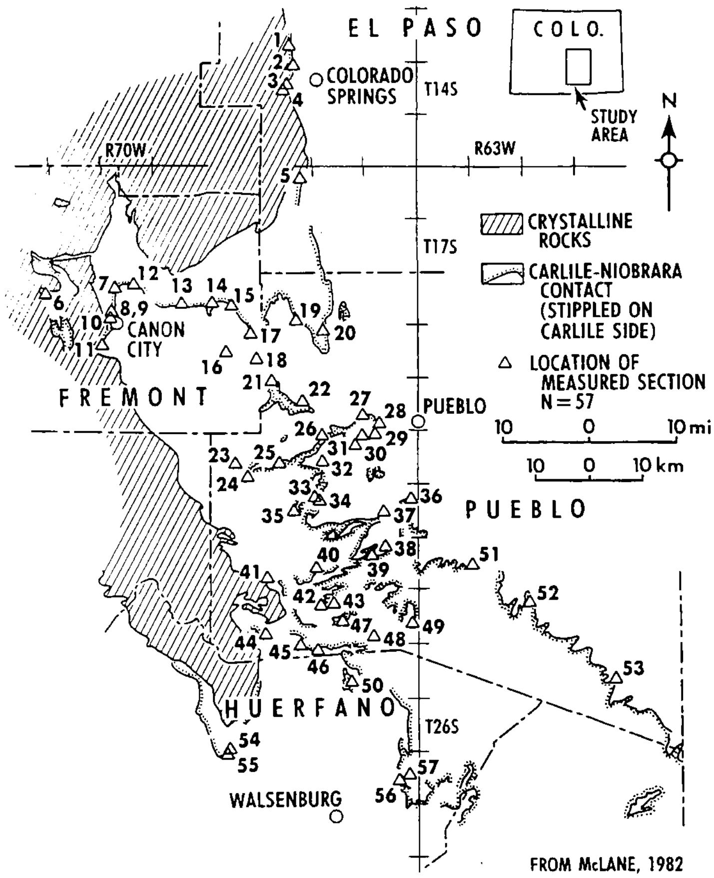


Fig. 4. Location map of Codell-Juana Lopez surface sections measured by McLane (1982) in south-central Colorado, U.S.A. From Krutak (1991).

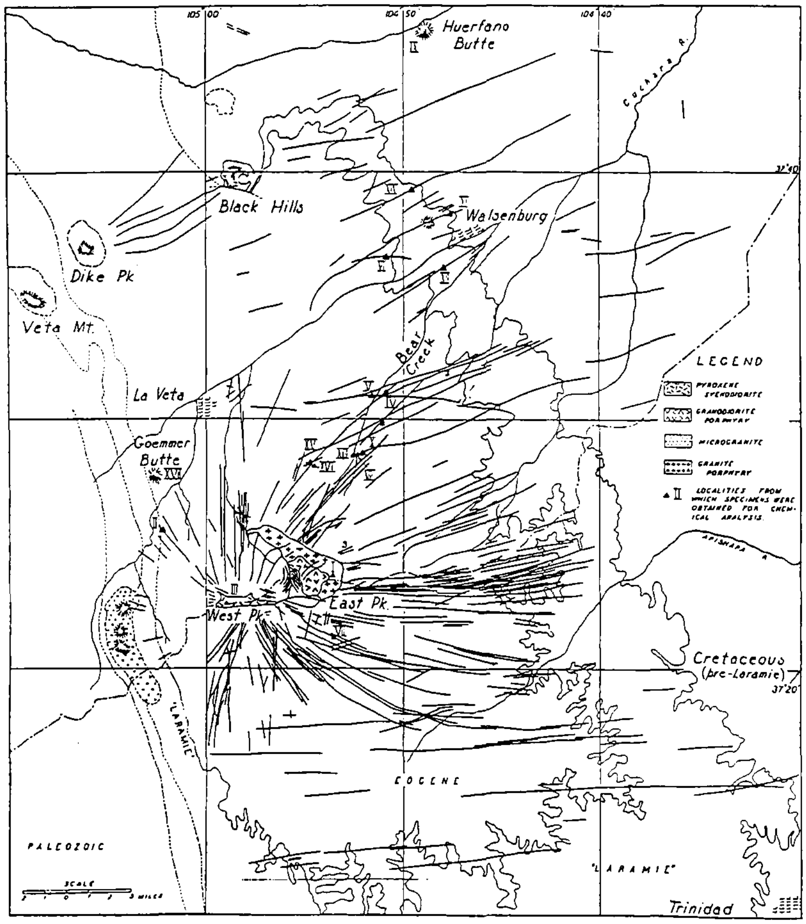


Fig. 5. Spanish Peaks stocks and associated dike swarms, southern Colorado. From Knopf (1936). With permission of New Mexico Bureau of Mines and Technology.

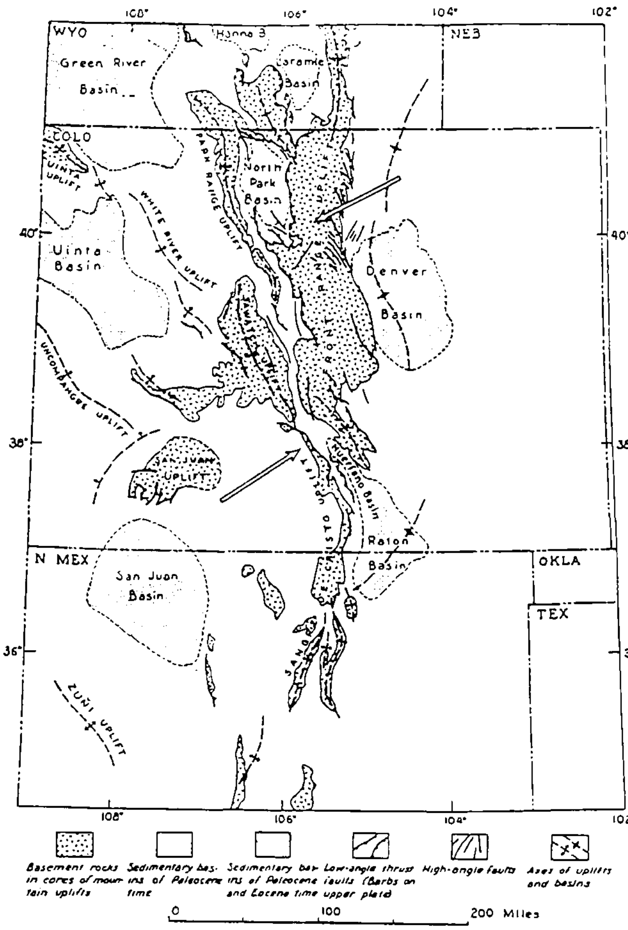


Fig. 6. Tectonic features of Southern Rocky Mountains. Structures are of Laramide age (see Couples, G.D. and Lageson, D.R., 1985 for a review of Laramide tectonics). Large arrows indicate directions of major thrusting. From King (1959, Fig. 69, p. 119). Reprinted by permission of Princeton University Press.

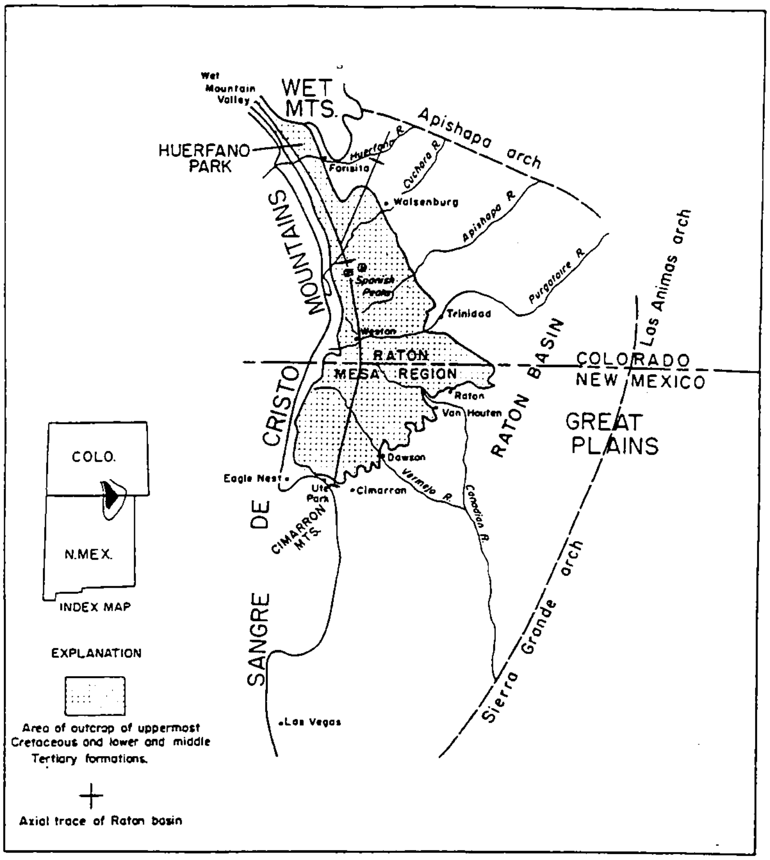


Fig. 7. Tectonic map of the Raton Basin, New Mexico and Colorado. From Johnson, R.B. *et al.* (1966, Fig. 1, p. 89). With permission of New Mexico Bureau of Mines and Technology.

AGE		FORMATION	THICKNESS
QUATERNARY		Alluvium	0 - 30
			Unconformity
TERTIARY	Miocene (?)	Devil's Hole formation	25' - 1,300'
			Unconformity
TERTIARY	Oligocene (?)	Farasita conglomerate	0'-1,200'
			Unconformity
TERTIARY	Eocene	Huerfano formation	0'-2,000'
			Unconformity
TERTIARY	Eocene	Cuchara formation	0'- 5,000'
			Unconformity
TERTIARY	Paleocene	Poison Canyon formation	0'- 2,500'
			Local unconformity
TERTIARY	Paleocene	Raton formation	0'-1,700'
CRETACEOUS	Upper Cretaceous	Vermejo formation	0'- 500'
CRETACEOUS	Upper Cretaceous	Trinidad sandstone	0'- 240'
CRETACEOUS	Upper Cretaceous	Pierre shale	1,600' - 2,300'

Fig. 8. Upper Cretaceous and Tertiary sedimentary rocks of the Raton Basin and Huerfano Park, Colorado and New Mexico. From Johnson, R.B. *et al.*, (1966, Fig. 2, p. 90). With permission of New Mexico Bureau of Mines and Technology.

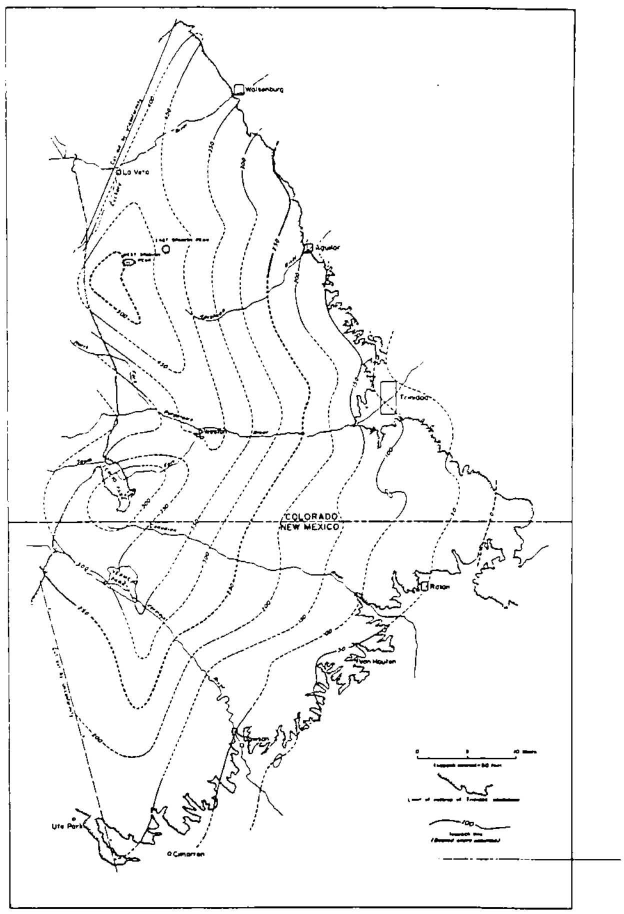


Fig. 9. Isopach map of the Vermejo Formation, Raton Mesa region, Colorado and New Mexico. From Johnson, R.B. *et al.* (1966, Fig. 5., p. 93). With permission of New Mexico Bureau of Mines and Technology.

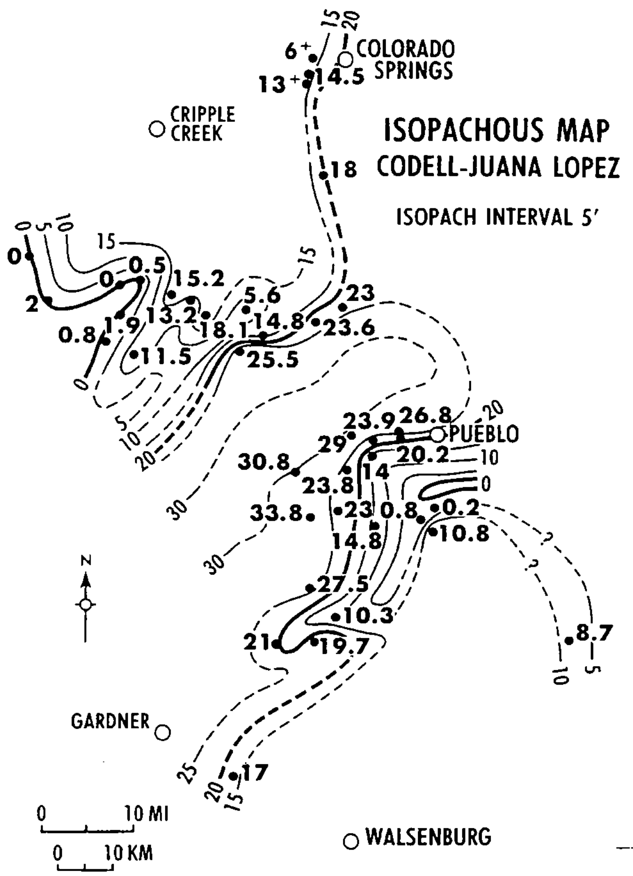


Fig. 10. Isopach map of Codell-Juana Lopez sequence, south-central Colorado, U.S.A. See Fig. 3 for numbers of individual measured sections and Fig. 11 for sand-shale ratio map. From Krutak (1991).

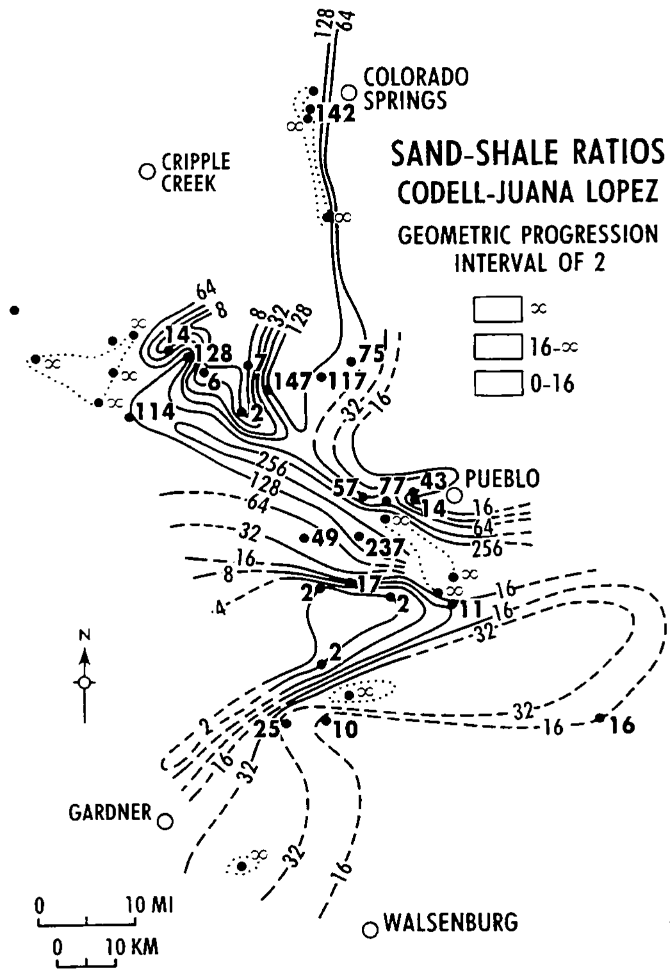


Fig. 11. Sand-shale ratio map of Codell-Juana Lopez sequence, south-central Colorado, U.S.A. See Figure 3 for numbers of individual measured sections and Fig. 10 for isopach map. From Krutak (1991).

Eyrie may thicken to as much as 6.5 ft (1.95 m), apparently the depocenter at this time. However, southeastward from Colorado Springs, the Juana Lopez thins markedly, and west of Pueblo, is only 0.5 ft (0.15 m) thick. Reisser (1976, Appendix II, p. 87) point-counted the Juana Lopez at Krutak's section 27. He found (*sic*) 43% monocrystalline quartz, 2% chert, 4% potash feldspar, 13% shell fragments, and 39% *Inoceramus* prisms.

CAÑON CITY AREA

Western Sections

Several sections in this area (Krutak, 1970, sections 24, 29, 30, 31, and 34) define, locally, a northwestern edge of Codell deposition. These include the Guffey Exit (30) and Parkdale Siding (29) sections as well as those at Wolf Park (34), Skyline Drive (24), and Benchmark 5732 (31). The isopach map (Fig. 10) indicates pronounced thinning in this area; sand-shale ratios are very high (Fig. 11), with a preponderance of sand.

No Codell exists at either Guffey Exit or Parkdale Siding (Webster Park Syncline area). Here, Juana Lopez calcarenites and biosparites directly overlie olive-gray, sandy or silty shale of the Blue Hill Member of the Carlile Shale. About 3.3-13 ft (1-4 m) of sandy shales overlie the Juana Lopez in these sections, and are surmounted by the micrites of the Fort Hays. Together, these sections define the feather-edge of Codell rocks. Similar lithologies and stratigraphic relationships occur at Wolf Park, Skyline Drive, and Benchmark 5732, although the shales underlying the Fort Hays are thinner.

Reisser (1976, Fig. 40, p. 45) showed the lower Juana Lopez at Skyline Drive (sample 24.2) consists largely of detrital quartz, aligned *Inoceramus* prisms and molluscan skeletal fragments. This section (24) probably represents a reworked offshore bar deposit (Fig. 12).

Eastern Sections

Those sections lying between Penrose, Colorado and Oil Creek (Fig. 3, sections 22, 23, 32, and 33) are quite different from the western sections of the Cañon City area. The Codell is well developed in these sections; whereas, the Juana Lopez is practically non-existent.

At Four Mile Creek (Fig. 3, section 23; see also Mclane's section 12), the lowest exposed sandstones are about 10 ft (3 m) thick. Krutak (1970) did not include these in the Codell, considering them as "strays" in the upper Blue Hill Shale. They are very pale orange, fine to medium-grained, and are riddled with *spreiten* burrows. Approximately 23 ft (7 m) of olive-gray, sandy shales overlie them. Mclane (Fig. 13) interpreted these sandstones and sandy shales as offshore bars.

Juana Lopez strata at Four Mile Creek (Krutak's sample 23.3) are quartzose, with *Inoceramus* prisms, but exhibit considerably more bone (fish) fragments than the Skyline Drive section (Reisser, 1976, Fig. 41, p. 45). These rocks probably represent the proximal edge of a subaerial beach? or a pond deposit localized in a swale behind a beach ridge (Fig. 12).

Three localities farther east (Krutak, 1970, sections 22, 32, and 33; Mclane, 1982, sections 13, 14, and 15) record an eastward or southeastward progradation of the shoreline. The Brush Hollow section (Krutak, 1970, section 33; Mclane, 1982, section 14) is a good example. At Brush Hollow, about 13 ft (4 m) of strongly bioturbated, yellowish-gray, calcareous sandstones interbedded with finely laminated, fine-grained sandstones overlie olive-gray Blue Hill shales. A 3.3 ft (1 m)-thick bed of grayish-orange, cross-bedded, bivalve-rich sandstone comprises the top of the Codell. This section, and Krutak's sections 22 and 32, appear to contain lower shoreface deposits overlain by foreshore sandstones. These deposits probably formed along the edge of a northeast-southwest trending barrier island complex (Fig. 13). The isopach map (Fig. 10) indicates these sections are relatively thin (10'-15'). Low sand-shale ratios (0-16 or 16-∞) predominate (Fig. 11).

Pinel (1983b, Fig. 4) mapped the Codell-Juana Lopez contact and constructed an isolith map of the upper ledge-forming Codell Sandstone at Brush Hollow and eastward towards Beaver Creek. In this region he demonstrated a widespread, irregular scour surface on the Codell with channels as much as 1.1 ft (35 cm) deep and 9.8 ft (3 m) wide, to broad areas as much as 1 ft (30 cm) deep and 50 ft (15 m) wide. He believed that this contact represents the top of a sequence of continentally derived marine siliciclastics (Codell) and the base of a sequence of intrabasinally derived carbonates (Juana Lopez). Pinel (1983, Fig. 5) also summarized 42 Codell sandstone and 22 Juana Lopez paleocurrent directions in this area. Based on tabular-planar cross-stratification measurements, the directions for both stratigraphic units are generally bimodal (NNW-SSE).

Lower Juana Lopez sandstones at Brush Hollow (section 33, sample 33.1) contain 51% monocrystalline quartz, 1% chert, 3% potash feldspar, 2% heavy minerals, 1% shell fragments, 42% *Inoceramus* prisms, and a trace of fragmental collophane (Reisser, 1976, Appendix II, p. 86). These rocks are interpreted as tidal flat materials (Fig. 12). A remnant of Juana Lopez rocks, preserved as irregular, lenticular pods of purplish biosparites, occurs in the upper portion of section 22. These coquinoid lenses may represent local molluscan biostromes (Fig. 12).

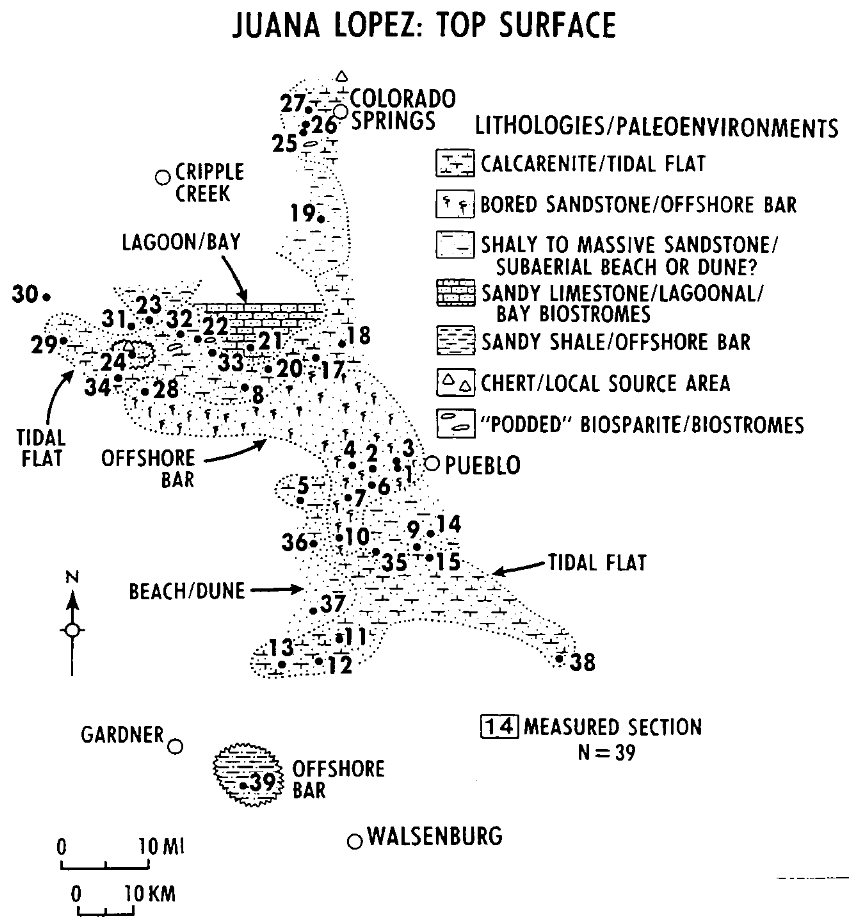


Fig. 12. Lithofacies/paleoenvironmental map of top surface, Juana Lopez Member of Carlile shale, south- central Colorado. U.S.A. Measured sections are numbered. Compare with Fig. 3. From Krutak (1991).

PUEBLO AREA

Western Sections

Several Codell sections between Beulah and Pueblo represent a series of lower shoreface to upper shoreface deposits intercalated with lagoonal materials. These are capped by a tidal deltaic-salt marsh? sequence.

Section 10 (Figs. 13, 14; Mclane's section 33) along Colorado State Road 7 is representative. Mclane gave a very detailed description of this section, and divided it into 5 lithologically distinct units (A-E). The Codell attains a thickness of about 23 ft (7 m) here, and is quite heterogeneous. Its sandstone-shale ratio is 17 (Fig. 11). The basal portion of the Codell (Zone B of Mclane) contains at least four types of sandstones and shales. These include hummocky cross-stratified, flat-laminated, bioturbated, and lenticular-bedded sandstone and shale units averaging 8-12 in (20-30 cm) thick. The upper portion of this section is strongly bioturbated. Here, Mclane (1983, p. 73) noted what he thought were 12-16 in (30-40 cm) long rill marks. He also found sets of intersecting ripples. This outcrop, and another along the same scarp to the south (Mclane's section 34, Fig. 13) are judged to represent a sequence of lower shoreface to middle shoreface-upper shoreface sandstones and shales capped by cross-bedded, ebb-tidal delta sandstones.

A thin (about 0.7 ft/0.2 m) bored biosparite represents a remnant of Juana Lopez at section 10. This lithic unit is thought to represent the remnant of an offshore bar.

Reisser (1976, Appendix II, p. 83, samples 10.1, 10.2, 10.3) showed that most of the Codell sandstones in section 10 contain more than 80% monocrystalline quartz, with chert, and potash feldspars comprising the bulk of the framework grains. Calcite replacement of quartz occurs in sample 10.2. Quartz overgrowths are present in sample 10.1.

Farther north, along the north side of Peck Creek (Krutak's section 4; Mclane's section 25) is a 30 ft (9 m)-thick Codell section which is almost completely bioturbated. Mclane divided this section into four intervals (F, G, H, and J), but did not mention its 3 in (8 cm)-thick cap of Juana Lopez biosparite. These bioturbated sediments were apparently deposited relatively slowly in a calm environment protected from wave action. This environment is also reflected in several other measured sections along the trend of Rock Creek Hill (Krutak's sections 2, 5, and 7) and may represent lagoonal materials which accumulated behind a postulated northeast-southwest trending barrier island.

In these sections, Reisser (1976, Appendix II, p. 83, samples 5.2, 5.3) found Codell mineralogies similar to those in section 10, although sample 5.2 contains 1% plagioclase feldspar and 2% heavy minerals.

The extremely thin overlying Juana Lopez at Mclane's section 25, perhaps included as Mclane's transgressive lag (Fig. 14), may represent the remains of an offshore bar sequence (Fig. 13).

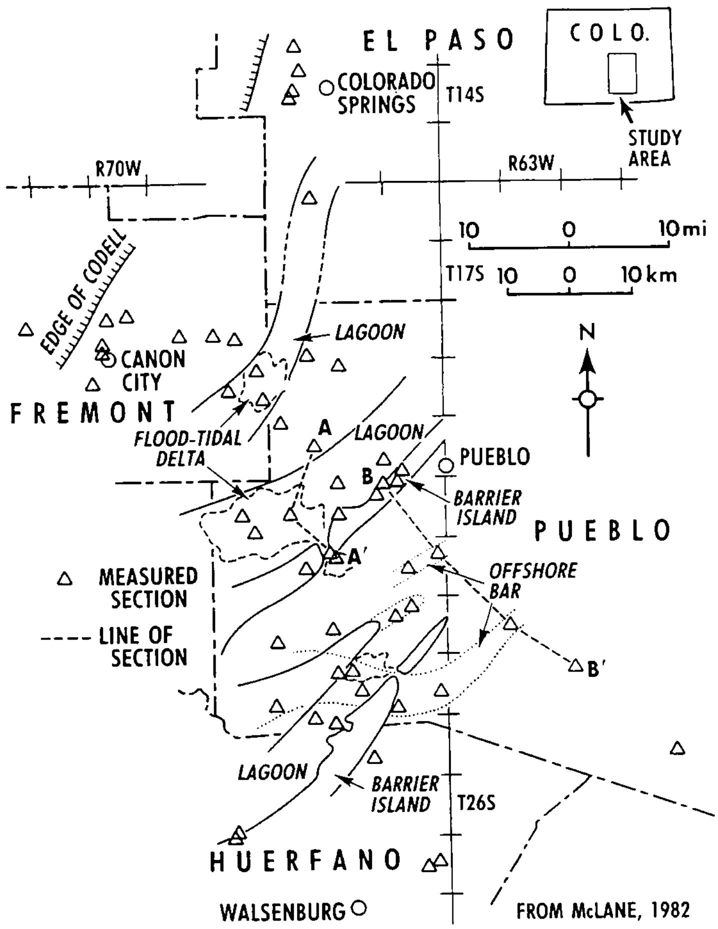
Other sections of the Juana Lopez just west of Pueblo (sections 1, 2, and 3 - Fig. 3) occur on the south and west flanks of the Rock Canyon Anticline, part of which is now submerged beneath the present-day Pueblo Reservoir. The Juana Lopez interval at Liberty Point and along the Arkansas River at other localities flanking the Rock Canyon Anticline (Glenister *et al.,* 1985) is represented by a disconformity-bounded zone of lenticular to ovate lenses of reworked "Inoceramite" cobbles. Locally, these lenses merge to form an irregular thin bed. Glenister *et al.* interpreted these materials as ravinement lag deposits left behind in depressions on the sea floor formed at fair-weather wave base.

Southeastern Sections

Codell outcrops occur at Lime, which is about 6 miles (10 km) south of Mclane's postulated barrier island trend. Krutak's section 14 (Mclane's section 36) indicates a paucity of sand (sandstone-shale ratio of 11 - Fig. 11). Instead, offshore muds and sands of the Blue Hill Member of the Carlile Shale accumulated here. Krutak indicated that only 0.3 ft (0.1 m) of Juana Lopez calcarenites and biosparites overlie Blue Hill shales at this locality. Codell sandstones are absent. Alternatively, Mclane thought the lower concretionary sandstones overlying dark shales at this locality represent Codell offshore bars (Fig. 15). Mclane did not recognize the thin remnant of Juana Lopez at these outcrops. These represent possible subaerial beach or dune? deposits (Fig. 12).

Another Codell section (15) occurs about 3.2 mi (5.2 km) southeast of Lime. Both the Juana Lopez and the Codell are well developed here. About 10 ft (3 m) of brown to tan, medium-gray sandstones filled with very abundant trace fossils overlie Blue Hill shales at this locality. The upper and lower portions of this sandstone are intercalated with very thin shale partings. About 2 ft (0.6 m) of Juana Lopez orange-brown calcarenites with limonitized borings and podded biosparites overlie the Codell. Sand-shale ratio is 11 (Fig. 11), reflecting the shale interbeds. The Codell sandstones at this outcrop are certainly stratigraphically higher than those at Lime, and as Mclane suggested, may represent a portion of a discrete offshore marine bar. The overlying Juana Lopez section probably represents tidal flat development (Fig. 12) as the shoreline retreated southeastward.

Reisser (1976, Appendix II, p. 84, sample 15.1) point-counted a sample from the Codell at section 15 about 3.6 ft (1.1 m) above the base of the unit. He found the framework



', B-B'. Modified

Fig. 13. Paleogeography of Codell Sandstone Member of Carlile shale (Upper Cretaceous), south-central Colorado, U.S.A. Lagoons on north were probably filled prior to development of southern barrier islands and lagoons. See Fig. 4 for numbers of measured sections and Figs. 14 and 15 for stratigraphic cross sections along A-A from Mclane (1982).

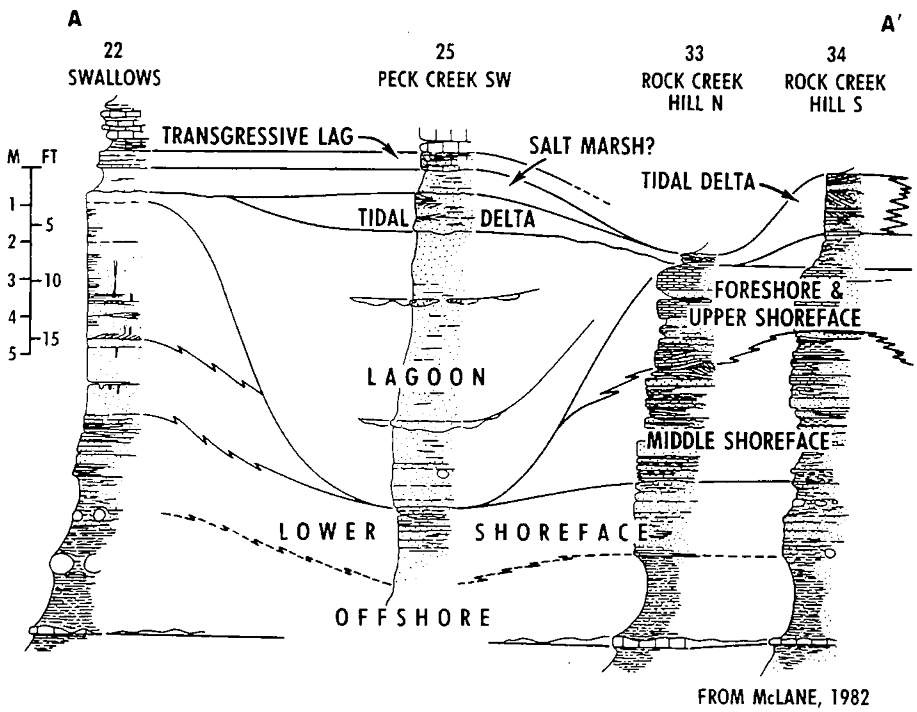


Fig. 14. Stratigraphic section A-A', showing interpreted paleoenvironments, Codell-Juana Lopez sequence, south-central Colorado, U.S.A. See Fig. 13 for map of line of section and Fig. 4 for numbers of measured sections. From Krutak (1991).

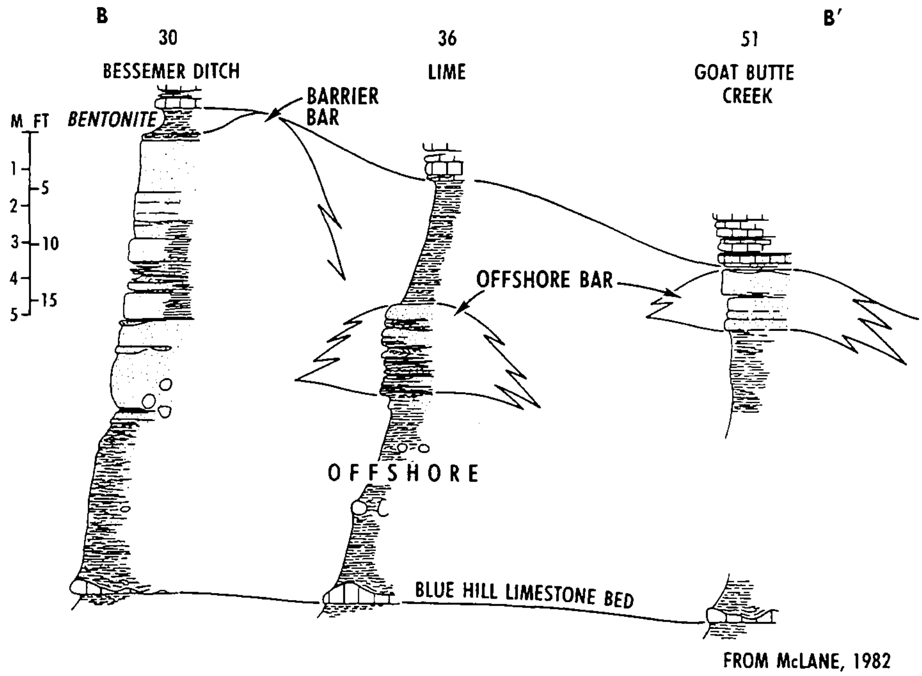


Fig. 15. Stratigraphic section B-B' showing interpreted paleoenvironments, Codell-Juana Lopez sequence, south-central Colorado, U.S.A. See Fig. 13 for map of line of section and Fig. 4 for numbers of measured sections. From Krutak (1991).

grains are 85% monocrystalline quartz, 14% chert, 1% potash feldspar, and about 1% plagioclase feldspar. Calcite cementation and replacement occurs; whereas, quartz overgrowths are absent.

COLORADO CITY- HUERFANO AREA

Codell deposits in the southwestern part of the study area underlie a provincial disconformity at the base of the Juana Lopez (sections 28, 37, 11, 12, 13, and 39). Codell sandstones at Stinking Spring (section 37) probably represent an even older series beneath an intramember diastem. This section, almost 26 ft (8 m) thick, is one of the thicker measured (Fig. 10). However, it has one the lowest sand-shale ratios (2 - Fig. 11).

Lower Codell sandstones at Rye (section 13), Colorado City Campground (section 12), Interstate 25 (section 11), and Stinking Spring (section 37) may represent a series of offshore bars capped by shoreface deposits and flood tide deltas (Fig. 13).

These sections have Blue Hill shales at their bases which grade upward into very fine-grained sandstones which are overlain by lenticular-bedded, horizontally-laminated, and hummocky cross-laminated sandstones. Bioturbated sandstones cap the bar sequence at Rye, Colorado City Campground, Interstate 25, and at Stinking Spring.

Mclane (1982, p. 82) believed the fine-grained, bipolar cross-laminated sandstones at the top of his Greenhorn Creek section (his section 43; *circa* Krutak's section 11), and at Graneros Creek (Mclane's section 46) represent flood-tidal delta deposits.

Curiously, Mclane infrequently mentioned the Juana Lopez at these localities. It is present as a very thin (about 0.3 ft/1.0 m/) orange-brown calcarenitic sandstone capped by podded biosparite at the Interstate 25 outcrop (Section 11). Here, Juana Lopez detritus fills fissures (or borings?) in the upper surface of the Codell. Thin (about 0.7 ft/0.2 m/) dark yellowish-orange to brown, shark tooth calcarenites and phosphorites of the Juana Lopez extend downward as channels cut into underlying yellowish-gray Codell sandstones and sandy shales (Fig. 16). The Juana Lopez also occurs at Colorado City (section 12) and at Rye (section 13), where it is interpreted as a tidal flat deposit (Fig. 12). At Stinking Spring (section 37) it may represent a subaerial beach or dune? deposit. Mclane did not note its presence in his sections 54 and 55 in the Huerfano River area, although it is present at Krutak's section 39 in the same area.

Mclane measured two of his southernmost sections on the Cucharas River (sections 56 and 57). These sections contain light gray to medium gray, very fine-grained, bioturbated, soft, shaley sandstones with abundant *Ophiomorpha*. He interpreted these sandstones as offshore shelf deposits. He also noted a low angle unconformity between the Codell and Juana Lopez in these sections.

Krutak measured about 9 ft (2.7 m) of Codell at his southeasternmost exposure (section 38, Doyle's Arroyo) where it has a sand-shale ratio of 16 (Fig. 12) and probably represents a portion of a shelf sand. Figs. 17 and 18 illustrate the upward coarsening, rounding, and sorting of the Codell at Colorado City Campground (section 12). The lower Codell (12.1) is sub-angular and angular, and contains very fine-grained quartz, chert, and feldspar. Secondary quartz and chert cements the rock. Medial Codell sandstones (12.2) are subrounded to subangular, fine-grained, with quartz, chert, and feldspar. Cements are quartz and chert. Upper Codell arenites (12.3) contain rounded to subrounded, medium-grained quartz and chert. Quartz and chert, along with calcite, comprise the cements. Juana Lopez calcarenites (12.4) contain abundant bone and are cemented with limonite. Similar petrographic trends are evident in sections 13 and 38.

The size-sorting pattern demonstrated by Figs. 17 and 18 appears to support the general sedimentary regime proposed by Mclane (1982) for Codell deposits. It may also explain Juana Lopez paleoenvironments. The lower energy offshore bars surmounted by higher energy shoreface sands which culminate in even higher energy flood-tide deltas, comprise a series of genetically related sandstones whose petrographic characteristics corroborate the paleoenvironmental interpretation.

However, Glenister and Kauffman (1985) offered slightly different paleoenvironmental interpretations for the Codell at Pueblo. They divided the Codell Sandstone at Rock Creek Anticline into three units. Their lower unit, 6-7 ft (1.8-2.0) thick, is thought to be storm sandstones of lower shoreface origin, deposited below fair-weather wave base, but in reach of storm waves. A middle unit, 17.7 ft (5.4 m) thick, with a diverse trace fossil association, forms the main sandstone bluff and is believed to comprise primarily middle-shoreface sandstones. The upper unit, 6.8 ft (2.1 m) thick, is highly bioturbated, and contains very abundant limestone-filled burrows originating from overlying Niobrara beds. They interpreted this unit as a middle to upper shoreface transition sequence whose top locally appears to contain tree roots. This suggests partial or complete emergence prior to Niobrara deposition.

PETROGRAPHY AND DIAGENESIS

Codell Sandstone Member

Petrographically, the Codell is a coarsening upward unit of quartz arenites and subarkoses. Figs. 19 and 20 depict eight measured sections chosen from the 39 measured by Krutak (1970). Reisser (1976) sampled and

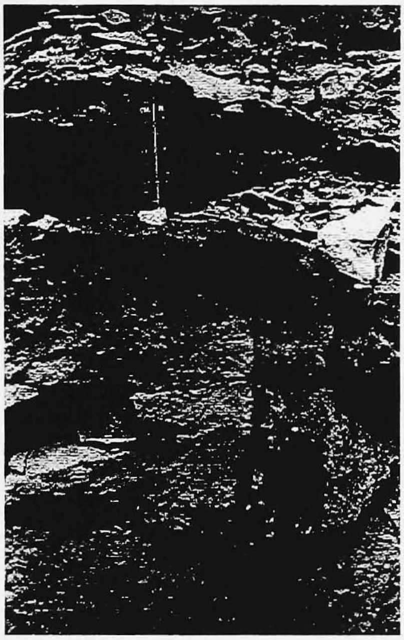


Fig. 16. Codell-Juana Lopez contact at Interstate 25 outcrop (section 11). Thin, dark yellowish-orange Juana Lopez shark tooth calcarenites and phosphorites (just below scale) fill channels cut into underlying Codell rocks. See Fig. 3 for location.

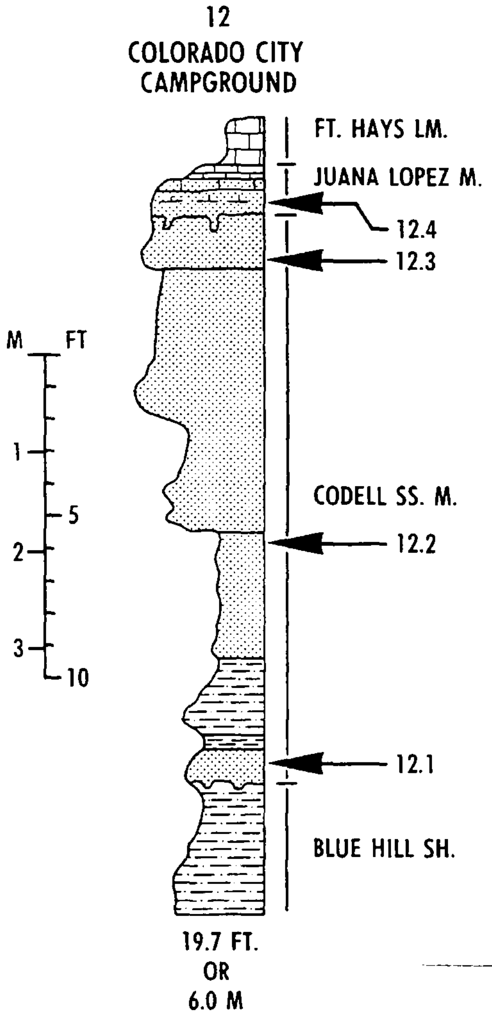


Fig. 17. Codell-Juana Lopez measured section 12, Colorado City Campground, south-central Colorado, U.S.A. See Fig. 3 for map location of this section and Fig. 18 for petrographic details of samples 12.1-12.4. From Krutak (1991).

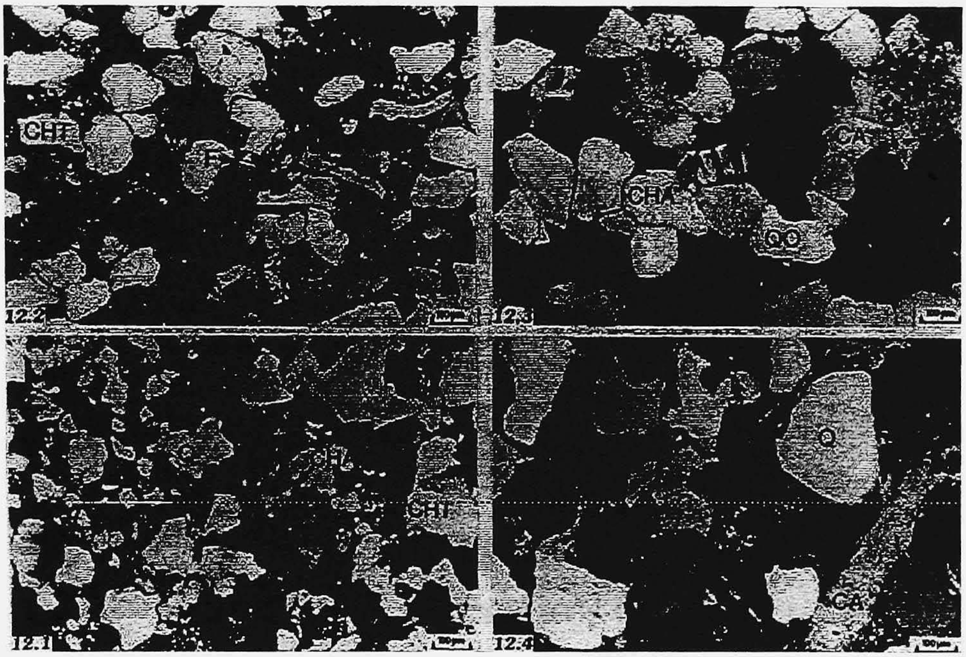


Fig. 18. Thin section photomicrographs of Codell-Juana Lopez samples 12.1-12.4, cross polarized light. Fig. 17 shows the stratigraphic position of each thin section. Note upward coarsening, rounding, and sorting as well as increase in calcite cementation. B=bone; CA=calcite; CHA=chalcedony; CHT=chert; F=albite feldspar; Q=quartz; QO=quartz overgrowth. From Krutak (1991).

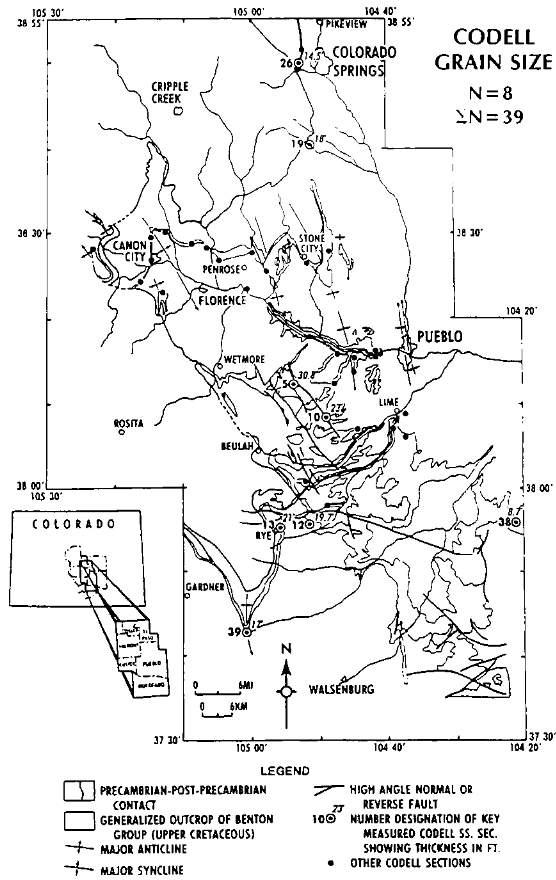


Fig. 19. Map of eight (N=8) measured sections of Codell Sandstones chosen to illustrate variations in grain size. Grain size plots for each section are shown in Fig. 20. Total number of measured sections (Fig. 3) is 39 (Sum of N=39). Sandstones are either quartz arenites or subarkoses. All 43 Codell thin sections analyzed fall into these clans (Fig. 20). From Krutak (1991).

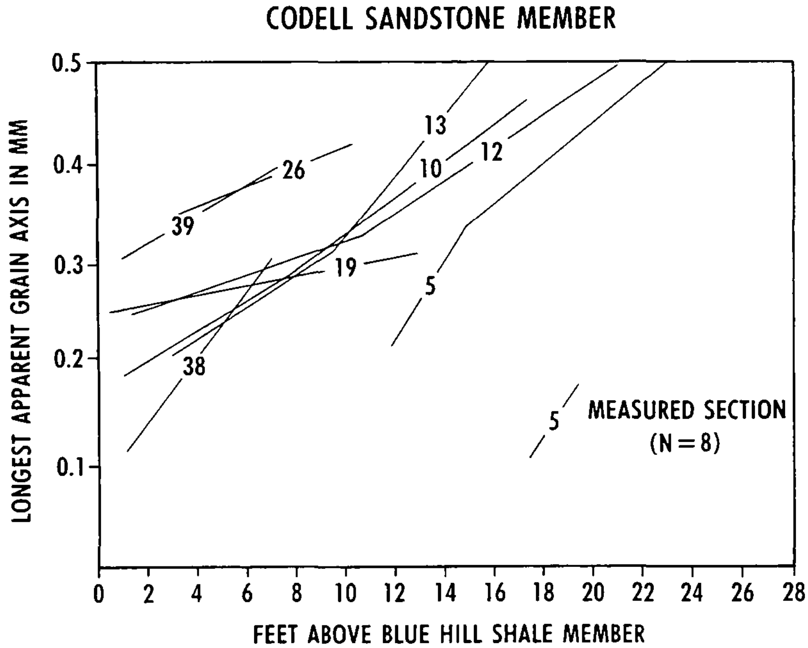


Fig. 20. Bivariate plot showing coarsening upward grain size in Codell Sandstone Member, south-central Colorado, U.S.A. Each solid line represents the measured (from thin section data) upward coarsening in a specific measured section. Numbered sections (N=8) key to map (Fig. 19). From Krutak (1991).

point-counted (300 grain counts) each of these sections. Reisser's results indicate similar upward coarsening trends in all eight sections. This coarsening upward is paralleled by an upward increase in sorting and roundness, and to a lesser degree, by an increase in mineralogic maturity. Lowermost sandstones often contain a matrix of fine silt and clay and are moderately sorted. These basal sandstones are usually very fine-grained, subangular to angular subarkoses. Above the lower sandstone beds, the Codell is typically fine-grained and subangular; it grades upward to medium-grained and subrounded. These sandstones are classified as quartz arenites and subarkoses. All forty three Codell thin sections analyzed fall into these clans (Fig. 21).

Codell sandstones tend to be well-cemented with cements typically making up 25%-30% of the rock. In some cases cements constitute over 50% of the bulk rock volume. Quartz, chert, calcite, and in one rare instance hematite, form cements. Clay matrix and precipitated chert cement some lower sandstones. Cements may be mixed, or only one or two cements may occur. Quite often, cements are stained with limonite. In most instances, cements are pore fillings since the rock is structurally supported by the framework; however, sometimes the grains appear to "float" in calcite cement.

Quartz comprises the bulk of terrigenous detritus in the Codell. Mean quartz content is 85.7% and includes monocrystalline grains with straight and undulose extinction as well as rare polycrystalline grains. Strained and unstrained quartz occurs in subequal amounts with unstrained grains predominating. Polycrystalline quartz is virtually absent in the Codell, typically making up less than 1% of the framework. Remnant fossil outlines occur in some chert grains; most grains are microcrystalline, but some grains of chalcedony occur. Feldspars average 3.3% in the Codell and usually consist of untwinned orthoclase with accessory microcline and plagioclase (mostly oligoclase). Rare altered metamorphic rock fragments occur. Mica (biotite and muscovite) comprises 1%-2% of some of the silty and shaley lower Codell sandstones; it is often deformed around framework grains Heavy minerals are dominantly zircon and tourmaline, but traces of rutile and opaques (pyrite, hematite, and limonite) also occur. Other opaques, which may be leucoxene or magnetite, are present. All these heavy minerals occur as both well-rounded and angular varieties. Glauconite occurs rarely as roughly spherical grains.

Collophane, which may be isotropic or weakly birefringent, occurs commonly in the Codell. Such fragments are attributable to marine vertebrates. Fish bone fragments and shark teeth of both the cutting and crushing types may be abundant. Molluscan fragments are also present and consist of *Inoceramus* prisms, and other broken fragments of bivalve and gastropod shells.

Calcite cements much of the upper Codell. It occurs as large "poikilitic" crystals surrounding framework grains (Fig. 22). It is often twinned and may be stained by limonite. Siliceous precipitates include secondary quartz overgrowths deposited in optical continuity with detrital quartz grains as well as microcrystalline chert cement. Chert cement may be stained by limonite.

None of the Codell thin sections studied possess thin section porosity. Permeability measurements are unavailable.

Figure 23 is a proposed diagenetic scheme for Codell sandstones and lowermost quartzose Juana Lopez rocks. The sequence 1-3 (authigenic syntaxial quartz overgrowths; chert cementation; dissolution and corrosion of quartz, chert and feldspar) is based on petrographic observations. Step 4 (porosity development) is hypothetical, but may occur in the subsurface. Steps 5-7 (calcite cementation, limonitization, dehydration of limonite to hematite) are also from thin section evaluation. Although surface oil-staining is known to occur in the Codell at Krutak's southern-most measured section (section 39) southeast of Gardner (Fig. 3), step 8 (oil and gas generation, migration and emplacement) remains problematic, although there is Codell CH_4 (methane) at Arco's Sheep Mountain unit in the Huerfano Basin.

Carraway (1990, p. 142) summarized the petrography and genetic history of the Codell in the Denver Basin of northern Colorado. She also recommended stimulation programs that would enhance Codell production when it is encountered.

Her analyses indicate the Codell is a subarkosic arenite composed primarily of quartz and subsidiary amounts of plagioclase feldspar and clay minerals. Phyllosilicates (illite and illite/smectite) may make up 22% of the total bulk volume of the Codell. Dissolution of late stage carbonate cement and labile framework grains often produces moldic porosity in these Denver Basin Codell reservoirs.

Because of the high clay content, reservoir stimulation fluids capable of minimizing the effects of swelling clays should be used during Codell well completions. Various Denver Basin operators have used cross-linked gels, polymer emulsions and methanol/CO_2 blends to overcome these problems (Carraway, 1990, p. 142).

Carraway also indicated that hydraulic fracturing of the Codell is critical to effective well completions, since the Codell is usually so 'tight.' Fracturing is done through tubing, the customary proppant being sand. Operators usually employ acidic water-gels that are stable at high temperatures.

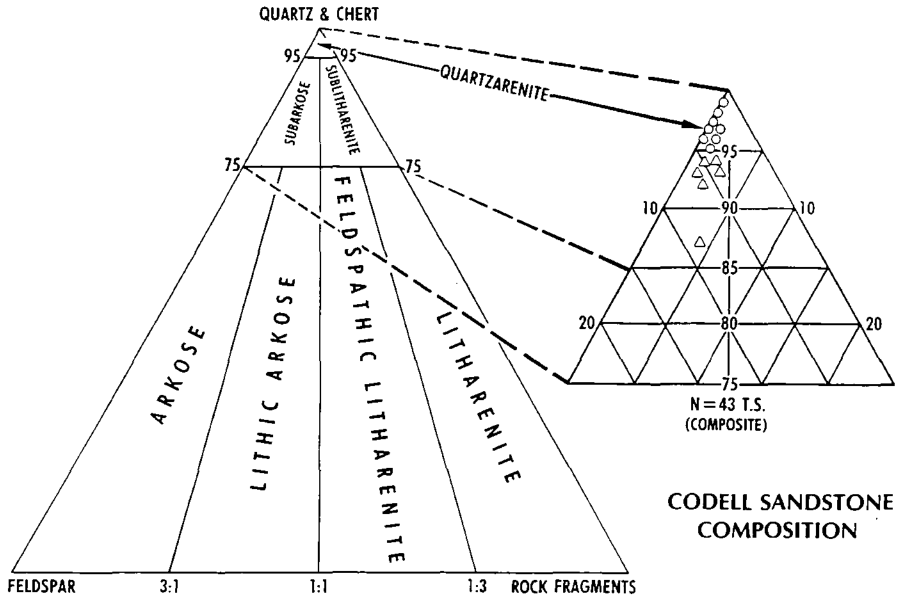


Fig. 21. Ternary plot of Codell Sandstone composition based on 300 grain counts of 43 thin sections (N=43 T.S.). From Krutak (1991).

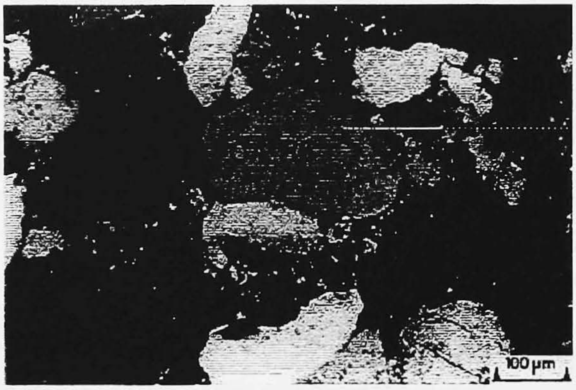


Fig. 22. Thin section photomicrograph of calcite rim cement (CA RC) surrounding quartz grain; cross-polarized light. Most calcite is stained by limonite. Sample 33.1, 15.1 ft (4.6 m) above base of Codell Sandstone, Section 33, Brush Hollow, Colorado. See Fig. 3 for location. From Krutak (1991).

CODELL DIAGENESIS: SUMMARY
1) AUTHIGENIC SYNTAXIAL QUARTZ OVERGROWTHS:
2) CHERT CEMENTATION:
3) DISSOLUTION & CORROSION OF:
a) QUARTZ,
b) CHERT,
c) FELDSPAR,
4) POROSITY DEVELOPMENT:
5) CALCITE CEMENTATION:
6) LIMONITIZATION:
7) DEHYDRATION OF LIMONITE TO HEMATITE:
8) OIL/GAS GENERATION, MIGRATION, EMPLACEMENT.

Fig. 23. Proposed diagenetic sequence for Codell Sandstones and lowermost quartzose Juana Lopez rocks (Upper Cretaceous), south-central Colorado, U.S.A. From Krutak (1991).

Juana Lopez Member

Juana Lopez rocks occur in five facies (Fig. 12): 1) a calcarenite or limey sandstone unit, 2) a sandstone containing limonitized borings, 3) a shaley to massive sandstone sequence, 4) a sandy limestone or biosparite, and 5) a sandy shale of very limited areal extent. Figs. 24 and 25 show eight measured sections chosen to represent compositional trends in the Juana Lopez. The rocks vary compositionally between calcarenaceous sandstones containing as little as 17% allochemical framework grains to calcarenites (or biosparites in the classification of Folk, 1968) containing 100% allochemical grains of sand size or larger (Fig. 26). The Juana Lopez grades upward from basal calcarenitic sandstones with relatively abundant terrigenous framework grains to calcarenites (biosparites) with virtually no terrigenous detritus.

Juana Lopez materials are moderately well-sorted, contain few grains of less than medium sand-size, but may contain numerous shell fragments that are several millimeters in diameter. Terrigenous grains are well-rounded, but allochemical grains typically exhibit little or no rounding. *Inoceramus* prisms retain their original angular prismatic shape. These elongate prisms are often oriented parallel to bedding, as are shell and bone fragments. Dominant allochemical constituents of the Juana Lopez are single crystal calcite grains - *Inoceramus* prisms (Fig. 27). In western Kansas much of the Juana Lopez consists of these prisms (Hattin, 1962, 1975). Hattin termed these limestones "Inoceramites", and the term was later adapted extensively by Glenister *et al.* (1985). Other allochemical constituents of the Juana Lopez include mollusc shell fragments of a foliated rather than prismatic structure. These are probably bivalves of the Family Ostreidae (see Majewske, 1974). Phosphatic fossil material composed of collophane is common and is usually recognizable as shark teeth or fish bone (Fig. 28). Phosphatic fragments may comprise up to 8% of the Juana Lopez framework. Terrigenous framework grains in the Juana Lopez are essentially identical to those in the uppermost Codell. This detritus is dominantly quartz and chert and includes some untwinned orthoclase feldspar. Feldspars are medium to coarse sand-size and are rounded to well-rounded. Heavy minerals consist almost entirely of zircons and tourmalines; these exhibit varying degrees of roundness.

Juana Lopez cements are either sparry calcite or calcite carrying heavy limonite staining (Fig. 28). Dolomite cements are rare; they occur in one Juana Lopez section (Fig. 29); idiomorphic dolomite crystallites display cloudy brown centers and clear rims. Siliceous cements are absent in the Juana Lopez.

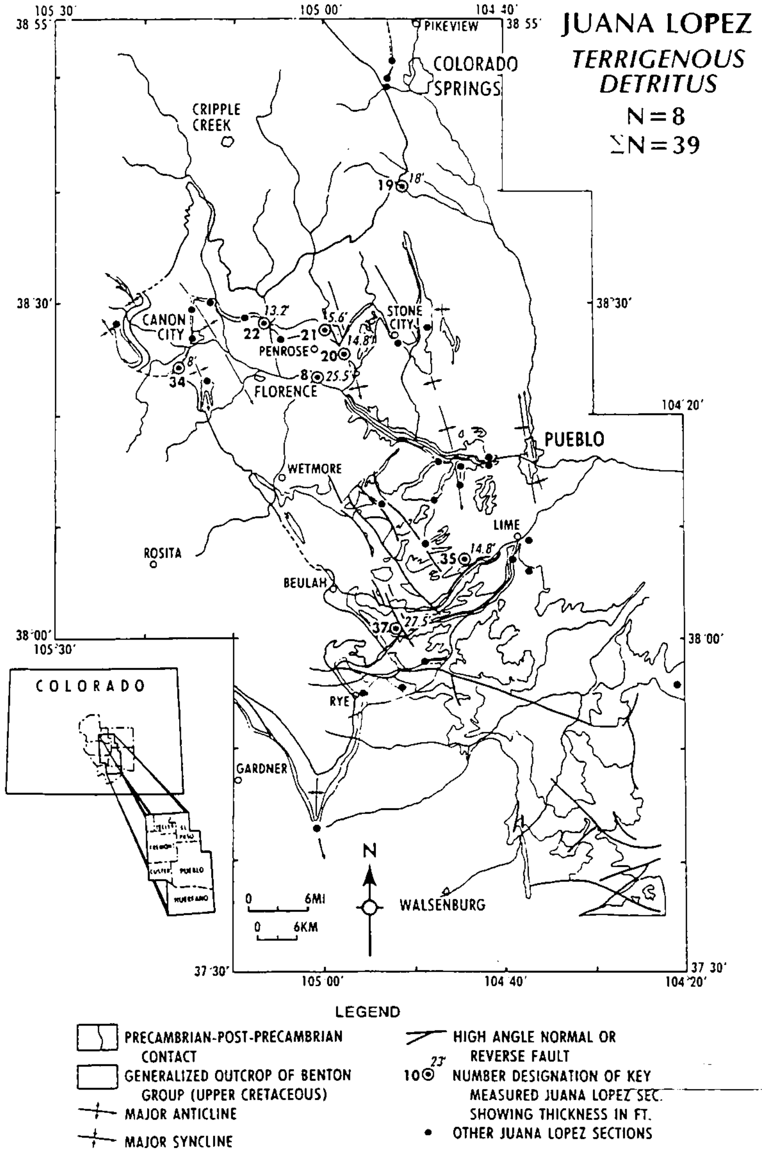


Fig. 24. Map of eight (N=8) measured sections of Juana Lopez chosen to illustrate variations in terrigenous detritus. Terrigenous framework plots for each section are illustrated on Fig. 25. Total number of measured sections (Fig. 3) is 39 (Sum of N=39). From Krutak (1991).

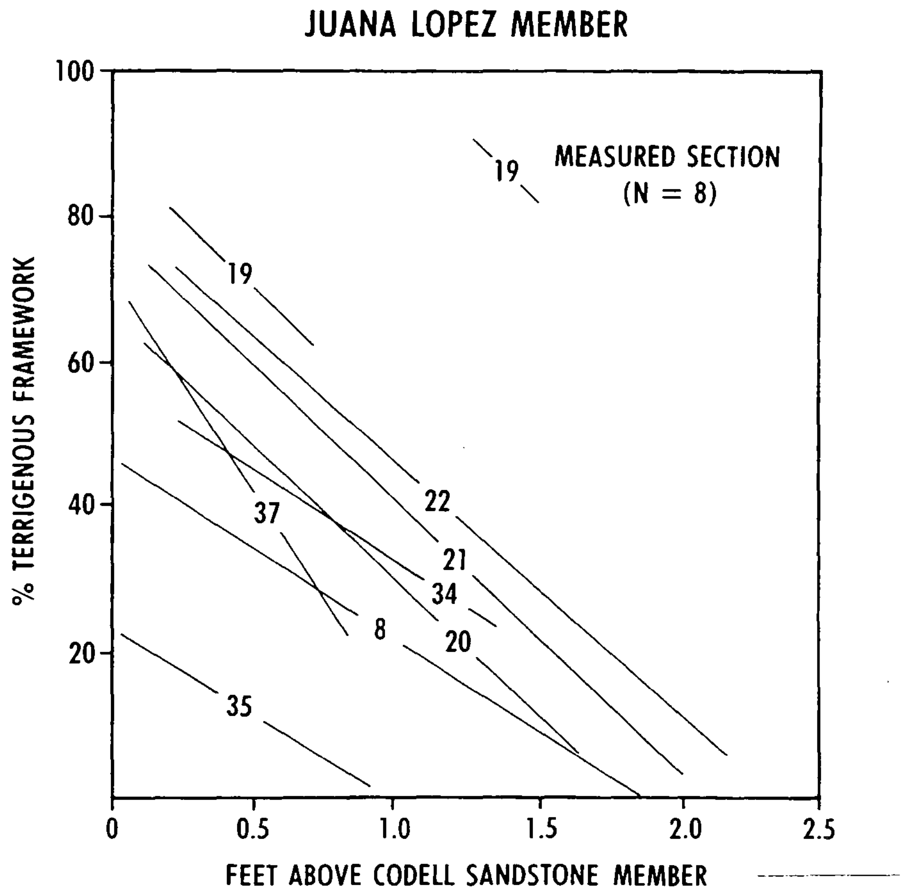


Fig. 25. Bivariate plot showing decrease upward in percentage terrigenous framework grains in Juana Lopez Member, south-central Colorado, U.S.A. Each solid line shows thin section data for a particular measured section. Numbered sections (N=8) key to map (Fig. 24). From Krutak (1991).

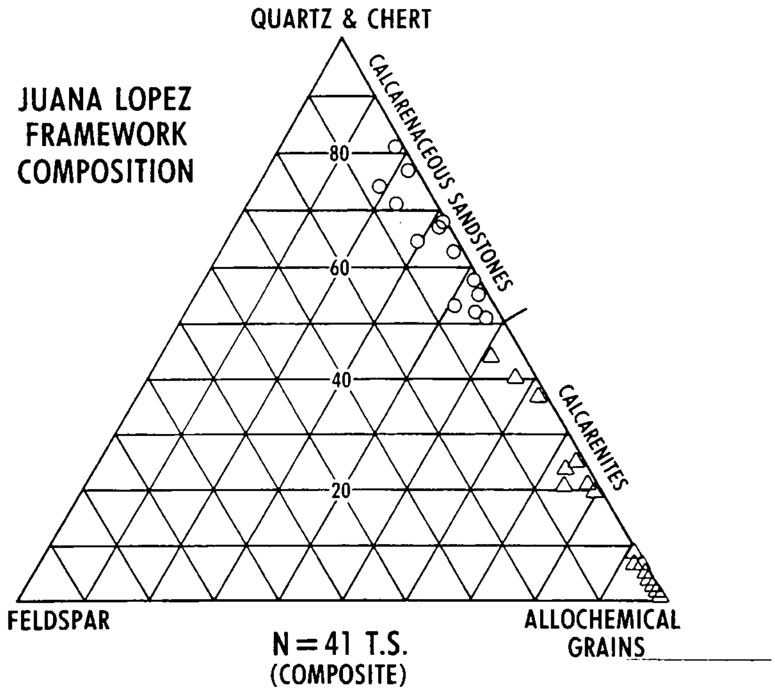


Fig. 26. Ternary plot of Juana Lopez framework composition based on 300 grain counts of 41 thin sections (N=41 T.S.). From Krutak (1991).

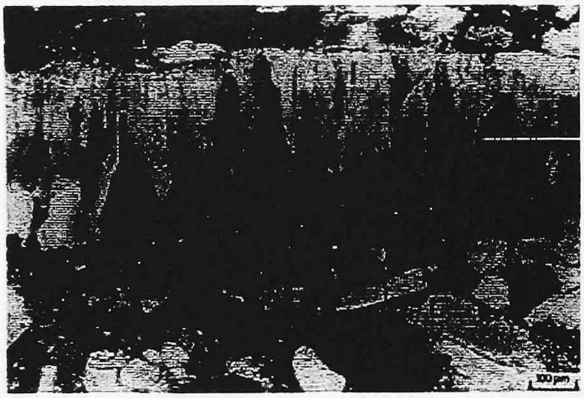


Fig. 27. Thin section photomicrograph of "Inoceramite" (I=*Inoceramus* prism) and limonitically stained (L) calcite, cross-polarized light. Sample 24.2, 3 ft (0.9 m) above base of Juana Lopez Member, Section 24, Skyline Drive, Colorado. See Fig. 3 for location. From Krutak (1991).

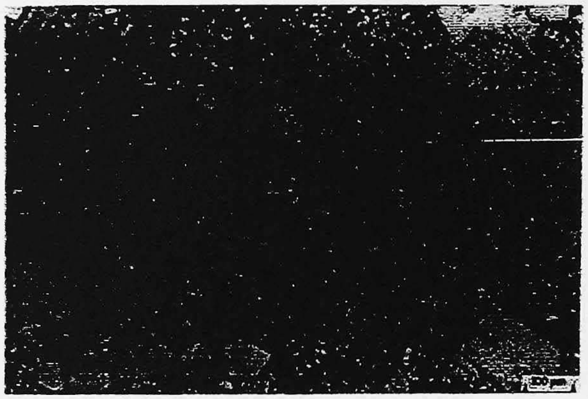


Fig. 29. Thin section photomicrograph of dolomite-cemented (D) calcarenite consisting of angular calcite fragments (CA), plane polarized light. Sample 9.1, 0.6 ft (0.2 m) above base of Juana Lopez Member, Section 9, Verde Road, Colorado. See Fig. 3 for location. From Krutak (1991).

Porosity is poorly developed in surface exposures of the Juana Lopez. Limited microporosity (Fig. 30) occurs at Lime (section 14). Vugular porosity (Fig. 31) is present at Interstate 25 (Section 11) and at Stinking Spring (section 37). Permeability values are unknown.

Figure 32 is the diagenetic scheme worked out from thin section studies for the Juana Lopez Member. Steps 1-4 (dolomitization, precipitation of calcite cement, limonitization, development of fracture and microporosity) are well displayed in thin section. Step 5 (oil/gas generation, migration, emplacement) may well occur in the subsurface of the Cañon City, Raton, and Huerfano Basins.

HYDROCARBON POTENTIAL

Figure 33 compares subsurface Codell-Juana Lopez rocks in the Denver Basin with their surface counterparts in the Cañon City-northern Raton Basins.

Weimer and Sonnenberg (1983a,b) showed that the Codell is well developed in the subsurface of the Denver Basin. It ranges in thickness from a wedge edge to as much as 100 ft (30.5 m) in thickness. It is well developed in the southern Denver Basin, is missing in a broad northeast trending area in the central part of the basin, and is intermittently present in the northern Denver Basin.

Recent petroleum discoveries have occurred in the bioturbated or relict shelf sandstones in the west central portion of the Basin. The traps appear to be stratigraphic.

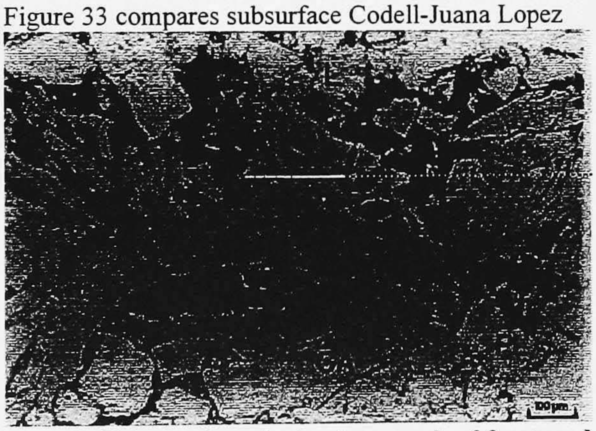


Fig. 28. Thin section photomicrograph of fractured bone fragment (B) with haversian canals (HC) cemented with limonitically stained (L) calcite (CA), plane light (PL). Sample 11.2, 0.6 ft (0.2 m) above base of Juana Lopez Member, Section 11, Interstate 25, ~ 2 miles east of Colorado City, Colorado. See Fig. 3 for location. From Krutak (1991).

Fig. 30. Thin section photomicrograph of microporosity (MP) in a Juana Lopez sparite, cross-polarized light. Sample 14.1, 0.6 ft (0.2 m) above base of Juana Lopez Member, Section 14, Lime, Colorado. See Fig. 3 for location. From Krutak (1991).

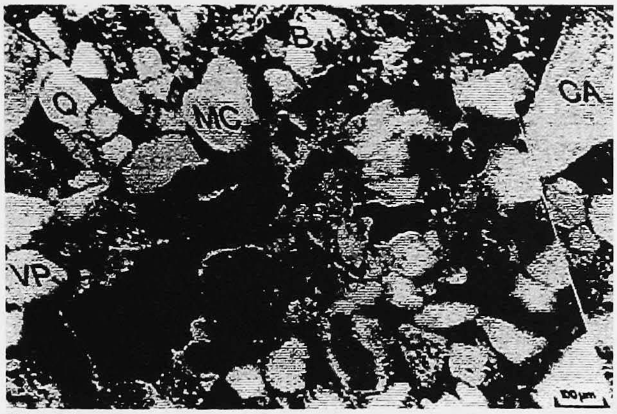


Fig. 31. Thin section photomicrograph of vugular porosity (VP) in a Juana Lopez calcarenite. MC= calcite meniscus cement; B=bone, CA=calcite; Q=quartz, plane-polarized light. Sample 11.2, 0.6 ft (0.2 m) above base of Juana Lopez Member, Section 11, Interstate 25, ~ 2 miles east of Colorado City, Colorado. See Fig. 3 for location. From Krutak (1991).

JUANA LOPEZ DIAGENESIS: SUMMARY

1) DOLOMITIZATION:
2) PRECIPITATION OF CALCITE CEMENT:
3) LIMONITIZATION:
4) FRACTURE AND MICROPOROSITY:
5) OIL/GAS GENERATION, MIGRATION, EMPLACEMENT:

Fig. 32. Proposed diagenetic sequence for Juana Lopez carbonates and calcarenites (Upper Cretaceous), south-central Colorado, U.S.A. From Krutak (1991).

According to Weimer and Sonnenberg (1983b) the Codell of the Denver Basin represents three paleoenvironments: 1) sheet-like marine (shoreline) bars overlying Blue Hill shales, 2) bioturbated, reworked marine shelf sandstones which may be associated with thin, irregular, relict, coarse-grained, conglomeratic shelf sandstones, and 3) sandstones of marine (?) origin filling large scour depressions (valleys?) cut into underlying Fairport or Greenhorn strata.

The marine bar facies occurs in Kansas and the southern Denver Basin, has good porosity and permeability, but is currently unproductive of hydrocarbons. Most oil and gas discoveries have been in the bioturbated or relict shelf sandstones in the west central portion of the Basin. The valley-fill? sandstones are tight, but are the thickest so far encountered in the Codell. They occur primarily in the Wyoming portion of the Basin, and have been sparsely productive of hydrocarbons.

Codell sandstones of the central and eastern portions of the Cañon City and northernmost Raton Basins occur as tidal delta, lagoonal, offshore bar, and barrier island deposits that average 19.7 ft (6 m) in thickness. Tidal delta sandstones encased in lagoonal shales appear to have the highest potential for trapping hydrocarbons. Buried offshore bars and barrier island sandstones probably have less potential. Subsurface extensions of these paleoenvironments have rarely been explored by the drill.

Juana Lopez rocks occur in the Denver Basin, but are generally too thin (less than 9.8 ft /3 m/) to resolve on standard scale (1”=100’) electric logs. Their facies are unstudied, and as far as known, have not produced hydrocarbons.

In the Cañon City and northern Raton Basins, Juana Lopez offshore bar and subaerial beach/dune? facies appear to have the most potential for hydrocarbon production, especially where these facies are sealed by tight micrites of the overlying Fort Hays Limestones.

Codell-Juana Lopez drilling depths in the Denver Basin range from 4003-8002 ft (1220-2439 m). Net pays range from 3-25 ft (0.9-7.6 m). Porosities range from 8-24% in Codell-Juana Lopez rocks of the Denver Basin, with permeabilities generally less than 0.5 md. Oil production ranges from 64-80 BOPD, with initial gas flow rates of 270-750 MCFD.

Drilling depths for Codell-Juana Lopez equivalents in the Cañon City-northern Raton Basins would probably be considerably less than 7874 ft (2400 m); perhaps less than 4003 ft (1220 m) in many instances. Net pays would probably be similar to those of the Denver Basin 3-25 ft (0.9-7.6m). Two exploratory wells have produced hydrocarbons in the Huerfano Park extension of the northern Raton Basin (Fig. 1). The Sam Taylor #2 (SE ¼, Sec 13, T26S, R71W), completed in 1974, produced 12 BOPD from the Codell. The Sheep Mountain Unit #13-1 (SW ¼, Sec l, T28S, R70W), completed in 1977, produced 50 MCF of carbon dioxide. Significant oil and gas production remains to be established.

The Sheep Mountain Codell CO_2 reservoir is intimately associated with the laccolithic intrusions of the area, which have interacted with the older sedimentary rocks to produce significant amounts of CO_2. The CO_2 has been injected into both the Dakota and the older Jurassic Entrada Sandstones. The Arco Oil and Gas Company Sheep Mountain Unit presently pipes large volumes of this gas to the Midland, Texas area where it is used to repressure depleted gas-drive reservoirs in the Permian Basin.

No core plugs have been analyzed from Codell-Juana Lopez strata in the Cañon City and northern Raton Basins.

HYDROCARBON POTENTIAL

ATTRIBUTE	BASIN	
	DENVER	CAÑON CITY-N. RATON
CODELL FACIES/THICKNESS	WEST CENTRAL SHELF SANDSTONES/4.1-6.1M (15-20 FT)	CENTRAL & EASTERN TIDAL DELTA, OFFSHORE BAR, BARRIER ISLAND/6M (20 FT)
JUANA LOPEZ FACIES/THICKNESS	UNKNOWN/<3M (10 FT)	SUBAERIAL BEACH/DUNE? OFFSHORE BAR/<1.8M (6 FT)
DRILLING DEPTHS NET PAYS	1219-2438M (4000-8000 FT) 0.9-7.6M (3-25 FT)	<1219M (4000 FT) ≈ 0.9 – 7.6M (3-25 FT)
OIL/GAS PRODUCTION	64-80 BOPD/270-750 MCFD	12 BOPD / 50 MCFD CO2
POROSITIES	8-24%	~8-24% (NO CORE PLUGS)
DISSOLUTION OF:		
QUARTZ	?	YES
CHERT	?	YES
FELDSPAR	?	YES
CALCITE	?	YES
PERMEABILITIES	<0.5 MD	NO MEASURED DATA

Fig. 33. Hydrocarbon potential of Codell-Juana Lopez (Upper Cretaceous) reservoir rocks in Denver versus Cañon City-northern Raton Basins, Colorado, U.S.A. From Krutak (1991).

Petrographic work by Krutak (1991) showed that diagenetic events removed quartz, chert, feldspar, and calcite from Codell-Juana Lopez rocks of the Cañon City-Raton Basins. These events, along with fracturing episodes, may have produced sufficient pore space for accommodation and eventual entrapment of hydrocarbons. Subsequent calcite cementatiuon might also have formed subtle diagenetic hydrocarbon traps which await discovery in these under-explored basins.

Clayton and Swetland (1980) summarized the organic geochemistry of oils produced from the Cretaceous section of the Denver Basin. Their results indicated that most of the hydrocarbons have been generated from source beds in the Mowry and Graneros shales, Greenhorn limestone, and Carlile shale. Their regional study suggested that these rocks become thermally mature along the axis of the Denver Basin.

Pratt (1981) showed that Cretaceous shales below the Codell at Rock Canyon Anticline west of Pueblo, Colorado are also potential source beds of petroleum. Her total organic carbon (TOC) values from the Hartland and Bridge Creek shales ranged from 1.8-5.4 wt% TOC.

Aulia (1982, p. 112) analyzed three Cretaceous shale outcrop samples (Skull Creek, Graneros) from the Cañon City-Pueblo area. Total organic carbon (TOC) values from these samples ranged from 0.52-3.38 wt% TOC. Such values exceed the minimum (~0.50 wt%) considered to be necessary to generate hydrocarbons (Welte *et al.*, 1975).

Aulia (1982, p. 113) also extracted vitrinite reflectance measurements (R_o) from the same samples. His sample JB-6, from the lower part of the Skull Creek, exhibited the most significant R_o values (mean of 0.698 R_o). This value exceeds the onset of the oil generation window (~0.500 R_o), but has not reached the maximum peak oil generation (~0.650 R_o) (Tissot and Welte, 1978, Fig. II 1.2).

Ritchie (1986) showed that hydrocarbons in the Codell Sandstone appear to have been generated from the underlying Carlile Shale. His vitrinite reflectance values (R_o 0.65-1.50) for the freshest, least altered particles are within the oil window. Ritchie's pyrolysis analyses suggest thermal maturities near the upper limit for oil and gas generation and preservation. His Van Krevelen plots indicated that the Codell contains mainly Type III organic material (continental origin with relatively low initial H/C ratios) and the Carlile more Type II material (marine derivation in a reducing environment).

TRACE FOSSILS

Mclane (1983) summarized the trace fossils of the Codell (Fig. 34) as well as the vertical facies sequences and postulated paleoenvironments (Table 1).

Dominant ichnogenera are: *Zoophycos*, *Teichichnus*, *Thalassinoides*, *Arenicolites*, and *Ophiomorpha*. Very fine-grained sandstones of the lower shoreface and lagoons usually contain feeding traces, such as *Zoophycos* and *Teichichnus*. *Ophiomorpha* and *Arenicolites*, typical dwelling burrows, occur often in well-sorted, laminated sandstones of the lower and middle shoreface, although *Ophiomorpha* may occur anywhere within shoreface or foreshore deposits.

The pellet-lined burrows of *Ophiomorpha* occur in three different forms in the Codell: 1) short vertical tubes, 2) long curved tubes, and 3) branching tubes. Middle-shoreface sandstones typically contain the long curved forms; whereas, branching forms are confined to the very top of the Codell. Its top, a disconformable surface, was probably supratidal when it formed.

Thalassinoides is not restricted to any one facies (Table 1), but is often present along the upper surface of the Codell, as well as in thin shale partings beneath foreshore and shoreface sandstones.

Wallace (1979) studied Codell trace fossils in north-central Kansas, referring most of them to the *Cruziana* ichnofacies, which is characteristic of littoral to shallow sublittoral deposits.

SUMMARY

Codell Sandstone Member

The Codell Sandstone, dated at ~87.75 mybp, is the end member of the R6 (late Middle Turonian) regressive sequence of Kauffman (1977a). It comprises the maximum regressive phase of the Greenhorn Hemicyclothem and furnishes an excellent model for sedimentation patterns at the end of one Cretaceous marine cycle in the Western Interior Basin of the United States (see Kauffman, 1977a, for an example of this model).

Codell rocks comprise a relatively small number of sedimentary facies. Mclane (1983) distinguished 6 lithofacies (A-F, Appendix 2) and presented a paleogeographic reconstruction of the Codell (Fig. 13). Three of these interpreted facies: 1) barrier island (Mclane's barrier bar), 2) lagoonal, 3) offshore bar (Table 1) are of special interest from the viewpoint of petroleum geology.

The barrier island succession records hydraulic conditions under gradual shoaling. Lenticular-bedded units, flat-lamina sets, and hummocky cross laminations occur near the base of this sequence, which is interpreted to have formed near wave base. Bioturbation destroyed sedimentary structures in some of these beds. Horizontal lamination, and low-angle laminations, interpreted to have formed in water shallower than wave base, occur higher in the vertical facies sequence. An ebb-tidal delta accumulated near the top of one of the barrier island sequences (Mclane's section 34, Krutak's section 10 -Figs. 3, 4). Rapidly moving tidal currents produced intersecting ripple trains; breaking waves formed rill marks in this upper flow regime domain.

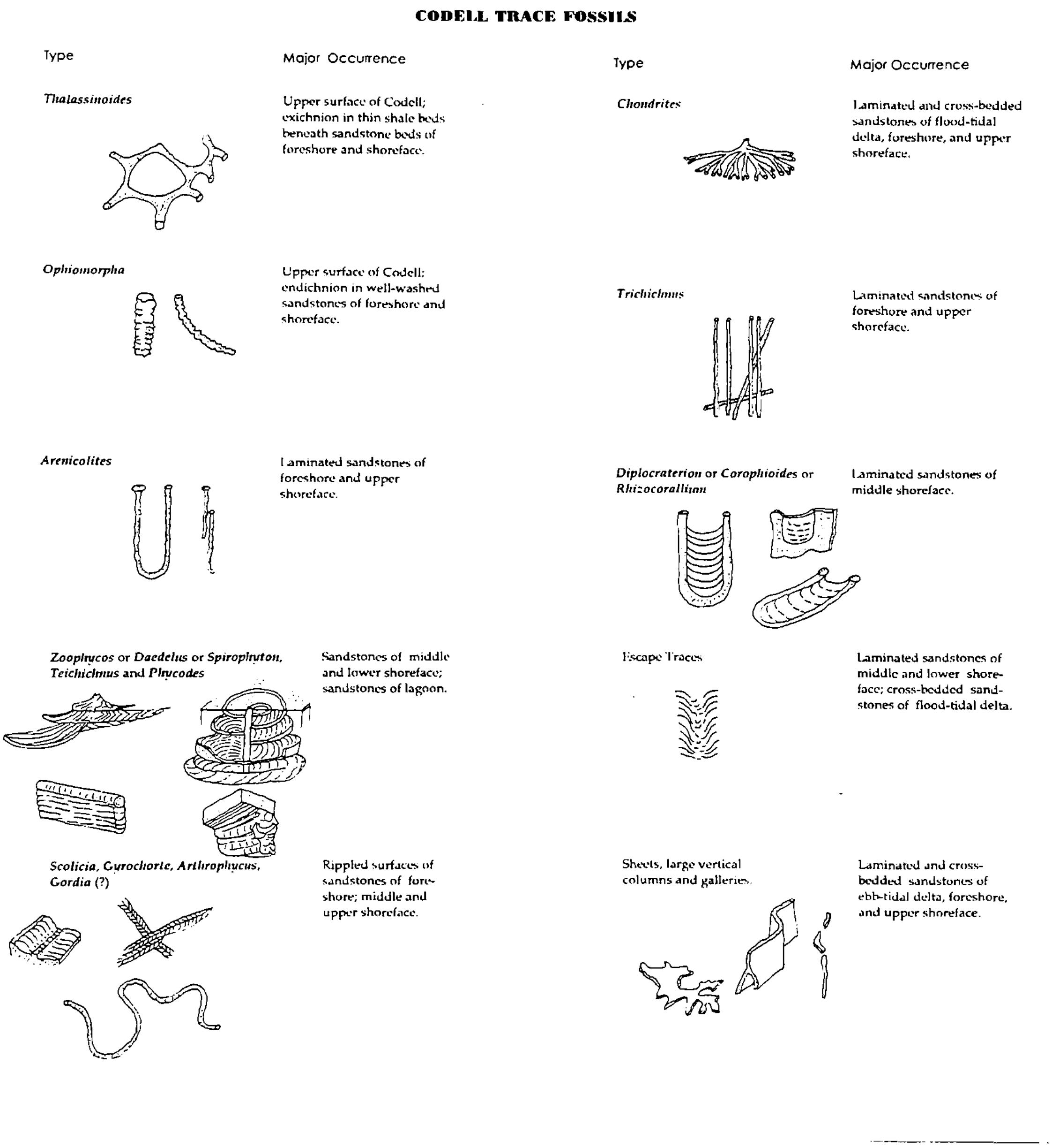


Fig. 34. Codell trace fossils. Adapted from Mclane (1983, Fig. 14, p.88).

Table 1. Vertical Facies Sequence in Barrier Bars, Lagoons, and Offshore Bars of Codell Sandstone

BARRIER BAR

Composition & Texture	Sedimentary Structure	Lebensspuren	Thickness	Contact	Environment
Fine to medium-grained, well-washed sandstone; shale clasts	Tabular cross-bed sets; flat-lamina sets; ripple mark; rill marks (?)	*Ophiomorpha*; *Chondrites*; *Thalassinoides*; "sheet" burrows	0 to 2 m (present locally)		Ebb-tidal delta
				Sharp	
Fine to medium-grained sandstone	Strongly bio-turbated	Spreiten-burrows; root casts (?)	0 to 1 m (present locally)		Backshore (?)
				Sharp	
Fine to medium - grained, well-washed sandstone	Flat lamination; low-angle inclined lamination; locally alternating with bioturbated beds; antidune beds in some places occur at top	*Ophiomorpha*; *Arenicolites*; "sheet" burrows	2 to 6 m		Foreshore and upper shoreface
				Commonly Sharp	
Fine-grained sandstone; dark silty, fissile shale; shale clasts; shells	Hummocky cross lamina; flat lamina sets; lenticular beds; bioturbated beds; scour surfaces; wrinkle mark; ripple mark	*Ophiomorpha*; *Thalassinoides*; *Rhizocorallium*; *Zoophycos*; *Teichichnus*; escape traces	4 - 6 m		Lower and middle shoreface
				Gradational	
Very fine to fine-grained sandstone	Strongly bioturbated; beds 10-20 cm thick; dark shale partings	*Zoophycos*; *Teichichnus*	1 - 2 m		Lower shoreface
				Gradational	
Dark, silty shale, grading upward to very fine-grained sandstone	Bioturbated	*Zoophycos*; *Teichichnus*			Offshore-shore-transition

Table 1. Vertical facies sequences in barrier island (barrier bar), lagoons, and offshore bars of Codell Sandstone Member of Carlile Shale. Adapted from Mclane (1983, Table 1, p. 87).

Lagoonal facies of the Codell commence with offshore-shoreface sediments along with lower shoreface deposits. Thick, homogeneous, strongly bioturbated sandstonesoverlie these materials. The lack of wave or current-formed sedimentary structures in these rocks suggests that lagoon -filling did not begin until barrier island construction was complete. During filling of the lagoon, periodic storms or spring tides carried thin accumulations of clean sand and mollusc shells through passes cut through the barrier island chain, and deposited these as thin sheets on the floor of the lagoon. When the lagoon floor approached sea level, a flood-tide delta sequence developed. The strong tidal currents of this delta laid down thin tabular, bipolar cross-bed sets and horizontal lamina sets across a large area of the lagoon.

Offshore bar sequences in the Codell are similar to the barrier island succession. Sedimentary structures indicative of lower and middle shoreface hydraulic conditions are present. In some areas, offshore-bar sands were buried by offshore muds. In other places, shoreface sediments prograded over offshore-bar sands.

Juana Lopez Member

Juana Lopez calcarenites and biosparites comprise a thin lag concentrate 1.6-5.2 ft (0.5-1.6 m) thick lying on a pronounced disconformity (see Krutak, 1970, for details) developed on top Codell Sandstones. Fisher *et al.* (1985) included these calcareous rocks in their model of the lowermost portion of the Niobrara Transgressive Hemicyclothem. However, in view of the evidence presented here and later in this summary, the writer believes the Juana Lopez Member is better grouped with the waning phases of the Greenhorn Regressive Hemicyclothem. The Member is overlain with pronounced unconformity by pelagic carbonates of the Niobrara Formation (Fort Hays Limestone). This unconformity is sometimes indicated by a bedding plane with no apparent evidence of physical disturbance; in other cases (Krutak, 1970), it merges with surfaces displaying evidence of scour and boring.

Mclane (1982) recognized two lithofacies (G and H). Krutak (1970) mapped 5 lithofacies (Fig. 12). In order of decreasing areal extent, they are: 1) a calcarenite or limey sandstone unit, 2) a sandstone containing limonitized borings, 3) a shaley to massive sandstone sequence, 4) a sandy limestone or biosparite, and 5) a sandy shale of limited areal extent.

Facies "one" (Fig. 12), interpreted as a tidal flat environment, lies at the very top of the Juana Lopez. This pale yellowish-orange calcarenite may be moderate brown in phosphorite-rich zones. Its thickness is variable, averaging about 2 ft (0.6 m). In many sections (sections 5, 18, 25, 38 - Fig. 3), bivalves occur, along with a concentrate of shark and ray teeth and associated collophane (evident in thin section). Its top surface does not display extensive scouring. Overlying Fort Hays micrites indicate deeper marine carbonate deposition as well as a complete lack of silicate detritus. Incipient dolomite crystallites (as seen in thin section), the strongly oxidized character of this surface, and the occurrence of a tooth and fossil concentrate at this level, indicates its top is of intertidal origin.

Facies "one" also contains lenticular or "podded" sparites. These occur as discrete lenses in certain geographic areas (sections 9, 13, 22, 15, and 26 - Fig. 3). In thin section, these rocks are biosparites, and like the surrounding calcarenites, contain collophane and small volumes of late stage dolomite. Their "podded" morphology, mineral composition, and sporadic occurrence indicates they are localized coquinoid thanatocoenoses of molluscan fragments and bone entombed in intertidal flats which were alternately exposed and inundated by tidal fluctuations during late Juana Lopez time.

Throughout most of the field area, the base of facies "one" is a disconformable surface, often marked by extensive borings which penetrate underlying beds (sections 11, 38 - Fig. 3). Many of the borings at the base of this unit are *Ophiomorpha* burrows. In some areas this discontinuity surface rises and falls through several minor stratigraphic units. Sometimes it merges laterally with an undisturbed stratification plane (between sections 26 and 27). In one area (between sections 13 and 39) it is truncated by a superjacent disconformable surface.

Facies "two", the bored sandstone facies (Fig. 12), is a very pale orange, medium-grained sandstone penetrated by limonitized borings which are filled with dark yellowish-orange, medium-grained calcareous sandstone. It occupies a slightly lower stratigraphic position than facies "one" (see Fig. 36), but in certain areas may form the only sand body present at the top of the Juana Lopez Member. Thicknesses vary from less than 1 ft (0.3 m) to 5.2 ft (1.6 m). The sandstone-filled borings present in this unit are distributed vertically and laterally throughout its volume. The areal extent of this unit (Fig. 12) is slightly less than the map distribution of facies "one."

In all the measured sections (see especially sections 1, 2, 3, 4, 6 and 7) the base of facies "two" is a bedding plane separating it from subjacent strata. Its top surface is variable. In most cases it is marked by the bored zone separating it from overlying calcarenites of facies "one."

The limonitized, bored sandstones of facies "two" are concentrates of all previous Juana Lopez materials. Their relatively small volume and comparatively wide areal extent suggest a modern analogue similar to the subtidal sand shoals or offshore bars paralleling the south flanks of the barrier islands of the Mississippi Sound, Gulf of Mexico.

Facies "three" of the Juana Lopez, the shaley to massive sandstone unit, consists of fine to medium-grained, calcareous, very pale orange sandstone, at times partially "dirtied" by sandy, olive-gray shale. It is an intergradational facies of facies "one," and is laterally equivalent to it (Fig. 10). Its top and bottom surfaces are the same as those of facies "one." Calcite occurs as cement in this facies, but is absent as particulate grains. The absence of carbonate detritus in the stratigraphic sections involved (14, 19, 23, 35, and 37 - see Fig. 3) is difficult to explain. At all other equivalent horizons in facies "one" it is a calcarenite rich in discrete particles of calcite spar as well as collophane.

Facies "three" occurs mainly on the periphery of the study area (with the exception of section 35), and is also confined to areas of marked thinning of the underlying Codell Member (Krutak, 1970, Fig. 7, p. 195). Facies "three" probably represents a supratidal sand accumulation (subaerial beach/dune complex?) which because of alternate elevation and depression of the fresh/salt water interface through it, and accompanying pH fluctuation, underwent intrastratal solution. Diagenetic remobilization of carbonate occurred, and calcite crystallized as a discrete cement between the silicate grains of this facies.

Sandy biosparites make up facies "four" of the Juana Lopez. This facies is present only locally in section 21, and intergrades with sections 8, 20, 22, and 23 (Fig. 9). Phosphatic material characterizes the basal surface of this facies. The surface is coeval with the basal surface of facies "one." This is interpreted as a provincial intramember disconformity. The top surface of this facies is a bedding plane directly overlain by limey shales, and is interpreted as a surface of continuous deposition.

Both the Juana Lopez and Codell Members are markedly thinner (5.6 ft/1.7 m/) in section 21 than in adjacent sections. The Table Mountain (~synonymous with the Beaver Creek Anticline of Pinel, 1983, Fig. 1, p. 68) anticlinal nose (Fig. 35), which plunges southeastward, is about 2.2 mi (3.6 km) east of section 21. Positive structural movements along this feature are reflected in stratigraphic intervals as old as Precambrian (Boos and Boos, 1957, p. 2665). Some uplift along its trend certainly occurred during the Laramide Orogeny (Grose, 1960). Pinel (1983, p. 69) indicated the Red Creek Arch separates the northern part of the Cañon City embayment from the Denver Basin, the axis of the main basin being about 15 mi (24 km) eastward. Upward movements of the Red Creek Arch during the late Cretaceous and early Tertiary may be responsible for moderate shoaling and resultant thinning of the Codell-Juana Lopez in this area.

Interestingly, Pinel pointed out that the Red Creek Arch and smaller associated folds (Beaver Creek, Turkey Creek, and Brush Hollow Anticlines), are possibly "draped fold" structures related to basement faults that extend southward from the southern end of the Colorado Front Range. For example, the Ute Pass Fault, a major structural feature, is 6 mi (10 km) east of the Red Creek Arch (Anderman and Ackerman, 1963). Facies "four" probably represents a thanatocoenose of molluscan fragments mixed with sand and phosphate pebbles derived from facies "one." Local molluscan biostromes growing in a shallow bay may account for the purer carbonates of this section. The isopach thins and low sand-shale ratios of this area (Figs. 10 and 11) furnish additional evidence for a shallow bay or lagoonal environment.

Facies "five" (Fig. 12) of the Juana Lopez is its lowest stratigraphic unit. It is a light-gray to medium-gray, shaley, fine-grained, noncalcareous sandstone. This sandy shale lies several feet below the rocks of facies "one" (Fig. 36). Both the upper and lower surfaces of this unit, which is 5.3 ft (1.6 m) thick in its "type section" (39), are interpreted as bedding planes representing surfaces of continuous deposition. Section 39 is on the south plunge nose of the Wet Mountain Arch (Fig. 35). Facies "five" probably reflects an early phase of Laramide positivism along the arch during Juana Lopez time. It may represent a shoal area - perhaps an end member of a series of northeasterly aligned offshore bars.

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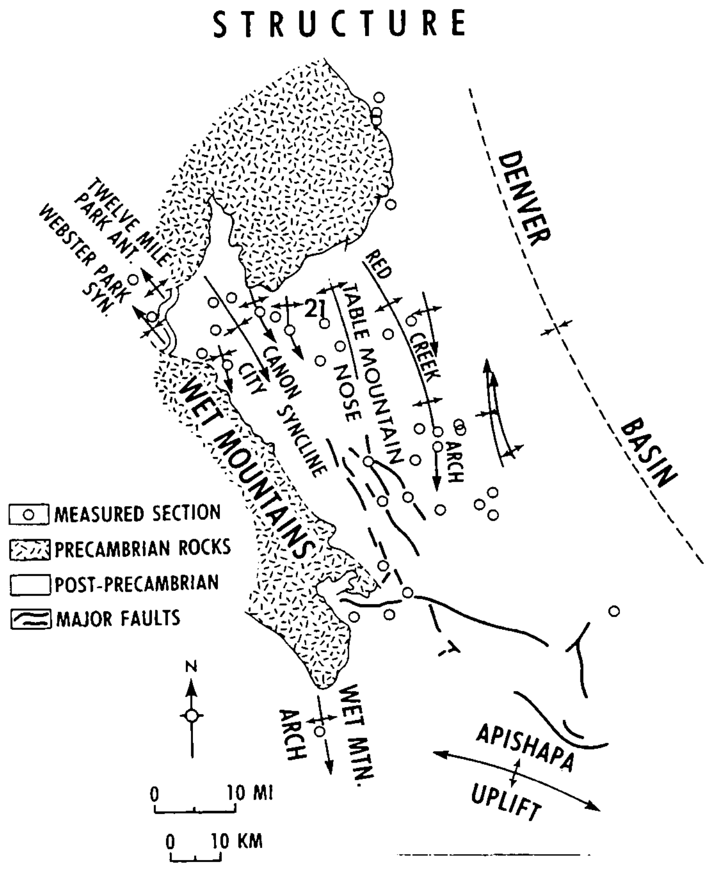

Fig. 35. Tectonic map of south-central Colorado. Black dots are measured sections of Codell and Juana Lopez Members of Carlile Shale (Upper Cretaceous). See Appendix I for numbers and detailed location of measured sections. From Krutak (1991).

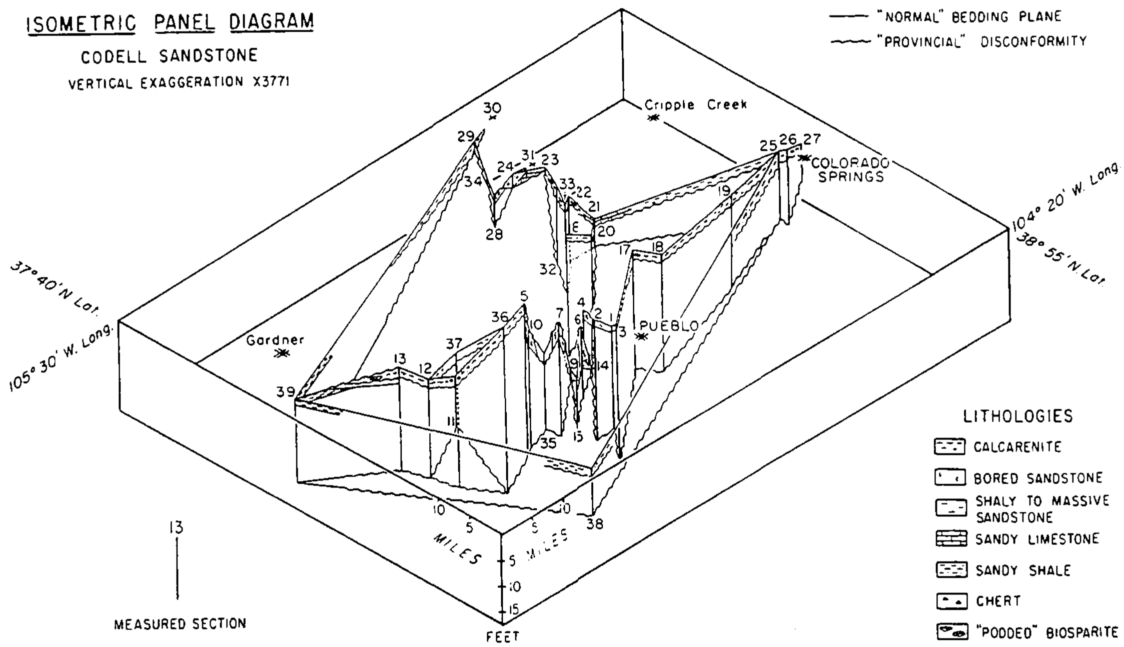

Fig. 36. Isometric panel diagram, Juana Lopez and Codell Sandstone Members of Carlile Shale (Upper Cretaceous), south-central Colorado. "Provincial" disconformity (wavy line) marks boundary between overlying Juana Lopez and underlying Codell. Numbers are measured sections. Juana Lopez subfacies are designated by lithologic symbols. Lower, blank part of diagram represents the thickness and lower surface of the Codell Sandstone Member. See Fig. 12 for a lithofacies map of the top of the Juana Lopez Member.

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Appendix I. Location of measured sections, Codell and Juana Lopez Members of Carlile Shale (Upper Cretaceous), south-central Colorado. Locations of sections in areas covered by the older 30' quadrangle maps are given by latitude and longitude to the nearest second of arc. All other quadrangles are 7.5' unless specified otherwise.

Section #	Location
1	1500' E. and 900' S. of NW corner Sec. 5, T. 21 S., R. 65 W., Bessemer Ditch area, NW Pueblo Quad.
2	1950' E. and 1050' S. of NW corner Sec. 2, T. 21 S., R. 66 W., Rock Canyon area, NW Pueblo Quad.
3	1550' E. and 1600' S. of NW corner Sec. 32, T. 20 S., R. 65 W., Prison Farm area, NW Pueblo Quad.
4	1350' E. and 1225' W. of SW corner Sec. 33, T. 20 S., R. 66 W., Peck Creek area, Swallows Quad.
5	1000' E. and 650' N. of SW corner Sec. 21, T. 21 S., R. 68 W., Bronquist Farm, Owl Canyon Quad.
6	2150' W. and 750' N. of SE corner Sec. 11, T. 21 S., R. 66 W., Boggs Creek, SW Pueblo Quad.
6a	3250' W. and 500' S. of NE corner Sec. 14, T. 21 S.,R. 68 W., Boggs Creek, SW Pueblo Quad.
7	3200' S. and 1400' W. of NW corner Sec. 20, T. 21 S., R. 66 W., Red Creek Road, Buelah NE Quad.
8	1450' E. and 350' N. of SW corner Sec. 16, T. 19 S., R. 68 W., Portland, Colorado, Florence Quad.
9	38° 07' 07" N. Lat., 104° 39' 00" W. Long., Verde Road, Pueblo 30' Quad, or Verde School Quad.
10	1850' W. and 800' S. of NE corner, Sec. 18, T. 22 S., R. 66 W., Highway 76, Buelah NE Quad.
11	2112' W. of SW corner Sec. 8, T. 24 S., R. 66 W., Interstate 25, Walsenburg 30' Quad, or Colorado City Quad.
12	1320' E. and 1056' N. of SW corner Sec. 25, T. 24 S., R. 67 W., Colorado City Campground, Walsenburg 30' Quad, or Colorado City Quad.
13	37° 55' 18" N. Lat., 104° 56' 00" W. Long., Rye, Colorado, Walsenburg 30'Quad.
14	1250' E. and 2300' N. of SW corner Sec. 12, T. 22 S., R. 65 W., Lime, Colorado, SE Pueblo Quad.
15	38° 06' 00" N. Lat., 104° 37' 15" W. Long., Cedar Valley Ranch, Colorado, Verde School Quad.
16	No data obtained; section too poorly exposed (2 miles north of Rye, Colorado on Colorado Highway 165, in highway cut on west side of highway); Rye Quad.
17	1750' E. and 3000' N. of SW corner Sec. 35, T. 18 S., R. 65 W., Stone City, Colorado, Stone City Quad.
18	1550' E. and 1100' N. of SW corner Sec. 35, T. 18 S., R. 67 W., White Butte, Lytle Road, Stone City Quad.
19	1100' W. and 1300' S. of NE corner Sec. 11, T. 16 S., R. 67 W., Deadman Cañon, Cheyenne Mountain Quad.

Appendix I. (continued) Location of measured sections, Codell and Juana Lopez Members of Carlile Shale (Upper Cretaceous), south-central Colorado. Locations of sections in areas covered by the older 30' quadrangle maps are given by latitude and longitude to the nearest second of arc. All other quadrangles are 7.5' unless specified otherwise.

Section #	Location
20	1200' W. and 2500' N. of SE corner Sec. 2, T. 19 S., R. 68 W., Beaver Creek Southeast; Pueblo 30' Quad.
21	800' N. of SE corner Sec. 21, T. 18 S., R. 68 W., Beaver Creek, Pueblo 30' Quad.
22	2975' W. and 1600' S. of NW corner Sec. 21, T. 18 S., R. 69 W., Phantom Canyon, Six Mile Creek, Florence Quad.
23	2600' E. and 1250' S. of NW corner Sec. 10, T. 18 S., R. 70 W., Four Mile Creek, Cooper Mountain Quad.
24	2750' W. and 500' N. of SE corner Sec. 29, T. 18 S., R. 70 W., Skyline Drive, Cañon City Quad.
25	1200' E. and 2350' S. of NW corner Sec. 22, T. 14 S., R. 67 W., Gold Camp Road, Manitou Springs Quad.
26	1200' E. and 1550' N. of SW corner Sec. 15, T. 14 S., R. 67 W., Pikes Peak Avenue, Colorado Springs Quad.
27	1200' W. and 625' N. of SE corner Sec. 3, T. 14 S., R. 67 W., Pikes Peak Avenue, Colorado Springs Quad.
28	500' E. and 2350' S. of NW corner, Sec. 21, T. 19 S., R. 72 W., Oak Creek Grade, Cañon City Quad.
29	500' W. and 1500' S. of NW corner Sec. 13, T. 18 S., R. 72 W., Parkdale Siding, Royal Gorge 15' Quad.
30	2640' S. and 1320' E. of NW corner Sec. 26, T. 17 S., R. 72 W., Guffey Road, Cover Mountain Quad.
31	2600' W. and 600' N. of SE corner Sec. 8, T. 18 S., R. 70 W., Bench Mark 5732, Cañon City Quad.
32	2400' E. and 2150' N. of SW corner Sec. 20, T. 18 S., R. 69 W., South Six Mile Park, Cañon City Quad.
33	1600' W. and 650' S. of NE corner Sec. 19, T. 18 S., R. 68 W., Brush Hollow, Florence Quad.
34	400' N. of SW corner, Sec. 7, T. 19 S., R. 70 W., Wolf Park, Royal Gorge 1:62,500 Quad.
35	38° 06' 53" N. Lat., 104° 44' 00" W. Long., Stinking Arroyo, St. Charles River, Pueblo 1:125,000 Quad.
36	600' W. and 150' N. of SE corner Sec. 15, T. 22 S., R. 67 W., Muldoon Hill, Buelah NE Quad.
37	850' W. and 600' N. of SE corner Sec. 27, T. 23 S., R. 67 W., Stinking Spring, Muldoon Hill Quad.
38	528' S. and 2640' E. of NW corner Sec. 28, T. 24 S.,R. 62 W., Doyle's Arroyo, Red Top Ranch Quad.
39	2640' E. and 1320' N. of SW corner Sec. 4, T. 27 S., R. 68 W., Huerfano River, Farisita Quad.

Appendix II. Codell and Juana Lopez facies (from Mclane, 1983, Appendix 2, p. 90). Sequence arranged from base (A.) to top (H.).

JUANA LOPEZ

H. Limestone, dark, fetid: pale to dark yellowish-brown, in some places sandy biosparite composed largely of inoceramid prisms; commonly recrystallized to medium sucrosic texture.

G. Sandstone, phosphatic: yellowish-brown to grayish-orange, fine to medium-grained, limonitic, containing rounded bone fragments, shark teeth, abraded fragments of bivalves, and pebbles of micrite.

F. Sandstone, calcareous, and sandy coquina: light-gray, sparkly, calcareous, laminated and burrowed, fine to medium-grained sandstone or sandy coquina of bivalves and gastropods; may occur as thin layers or pods in bioturbated sandstone, facies B.

CODELL

E. Sandstone, cross-bedded: yellowish-gray to grayish-orange, medium-grained, with tabular cross-bed sets.

D. Sandstone, laminated: very light-gray to yellowish-gray, fine to medium-grained, with horizontal and very low-angle lamination.

C. Sandstone and shales, lenticular-bedded: thin, rippled beds and lenses of very fine-grained sandstone or siltstone interbedded with dark-gray or olive-gray fissile shale.

B. Sandstone, bioturbated: light-gray to yellowish-gray, generally noncalcareous, thoroughly bioturbated, fine to medium-grained.

A. Siltstone, dark, bioturbated, muddy: medium-gray to dark olive-gray, noncalcareous, bioturbated, shaley; transitional between shales of Blue Hill below and overlying sandier beds of Codell.

Appendix III. Roadlog and Guide to Codell-Juana Lopez measured sections (Upper Cretaceous), Cañon City/Raton Basins, south-central Colorado.

FIRST DAY: Keeton Ranch Road to Manitou Springs/Garden of the Gods.

RESUME

The route of the first day's conference starts along the east side of the Front Range southwest of Cheyenne Mountain, Colorado. This area is structurally complex; a portion of the Cheyenne Mountain Fault zone (thrust?) has locally overturned both Paleozoic and Mesozoic strata of this region. The faulting is of probable late Cenozoic age and no doubt (judging from the steep face of Cheyenne Mountain which lies in fault contact with Cretaceous Pierre shales) continues today.

Our course parallels the east face of Cheyenne Mountain (site of the North American Aerospace Defense Command - NORAD) and turns west at North Cheyenne Canyon where clastic dikes have been injected into Precambrian granites. It then climbs the Front Range and traverses Pikes Peak granites up to Helen Hunt Falls where our route intersects the Gold Camp Road (the old narrow-gauge railroad line from Cripple Creek/Victor to Colorado Springs).

We will descend the lower Gold Camp Road to Bear Creek. Between the intersection above Helen Hunt Falls and Bear Creek, the route crosses (via various old railroad tunnels) two prominent overturned outcrops of Fort Hays/Codell and then passes back into granites and faulted Dakota/Codell/Ft. Hays rocks.

After intersecting Colorado Highway 24, our route turns westward to the center of Manitou Springs where we will examine the newly renovated thermal springs associated with the Ute Pass Fault. We then retrace our route eastward and turn north into the Garden of the Gods where we will examine various facies of the Fountain Formation (alluvial, marine - Glen Eyrie Member of the Fountain) as well as the spectacular faulted Paleozoics near the old Hidden Inn.

We will conclude the first day's trip at the intersection of Colorado Highway 24 and the turn-off to the Garden of the Gods.

Cumulative Mileage

0.0 Road log begins on Colorado Hwy. 115 at its intersection with Lytle Star Route (Keeton Ranch Road) 7.3 miles south of Colorado Springs, Colorado. Blue Hill shales surmounted by Codell Sandstone/Juana Lopez Member and Fort Hays Limestones crop out about ¼ mile southwest of this intersection (Krutak, 1970, measured section 19).

The Juana Lopez is ~ 1.7' thick and interpreted as a subaerial or beach/dune? deposit; underlying Codell is 18' thick (strike N-S; dip 21° E). Mclane (1982) interpreted the Codell there as a lagoonal deposit.

Walk ~ ¼ mile north on Keeton Ranch Road (Lytle Star Route) to observe overturned Dakota sandstones and shales with prod marks. Farther northwest, cross Little Fountain Creek to Keeton's Saddle and observe thrust? relations between Pennsylvanian Fountain Formation and Precambrian rocks.

Return to Colorado 115 and examine uppermost limestone in eastern roadcut (probable Fort Hays/Niobrara (Smoky Hill) contact. After discussion of Cheyenne Mountain thrust?, proceed northeast on 115 towards Colorado Springs.

Cumulative Mileage

0.50 Division of Fountain water system (left). Vertical to overturned Dakota Formation on left skyline (west).

1.20

1.70 Intersection of Old Cañon City Road and Highway 115 (May Museum Road). Highway 115 follows covered Pierre Shale to north. Cheyenne Mountain on skyline to left (northwest).
Highway 115 also traverses pediment surfaces and Quaternary alluvial deposits mapped by Benjamin Tator (1948 Ph.D. dissertation, Louisiana State University) many years ago.

0.50

2.20 Rock Creek.

0.20

2.40 May Natural History Museum of Tropics/Golden Eagle Campgrounds Museum Center (left).

1.40

3.80 Ft. Carson Gate 5 entrance (right). Blasted face of Cheyenne Mountain with NORAD (North American Aerospace Defence Command) entrance directly west (left) across highway. Engineers cored across Cheyenne Mountain Fault (thrust or high angle reverse?) when engineering for NORAD site was being done in late 1950s. Fault juxtaposes Precambrian granite and Cretaceous Pierre Shale. NORAD is an extensive system of caverns and tunnels blasted out of Precambrian Pikes Peak granite.

1.50

5.30 Fort Carson, Colorado "The Mountain Post" main gate (right).

0.70

6.00 Fort Carson, Gate 2 (right).

1.00

7.00 Intersection of Highway 83 (Academy Boulevard) and 115 (right). Excavations in low hills to west and southwest in Cretaceous Pierre Shale.

0.30

7.30 City limit, Colorado Springs, 6012' (right).

0.70

8.0 Star Ranch and Cheyenne Meadows intersection.

8.1 **1.10**

Cumulative Mileage

9.10 Cheyenne Mountain Boulevard intersection with Highway 115. Will Rogers' Memorial and "Shrine to Sun" on left lower skyline behind UMB Bank (left).

0.30

9.40 Highway 122 west (Broadmoor) intersection (right). Pike's Peak (14,110') on west skyline; Garden of Gods at foot of Rampart Range to northwest. Gold Camp Road visible on lower slopes of Front Range immediately west.

0.80

10.20 Cheyenne Road-Highway 115 intersection. Turn left (west) on Cheyenne Road (Highway 115 becomes Nevada Avenue at this point).

0.20

10.40 Intersection of Cascade and Cheyenne Road. Bear left.

0.90

11.30 Intersection of 8th Street (right) and Cheyenne Road.

0.70

12.00 Intersection of Cheyenne Road and Cresta Road. Continue across intersection.

0.80

12.80 Intersection of Cheyenne Road and Cheyenne Boulevard. Proceed west on Cheyenne Boulevard.

0.10

12.90 Intersection of Cheyenne Boulevard and Evans Road (Starsmore Discovery Center - Seven Falls). Turn right towards North Cheyenne Cañon Park.

0.50

13.40 Clastic and basic dikes (right) cutting Pikes Peak granite.

0.10

13.50 Stop on left to walk back to 13.40 where we will study clastic dike outcrops (watch for passing cars). Mechanisms for emplacement of these dikes controversial - we will discuss theories.

0.20

Cumulative Mileage

13.70 Ft. Carson practice climbing amphitheater (now abandoned). The Pinnacle, a granite knob immediately across the Cañon, was used as a direct-aid route for training Army rock climbers. Tyrolean traverses were also made in the amphitheater. Routes generally followed joint systems in the granites; old bolts are epoxied into the face, but are not trustworthy.

0.30

14.00 Middle Columbine Trail (right).

0.40

14.40 Mt. Cutler Hiking Trail (left).

1.20

15.60 Helen Hunt Falls and Bruin Inn (left switchback). Continue right up switchback. Optional stop at Falls and view of exfoliation domes in granites to west.

0.10

15.70 Upper Columbine Trail (right).

0.50

16.20 Intersection of North Cheyenne Cañon Road with Gold Camp Road. Turn right down Lower Gold Camp Road and then left to parking lot. Do not take High Drive. Spheroidally weathered granite weathering to grus crops out in parking lot. Various exfoliation domes in Pikes Peak granite occur along Gold Camp Road (look westward). Discussion of history of Gold Camp Road at parking lot. After discussion, exit parking lot to left and turn down Lower Gold Camp Road. Road for next 0.60 miles follows steep, almost one-way cuts (honk horn!) through granite outcrops.

0.60

16.80 Short narrow-gauge railroad tunnel.

1.00

17.80 Long narrow-gauge railroad tunnel.

0.20

18.00 Multi-use trail (left) with weathered grus in granite outcrops.

0.50

18.50 Scenic overlook of Colorado Springs (right). Broadmoor Hotel just below hair-pin turn as well as the "Pinnacle" and paved section of North Cheyenne Canon. Will Rogers Memorial on Cheyenne Mountain apparent on skyline.

Cumulative Mileage

0.60

18.60 Paved road begins.

0.40

19.00 Turn-out (right).

0.40

19.40 Intersection of Sunrise Lane (left) and Lower Gold Camp Road.

0.20

19.60 Subhorizontal Fort Hays Limestones (overturned).

0.20

19.80 Cuts in colluvium (right); intersection of Talc Lane (left) and Lower Gold Camp Road.

0.30

20.10 Intersection of Hydra Drive (right) and Lower Gold Camp Road.

0.30

20.40 Turn-out (right) to weathered grus quarry. Overturned Codell/Fort Hays beds occur in bend of road just beyond quarry. This is Krutak's 1970, 1991 section 25. Twelve feet of Codell are exposed with about 1 foot of Juana Lopez calcarenite. Juana Lopez interpreted as a tidal flat deposit. Beds strike N55W and are overturned 54° to SW.

0.20

20.60 Shattered Dakota sandstones.

0.20

20.80 Precambrian granites and schists.

0.10

20.90 Intersection of Lower Gold Camp Road and Bear Creek Road and bridge across Bear Creek. Turn northeast (abrupt right) down Bear Creek Road towards Bear Creek Cañon Park.

0.30

21.20 Dakota hogback.

0.60

21.80 Intersection of Bear Creek Road and Bear Creek Regional Park (right).

0.20

Cumulative Mileage

22.00 Intersection of Gold Camp Road and Lower Gold Camp Road with 26th Street. Continue down 26th via hairpin curves (Codell/Fort Hays hogback and Krutak's 1970, 1991 section 26 on left).

1.00

23.00 Fairview Cemetery (left).

0.40

23.40 Intersection of 26th and Cimarron (Highway 24); turn left (west).

0.50

23.90 Intersection of 31st Street and Highway 24. Go west on 24. Vertical Graneros shales and Dakota sandstones visible under "Legends Casino" sign on hill.

1.40

25.30 Business exit (Highway 24) to Manitou Springs (turn right) and loop back on Business 24 to Manitou Springs, Colorado.

0.40

25.70 Intersection of Crystal road and Business 24. Proceed west into downtown Manitou Springs.

0.70

26.40 Cliff Dwellings (right).

0.30

26.70 Turn right on Cañon Drive and drive to center of City Park near spa called "Manitou Springs Spa and Baths."

0.20

26.90 Park vehicles near City Park. Drink from carbonated Wheeler Spring fountain and examine exhibits of restored thermal springs in old "Manitou Springs Spa and Baths." Discuss possible connection between Ute Pass Fault and geothermal activity. Then make U-turn past Wheeler House and turn back east on Highway 24.

0.30

27.20 Intersection of Ruxton Avenue (Cog Railway) and Manitou Avenue (Highway 24). Proceed east on 24 towards Colorado Springs.

1.30

28.50 Turn left across Highway 24 to Garden of Gods road.

0.20

Cumulative Mileage

1.30

28.50 Turn left across Highway 24 to Garden of Gods road.

0.20

28.70 Turn right on El Paso Road (24), then left on Garden of Gods road.

0.10

28.80 Entrance marker, Garden of the Gods - Pennsylvanian Fountain outcrops on right.

0.40

29.20 Balanced Rock, Fountain alluvial deposits which dip southeast. Suttner *et al.* (1984) have found marine conodonts in red mudstone facies at this outcrop. This interval (the Balanced Rock interval) consists of fine-grained marine sandstone near its base and coarse, fluvial sandstone and conglomerate.

0.30

29.50 Garden of Gods trading post (right); stay left.

0.10

29.60 Large parking lot (left).

0.20

29.80 Intersection with turn-around. Turn right towards Visitor Center.

0.40

30.20 Scotsmans' picnic area (right).

0.90

31.10 Overlook (right). View west is towards Pikes Peak and Cog Railway. Bear Creek Cañon and Lower and Upper Gold Camp road visible below exfoliation dome to far left of south ridge extending from Pikes Peak. Outcrops of Fountain dip ~ 45° east. On north, Fountain (left) and Permian Lyons sandstones (right) dip almost vertically.

0.20

31.30 Intersection; make sharp left turn.

0.10

31.40 South Garden parking lot (right).

0.10

Cumulative Mileage

31.50 Road marker (right) indicating Indian Trail used by Plains Indians to Ute Pass; vertical Lyons hogback immediately ahead.

0.40

31.90 Intersection; turn left.

0.30

32.20 Outcrops of gypsiferous Ralston Creek Member of Jurassic Morrison Formation on left; Dakota hogback on right.

0.10

32.30 Main parking lot (left). Park and walk short distance west to backside of Fountain hogback to observe high angle reverse fault (with spectacular drag and antithetic faults) juxtaposing Permian Lyons sandstones and Fountain arkoses. Anchor points of technical rock climbers visible high on "prow" of Fountain "flatiron."

0.50

32.80 Old road to Hidden Inn (left), now closed.

0.20

33.00 Intersection of Juniper Way with one-way road (left).

0.90

33.90 Spring Cañon picnic area (right).

0.30

34.20 Rampart Range Road (turn right).

1.60

35.80 Intersection of private estate road (left). Road to this point has followed alluvial facies of Fountain formation.

1.30

37.10 Intersection with private road (new housing development) on left.

0.10

37.20 Glen Eyrie Member of Fountain formation (right road-cut). This greenish shale contains partly silicified Paleozoic bryozoa, brachiopods, and crinoids. Optional collecting stop.

1.10

Cumulative Mileage

38.30 Pike National Forest (right) and overlook into Queen's Canyon. Spectacular panorama of Sawatch sandstones (Ordovician) lying nonconformably on Precambrian Pikes Peak granites. Make U-turn and proceed back down Rampart Range Road to intersection with Juniper Way.

End first day at Highway 24-Garden of Gods intersection.

SECOND DAY: Keeton Ranch Road to Florence, Colorado.

RESUME

During this second day, we will drive southwest on Highway 115 towards Penrose, Colorado. The route between Penrose and the Keeton Ranch Road crosses the strike of Dakota sandstones and shales as well as the Jurassic Morrison Formation. As we move through Deadman's Cañon, notice the striking "flat-irons" of Fountain Formation exposed along the mountain front. Locally, the Fountain oversteps older, underlying rocks (Ordovician Manitou Dolomite, Harding sandstones) and comes to rest directly on Pikes Peak granite.

We will have the opportunity to examine the gypsiferous member of the Morrison Formation (Ralston Creek Member) as well as Permian Lyons Sandstone units as we move farther southwest towards Penrose, Colorado. As we drop down into the valley of Beaver Creek, we will traverse well exposed outcrops of Graneros shales, Greenhorn limestones, Carlile shales and finally back into the Codell/Juana Lopez sequence.

After intersecting Highway 50 and driving into Cañon City, Colorado, we will examine the Codell/Juana Lopez sections exposed along Four Mile Creek and at Skyline Drive, Colorado. During this phase of the trip we will also visit the site of the second oldest oil well drilled in the U.S. and the early Cope/Marsh dinosaur quarries.

We then examine the west side of Webster Park syncline, a graben whose west side is thrusted. Webster Park lies on the west side of the Royal Gorge of the Arkansas (the Arkansas has cut a canyon more than 1000 ft deep across an uplifted horst of Precambrian rocks).

After viewing the Royal Gorge, we will retrace our route to Cañon City and then drive southward across the Arkansas River up the Oak Creek Grade road. The road traverses the western limb of the Cañon City Syncline and also intersects an interesting Codell/Juana Lopez section as well as old coal mines in the Vermejo Formation. The day ends after a brief drive into Florence, Colorado (site of the near-by Florence oil field).

Cumulative Mileage

0.00 Reassemble at Keeton Ranch Road about 13 mi southwest of Colorado Springs on Highway 115.

0.40

0.40 Dakota hogback on right; one older stratigraphic classification used the nomenclature Lakota, Fuson, Dakota (in ascending order). The lower conglomeratic sandstone was the Lakota, the shaley intermediate sequence (the "blue-ribbon" shale of older publications) the Fuson, and the upper sandstones the Dakota.

0.10

0.50 Slumped Morrison outcrops on right.

0.20

0.70 Slumped Triassic Lykins Formation on right; graveyard opposite (Deadman Canyon site).

0.10

0.80 Calle de Fuente (right). Vertical Lyons hogback across highway to southwest. Older maps call the nearby stream Little Bear Creek.

0.10

0.90 Roca Roja (right); entrance to Red Rock Valley Estates. Fountain arkose dips easterly in low ridges to right. Road follows Lyons strike valley to southwest. This estate complex has a water shortage. They must purchase water from the Louisiana State University geology field station on the opposite side of Keeton's Saddle.

1.10

2.00 Paseo Corte (right).

0.30

2.30 Lyons/Fountain transition zone. Beds dip about 15° southeasterly.

0.30

2.60 Little Turkey Creek Road (right). Dakota cuesta on skyline straight ahead.

0.70

3.30 Hitchrack Ranch Road (right). Wet Mountains (Sierra Mojada) on horizon ahead.

0.20

3.50 Lyons sandstones on either side of roadcut. Three prominent knobs on left ahead known locally as the "Three Sisters."

1.10

Cumulative Mileage

4.60 Intersection of Highway 115 with Wildhorse Road (Turkey Creek Ranch Road) on left. Road to left goes to Wildhorse Anticline, where Colorado School of Mines students learned plane table mapping at one time.

0.50

5.10 Turkey Cañon Ranch road and Turkey Creek Recreation Area (left); also location of Penrose House.

2.10

7.20 Juniper Valley Road and J.V. Dining Room. Turn left to parking lot. South in far distance are East and West Spanish Peaks (near La Veta, Colorado) and south end of Wet Mountains. Note strong southwest dip of hogbacks in distance off the Red Creek Arch.

0.50

7.70 Barrett Road (right) to Ford's Mountaindale RV Park Campground.

2.20

9.90 Fremont County line.

0.80

10.70 Quarries in hills to right produced alabaster from Ralston Creek Member of the Morrison Formation.

0.20

10.90 Brief stop to sample Ralston Creek Member.

0.50

11.40 Table Mountain Ranch Road (right). Dakota cuesta on skyline ahead.

0.40

11.80 Lenticular alabaster in roadcuts on left.

0.50

12.30 More lenticular alabaster on left.

0.30

12.60 Slumped Dakota Formation on left.

0.80

13.40 Morrison channel sands and greenish shales outcrop on right. Canyon ahead developed mainly on slump blocks of Jurassic Morrison.

1.10

Cumulative Mileage

14.50 Maroon, green and orange shales of Morrison crop out on left; most represent rotated slump blocks.

0.70

15.20 Precariously tilted Dakota sandstone block known locally as "Lot's Wife" (right).

0.20

15.40 Crossing Dakota/Morrison contact. Road begins to climb section from lower to upper Dakota sandstones.

1.90

17.30 Farm Road 45 (right). Begin descent into Beaver Creek. Sangre de Cristo Range visible in far distance behind Wet Mountains. Wets make up most of nearer skyline. Low cuesta of Greenhorn Limestones holds up lower valley wall of Beaver Creek. Upper rim of Beaver Creek held up by Codell/Ft. Hays.

1.10

18.40 Beaver Creek.

0.10

18.50 Beaver Creek Ranch (left).

0.30

18.80 Begin crossing outcrop belt of Greenhorn Limestones (quarry on hill at upper right).

0.30

19.10 K Street (left). Codell/Ft. Hays crops out on hill to left.

0.40

19.50 G Street (left).

0.40

19.90 Third Street (right) and Brush Hollow Reservoir. Turn right (west).

0.20

20.10 E Street. Turn right (north) towards Brush Hollow boat ramp.

0.30

20.40 Cross irrigation ditch.

0.20

20.60 Cattle guard. Road begins to climb dip slope developed on Ft. Hays.

1.50

Cumulative Mileage

22.10 Crest of hill. Codell/Ft. Hays cuesta on left.

0.20

22.30 Turn left at Fremont 129 road.

0.30

22.60 Following strike valley in Blue Hill Shale. Codell/Juana Lopez and Ft. Hays form cliffs to immediate left. Krutak's 1970 measured section #33 is located in this vicinity. Juana Lopez at this locality interpreted as lagoonal bay biostromes. Pinel (1983b) mapped a widespread irregular scour surface at the Juana Lopez/Codell contact in this area. Stop to examine section.

0.60

23.20 Cattle guard and entrance to Brush Hollow Reservoir. Drive across intersection to edge of lake and turn around.

0.20

23.40 Turn around and retrace route back to Fremont 129 road.

0.30

23.70 Blue Hill shale crops out in low hill on right.

0.80

24.50 Turn right on E Street.

2.20

26.70 Turn left on Third Street.

0.20

26.90 Turn right on Highway 115 towards Penrose, Colorado.

0.50

27.40 Fourth Street intersection (cross-road).

1.10

28.50 Mr C. Restaurant (right) and city of Penrose exit (left).

0.80

29.30 Intersection of Highway 50 and 115. Turn right (west) to Cañon City, Colorado.

0.70

30.00 Arroyo (right).

0.30

30.30 Road to "Well" (left).

Cumulative Mileage

0.40

30.70 Flaming T Chuckwagon (right).

0.50

31.20 Holocene? pediment conglomerates capping slightly tilted Niobrara beds (right).

0.30

31.50 Top of rise. Wet Mountains on skyline from 9-12 o'clock. Vermejo sandstones capping Pierre shale at 10 o'clock. These are in the axis of the Cañon City Syncline. Twin Peaks visible at 1 o'clock. Two prominent water gaps in Dakota hogback are at 2:30 and ~2:45 o'clock respectively. Western water gap is Six Mile Creek (Phantom Canyon); eastern gap is upper Beaver Creek (Eight Mile Creek), site of University of Oklahoma Geology field camp.

0.40

31.90 Eight Mile Creek gravel pit (right).

0.60

32.50 Eight Mile Creek.

0.45

32.95 Intersection of Colorado Highway 50 and Airport Industrial Park (left).

0.35

33.30 Historic marker: Upper Arkansas River Valley (right).

0.25

33.55 Phantom Canyon Road (right) to Victor and Cripple Creek, Colorado.

1.25

34.80 North-south arroyo.

1.20

36.00 East Cañon correctional complex (left).

0.30

36.30 Mackenzie Avenue-Highway 50 crossing.

0.60

36.90 BLM (Bureau of Land Management) office (left).

0.35

Cumulative Mileage

37.25 Dozier Avenue; stoplight, turn right (north) towards United States Department of Agriculture building and Wal-Mart.

1.45

38.70 Van Loo Avenue (turn left).

0.40

39.10 Keep left (Dozier Road turns abruptly westward).

0.30

37.20 Drake Drive (right).

0.40

37.60 Intersection of Field Road and Central (turn right/north/).

0.10

37.70 Intersection of Field Road and Elizabeth (right).

0.70

38.40 Mary's Magazine (1035 Field) on left.

0.40

38.80 Intersection of North Street and Field. Road follows approximate axis of Cañon City syncline which plunges southerly behind us. Prominent hogback to left (west) is the Dakota sandstone. Lower white scarps are Ft. Hays/Codell which dip steeply eastward.

0.30

39.10 Intersection of Melvina and Field Road.

0.50

39.60 Hereford Drive (left). Begin descent of blind hill (careful!).

0.30

39.90 Sawmill (left). Mill on site of old Cañon City dump which was situated on Pierre shale concretionary zone.

0.75

40.65 Bradley Metals (left), 1802 Field Road.

0.20

40.85 Krutak's Codell section #23 (Four Mile Creek section). Lowest exposed sandstones here are about 3 m thick. Krutak (1970) did not include these in the Codell, but considered them "strays" in the upper Blue Hill

Shale. Mclane (1982) interpreted these sandstones and sandy shales as offshore bars. Juana Lopez strata at this locality are quartzose, with *Inoceramus* prisms. Krutak (1991) interpreted them as the proximal edge of a subaerial beach? or pond deposit localized in a swale behind a beach ridge.

0.15

41.00 Bridge across Wilson Creek.

0.15

41.15 Top of Dakota Sandstone (south dip).

0.05

41.20 Cattle guard paralleling Four Mile Creek.

0.20

41.40 Maroon Morrison shales (left) and thin channel? sandstones.

1.00

42.40 Domestic water supply tank (right).

0.90

43.30 Garden Park Fossil Area (right). Nearly complete skeletons of *Allosaurus*, *Apatosaurus*, *Camarasaurus*, *Ceratosaurus*, *Diplodocus*, *Haplocanthosaurus* and *Stegosaurus* were excavated from Morrison beds (*ca.* 135 mybp) of this area. The Cleveland Museum of Natural History quarry site (*Haplocanthosarus*) is across Four Mile creek. Note the sign descriptions of the O.C. Marsh quarry site. We will visit these shortly.

0.25

43.55 Garden Park memorial stone (left).

0.05

43.60 Arroyo (left). A short distance up this arroyo is the Marsh quarry site which contains spectacular channel sandstones as well as mollusc-ostracode sandstones. Turn around and retrace route back towards Cañon City.

2.50

46.10 Defaced stone marker (right) marking site of second oldest oil well (1862) drilled in the United States. Well site (on low terrace across creek) based on ozocerite outcrops in bed of creek to east. Site now occupied by remains of a uranium? prospect in creek bed. Note weak roll-over in both Dakota and Morrison sandstones that indicates the presence of a structural dome.

1.00

Cumulative Mileage

47.10 Y in road; keep right on Red Canyon Road.

1.20

48.30 Royal Gorge rifle range (right).

0.50

48.80 Intersection of Red Canyon (Phelps) and High Road (turn right).

0.10

48.90 Turn left (south) on paved road (Red Canyon Road).

0.60

49.50 Intersection of Red Canyon and South Street (bear right).

0.65

50.15 Intersection of 15th Street and South Street; turn left (south).

0.45

50.60 Intersection of 15th Street and Central Avenue. Drive straight ahead.

0.20

50.80 Royal Gorge Manor/Odd Fellows Complex (left).

0.70

51.50 Intersection of Main and 15th Street. Drive across intersection.

0.05

51.55 Intersection of 15th and Royal Gorge Boulevard (Highway 50). Turn right (west).

0.50

52.05 Intersection of Highway 115 and Highway 50; continue due west (8 miles to Royal Gorge).

0.60

52.65 Second Street (right) and Veteran's Park (left).

0.25

52.90 Colorado Correctional Facility (right) built in front of Dakota hogback.

0.45

53.35 Jurassic Entrada sandstones and Morrison Formation (right) at abrupt curve in highway.

0.30

Cumulative Mileage

53.65 Colluviated Entrada (right). Hogbacks of Ordovician Manitou dolomite and Harding sandstones at 9:00 o'clock below Precambrian granites on skyline.

1.70

55.35 Skyline Drive exit, ½ mile (right) and Entrada (below) and Morrison Formations (above).

0.55

55.90 Skyline Drive exit (right) and Razor's Ridge gift shop.

0.25

56.15 Green to maroon Morrison shales and tan conglomeratic sandstones (left).

0.40

56.55 Approximate Morrison/Dakota contact. Quarries in Ordovician Manitou dolomite at 3 o'clock.

1.10

57.65 Parking area (right). Exit vehicles and walk across road for overview of Cañon City Syncline. Note low-lying Codell/Ft. Hays hogbacks developed at base of Skyline Drive and intermediate low Greenhorn Limestone strike ridges.

0.20

57.85 Dakota bedding plane surfaces (right).

0.10

57.95 Switchback.

0.10

58.05 Dakota bedding plane (left) dipping steeply eastward.

0.15

58.20 Approximate Dakota/Graneros contact.

0.20

58.40 Approximate Graneros/Greenhorn contact.

0.15

58.55 Carlile (Blue Hill)/Juana Lopez contact. This is section #24 of Krutak (1970). It is cemented with dolomite (very rare in the Juana Lopez) and consists of ~2 ft of calcarenites and biosparites (Inoceramites) that directly overlie olive-gray, sandy or silty shale of the Blue Hill Member of the Carlile Shale. The rocks are interpreted to represent a reworked offshore bar deposit. The Codell is absent here.

Cumulative Mileage

0.05

58.60 Intersection of Skyline Drive (Floral Avenue) and 5th Street. Turn right on 5th towards Highway 50.

0.60

59.20 Intersection of 5th Street and Main.

0.10

59.30 Intersection of 5th Street and Royal Gorge Avenue (Highway 50). Turn right and retrace route west towards Colorado State Penitentiary.

3.45

62.75 Skyline Drive exit again (right).

1.15

63.90 Puddingstone rock quarry (right lower skyline) in Fountain? Formation. At 2'oclock the southeast nose of a sharply plunging anticline is visible. This plunges off the Precambrian high of the Twin Peaks area (granites).

0.75

64.65 Paleokarst (left) developed in upper phase of Williams Canyon? or lower part of Fountain.

0.20

64.85 Manitou (or Williams Canyon) outcrops (left) in small roadcut (Arroyo Seco Road).

0.35

65.20 Ordovician ostracoderm locality (right) in Harding sandstones, at one time reputed to be the oldest evidence of jawed vertebrates in North America. Stop to collect ostracoderm plates.

0.10

65.30 Pikes Peak granite (Precambrian)/Manitou contact. Note relatively flat contact plane, and time period of hiatus(the so-called Lipalian interval).

0.15

65.45 Massive outcrops (right) of Pikes Peak granite.

0.50

65.95 Weathered granite outcrops (left).

1.40

Cumulative Mileage

67.35 Royal Gorge of Arkansas (left) and Thunderbird Motel. High fourteen-thousanders of Sangre de Cristos on western skyline.

1.20

68.55 Highway 9 (76) Guffey Road (right).

0.20

68.75 Vertical to overturned Dakota/Morrison units (left).

0.05

68.80 Basic dikes cross-cutting granites.

0.15

68.95 Lensoid basic dike and other dike sets cross-cutting granites (turn-out on right to examine). Webster Park graben at 12 o'clock. Highway winds downward towards west entrance of Arkansas River into the Royal Gorge.

1.00

69.95 Parkdale (right).

0.10

70.05 Arkansas River bridge and west entrance of river into Royal Gorge.

1.60

71.65 Overturned Ft. Hays/Juana Lopez contact (left). This is section #29 of Krutak (1970). Inverted section due to thrusting from the west. Juana Lopez rocks at this locality are interpreted as a tidal flat deposit. Turn around at Parkdale Siding and retrace route back to Cañon City.

4.40

76.05 Royal Gorge turn-off (right). Turn right for over-view of the gorge.

1.25

77.30 Buckskin Joe and Mother Lode rock shop (good pegmatite fragments).

0.95

78.25 Buckskin Joe scenic route (right).

0.20

78.45 Hill at 11 o'clock is old Colonna Co. (Tezak Brothers) pegmatite mine (special permission required for entry). Road turns sharply right.

Cumulative Mileage

0.30

78.75 Entrance to city of Cañon, Royal Gorge Park (right).

0.90

79.65 Picnic area (left and right) and sign "1/2 mile to entrance of Royal Gorge." Make sharp left turn onto dirt road.

0.30

79.95 Keep right at Picnic area sign.

0.20

80.15 Park at right and hike 1/8 mile down steep trail for overlook of ptygmatic folds and schists of Royal Gorge and bridge/tramway. Wet Mountains in foreground; high Sangre de Cristos in background. Webster Park graben in background. After hiking back up trail, enter vehicles and follow dirt road back to pavement.

0.50

80.65 Intersection of Royal Gorge Road. Turn right back to Highway 50 (careful; steep grade for next 1.2 miles).

3.55

84.20 Intersection of Royal Gorge Road/Highway 50. Turn right (east) towards Cañon City.

6.55

90.75 Road 5332, Cañon City (right).

0.60

91.35 Tunnel Drive (right).

0.30

91.65 115-50 exit. Turn right (south) on 115 towards Florence, Colorado (9th Street).

1.20

92.85 Bridge over Arkansas River.

1.00

93.85 Intersection of Highway 115 and Elm Street. Turn right on Elm.

0.30

94.15 Elm/Valley Road intersection. Turn left (south) on Valley Road (County Road 143). Stay on Oak Creek Grade road.

0.60

Cumulative Mileage

94.75 Forge Road (right).

0.60

95.35 Shadow Hills Golf and Country Club (left).

0.25

95.60 Cotter Corporation Road (left).

0.20

95.80 Railroad crossing.

0.50

96.30 Vertical Vermejo sandstones (left). We are now on the west flank of the Cañon City syncline.

0.25

96.55 Clinker coal and coal prospect in Vermejo sandstones.

0.65

97.20 Vertical Codell/Ft Hays contact. Dakota hogback to right. This is section #28 of Krutak (1970). About 2.5 ft of Juana Lopez overlies 9 ft of Codell at this locality. The Juana Lopez may represent an offshore bar accumulation lying on upper shoreface sandstones of the Codell.

0.10

97.30 Weathered, steeply dipping Greenhorn limestones (left).

0.50

97.80 Turn around and drive back to Highway 115.

3.8

101.60 Intersection of Oak Creek Grade and Elm Street. Turn right (east).

0.30

101.90 Cañon City Public Works Facility and intersection of Elm Street with Highway 115. Turn right (east) on 115.

0.60

102.50 The Belvedere, a local eatery (right).

2.10

104.60 Brookside (right).

0.65

105.25 Outcrops of Vermejo sandstones in bluffs (right).

0.15

Cumulative Mileage

105.40 McKenzie Road (left)/Highway 115 intersection. Abandoned graffiti-covered store on right. A few old stripper wells in the axis of the Cañon City Syncline (Florence Oil Field) are off McKenzie Road.

0.85

106.25 Rockvale/Coal Creek intersection (County Road 11A) (right).

1.25

107.50 Railroad crossing. Pleistocene? gravels lying disconformably on Pierre shales (right).

0.05

107.55 Florence city limit (elevation 5187 ft).

0.55

108.10 Skyline Super Foods (right).

0.20

108.30 South Santa Fe and West Main (Highway 115) intersection in downtown Florence, Colorado.

0.10

108.40 Intersection of Highway 67/115, downtown Florence.

0.30

108.70 Intersection of Highway 67/115. Turn right (south) on 67 to Wetmore, Colorado.

End of second day - Highway 67/115 intersection.

THIRD DAY: Florence, Colorado to Farisita, Colorado.

RESUME

On this third day, we will drive southward towards Wetmore, Colorado (Hardscrabble Creek), but instead of going into Wetmore, we will intersect Siloam Road, which was part of the old army supply trail leading from Denver to Santa Fe, New Mexico. Various units of the Codell/Juana Lopez crop out along this route (Krutak, 1970, Section 5). After intersecting state highway 78 about 5 miles east of Beulah, Colorado, we turn eastward towards Pueblo. Excellent outcrops of the Codell/Juana Lopez occur along this highway and we will study one in particular (Krutak, 1970, Section 10).

After retracing our route to the burial site of the Muldoon Giant (P.T. Barnum's 1877 hoax to garner publicity for his various enterprises), we will turn south

on the 3-R Ranch Road and parallel the eastern front of the Wet Mountains. As we approach state highway 165, the
Rattlesnake Buttes (mentioned in James Michener's novel Centennial) loom up on the horizon as well as the famous Spanish Peaks (classic Tertiary stocks and radial dike systems - see Fig. 5) and the Culebra Range in northern New Mexico.

At the intersection of Highway 165, we turn westward and drive about 7 miles up to Rye, Colorado where we will examine a Codell/Juana Lopez section exposed on Rattlesnake Mountain. Our route then follows 165 back down to Interstate 25; there we will study another very well exposed Codell/Juana Lopez section (Krutak, 1970, Section 11).

The final leg of the field seminar takes us south and west towards Walsenburg, Colorado. We will exit Interstate 25 at Red Creek Road and drive westward towards the Calumet #2 coal mine (now abandoned), where coals contained within the Vermejo Formation were mined. This mine, on state highway 69, marks the beginning of the last section of the field trip. We will proceed westward along Highway 69 towards the crossing of the Huerfano river with the south-plunging nose of the Wet Mountain Arch. The field seminar ends at Codell section #39 (Krutak, 1970) just east of Gardner, Colorado where Arco produces subsurface CO_2 from both Dakota and Entrada sandstones at their Sheep Mountain Field. The Codell produces methane rather than CO_2.

Cumulative Mileage

0.00 Reassemble at Persolite Manufacturing Co. on Highway 67 just south of Highway 67/115 intersection in Florence, Colorado.

0.05

0.05 Railroad track and Mountain Division of SW Portland Cement Co., Florence, Colorado.

0.65

0.70 River Valley Inn (left).

1.20

1.90 Federal Correctional Complex (left), U.S. Department of Justice.

2.40

4.30 Fremont County Road 15, Mountain Park turnoff (right).

0.90

5.20 Bridge.

0.30

Cumulative Mileage

5.50 Bridge.

1.00

6.50 Siloam Road (turn left) = Fremont County Road 106.

1.00

7.50 Narrow bridge (bear right).

1.60

9.10 New Hope Cemetery (left).

0.50

9.60 Road 298T (bear left).

0.10

9.70 Sharp right (turn onto Road 297).

1.10

10.80 Intersection of Road 297 with Colorado 78; turn left (east) on 78.

0.80

11.60 Overhead pipeline crossing.

0.60

12.20 Pueblo County line.

2.40

14.60 Holmes Road (right).

0.45

15.05 Bridge.

0.45

15.50 Don K Ranch road (Siloam Road); turn right (south).

1.75

16.25 Abrupt right turn.

0.55

16.80 Abrupt left turn.

1.40

18.20 Cattle guard; bear left.

0.55

18.75 Bridge in swale. Codell/Ft. Hays holds up knob on left. This is approximate location of Krutak's (1970), Section 5 (Bronquist Farm). The entire Codell-Juana Lopez sequence is 30.8 ft thick at this locality. Capping the sequence is a 1.5 ft thick, richly fossiliferous (shark and fish bone) phosphatic calcarenite of the Juana Lopez underlain by about 29.3 ft of Codell sandstones. As elsewhere in the Codell, the average grain size of Codell quartzarenites at this section increases from the base of the section upwards (~200-500 microns /longest apparent grain axes in microns/ see Krutak, (1991, Fig. 15, p. 129).

0.85

19.60 Don K Ranch entrance (right). This is a famous dude ranch which caters to the image of the western cowboy. They have been in business for many years.

0.20

19.80 Graneros shale and Greenhorn limestone strike ridges (left).

0.55

20.35 Cattleguard.

0.95

21.30 Blue Hill/Codell/Ft. Hays rocks hold up hill at left.

0.30

21.60 Crossing Greenhorn strike ridge.

0.20

21.80 Intersection of Siloam and Red Creek Springs Road.

0.05

21.85 Bridge on Siloam Road.

0.65

22.50 Dakota sandstone quarries (left).

0.90

23.40 Beginning at this point, the road is constructed on the top of the Dakota sandstone.

1.50

24.90 Intersection of Savage Road and Siloam Road; turn left.

0.40

25.30 Intersection of McDowell Road and Savage Road; bear right.

0.70

26.00 Even Road (right).

0.50

Cumulative Mileage

26.50 Sharp left.

2.10

28.60 Sharp right.

0.90

29.50 Old log cabin (left).

0.20

29.70 Bridge.

0.80

30.50 Curve left.

0.55

31.05 Pavement begins.

0.25

31.30 Intersection of Siloam Road and Colorado 78 (Beulah Road). Turn right towards Beulah (5 miles west).

0.40

31.70 Muldoon Giant marker. Site of the reburial of the fake fossil man concocted (for publicity purposes) by P.T. Barnum and George Hull on Sept. 16, 1877. The Beulah Historical Society exhumed the "remains" from the original burial site (exact location probably near Muldoon Hill which is nearby) and had them reinterred here with pomp and ceremony (Sweetgrass Band playing) on July 22, 1984. The epitaph on the tomb reads: "Here lies the Solid Muldoon whose moniker came from a tune. A great man was he, may his spirit roam free. Long live our Solid Muldoon." Apparently the "remains" were more than 8 ft long. They were fabricated to resemble fossil material by P.T. Barnum in New York state, shipped to Pueblo and then secretly buried near Muldoon Hill. Barnum then announced their discovery and they were hauled by horse and buggy to a display site in Pueblo where the curious could view them for a price.

Turn around and drive east (left) on Highway 78 towards Pueblo, Colorado.

1.40

33.10 County Road 224 (right).

0.80

33.90 Waterbarrel Road (right).

0.85

34.75 Mile marker 19 (right).

0.40

Cumulative Mileage

35.15 Greenhorn limestone outcrops (left).

0.15

35.30 Dakota sandstones crop out at 7:30 o'clock in arroyo on left. Blue Hill shales overlain by Codell/Ft. Hays cap bluffs from 9 o'clock to 2 o'clock.

0.65

35.95 Bridge.

1.80

37.75 Base of steep hill. Road climbs section from Graneros shale (base @ 10 o'clock) through Greenhorn up to skyline where Codell/Ft. Hays crops out. Pikes Peak on horizon at 9:00 o'clock.

0.30

38.05 Blue Hill/Codell contact (left). Section climbs from base of Codell through Juana Lopez at top of hill. This is section 10 of Krutak (1970) and section 33 of Mclane (1982). Stop to discuss stratigraphy.

The Codell is 23 ft (7 m) thick here and is quite heterogeneous. Mclane described at least four types of sandstones and shales at this outcrop (hummocky cross-stratified, flat-laminated, bioturbated, and lenticular-bedded units). The upper part of section contains 12-16 in (30-40 cm) long rill marks as well as sets of intersecting ripples. Mclane interpreted these to represent a series of lower shoreface to middle shoreface-upper shoreface sandstones and shales capped by cross-bedded, ebb-tidal delta sandstones. The Juana Lopez at this locality consists of a thin (0.7 ft/0.2 m) bored biosparite that Krutak (1991) interpreted to represent an offshore bar. Reisser (1976) point-counted the Codell here and showed that it contains more than 80% monocrystalline quartz, with chert and potash feldspars comprising most of the framework grains. Turn around and drive back westward towards Beulah, Colorado on Highway 78.

3.20

41.25 Dakota sandstones faulted against Graneros shales (left). Fault plane strikes N30°W and dips 64°SW; slickensides and drag indicate the fault is normal.

3.50

44.75 Muldoon Giant historic marker again (right).

0.45

45.20 Siloam Road (right).

0.35

45.55 Mountain Shadows Mobile Estates (left).

0.60

Cumulative Mileage

46.15 3-R Road (left). Turn left. Road winds south along top of Dakota sandstone. This road follows one of the oldest trails in southern Colorado. The trail was a major military route between Camp Weld near Denver and Fort Garland in the San Luis valley. Mount Signal, four miles southwest, marks the entrance into Beulah valley. Originally the valley was known as Fisher's Hole, after Robert Fisher, an early mountain man. When first settled, the valley was called Mace's Hole, after the legendary Juan Mace, who rustled cattle and used it as a hideout. The town was renamed Beulah in 1876.

0.65

46.80 Bridge (turn right).

0.30

47.10 Rancho San Carlos (right).

1.00

48.10 Bridge. Wet Mountains at 12 o'clock on horizon.

1.75

49.85 Old Hum Road (right).

0.25

50.10 Narrow bridge.

1.45

51.55 Sharp right turn.

0.35

51.90 Sharp left turn.

1.65

53.55 Intersection of Haynes Road and 3-R Road. Turn left.

0.65

54.20 Triple Y Ranch (right).

0.70

54.90 Curve right.

1.50

56.40 Bridge and intersection of Burnt Mill Road and Crow Cut- Off. Turn right (west) on Crow Cut-Off.

1.05

57.45 Greenhorn limestones (right) in arroyo.

0.45

57.90 Codell/Ft. Hays contact (left).

Cumulative Mileage

0.15

58.05 Blue Hill/Codell contact at 11 o'clock.

0.25

58.30 One lane bridge.

0.85

59.15 25 mph marker. Two prominent buttes at 12 o'clock are Rattlesnake Buttes. These were mentioned in James Michener's novel "Centennial." Spanish Peaks (Breasts of the World) at 2:30; Cuerno Verde Peak at 3:30; Culebra Range (in New Mexico) from 2:30-2:45; Apache Range (a southern spur of the Wet Mountains) at 3:00 o'clock.

0.05

59.20 Intersection of Broadmore and Crow Cut-Off. Turn left on Crow Cut-Off.

0.45

59.65 Begin paved road.

0.45

60.10 Bridge. Ft. Hays limestones on left in arroyo.

0.35

60.45 Jefferson Boulevard (left).

0.25

60.70 Craver Middle School (left).

0.40

61.10 Bent Brothers Boulevard (right).

0.20

61.30 Intersection of Colorado 165 and Crow Cut-Off. Turn right (west) towards Greenhorn Mountain.

0.40

61.70 Ol Zan's (Alexander Hicklin, founder of the Greenhorn Valley) Place (bar and restaurant) on right.

0.05

61.75 Bent Brothers Boulevard and Greenhorn Valley Professional Center (right).

0.35

62.10 Ft. Hays limestones and Codell/Ft. Hays contact (right).

0.50

Cumulative Mileage

62.60 Greenhorn Meadows Park (left). A memorial marking the site of the defeat (and death) of the Comanche chief Cuerno Verde (the Cruel Scourge) is near Greenhorn Creek in the Park. In 1779, Juan de Anza, the Spanish governor from Santa Fe, chased Cuerno Verde and his mauraders from the southern San Luis Valley around the north end of the Wet Mountains and then southward until he and his troops finally caught up with them at this site.

0.10

62.70 Cuerno Verde Boulevard (right).

0.20

62.90 Greenhorn Road (Highway 181) on right.

0.55

63.45 Blanco Street (right).

0.35

63.80 Alondra Drive (right).

0.65

64.45 Sancho's Bar (right).

0.15

64.60 Bridge over Cold Spring Creek. Codell/Ft. Hays contact in bluff on left (south) side of Greenhorn Creek.

0.30

64.90 Stanley Avenue (left).

0.75

65.65 Gift shop (right).

0.35

66.00 Greenhorn limestones dipping steeply eastward off the flank of a "box" fold.

0.30

66.30 South plunging nose of "box" fold outlined by rollover in Dakota sandstones (right).

0.40

66.70 Valley View Drive (right) and Rye Trout Farm (left) intersection. Continue west on highway 165.

0.40

67.10 Decibel Credit Union (right).

0.15

Cumulative Mileage

67.25 Ludvik Propane yard (right) and St. Aloysius Catholic Church (left).

0.25

67.50 Turn left off highway 165 onto Main Street (Park Road) into Rye, Colorado (elevation 6900 ft).

0.05

67.55 Rye Methodist Church (right).

0.05

67.60 Oak Street (left) and Eagle River Pewter Company.

0.10

67.70 Intersection of Boulder Avenue and Main Street and Rye Volunteer Fire Department (left). Continue across intersection due west towards mountain front.

0.05

67.75 Rye House Inn and RV Park-Cabins (left). Co-owned by Paul R. and Jerri N. Krutak.

0.20

67.95 Columbine Road (left).

0.20

68.15 City of Rye water works (right).

0.15

68.30 Singer Lane (left)/Park Road intersection. Park and walk up steep dirt road about 20 yards northeast of Singer Lane/Park Road intersection to top of Rattlesnake (Spring Mountain) Hill.

This is Krutak's (1970) section 13. Stop to overview the village of Rye and discuss stratigraphy. The lower Codell here is interpreted as an offshore bar; bioturbated sandstones cap the bar sequence at this locality. The thin, overlying Juana Lopez probably represents a tidal flat deposit. After discussion, walk back to cars, and drive back through Rye to Colorado 165 and eastward towards Interstate 25.

1.00

69.30 St. Aloysius Catholic church (right).

2.10

71.40 Palomar road (right).

0.20

71.60 Colorado City sign (right).

Cumulative Mileage

0.05

71.65 Stanby Avenue (right).

0.35

72.00 Cold Spring Creek bridge.

1.70

73.70 Greenhorn Road (Highway 181) on right. This is old cut-off to town of Greenhorn and Apache. Cliffs at 12 o'clock are upper Dakota sandstones.

0.30

74.00 Greenhorn Meadows Park (turn right).

0.05

74.05 Sign at creek reads "In this vicinity the Comanche chief Cuerno Verde (Greenhorn), the "Cruel Scourge", was defeated and killed by the Spaniards under Governor Juan B. Anza on Sept. 3, 1779. The nearby mountain and stream take their name from the chief. Anza's was the first Mexican expedition through this part of Colorado.

Continue east past sign on dirt road toward Greenhorn Meadows baseball diamonds.

0.20

74.25 CCC (Civil Conservation Corps) bridge (right) over Greenhorn Creek. Krutak's (1970) Colorado City Campground section (12) was measured here on opposite side (south)of Greenhorn Creek (see Figs. 17and 18 of this Guidebook). The section displays a coarsening upward Codell sequence capped by calcarenitic Juana Lopez rocks believed to represent tidal flat deposits.

0.90

75.15 Intersection of dirt road with pavement. Turn left (north) on black-top to Colorado 165.

0.10

75.25 Intersection with Highway 165. Turn right. Ft. Hays limestones crop out directly across road at 12 o'clock.

0.50

75.75 Greenhorn Valley Bank (left).

0.25

76.00 Stewart's Thoroughbreds (right).

0.25

76.25 Greenhorn Valley Tru-Value Hardware (right).

Cumulative Mileage

0.60

76.85 Delicatessen (right).

0.25

77.10 Applewood Drive (right).

0.40

77.50 Greenhorn Mountain Resort (right) and entrance (left) to new I-25 tourist directory.

0.15

77.65 Bridge across I-25. Drive across and turn left (north) on frontage road in front of Texaco Cafe. Continue north to end of pavement onto gravel frontage road.

0.50

78.15 Codell/Ft. Hays contact at Krutak's (1970) section 11. Note minor faulting. This section (Codell+Juana Lopez) is10.3 ft thick. Codell materials at this outcrop probably represent offshore bar deposits overlain by bioturbated sandstones which are capped by Juana Lopez tidal flat deposits. Note the pronounced filled borings of Juana Lopez cutting into the underlying Codell as well as the "podded" biosparites incorporated into basal Ft. Hays limestones.

Walk back to vehicles and turn around and retrace route back to I-25.

0.45

78.60 Turn right across I-25 and then left on I-25 (south) towards Walsenburg, Colorado.

1.05

79.65 Un-named creek (right).

0.80

80.45 Dakota crops out (left) as road climbs hill.

0.75

81.20 Columbia House (right).

0.45

81.65 Graneros Gorge exit (right).

1.10

82.75 Graneros Creek.

0.25

83.00 Graneros shale outcrops (right).

0.20

83.20 Greenhorn limestones and shales (left).

Cumulative Mileage

0.50

83.70 Blue Hill/Codell/Ft. Hays outcrops (left).

0.10

83.80 Crest of hill. Huerfano (Orphan) Butte at 12 o'clock, Greenhorn Peak at 3 o'clock, Spanish Peaks from 1-3 o'clock.

0.30

84.10 Underpass.

0.20

84.30 Huerfano County line. We are now on the north flank of the Raton Coal Basin.

1.95

86.25 Exit 67, Apache (right).

0.15

86.40 Underpass.

1.30

87.70 Exit 64 (Lascar Road), right.

1.25

88.95 Underpass.

2.30

91.25 Bridge.

2.35

92.80 Huerfano River and Huerfano Butte (left across highway).This butte was a conspicuous landmark used by Indians as well as early trappers and travelers along the Santa Fe cut-off trail.

0.90

93.70 Exit 59, Butte Road (right).

2.25

95.95 Exit 56, Red Rock Road; turn right (west) on Red Rock Road.

2.00

97.95 Cattleguard and TV relay station. Dike (Silver Tip) Mountain at 1 o'clock on horizon; Calumet #2 coal mine dumps in foreground at 1:30 o'clock. Sheep Mountain (flat-topped) at 2 o'clock with Sangre de Cristos in far background from 2:00-2:30 o'clock. Badito Cone (near south end of Wet Mountains) in near distance at 2:30 o'clock.

0.70

Cumulative Mileage

98.65 Intersection with Colorado 69. Turn right (north).

0.05

98.70 Calumet #2 coal mine (left). Mine produced Vermejo-age coal. Greenhorn Peak at 12 o'clock.

1.10

98.80 Culvert.

0.75

99.55 Sharp left curve and old coal mine dumps.

0.30

99.85 Sharp left curve.

0.90

100.75 Curve left. Badito Cone at 2:30 o'clock. Sangre de Cristo Formation (Pennsylvanian-Permian) red beds visible to left of Badito Cone.

0.30

101.05 Paris Ranch road (left) and old coal town foundations.

0.30

101.35 Vermejo sandstone outcrops (left).

0.55

101.90 Vermejo sandstones and coals (left).

0.15

101.05 Ranch road (left).

0.50

102.55 Arroyo.

0.20

102.75 Ranchito (left) and old coal mine dumps (note red clinker coal).

0.30

103.05 Top of rise. Mahogany Hills (sills) on lower skyline from 10:00-11:30 o'clock.

1.00

104.05 Cattle underpass.

0.60

104.65 Double DU Ranch (left).

0.20

104.85 Bridge.

0.90

Cumulative Mileage

105.75 Cattle underpass.

0.45

106.20 Niobrara outcrops (left).

0.25

106.45 Pierre shales (left).

0.30

106.75 Niobrara rocks dipping steeply westward (left).

0.10

106.85 Ft. Hays/Codell contact (Krutak, 1970, section 39). Drive 0.10 mile farther west to park at turn-around.

0.10

106.95 Turn-around (right) and park at Badito (old adobe house in creek bed is built on site of ancient Spanish Fort). Yellowstone Road to south leads to La Veta Pass and the town of La Veta, Colorado. Old wagon road to Sangre de Cristo Pass climbed the hillside to the south.

The combined thickness of the Codell/Juana Lopez at this locality is about 20 ft. Most of the Codell is light gray to very pale orange sandstones and shaly sandstones that total about 17 ft. A thin (2.75 ft) Juana Lopez biosparite caps the section. Krutak (1991) interpreted the Codell at this locality to be an offshore bar sequence.

0.25

107.20 Bridge over Huerfano River and entrance to Huerfano Park. The little, almost defunct village of Farisita, Colorado is about a mile west; beyond this the road leads to Gardner, Colorado and Arco Permian's Sheep Mountain CO_2 field.

End of field excursion.

TOC