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Cover

View to southeast toward the Henry Mountains from the Old Notom Road, 3190 S. (BLM 0086) across Morrison and Cedar Mountain Formations to characteristic double escarpment formed of the Mancos Group on the northern end of the Henry Mountains basin.

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Revisiting the Cretaceous Mancos Group in Utah—Problems, Previous Methods, and New Perspectives on a World-Class Cretaceous Marine Section

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ABSTRACT

The Mancos Group is an upper Cenomanian-middle Campanian lithostratigraphic unit that records large-scale changes in sedimentation patterns associated with the incursion of the Western Interior seaway across western Colorado into central Utah. Understanding the stratigraphic relationships in this unit is of critical scientific importance to understanding marine stratigraphic sequences across the globe.

This field trip focuses on synonymizing units into consistent lithostratigraphic packages in the framework of biostratigraphy and currently available geochronology. Field trip stops emphasize the hierarchical division of each Mancos unit, the information present/absent for correlation, and fossil occurrences and how they relate to paleoenvironment and index fauna, as well as disparate sedimentological characteristics (grainsize, bioclastic content, glauconite abundance, cementation).

INTRODUCTION

This field trip is part of the 75th annual meeting of the Rocky Section, Geological Society of America, and focuses on the proposed lithostratigraphic framework and molluscan biostratigraphy of the Cretaceous Mancos Group in east-central Utah. The field trip will examine surficial exposures from the northern Henry Mountains basin across the southeastern Uinta Basin, northern Paradox Basin, and southwestern Piceance Basin along the Book Cliffs to approximately Loma, Colorado, and along the western Book Cliffs to the northern end of the San Rafael Swell north of Helper, Utah, into the mouth of Price Canyon (Figures 1 and 2). The Mancos Group has important implications for subsurface fluid flow (hydrocarbons, groundwater, and carbon sequestration) as the shale and mudrock units provide a thick seal and are an important aquitard (Lines et al., 1983; Goodknight and Smith, 1996), whereas permeable sandstone units serve as conduits and reservoirs relative to fluid flow. Numerous studies have been conducted on the clay-rich shale to understand the quality of the seal in terms of inter- and intra-granular permeability (Goral et al., 2020), fracture and rock mechanics (Petrie et al. 2014; Chandler et al., 2016; Choens et al., 2019), and fluid-rock interactions (Espinoza et al., 2018; Sheng et al., 2021). Studies of the coarser lithologic bodies (e.g., Ferron Sandstone, Emery Formation, and Prairie Canyon) within the Mancos Group have focused on understanding reservoir characteristics as well

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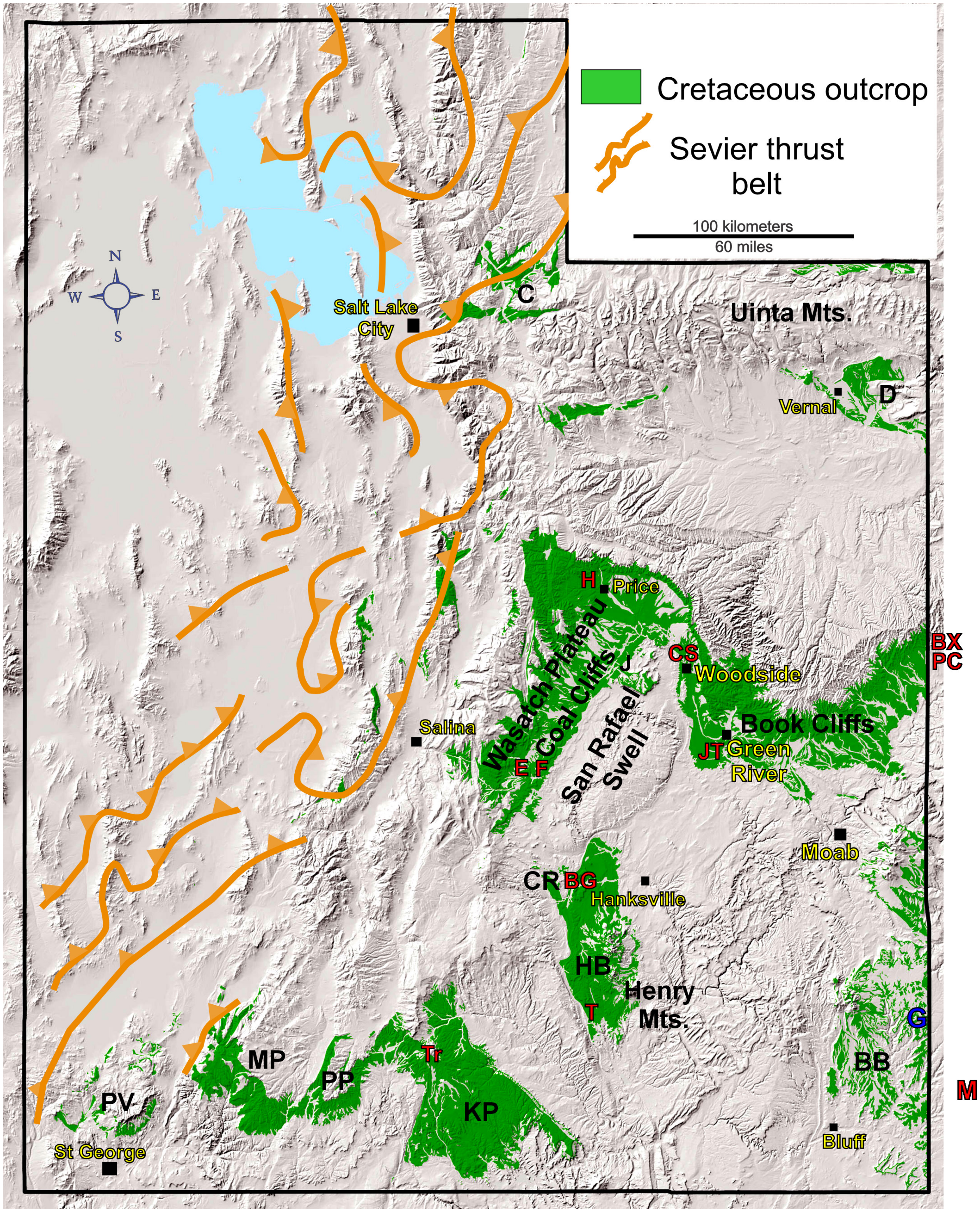

Figure 1. Utah's Cretaceous outcrop belt relative to the Sevier thrust belt. Black text indicates important depositional areas: BB = Blanding basin, C = Coalville area, CR = Capitol Reef National Park, D = Dinosaur National Monument, HB = Henry Mountains basin, KP = Kaiparowits Plateau, MP = Markagunt Plateau, PP = Paunsaugunt Plateau, PV = Pine Valley Mountains, Blue G = western extent of Greenhorn Formation into the Blanding basin. Red letters indicate location of type sections: BX = Bar X Shale, BG = Blue Gate Shale, CS = Coon Spring Sandstone Member, E = Emery Formation, F = Ferron Formation, H = Helper Formation, JT = Jessies Twist Member, M = Mancos Group, PC = Prairie Canyon Formation, T = Tununk Shale, Tr = Tropic Shale. From Kirkland et al. (2024).

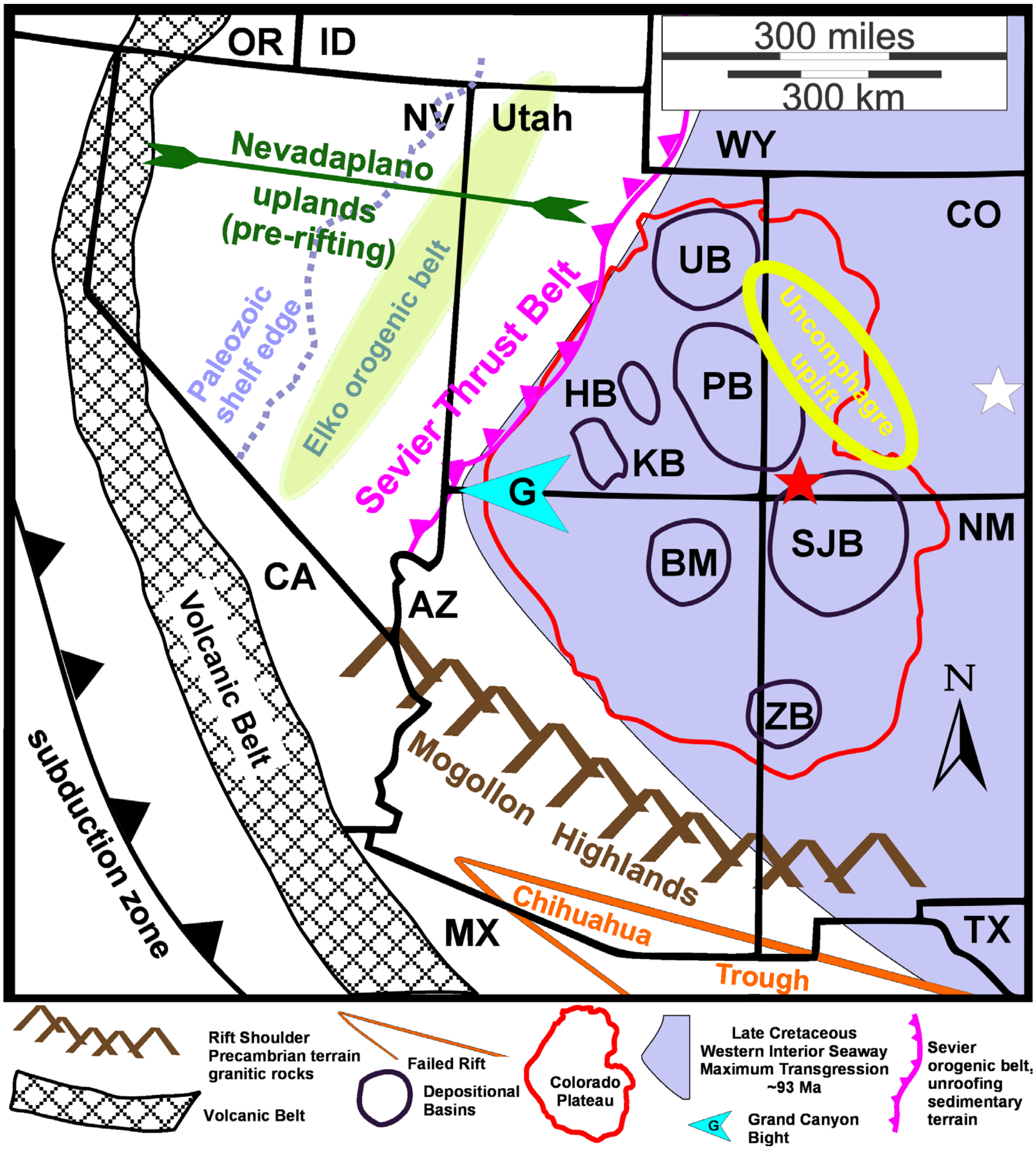

Figure 2. Late Jurassic through Late Cretaceous tectonic framework for the southwestern United States. Depositional basins: BM = Black Mesa Basin, G = axis of the Grand Canyon Bight, HB = Henry Mountains basin, KB = Kaiparowits Basin, PB = Paleozoic, Paradox Basin, SJB = San Juan Basin, UB = Uinta Basin, ZB = Zuni Basin. Red star = Mesa Verde National Park, type area for Mancos Group. White star = approximate location of classic upper Cretaceous sequence west of Pueblo, Colorado, Colorado Front Range. Modified after Kirkland et al. (2024).

as sequence stratigraphic relationships of these units (Gardner, 1993, 1995; Cole et al., 1997; Hampson et al., 1999; Anderson et al., 2004; Barton et al., 2004; Forster et al., 2004; Gardner et al., 2004; Garrison and van den Bergh, 2004; Ryer, 2004; Stevens, 2004; Edwards et al., 2005a, 2005b). The less permeable lithologies have been targeted as shale gas reservoirs and investigated as organic-rich source rocks (Schamel, 2008; Chidsey and Vanden Berg, 2015; Hawkins et al., 2016). Additionally, the surficial/shallow subsurface meteoric processes in the Mancos have implications for groundwater and surface water (Morrison et al., 2012; Mast et al., 2014; Tuttle et al., 2014), as well as it being loci for landslide hazards (Varnes, 1949; Godfrey, 1997).

The Mancos Group is a thick, widespread Upper Cretaceous marine and marginal marine sequence preserved within many basins across the Colorado Plateau region (Figure 2). A highly refined invertebrate biostratigraphy permits detailed correlations of these Upper Cretaceous strata to be made across the Western Interior and internationally (Figure 3) and has been most recently summarized by Cobban et al. (2004) and Singer et al. (2023). The Mancos Shale was initially named by Cross (Cross and Purington, 1899) for "typical exposures" that occur in the Mancos River Valley between the LaPlata Mountains and Mesa Verde near Mancos, Colorado. In this area the unit consists predominantly of marine shale and mudstone with subordinate lithologies including thin beds of limestone (Four Corners Region only), calcarenite, bentonite, concretions, and sandstone. In its type section, in the northern part of the San Juan Basin, the Mancos Shale records nearly continuous marine deposition from late Cenomanian to earliest Campanian time (Leckie et al., 1997).

Kirkland et al. (2024) formally proposed to raise the Mancos Shale to Mancos Group (from that of a formation across the region) as its traditional members in Utah are already mapped as separate formations. This work extended the original members defined for the Mancos Shale in central Utah eastward as formations separating the members recognized in the Mancos Shale reference section (Figure 4) at Mesa Verde, Colorado, by Leckie et al. (1997). At the Mesa Verde reference section, the only discrepancies with the central Utah section included raising of the Juana Lopez Member to formational status separating the Tununk interval and Blue Gate Shale, and dividing the Tununk interval into two formations, a lower Greenhorn Formation and an upper Carlile Shale where the limestone-shale couplets of the Bridge Creek Member are recognized.

Jameson (1911) originally applied the term "Mancos Group" to 6698 feet (2042 m) of marine shale and sandstone between the Dakota and Mesa Verde Formations in western Wyoming. This section included what we now identify as the Lower Cretaceous, Albian-age Skull Creek Shale up into the Campanian-age Pierre Shale. "Mancos Group" was also applied to the marine Upper Cretaceous section in northwestern New Mexico by Zakis (1952), as well as a 1957 study of microfossils in the Book Cliffs (Sarmiento, 1957). In describing the Mancos in the Henry Mountains basin region, Peterson

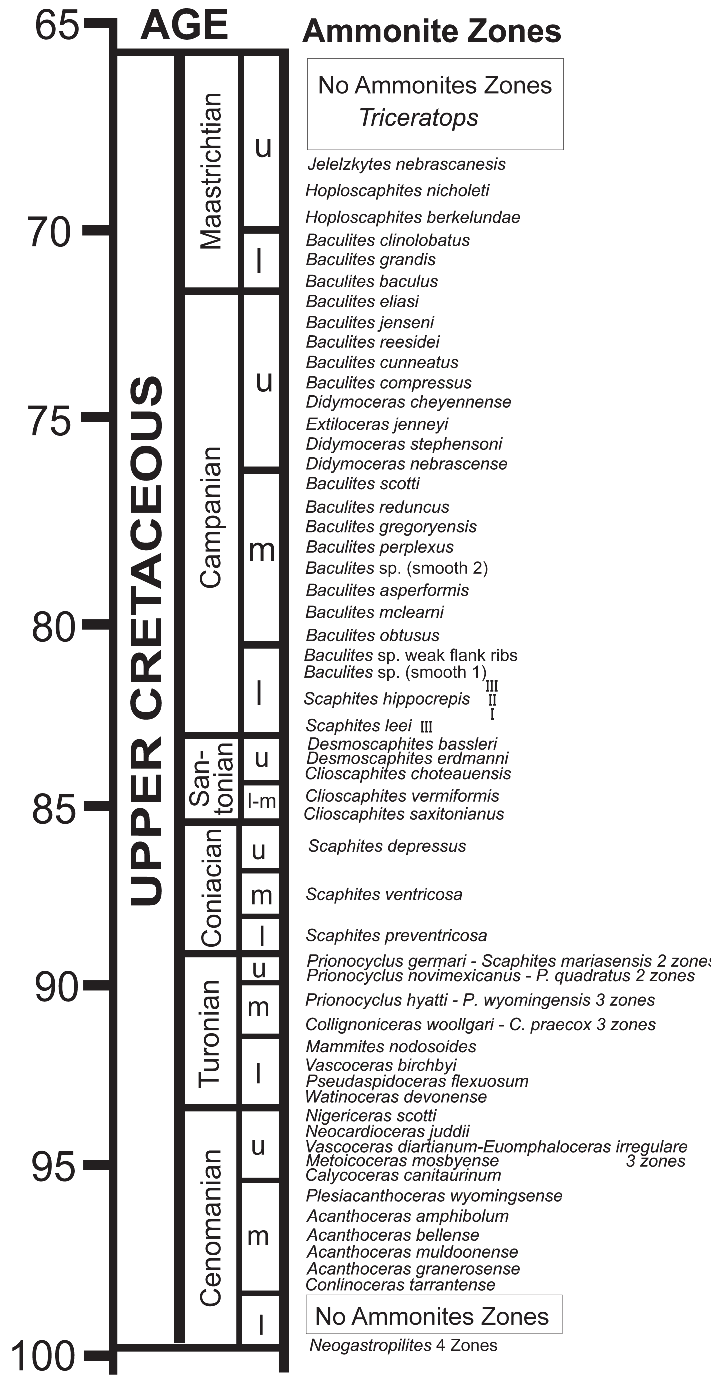

Figure 3. Upper Cretaceous time scale used herein vs. current ammonite zonation. Data compiled following Cobban et al. (2004) and Singer et al. (2023).

and Ryder (1975, 1980), noted that the five mappable members were present and should be raised to formation status. Molenaar and Wilson (1990) more formally raised the Mancos Shale to group rank on the north

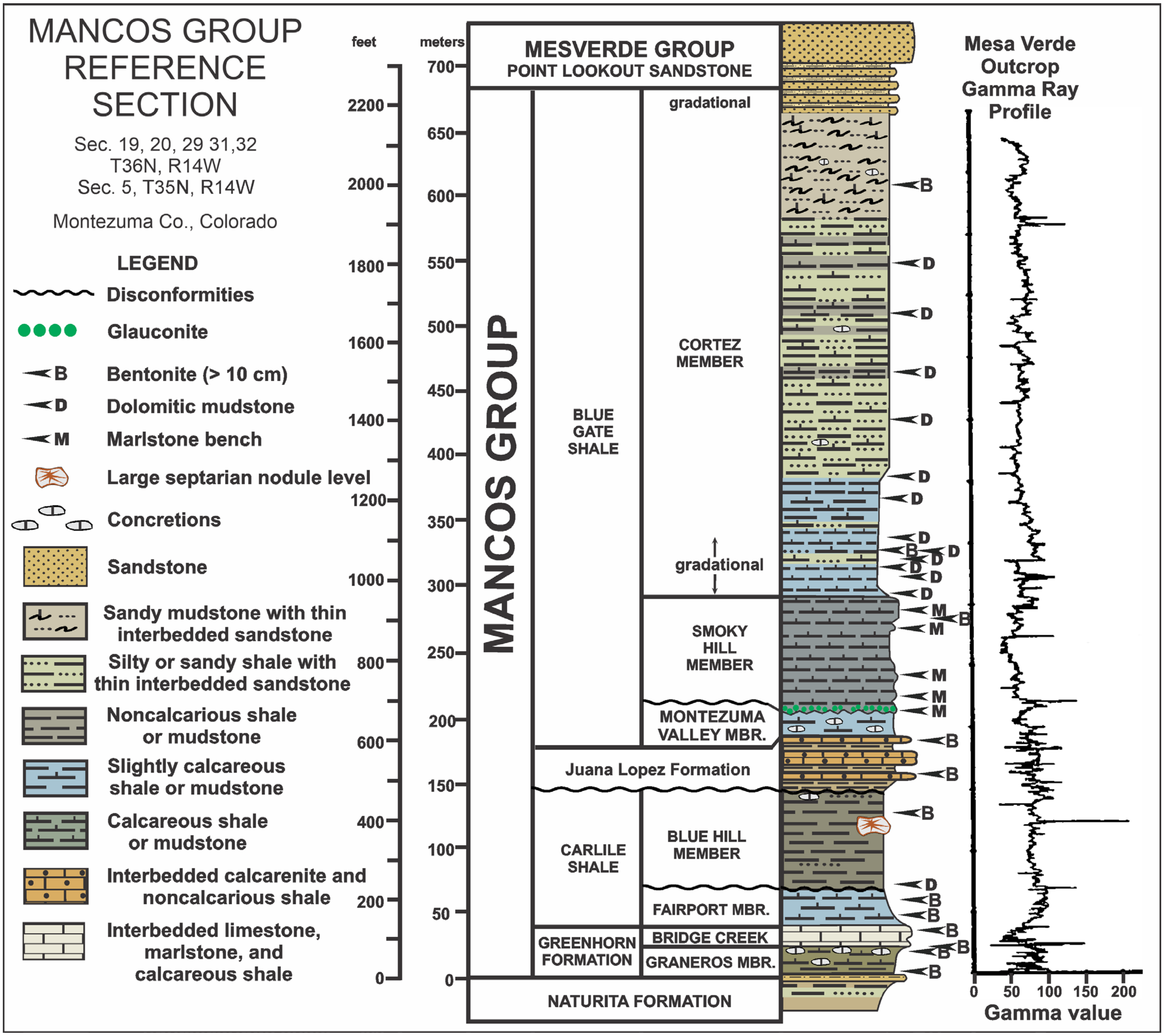

Figure 4. Mancos Group reference section at Mesa Verde National Park. Correlation of gamma-ray profile of the Mancos Group principal reference section with geophysical log profiles from the northern part of the San Juan Basin. Modified after Leckie et al. (1997) with stratigraphic nomenclature proposed by Kirkland et al. (2024).

sides of the Uinta and Piceance Basins because the Frontier and Mowry Formations were widespread mappable units (formation status): "The Mancos is raised to group rank in the report area where it is divided into, in ascending order, the Mowry Shale, an unnamed shale unit, the Frontier Formation, and the main body." On the north side of the Uinta Mountains, the term Mancos is not used. Despite the aforementioned exceptions, group rank has not been widely applied to the Mancos Shale across the core of its outcrop area. At best, it can be said that Group usage has been tentative across the Uinta and Piceance Basins (Kirschbaum, 2003; U.S. Geological Survey Uinta-Piceance Assessment Team, 2003).

The Mancos Group records several global tectono-eustatic sea level rise and fall sequences or cyclothems. Whereas it was initially described more simply in the central Western Interior of the United States as consisting of symmetrical packages of sediments recording transgression of deepening marine strata over coastal terrestrial strata followed by shallowing marine environments with regression of the sea from the region (Kauffman, 1969, 1977; Kauffman and Caldwell, 1993), it was soon determined that these cyclothems were highly asymmetric, as the shallow marine environments were typically sediment starved. The clastic sediment supply was trapped in the coastal estuarine environments having rising depositional baselevel, with disconformities representing more minor sea level rise events. (Ryer, 1976, 1977, 1984; Molenaar, 1983; Molenaar et al., 2002). Three major third-order cyclothems are recorded by the Mancos: (1) The Cenomanian into Middle Turonian Greenhorn Cyclothem recorded by the Naturita Formation, Tununk Shale, and lower Ferron Formation, (2) the Middle Turonian through Lower Campanian Niobrara Cyclothem recorded by the upper Ferron Formation, Juana Lopez Formation, Blue Gate Shale, Emery Formation, Helper Formation, and Prairie Canyon Formation, capped by the regressive marine Star Point Sandstone and lower half of the Blackhawk Formation (see below), and (3) the upper Lower through Middle Campanian Claggett Cyclothem recorded by the upper regressive Blackhawk Formation, Bar X Shale, lower Castlegate Sandstone, Buck Shale and interfingering Sego Sandstone, and Anchor Mine Shale.

The unconformity bound Sage Breaks hemicyclothem of the upper Carlile Shale is generally included at the transgressive phase of the Niobrara Cyclothem as these unconformities are largely amalgamated across the central Western Interior seaway (Hattin, 1975; Glenister and Kauffman, 1985; Mereweather et al., 2007). The upper Middle Turonian through Turonian Sage Breaks hemicyclothem is recorded by the upper Ferron Formation, Juana Lopez Formation, and Montezuma Valley Member of the Blue Gate Shale. Kauffman et al. (1977) proposed the Juana Lopez Formation and the overlying Montezuma Valley Member represented a T7a-R7a transgressive-regressive cycle of within the overall Niobrara Cyclothem (Kauffman, 1969; Kauffman et al., 1977; Barlow and Kauffman, 1985; Leckie et al., 1997; Nelson and Sonnenberg, 2021).

MANCOS GROUP

The lower contact of the Mancos Group is bound by the transgressive Naturita (formerly Dakota) Formation (Carpenter, 2014) and the upper contacts marked by regressive deposits of the Mesaverde Group that, from south to north, includes the Moreno Hill Formation, Toreva Formation, Gallup Sandstone, Crevasse Canyon Formation, Straight Cliffs Formation, Muley Canyon Sandstone, Emery Formation, Star Point Sandstone, Blackhawk Sandstone, Castlegate Sandstone, Sego Sandstone, and Point Lookout Sandstone (Peterson and Kirk, 1977; Fouch et al., 1983; Eaton et al., 1987; Eaton, 1990, 1991; Franczyk et al., 1992; Dyman et al., 1993; Elder and Kirkland, 1993a, 1993b; Cole et al., 1997; Leckie et al., 1997).

The proposed Mancos Group lithostratigraphic units are subsequently described in roughly stratigraphic order below as Tununk Shale (Jessies Twist Member, Coon Spring Sandstone Member, Blue Hill Shale Member), Ferron Formation, Juana Lopez Formation, Blue Gate Shale (Montezuma Valley Member, Smoky Hill Member), Emery Formation, Helper Formation, Prairie Canyon Formation, and Bar X Shale.

Tununk Shale

The Cenomanian-Turonian Tununk Shale (Day 1, Stop 2, 4, 6, 7; Day 2, Stop 5) is named for its occurrence in the Henry Mountains region (Figures 1 and 5) by Gilbert (1877). The Tununk Shale is well-exposed across the Henry Mountains basin (Hunt, 1941; Hunt et al., 1953), as well as along much of the San Rafael Swell below the Coal and Book Cliffs. On the east side of the Swell, Molenaar and Cobban (1991) noted the Tununk thinned to the southeast, at 400 feet (120 m) thick near Farnham Dome to about 300 feet (90 m) thick near Thompson Springs. Farther east, Merewether et al. (2006) measured a total thickness of 236 feet (72 m) near Mack, Colorado. The Tununk may also form the base of the Mancos Group across much of the

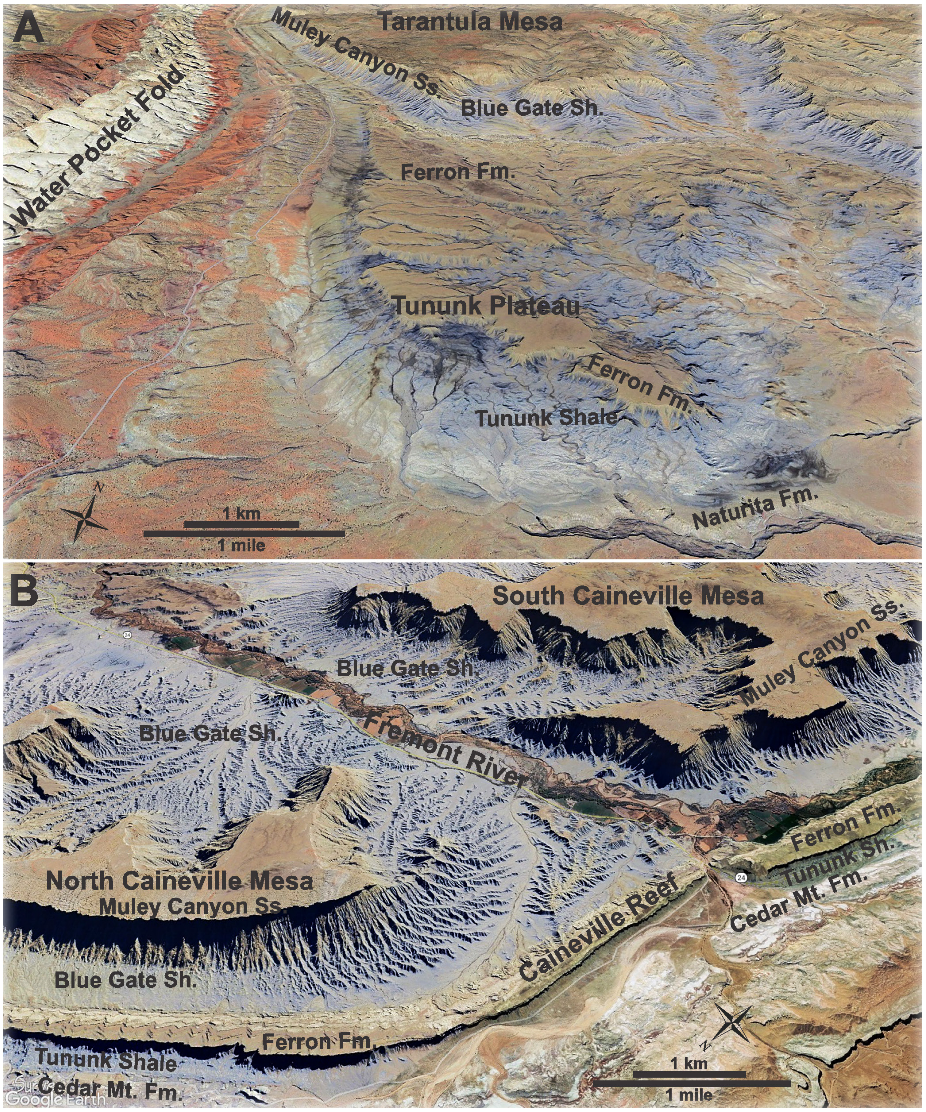

Figure 5. Type areas of the Tununk and Blue Gate Shales. (A) Type area of the Tununk Shale on the flank of Gilmore's (1880, plate 1) Tununk Plateau on the southwest side of the Henry Mountains on the south side of the Henry Mountains basin. Oblique view from the south-southwest. (B) Type area of the Blue Gate Shale around the Blue Gate (Fremont River water gap) between the North and South Caineville Mesas. Oblique view from the northwest. Image source Google Earth ©2023.

Blanding basin in southeastern Utah. The Tropic Shale across southern Utah (Elder et al., 1994; Leithold, 1994; Eaton et al., 2001; Tibert et al., 2003; Lauren and Sageman, 2007; Titus et al., 2016; Jones et al., 2019) and the Mancos Shale at Black Mesa in northeastern Arizona (Kirkland, 1991; Leckie, et al., 1991) are fully correlative with the Tununk Shale (Peterson and Kirk, 1977; Eaton et al., 1987; Titus et al., 2016) and should be considered as part of the Mancos Group (Kirkland et al., 2024) as the Tropic Shale of the Mancos Group.

The Tununk Shale unconformably overlies either the Cedar Mountain Formation/Burro Canyon Formation or the Naturita Formation (Eaton et al., 1990; Molenaar and Cobban, 1991) across a transgressive unconformity that is often marked by a reworked shell lag of *Pycnodonte newberryi newberryi* and/or *P. newberryi umbonatus*, oyster taxa specifically indicative of the late Cenomanian or early Turonian, respectively, and offshore water depths up to 100 feet (30 m) (Kirkland, 1996). To the south and east, coquinas of *P. newberryi newberryi* cap the Naturita Formation. Across the western outcrops, the basal Tununk unconformity is characterized by an abundance of *Pycnodonte* with chert and quartzite pebbles up to several centimeters across that are interpreted to have been derived from the basal conglomeratic beds of the Naturita Formation as they were reworked off the crest of the San Rafael Swell during the late Cenomanian. On the western side of the San Rafael Swell, the pycnodonts are represented by subspecies *P. newberryi umbonata*, a variety with a smooth umbonal (beak) area characteristic of the basal Turonian (Eaton et al., 1990; Kirkland, 1991, 1996; Molenaar and Cobban, 1991; Kirkland and Madsen, 2007; Santucci and Kirkland, 2010; Kirkland et al., 2016). The upper contact of the Tununk Shale is a gradational transition into the lower Ferron Formation to the west and is unconformable with the Juana Lopez Formation along the Book Cliffs to the southeast (Molenaar and Cobban, 1991). From the east side of the Swell to Colorado the Tununk Shale can be divided into three lithostratigraphic units: the fine-grained "Jessies Twist" Member and Blue Hill Shale, separated by an intervening sandy interval, termed the Coon Spring Sandstone.

Jessies Twist Member

In the Book Cliffs region of eastern Utah and western Colorado, we propose calling the stratigraphic interval between the basal Tununk unconformity and the overlying Coon Spring Member, the Jessies Twist Member (Figure 6) with a type section to the southwest of Green River, Utah (Day 1, Stops 6 and 7; Day 2, Stop 5). With only a 1.5° northeastward dip (Marshall, 1955), it is estimated that the thickness of the Jessies Twist Member in its type area is roughly 120 feet (37 m). Nearby, Katich (1951) measured a section across the airport road 1 mile (1.6 km) south of Green River reporting 125 feet (38 m) of what we interpret to represent the Jessies Twist Member.

This unit is often poorly exposed in the region, but the base is marked by a small (1- to 2-inch thick [2–5 cm]) basal chert-pebble conglomerate, which is overlain by a dark-gray slightly calcareous shale (20 to 30 feet thick [6–9 m]) with a prominent bentonite (2 feet [50 cm] thick) grading upwards into 100 to 120 feet (30–36 m) of medium- to dark-gray bioturbated siltstone (Molenaar and Cobban, 1991). The upper contact of the Jessies Twist Member is gradational with the overlying Coon Spring Member having increasing sand content. The 2-foot-thick (0.6 m) bentonite noted in the middle unit is almost certainly Bentonite "C" of Elder (1988). We believe that the oyster *Pycnodonte* associated with the basal conglomerate in the Green River area may also represent *P. newberryi umbonata* indicating an earliest Turonian age (as in Capitol Reef National Park; Kirkland, 1996; Kirkland et al., 2016) in this region as well. The base of the Tununk is younger in eastern Utah and western Colorado where *Pycnodonte newberryi newberryi* occurs, indicating a late Cenomanian age for the base of the Tununk Shale in this area (Merewether et al., 2006). To the north, the inoceramid *Mytiloides* cf. *M. mytiloides* is found 15 feet (4 m) above the base of the Tununk Shale at Farnham Dome, also indicating an early Turonian age for the basal part of the Tununk. The upper age is bound by the occurrence of *Collignoniceras woollgari regulare* in the overlying Coon Spring Member, which is middle Turonian.

Coon Spring Sandstone Member

The type section of the Coon Spring Sandstone Member is northwest of Woodside, Utah (Figure 1). This unit was described by Molenaar and Cobban (1991) at the 45-foot-thick (14 m) type section as a gradationally based, very fine grained, poorly bedded, bioturbated sandy mudstone grading upward into fine-grained, muddy sandstone capped by 2 feet (60 cm) of resistant, cross-bedded, calcareous sandstone. This upper bed in the Coon Spring is best recognized by the break in slope formed by a zone of large, often fossiliferous sandstone concretions 5 feet (1.5 m) thick. The name Coon Spring Sandstone (Day 1, Stops 6 and 7; Day 2, Stop 5; Day 3, Stop 2) replaced terms used for the unit in the subsurface (part of the "Dakota silt;" Munger, 1965) and on the surface ("Woodside Sandstone;" Cotter, 1975, 1976). Molenaar and Cobban (1991) give no reason for abandoning the name "Woodside" from Cotter (1975). However, it might be due to the use of Woodside (a priori) to describe Triassic rocks along the Wasatch Front in Utah as Woodside Shale (type area Woodside Gulch, Park City area of Boutwell [1907]; also used by Johnson [1959] and Black [1965]) or Woodside Formation (Eardley, 1933; Reeside et al., 1957; Witkind 1995) and Woodside Sandstone (Witkind, 1994 [used both formation and sandstone]), and in eastern Idaho/western Montana the Woodside Sandstone (Witkind, 1972; Peterson and Witkind, 1975; Mitchell and Bennett, 1979). Kummel (1954) used Woodside Formation across southeastern Idaho, western Wyoming, and northeastern Utah. Use of the term "Woodside" was further com-

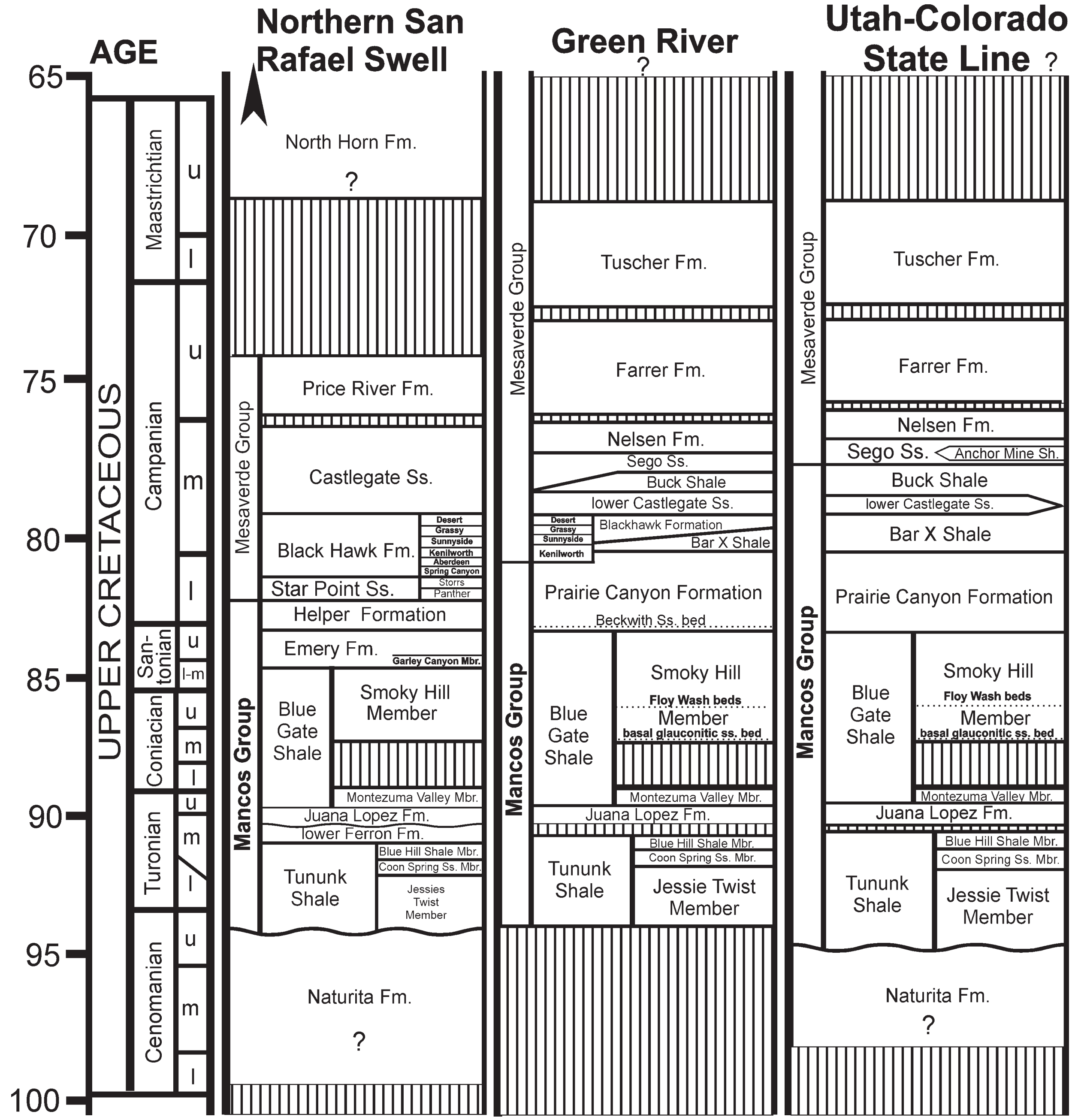

Figure 6. Summary of stratigraphic nomenclature for the lower Mancos Group in the southern Uinta Basin region. Modified after Kirkland et al. (2024). l = lower, m = middle, u = upper. Correlations based on ammonite zones in Figure 3.

plicated by Swift (1987) who applied the term Woodside Sandstone to beds that were Santonian in age for a unit near the town of Woodside, Utah. We discuss this issue and its resolution in the Prairie Canyon Formation section. The Coon Spring Sandstone Member is best developed in the area northwest of Green River extending north to Farnham Dome beyond which, and along the west side of the San Rafael Swell, it is no longer possible to readily separate the Tununk Shale into members. To the south it appears to be represented by a finer unit near Hanksville and Caineville (M.A. Kirschbaum, U.S. Geological Survey, communication in Molenaar and Cobban, 1991; Li and Schrieber, 2018). Merewether et al.'s (2006) Blue Hills Shale Member in their Mack, Colorado, section probably represents the eastern surficial expression of the Coon Spring Sandstone with the upper 85 feet (26 m) representing the Blue Hill Shale Member proper.

The dominant fossil in the Coon Spring Sandstone Member is the large epifaunal oyster *Rhychostreon suborbiculata*, along with common *Pinna kauffmani*, infaunal bivalves, and gastropods indicating a shallow open-marine sand flat environment (Kauffman, 1967, 1969; Kauffman et al., 1977; Kirkland, 1991, 1996). The lower Middle Turonian ammonite *Collignoniceras woollgari* has been found throughout the Coon Spring Sandstone Member with fossils identifiable to the subspecies *Collignoniceras woollgari regulare* in sandstone concretions at Westwater, Utah, refining the age to the upper subzone of *C. woollgari* (Cobban et al., 2006). The presence of *Collignoniceras woollgari regulare* in the Hopi Sandy Member of the Mancos Shale at Black Mesa in northeastern Arizona (Kirkland 1991, 1996) and small *Collignoniceras woollgari* in the Fairport Shale Member up to the disconformity below the Blue Hill Shale Member supports a correlation of Hopi Sandy Member to the Coon Spring Sandstone Member associated with the Fairport-Blue Hills disconformity (Leckie et al., 1991; Leithold, 1994). Additionally, Molenaar and Cobban (1991) noted, "A relatively resistant unit consisting of interbedded, very fine-grained sandstone and siltstone that occurs in the middle of the Tununk Member in the Hanksville and Caineville areas, 55 to 65 miles (88–105 km) southwest of Green River, is probably equivalent to the Coon Spring Sandstone Bed (M.A. Kirschbaum, U.S. Geological Survey, verbal communication, 1989)." The Coon Spring apparently was deposited as an apron on the south side of the Vernal High (Merewether and Cobban, 1986a, 1986b; Ryer and Lovekin, 1986; Li and Schrieber, 2018), and sediments of the Coon Spring may have been derived from there as well (southern paleocurrents of Cotter [1975] and Molenaar and Cobban [1991]). Whereas the correlative Hopi Sandy Member of Black Mesa, Arizona, was derived from the Mogollon highlands to the south (Kirkland, 1991).

Blue Hill Shale Member

The distinct "blue" shale beds overlying the *Ostrea* shale (Fairport Chalky Shale) were named by Logan (1897) for the outcrop in western Kansas where it underlies the Codell Sandstone (Hattin, 1962; Glenister and Kauffman, 1985). With the type section of the Blue Hill Shale Member this far east, it is the most widely distributed member in the Tununk Shale. It is noncalcareous and largely unfossiliferous mudstone that ranges from 80 to 140 feet (24–43 m) thick near Green River (Katich, 1951; Molenaar and Cobban, 1991). However, throughout the Book Cliffs region it is considerably siltier and includes more intercalated thin sandstone layers than are present in the member farther east. The lower contact with the underlying Coon Spring Sandstone Member is gradational with the basal Blue Hill (Day 1, Stops 6 and 7; Day 2, Stop 5; Day 3, Stop 2) consisting of very fine, soft, argillaceous sandstone fining over tens of feet into mudstone and shale. Its upper contact with the Juana Lopez Formation is a sharp and disconformable boundary, whereas its upper contact with the overlying Ferron Formation to the north and west is gradational and intertonguing. In the Farnham Dome area this interval averages about 130 feet (40 m) thick and forms a slope beneath the resistant Ferron. It is expressed as the slope beneath the cuesta-forming Juana Lopez Formation to the south and east. Near the Woodside anticline, a thick ash bed is present above a resistant, blue-gray, sandy mudstone marker bed, 1 foot (25 cm) or less thick, about 30 feet (9 m) above the top of the Coon Spring Sandstone Member or equivalents, as well as a geophysical log gamma spike at this level farther south (Molenaar and Cobban, 1991). Whereas this interval is rather low in the member in eastern Utah, it may correlate to a thick ash much higher in the Blue Hill Member at Mesa Verde, Colorado (Leckie et al., 1991). The upper part of the Blue Hill Shale Member is considered to have been deposited during the *Prionocyclus hyatti* Zone as is the equivalent lower Ferron Formation overlying it to the north of the Woodside anticline and along the west side of the San Rafael Swell. This may account for the relative difference in the position of the thick Blue Hill bentonite unit. In the northern Uinta Basin, the thin Tununk Shale sequence consists only of the Blue Hill Shale Member. In the north, Kirkland has observed *Prionocyclus hyatti* in these beds in a road cut on the east side of the of the Green River near Jensen, Utah, in 1985.

Ferron Formation

The Ferron Sandstone was initially a member named by Lupton (1914) for the sandstone, shale, and coal beds in Castle Valley near and to the south of the town of Ferron, Utah. Kirkland et al. (2024) proposed that the Ferron be raised to formation status with elevation of the Mancos to a group following the initial suggestion of Ryer (2004) for the Ferron. Whereas no type section was described, Lupton (1916) included a section from the Ivie Creek area south of the town of Emery, Utah. Back then a type section was not required, although Ryer (2004) thought this area would have been chosen, where the unit is 476 feet (145 m) thick, because it is representative of the Ferron strata (Figure 7). Davis (1954) subdivided the Ferron into upper (Day 1, Stops 2 and 5) and lower (Day 3, Stop 5), with the lower Ferron up to 70 feet (21 m) thick of fine-grained, carbonaceous, calcareous marine sandstone and siltstone containing two very persistent calcareous concretion zones that thicken to the northwest of Emery. The upper unit includes coal-bearing marine and fluvial sandstone (as in the Ivie Creek area) thickening to the west-southwest (Katich, 1953). A petrographic difference further substantiated the upper and lower provenance sources with the increasing presence of garnets in the upper Ferron toward the south (see Knight, 1953 for details). The lower Ferron was subdivided into four units by Cotter (1975): the Farnham, Woodside, Washboard, and Clawson. The Woodside unit should be removed from nomenclature given that Molenaar and Cobban (1991) identified it as the Coon Spring Sandstone. Kirkland et al. (2024) tentatively proposed the Washboard and Clawson should become elevated to members within the informal lower division of the Ferron Formation, and the Farnham unit, which is of limited lateral extent and is enclosed within the Washboard (Cotter 1975, 1976), should remain as a unit within the Washboard Member. Subsequent to Cotter (1975), only Becker et al. (2010) have subdivided the lower Ferron Formation to the area around Farnham Dome at the north end of the San Rafael anticline (Riemersma, 1989; Molenaar and Cobban, 1991; Riemersma and Chan, 1991; Edwards, 2003, 2005a). To better constrain these relationships, we suggest that additional stratigraphic work is needed across the Farnham Dome area.

In the uppermost Tununk Shale, immediately below the lower Ferron Formation, Becker et al. (2010) identified a possible *Collignoniceras woollgari*. Conversely, given the high density of secondary flank ribs and the lack of long, clavate tubercles on the venter, we think this ammonite represents a juvenile specimen of *Prionocyclus hyatti* (cf. Kennedy et al., 2001). Medial middle Turonian index fossils of the *Prionocyclus hyatti* Zone occur throughout strata of the lower Ferron. Above the lower Ferron, the younger *Prionocyclus macombi*, *Cameleolopha* (formerly *Lopha*) *lugubris* are present in the overlying Juana Lopez Formation (Riemersma, 1989; Molenaar and Cobban, 1991; Riemersma and Chan, 1991). The two members of the lower Ferron Formation interfinger with the Tununk Shale south of Emery, as two discrete sandstone beds before pinching out south of Interstate 70 (I-70) (Chidsey and Anderson, 2019). The upper Ferron is reported to range from the upper part of *Prionocyclus hyatti* to upper *Scaphites preventricosus* Zones in Castle Valley region (upper Ferron suggested type location) indicating a middle Turonian to early Coniacian age, which is equivalent with the Juana Lopez Formation to the east. Whereas the upper Ferron in the Henry Mountains basin is entirely Turonian in age (from *P. hyatti* to *P. macombi* Zones) (Gardner and Cross, 1994, and references therein). The base of the upper Ferron in Castle Valley is a gradational contact with the Tununk (Cotter, 1975; Peterson and Ryder, 1975; Ryer, 1981), whereas the top is a sharp flooding surface with local indication of erosion during transgression (Garrison and van den Bergh, 2004). The top of the upper Ferron is represented by a significant unconformity across much of southern Utah, with up to 130 feet (40 m) of relief in the Henry Mountains basin (Peterson and Ryder, 1975; Gardner, 1994).

Clawson Member of the Lower Ferron Formation

Cotter (1975) named the Clawson Member, east of the town of Clawson, Utah, for the poorly sorted, heavily bioturbated sandy siltstone to sandstone with large, brown, carbonate concretions. The Clawson is typically 18 to 27 feet (6–9 m) thick (thickest 45 feet [13.7 m] near Ferron, Utah), stretching from at least northeast

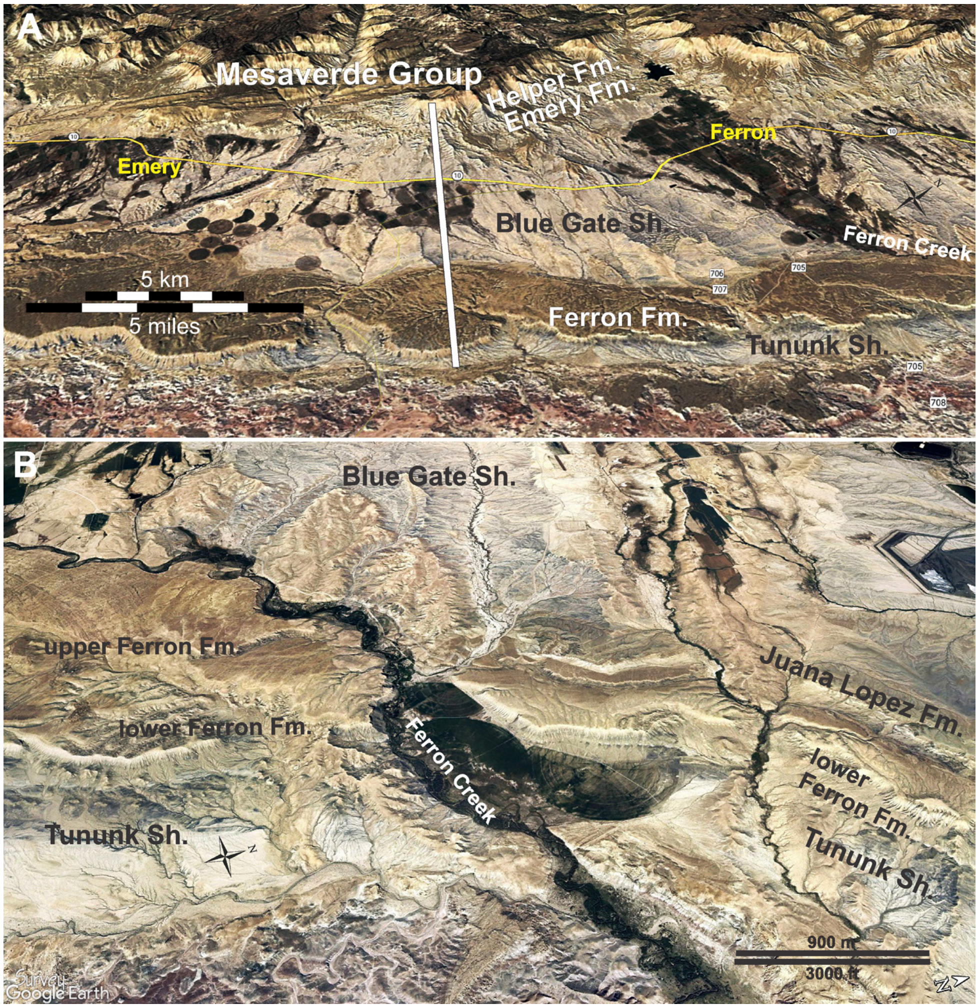

Figure 7. Type area of Ferron Formation. (A) Oblique view from east of type area of the Ferron Formation between Emery and Ferron, Utah. White bar indicates the extent of the Mancos Group. Town sites on Utah State Route 10, both labeled in yellow. (B) Oblique view from east of the Ferron Creek area across which significant nomenclatural changes have been proposed (e.g., Witkind et al., 1987; Witkind, 1988). Image from Google Earth ©2023.

of Huntington to where it grades into the Tununk Shale southeast of Emery, Utah (Cotter, 1975). Cotter suggested both boundaries were gradational with the muddy interval between the Clawson and the overlying Washboard. The Clawson Member contains *Prionocyclus hyatti* (biozone namesake), *Inoceramus howelli*, *Inoceramus flaccidus*, and *Placenticeras pseudoplacenta* (Molenaar and Cobban, 1991).

Washboard Member of the Lower Ferron Formation

The Washboard Member sits gradationally above the Clawson Member, separated by an intervening muddier interval, as a less than 30-foot-thick [10 m] unit, dominantly composed of thin laminated sandstone and bioturbated silty sandstone named for Washboard Wash (Cotter, 1975). Cotter (1975) proposed that the Washboard is more laterally extensive than the Clawson stretching from Farnham Dome as thin laminated sandstone interbeds and local hummocky bedded sandstone (Farham Unit) to the south of the old railroad stops of Mounds and Cedar as a bioturbated silty sandstone with large concretions. With the exception of Becker (2010) subsequent researchers have not extended either the Clawson or Washboard Members into the Farnham Dome area (Day 3, Stop 5) (Riemersma, 1989; Riemersma and Chan, 1992; Edwards, 2003, 2005). On the north and east side of the San Rafael Swell the upper contact with the Juana Lopez Formation is sharp, often marked with a sand unit or pebble lag having common and diverse shark teeth (Becker et al., 2010), that fines to the east along the south side of the Book Cliffs where this thin bed overlies the Tununk Shale (Riemermsa, 1989; Molenaar and Cobban, 1991; Riemersma and Chan, 1992; Edwards, 2003;

Edwards et al., 2005; Becker et al., 2010). The Washboard Member locally contains the middle Turonian *Cameleolopha* (formerly *Lopha*) *bellaplicata* that is associated with the *P. hyatti-macombi* Zones (Molenaar and Cobban, 1991; Hook and Cobban, 2012).

Juana Lopez Formation

The Juana Lopez Formation (Day 2, Stop 6; Day 3, Stops 2 and 4) is 107 feet (32.6 m) thick in its type area in north-central New Mexico. Here it includes the lower Middle Turonian *Prionocyclus macombi* Zone up into the basal Upper Turonian *Prionocyclus novimexicanus* Zone (Dane et al., 1966; Hook and Cobban, 1980, 2013; Cobban et al., 2006). The Juana Lopez is characterized as an alternating sequence of interbedded dark olive-gray noncalcareous shale and calcarenite composed largely of calcite prisms from inoceramid shells and oyster shell fragments. Along the southside of the Book Cliffs the Juana Lopez is 80 to 100 feet (24–30 m) thick (Molenaar and Cobban, 1993). Fossiliferous concretions are common particularly in the upper parts of this formation. Katich (1951) first recognized these strata (his “Castlegate Shale”) as a distinctive sequence of interbedded thin sandstone and dark shale preserving a *Prionocyclus wyomingensis* fauna above his “Woodside Sandstone” (equivalent to lower Ferron Formation) around the north end of the San Rafael Swell to the south in Ferron Creek, where the beds interfingered with the Ferron Sandstone (equivalent to upper Ferron Formation). Across most of the Book Cliffs region from south of Farnham Dome and to the east as far as the Canyonlands Field Airport north of Moab, the Juana Lopez includes a sharp basal medium- to coarse-grained sandstone with grain-supported chert pebbles and shark teeth interpreted to represent a transgressive unconformity that cut out the more distal facies of the lower Ferron Formation (Molenaar et al., 1993; Becker et al., 2010, 2012). Farther to the east and southeast, a basal calcarenite bed marks the base of the Juana Lopez and includes the *Prionocyclus macombi* Zone (Leckie et al., 1997; Merewether et al., 2006, 2007). The unconformity below the Juana Lopez shows no evidence of subaerial exposure or incision by channels (Riemersma and Chan, 1992).

The upper contact of the Juana Lopez Formation is generally difficult to discern at outcrop where it occurs at the top of the long dip slope formed above the ridge of resistant sandstone and calcarenite in the *Prionocyclus wyomingensis* Zone. The top of the Juana Lopez should be placed lithostratigraphically at the top of the highest calcarenite or fine sandstone layer, above which, the shale beds are lighter in color and calcareous, marking the base of the Blue Gate Shale. The underlying dip slope is typically shingled by thin plates of sandstone and calcarenite. Fossils of *Scaphites ferronensis* and *Scaphites whitfieldi* indicate the age of the formation ranges into the basal Upper Turonian *Prionocyclus novimexicanus* Zone. From the south side of the Farnham Dome along the entire Mancos Group outcrop belt, the Juana Lopez is characterized by differential weathering of a low hogback formed by a resistant series of calcarenite beds deposited during the latest Middle Turonian *Prionocyclus wyomingensis* Zone. These beds are characterized by distinctive assemblage of fossils including *Scaphites warreni* (zone name bearer), *Inoceramus dimidius*, and *Cameleolopha* (formerly known as *Lopha*) *lugubris* (Cobban, 1951; Walaszczyk, and Cobban, 2000; Kennedy et al, 2001; Cobban et al., 2006; Hook and Cobban, 2012). Below these beds is a slope-forming interval of varied thickness characterized by concretions that commonly preserve the mollusks *Prionocyclus macombi* and *Inoceramus dimidius*. Along the Ruby Ranch Road (Day 2, Stop 6), the base of the *Prionocyclus wyomingensis* Zone overlies the basal Juana Lopez disconformity. Farther east along the Colorado-Utah state line, nearly the entire Juana Lopez may have been deposited in the underlying *Prionocyclus macombi* Zone (Merewether and Cobban, 2006).

Molenaar and Cobban (1993) proposed that the Juana Lopez did not extend west of Farnham Dome and instead grades laterally into the Ferron Formation. Marking a rare instance where the authors disagree with them, we noted on the west side of Farnham Dome that rippled fine-grained sandstone and shale and sandy calcarenite preserving *Prionocyclus wyomingensis* and *Scaphites ferronensis* are present above the top of the lower Ferron Formation dip slope. These beds are in turn capped by a thick sequence of dark olive-gray, noncalcareous shale capped in turn by Pleistocene terrace gravels. These shale beds are characteristic of the Juana Lopez Formation. Furthermore, Kevin Bylund (unpublished guidebook, 2002) has shown Kirkland fossiliferous outcrops characteristic of the Juana Lopez overlying the lower Ferron Formation from north of Ferron Creek to well north of the Cleveland, Utah, area. As opposed to many publications (i.e., DeReuil and Birgenheier, 2018), the Juana Lopez Formation is interpreted to correlate with the upper Ferron Formation to the southwest as had previously been noted by Katich (1951) in his unpublished Ph.D. dissertation, with the lower Ferron underlying it. The upper *Prionocyclus wyomingensis-Scaphites ferronensis*-bearing and younger Juana Lopez strata extend west across the northern San Rafael Swell and continue south until these beds merge into the northern extent of the upper Ferron "Last Chance delta" at Ferron Creek.

Blue Gate Shale

The type area of the Blue Gate Shale is exposed around the "Blue Gate" between the South and North Caineville Mesas in western Wayne County, Utah (Figure 5B). This unit is largely correlative with the Montezuma Valley Member, Smoky Hill Member, and lower 535 feet (163 m) of the Cortez Member as defined in the Mancos Group type area at Mesa Verde National Park (Gilbert, 1877; Leckie et al., 1997, Molenaar et al., 2002). To the north along the southern Coal Cliffs, the Blue Gate (Day 1, Stops 1, 5, and 8; Day 2, Stop 6) is restricted to the interval between the top of the upper Ferron Formation or Juana Lopez Formation to the base of the Emery or Prairie Canyon Formations (Figure 6). The Blue Gate on the western side of the San Rafael Swell is lower Coniacian to upper Santonian and about 3500 feet (1070 m) thick. Around the north end of the San Rafael Swell to just east of Price, Utah, the Blue Gate ranges from late Turonian to latest Santonian in age. From the northern part of the San Rafael Swell along the entire Book Cliffs eastward into Colorado, the Blue Gate can be divided into two members—the lower upper Turonian Montezuma Valley Member and an unconformably overlying and much thicker Smoky Hill Member. The Montezuma Valley Member has not been recognized along the western side of the San Rafael Swell or in the Henry Mountains region where it is currently impossible to divide the Blue Gate Shale into members. To the east the Blue Gate Member is largely replaced by the Niobrara Formation with the northward and western limits of the Fort Hays Limestone angling to the west between Pagosa Springs south and north of Fruita in the Grand Valley, Colorado. The Fort Hays Limestone and the Niobrara Formation do not seem to cross the Douglas Creek arch into the Uinta Basin (Cole and Hood, 2014; Nelson and Sonnenberg, 2021).

Montezuma Valley Member

The Montezuma Valley Member was first described at Mesa Verde National Park where it consists of 53 feet (16.2 m) of slightly silty to slightly sandy calcareous shale that contains numerous septarian concretion horizons (Leckie et al., 1997). In western Colorado near Mack, it is represented by an interval that Merewether et al. (2006) recognized as 115 feet (35 m) of medium- to dark-gray, slightly calcareous shale with fossiliferous concretions preserving *Scaphites whitfieldi* sharply overlying (conformably or disconformably) the Juana Lopez Formation. The lower Blue Gate is generally poorly exposed across the study area, and the presence of concretions, calcareous shale, and an upper Turonian fauna are the best indicators of the Montezuma Valley Member. This interval between the top of the Juana Lopez and the glauconitic sandy unit F-1 of Anderson and Harris (2006) and Ressetar et al. (2014) represents the Montezuma Valley Member with the thickness ranging between 160 and 260 feet (50–80 m) across the Uinta Basin. The upper contact of the Montezuma Valley Member is unconformable with the overlying Smoky Hill Member, which is recognizable at a distance as a yellowish-band in a low bluff on the northeast side of the Loma exit off I-70 in western Colorado (Day 2, Stop 1). The Montezuma Valley is upper Turonian in age based on the presence of *Prionocyclus novimexicanus* (biozone namesake) and *Mytiloides incertus* along Ruby Ranch Road southeast of Green River (Kirkland et al., 2024). It also includes the *Prionocyclus novimexicanus* and *Scaphites whitfieldi* fauna (Stephen et al., 2012) a few feet above the top of the Juana Lopez Formation in the Canyonlands Field Airport (Courthouse syncline) area, north of Moab, and near the Grassy Railroad Siding north of Woodside on the east flank of the San Rafael Swell (Forster et al., 2020).

Smoky Hill Member

As also documented at Mesa Verde National Park (Leckie et al., 1991), the lower calcareous shale of Smoky Hill Member along the Book Cliffs unconformably overly the Montezuma Valley Member (Day 2, Stops 1 and 7; Day 3, Stop 1). Conversely, the upper Smoky Hill Member is a noncalcareous shale over hundreds of feet thick below its sharp contact with the overlying Prairie Canyon Formation. The Smoky Hill is thickest in the west, ranging from about 2900 feet (885 m) to around 1900 feet (580 m) in the central and eastern Uinta Basin (Ressetar et al., 2014). The base of the unit is denoted by a glauconite-bearing sandy mudstone zone (Figure 6) that is widespread across outcrops of western Colorado from Mesa Verde northward to Mesa County (Leckie et al., 1997; Merewether et al., 2006; Ball, 2015; Nelson and Sonnenberg, 2021). In the subsurface this is referred to as the F-1 glauconite zone of Anderson and Harris (2006) and Ressetar et al. (2014). This unconformity at the top of the underlying Montezuma Valley Member/base of Smoky Hill Member apparently extends across nearly the entirety of the Cretaceous Western Interior seaway marking the base of the main Niobrara sequence (Merewether et al., 2007).

The oldest fossils recognized in the lower Smoky Hill Member in the Book Cliffs area are of middle Coniacian age. Along the Ruby Ranch Road to the southeast of Green River these include *Inoceramus undabundus* (Walaszczyk and Cobban, 2006) previously identified as *Inoceramus (Platyceramus) stantoni* in the revision of the Mancos Shale (Leckie et al., 1997). Up section, thick inoceramid shell fragments interpreted to represent *Volviceramus involutus* are found through the Coniacian above the base of the Smoky Hill with species of *Magadiceramus* ranging through the entirety of the upper Coniacian (Kirkland et al., 2024). The basal glauconitic unit may also be present along the Ruby Ranch Road, where a less distinctive yellowish-band is associated with fragments of *Volviceramus* shells (Kirkland et al., 2024). The shell fragments are identified by their thick shells (about 1 cm thick), smooth external surface lacking evidence of rugae as in the thinner-shelled, lower Coniacian species of *Cremnoceramus* or basal middle Santonian *Volviceramus koeneni*. The curved shell fragments suggest enrolled shells, unlike the large Santonian species *Platyceramus*, which occurs in abundance up section (Walaszczyk and Cobban, 2000; Cobban et al., 2006). These examples of *Platyceramus cycloides* are so abundant northeast of Green River that this area has been nick-named the "*Platyceramus* Hills" (Day 1, Stop 8). Farther west, in the Sevier foredeep basin on the west side of the San Rafael Swell from Castle Dale south to about I-70, lower Coniacian inoceramid *Cremnoceramus deformis* and ammonites *Forresteria alluaudi* and *Scaphites preventricosus* occur (Kennedy and Cobban, 1991; Gardner and Cross, 1994; Bylund and Stephen, in press). These same fossil indicators of the lower Coniacian are present even farther west in Sanpete Valley and to the north near Manti, and record the farthest evidence of the westernmost extent of marine strata of the Niobrara Cyclothem and the Mancos sea in general.

A distinct bluff held up by a series of thin sandstone beds in the lower Smoky Hill Member can be traced from Green River north to Woodside. Kennedy and Cobban (1991) report *Scaphites ventricosus* in a low ridge-forming sandy unit 19 miles (31 km) north of Green River. This bed potentially overlaps *Scaphites depressus* (as asserted by Landman et al., 2017) in the basal upper Coniacian. However, concretionary sandstone beds outcrop below the main sandstone unit at the first stop on Day 3 and may well be the source of the *Scaphites ventricosus*. To the south along Ruby Ranch Road another more distinctive sandstone-capped bluff extends across Floy Wash and is associated with upper Coniacian fauna, which includes *Mytiloides crenulatus*. Based on our cursorial examination of these outcrops (Kirkland et al., 2024), it is possible that the Smoky Hill Member includes a series of silty and sandy horizons. However, the zone preserving the *Scaphites depressus* fauna is certainly the most prominent and we suggest naming this sandy interval the "Floy Wash sandstone bed" (Figure 6) (Day 2, Stop 7). To the east, this bed was potentially recognized by Willis (1994) and mapped as the M-2 unit across the Agate quadrangle. In the subsurface of the Uinta Basin, this unit has potentially been recognized by Ressetar et al. (2014) as the "Blue Gate silt."

Emery Formation

The Emery Sandstone (referred to now as the Emery Formation) was first described by Spieker and Reeside (1926) as a member of the Mancos Shale for a series of interbedded sandstone, siltstone, and silty shale below the Wasatch Plateau southwest of Emery, Utah (Day 1, Stop 1). These strata were traced along the Coal Cliffs, where, at the northern end of the outcrop near Price, Utah, the lower bench-forming interval of the Emery (Day 3, Stop 7) was formally described as the Garley Canyon Sandstone (Fouch et al., 1983). The Emery Formation is only mapped eastward to just north of Price (Witkind, 1995), where the sandstone beds interfinger into the upper Blue Gate Shale. In outcrop, the Emery can only be traced south of I-70 until the beds are covered by colluvium near the Last Chance monocline west of Cathedral Valley. It has been noted that they extend west into the subsurface for a few miles before merging with the Mesaverde Group along with the subsurface interfingering pinch-out of the overlying Helper Formation (Ryer, 1984; Franczyk et al., 1992; Edwards et al., 2005). A 204-foot-thick (62.1 m; third informal unit) sandy interval in the middle of the Cortez Member at Mesa Verde National Park is correlative with the Emery Formation (Leckie et al., 1997).

Smith (1983) replaced the improper use of the Emery Sandstone in the Henry Mountains basin (Hunt, 1946) with Campanian-age Muley Canyon Sandstone Member of the Mancos Shale, which Eaton (1990) later raised to formational rank. Ryer (1984) noted that the Emery is 820 feet (250 m) thick on the southern end of the Wasatch Plateau and Caroll (1987) plotted approximately 1150 feet (350 m) on the north end of the Coal Cliffs west of Price Canyon. Edwards et al. (2005) recorded a range of 740 to 1640 feet (225–500 m) although his measured sections only ranged from 740 to 984 feet (225–300 m) and indicate that the Emery Formation thickens rapidly westward in the subsurface. Edwards et al. (2005) documented 17 coarsening upward parasequences within the Emery that he correlated along the Wasatch Plateau with coal-bearing fluvial sequences capping some of these sequences in the subsurface to the west. They noted that the bulk of the Emery consisted of partially amalgamated, bioturbated or hummocky cross-stratified, well-sorted, fine- to very fine grained sandstone arranged in upward-coarsening and -thickening beds interspersed with silty shale. Across the mouth of Price Canyon, Caroll (1987) and Russon (1987) noted a dozen sandstone beds in the Emery Formation above the Garley Canyon Sandstone, for which Caroll (1987) named the upper three as new members of the upper Mancos Shale. These were from bottom to the top of sequence: (1) the 21-foot-thick (6.7 m) Dempseyville Sandstone Member overlain by 121 feet (27 m) of mostly covered shale, below (2) the 47.9-foot-thick (14.6 m) Bull Point Sandstone overlain by 66 feet (20 m) of silty shale, below the locally capping (3) the 23 feet (7 m) of Wildcat Canyon Sandstone. These stratigraphic units are west of Kirkland et al. (2024) study area as mapped and deserve further investigation. The top of the Wild Cat Sandstone was picked as the base of the newly defined Helper Formation discussed below. Kirkland et al. (2024) questioned if any of these sandstone members, which they noted as largely lenticular, warrant member status.

One of us, K.G. Bylund, has collected many examples of *Clioscaphites vermiformis* from the basal Emery Formation northward into the Garley Canyon Sandstone Member, as first noted by Cobban (1976). Cobban (1976) also noted the collection of a partial *Desmoscaphites bassleri* and *Cataceramus balticus* at the top of the Emery just east of U.S. Highway 6/191 between Spring Glen and Helper north of Price. This locality is east of where the upper Emery is mapped (Weiss et al., 2004) but is still clearly near the top of the Emery Formation proper and may be correlated below the lenticular Wildcat Sandstone bed of Caroll (1987). These index fossils would bracket Emery deposition as ranging from within the middle Santonian to latest Santonian in the area around Price (Cobban et al., 2006; Singer et al., 2023). This correlation indicates that the Helper Formation correlates with the upper Smoky Hill Member in the eastern Book Cliffs (Figures 6 and 8). The sandstone-filled scours at the base of Match Mesa's Prairies Canyon sequence (Stevens 2004; Chaiwongsaen, 2007), and our Beckwith sandstone bed (described nomenclatural change below) at the base of the western Book Cliffs, may correlate to the transgressive surface at the top of the Helper Formation.

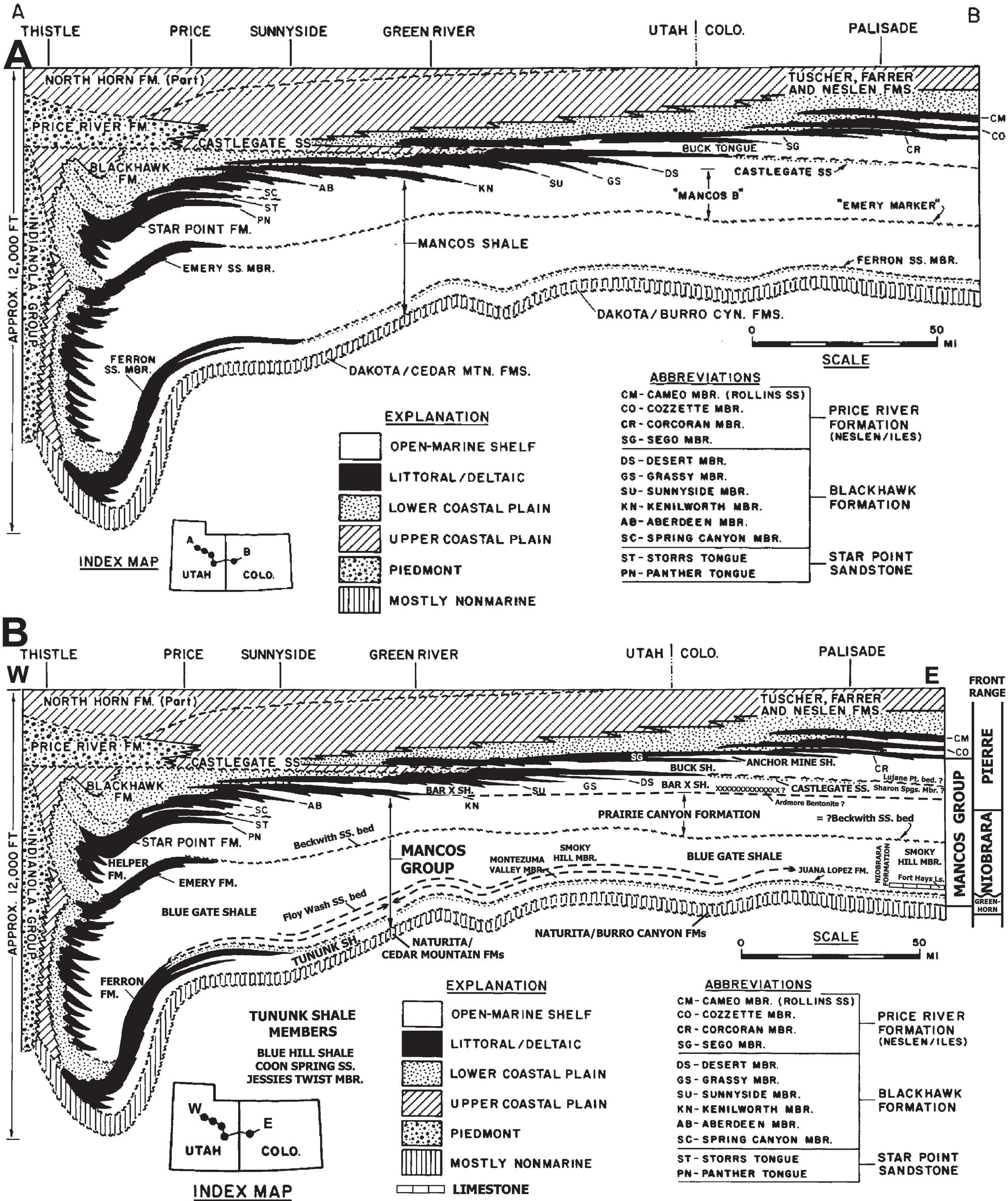

Figure 8. Cross section of the Cretaceous along the Book Cliffs. (A) Original cross section from Cole (1987) working with Robert Young. (B) Cole (1987) modified to reflect proposed nomenclature. Note scale does not permit plotting of the members of the Tununk Shale on cross section. Members of the Tununk Shale can only be differentiated by medial Coon Spring Sandstone Member extending from north of Sunnyside southwest into westernmost Colorado.

The lowest sandstone interval of the Emery Formation (Day 3, Stop 6) forms a double-tiered sandstone bench at the northern end of the San Rafael Swell northwest of Price, Utah. This unit has been formally described as the Garley Canyon Sandstone Member (Fouch et al., 1983). This unit records two major coarsening upward sequences (Fouch et al., 1983; Edwards, 2005). This member ranges from its lateral pinch-out east of Helper, Utah, to 209 to 233 feet (64–71 m) thick to the west on the Standardville Quadrangle (Carol, 1987) before merging to the south into the lower Emery Formation west of Price. It is mapped from the southern border of Carbon County on the west side of the San Rafael Swell northward to the east side of U.S. Highway 6/191 north of Price (Witkind, 1988, 1995). The Garley Canyon Member is middle Santonian (Figures 3 and 5), dated to the *Clioscaphites vermiformis* Zone (Cobban, 1976; Edwards et al., 2005; Cobban et al., 2006; Singer et al., 2023).

Helper Formation

The proposed "Helper Formation" (Day 1, Stop 1; Day 3, Stop 7), and the underling Emery Formation that bounds it, only occurs in the western part of the San Rafael Swell, extending from Helper down to I-70. The Helper is denoted as a formation rather than a shale interval, because it is dominantly poorly bedded or structureless silty-sandy mudstone with sandier zones increasing into the overlying Star Point Sandstone (Kirkland et al., 2024). The Helper Formation is 540 to 650 feet (164–201 m) thick in this region.

The basal contact of the Helper Formation is sharp with the top of Caroll's (1987) 23-foot-thick (7 m) "Wildcat Canyon Sandstone" bed which caps the Emery Formation in this area. The upper contact is a rapid gradational transition, which can be defined as the transition from a dominance of silty to sandy mudstone with subsidiary sandstone beds to more than 50% sandstone with the basal 79 feet (24 m) of the Helper generally fining upwards from a sandy mudstone with minor occasional sandstone beds. The Santonian-Campanian boundary probably lies within the lower part of Helper Formation based on the occurrence of *Baculites aquilaensis* 300 feet (91 m) below the base of the Star Point Sandstone about 1 mile (1.6 km) east of Kenilworth, Utah. This baculite is characteristic of the range of lower Campanian forms of *Scaphites hippocrepis* (Reeside, 1927; Cobban, 1976) suggesting that the Helper Formation correlates to the lower parts of the Prairie Canyon Formation to the east. The Helper merges into the Prairie Canyon just east of Kenilworth, Utah, with the pinch-out of the overlying Star Point and the projected eastern limit of the top of the underlying Emery. Near the top of the Helper is a 16.5-foot-thick (5 m) unit named the Trail Canyon Sandstone member within the upper Mancos Group (Caroll, 1987; Hansen, 1996). This unit is 95 to 118 feet (29–36 m) below the Star Point west of Price Canyon. The Trail Canyon was apparently never officially defined in a publication nor can it be used because the name Trail Canyon is already defined for a unit in the Oquirrh Group of Idaho (Cramer, 1971).

Prairie Canyon Formation

Originally known widely as the "Mancos B" (e.g., Cole, 1987; Cole and Young, 1991), the Prairie Canyon Formation (Day 2, Stops 2 and 3) is 1000 feet (300 m) thick near the Utah-Colorado border. Across the outcrop belt the unit can range from 384 to 1220 feet (117–372 m) in thickness (Cole et al., 1997). The Prairie Canyon Formation crops out along a lengthy swath at the base of the Book Cliffs from north of Woodside, Utah, to east of Grand Junction, Colorado (Hampson et al., 1999). The Prairie Canyon Formation is correlative to the upper 755 feet (230 m) (upper three informal units) of the Cortez Member of the Mancos Group at Mesa Verde National Park (Leckie et al., 1991).

The lower contact of the Prairie Canyon Formation is a sharp change from fissile, silty claystone to interlaminated sandstone and shale around 2300 feet (700 m) above the base of the Blue Gate Shale. The lower Prairie Canyon is often covered in outcrop, although the more resistant nature of the cleaner, better-cemented, sandstone layers often result in a change of the topographic profile (Cole et al., 1997). Conversely, a shift to finer lithologies 295 to 425 feet (90–130 m) below the lower Castlegate (Cole et al., 1997; Gall et al., 2020) marks the top of the unit. This shift is more subtle in outcrop and is best mapped at the color change between olive-gray silty and sandy Prairie Canyon strata and dark olive-gray, organic-rich shale of the overlying Bar X Shale. The gradational upper contact is more easily recognized in the subsurface with geophysical logs.

The lower interval of the Prairie Canyon Formation is composed of 358 feet (109 m) of thinly interbedded, very fine grained sandstone (discontinuous in nature) and shale, with scattered sandy dolomite concretions overlying a scoured coarse-grained surface preserving *Desmoscaphites bassleri* (Cole et al., 1997). The correlation of the basal beds of the Prairie Canyon is controversial. Fouch et al. (1983) illustrated the lower part of the Prairie Canyon as a sandy zone with discontinuous beds that stretched from the distal parts of the Emery Formation near Sunnyside, Utah, extending to the Utah-Colorado border. Franczyk et al. (1992) suggested that these discontinuous sand bodies of the uppermost Santonian (*Desmoscaphites bassleri* Zone; at the base of the Prairie Canyon Member) go from near Hanksville, Utah, northward into Wyoming. This lower interval of the Prairie Canyon has been mapped as an extension of the Emery Formation (Clark, 1928; Cullins, 1968; Russon, 1987) or "Mancos B" within the subsurface (Kellogg, 1977; Cole, 1987). Additionally, there seems to have been some nomenclature confusion as to whether this unit relates to the Woodside Sandstone. Hampson (1999) notes that Cotter (1975), in defining it, made it a lower sandstone unit of the Ferron Formation southwest of Woodside, Utah. Hampson also noted that Swift et al. (1987) and Chan et al. (1991) correlated it to the Emery Formation. This confusion began with Swift et al. (1987) in noting that the occurrence of *Desmoscaphites bassleri* in a sandstone unit below the Book Cliffs east of Woodside as reported by Reeside (1927) and Cobban (1987) was from the same "Woodside Sandstone" described by Cotter (1975) that is now accepted as the Coon Spring Sandstone Member (Molenaar and Cobban, 1991). Given the current referral of this sandstone interval to nomenclature already used in the Triassic (see above explanation in the Coon Spring section), we propose to rename the Woodside Sandstone of Swift et al. (1987) and the Emery marker of Cole (1987) to the Beckwith sandstone bed (Figures 6 and 8)—an unconformable marker bed at the base of the Prairie Canyon Formation. The Beckwith sandstone bed is best expressed around the base of the Beckwith Plateau. The term, Beckwith Formation, was used by Veatch (1907) for Early Cretaceous beds in southwestern Wyoming, but was formally abandoned only nine years later by Mansfield and Roundy (1916). Although we define the Beckwith sandstone bed as an informal unit here, we plan to formalize its nomenclature in the near future.

Cole et al. (1997) considered the lower Prairie Canyon Formation to extend from the upper *D. bassleri* to *S. hippocrepis I* Zones, with the middle Prairie Canyon to be dominantly within the *S. hippocrepis II* Zone. Cole also considered the upper Prairie Canyon to be from the *S. hippocrepis III-Baculites* sp. (smooth) Zones indicating latest Santonian through early Campanian age for the entirety of the formation. Farther west from the type area near Green River, Utah, the main sand interval of Hatch Mesa Sandstone (Day 2, Stop 8) and the Middle Mountain-Gunnison Butte lenticular body have been mapped as equivalent to the Kenilworth Member in age (KP2 of Pattison, 2005). However, the lowermost isolated dolomitic sand bodies of the Hatch Mesa area are *Desmoscaphites bassleri* Zone equivalent to the top of the Emery Formation in the uppermost Santonian (Stevens, 2004; Chaiwongsaen, 2007), and the intervening coarse channelized sandstone and oolite contain *Scaphites hippocrepis* (Cobban IDs in Stevens' [2004] stratigraphic framework). Stevens (2004) has suggested that in the Hatch Mesa area that the lower Prairie Canyon Member includes a basal interval of channelized coarser sediment and dolomitic sandstone with dolomicrite within dominantly mudstone beds. Fossils of the *D. bassleri-S. hippocrepis* Zones support a correlation westward to the Beckwith sandstone bed and uppermost Emery Formation.

Given the somewhat contradictory biostratigraphic determinations and the lack of figured specimens and, for the most part, the complete absence of curated proxy specimens, we follow the consistent reports of *Desmoscaphites bassleri* occurring at the scoured base of the type section of the Prairie Canyon Formation. The *Desmoscaphites bassleri* is below the basal dolomitic sandstone beds in the Hatch Mesa area, and in the Beckwith sandstone bed (Day 3, Stop 3), which is along the base of the eastern Book Cliffs from Green River to the north of Sunnyside, Utah, and at the top of the Emery Formation north of Price, Utah (Reeside, 1927; Cobban, 1987; Cole et al., 1997; Stevens 2004; Chaiwongsaen, 2007; Casaleggio, 2009). This surface is tentatively identified as representing a transgressive disconformity marking sea-level rising and expanding shoreward over the Emery Formation. Thus, this scoured surface marks an appropriate mappable lower contact for the base of the Prairie Canyon (Cobban et al., 2006; Singer et al., 2023).

The middle Prairie Canyon Formation is 413 feet (126 m) thick in the type area (Day 2, Stop 3). Cole et al. (1997) described four coarsening upwards sequences (Sequence A through D) that are prominent in outcrop due to their sandy nature. These intervals commonly include poorly to moderately sorted, bioturbated siltstone-sandstone with prominent dolomite marker beds similar to those in the Cortez Member (Figure 4) of the Blue Gate Shale at Mesa Verde (Leckie et al., 1997). Persistent dolomite-cemented markers are present to the west (Salt Wash to Strychnine Wash areas, Utah) and have been named in descending stratigraphic order as W, X, Y, Z (Hampson et al., 1999). These intervals/markers are not correlated into the A through D intervals of the type area but are correlated through subsurface data to the middle interval of the Prairie Canyon (Hampson, 2016).

The rarity of biostratigraphically significant fossils and the absence of proxy specimens in curated collections has hindered the correlation of beds within the Prairie Canyon Formation across the region (Kirkland et al., 2024). The Hatch Mesa Sandstone, which forms a bench dominated by interbedded ripple-laminated sandstone and mudstone topped by three bentonite beds, may correlate with the middle Prairie Canyon Formation (Stevens, 2004). Conversely, due to lack of biomarkers, Hampson (2010) agreed more with Pattison (2005) in correlating the Hatch Mesa Sandstone (middle interval of Prairie Canyon Member of Stevens, 2004) to the second sand body in the Kenilworth Member, suggesting middle Prairie Canyon based off well log correlation (middle Prairie Canyon of Stevens, 2004—the type area roughly equivalent to much of the Kenilworth). Kirkland et al. (2024) suggest that tracing the beds laterally in outcrop indicates that the Kenilworth Member of the Blackhawk Formation broadly correlates to the upper part of the middle and upper interval of the Prairie Canyon (Figures 6 and 8), but biostratigraphic testing is critical.

The upper interval of the Prairie Canyon Formation is dominantly shale with variable silt-sand content with abundant sandy dolomite concretions. It is 413 feet (126 m) thick at the type locality (Cole et al., 1997). Well-log correlation of Chaiwongsaen (2007) and Hampson (2010) suggests the upper Prairie Canyon correlates to the interval of the upper part of the Kenilworth Member to near the top of the Grassy Member in the west. However, by tracing the relationships of the overlying Bar X Shale to the west into the Blackhawk Formation, it is apparent that the top of the Prairie Canyon essentially correlates to the top of the Kenilworth Member of the Blackhawk. Thus, to the west, the Prairie Canyon interfingers into the lower Blackhawk and Star Point Sandstone with the name for its lower part being replaced by Helper Formation north of Price, where that sequence is sandwiched between the top of the underlying Emery Formation and overlying base of the Star Point Sandstone. Instead, Howell and Flint (2002) suggest that the Prairie Canyon correlates with the upper Blackhawk. To the east the Prairie Canyon Formation is traceable across the Piceance Basin (Hampson, 2016), beyond which it would grade into the upper Smoky Hill Member of the Niobrara Formation and the basal Pierre Shale.

Gill and Hail (1975) show *Baculites* sp. (weak flank ribs) around 26 feet (8 m) below the top of the Prairie Canyon at the type locality. Kirkland identified *Baculites* sp. (weak flank ribs) in the shale beds close to the basal contact of the overlying Bar X Shale at Prairie Canyon, western Colorado, suggesting the total Prairie Canyon Formation spans the upper Santonian *D. bassleri* Zone to the lower Campanian *Baculites* sp. (smooth form)-*Baculites* sp. (weak flank ribs) Zone (Cobban et al., 2006; Singer et al., 2023).

Bar X Shale

Kirkland et al. (2024) proposed naming the shale interval between the top of the Prairie Canyon Formation up to the base of the Mesaverde Group the Bar X

Shale (Day 1, Stop 8; Day 2, Stops 2 and 3) for the Bar X Ranch area in easternmost Utah along the west side of Prairie Canyon (Figures 1 and 8). The type section is 337.5 feet (102.9 m) thick. The formation consists of dark olive-gray shale and silty shale with light yellowish-brown sideritic siltstone beds and large fossiliferous dolomitic concretions. The upper 70 feet (22 m) includes many more interbeds of fine sandstone and grades through more than 10 feet (~3 m) of interbedded thin sandstone and silty shale into the overlying Castlegate Sandstone. These upper beds grade into the Desert and Sunnyside Members of the Blackhawk Formation farther west in eastern Utah. Its lower contact with the underlying Prairie Canyon Formation is placed where sandy and silty shale is rapidly replaced by darker more carbon-rich shale. Farther west, its lower contact is placed similarly, with the correlative top of the Kenilworth Member of the Blackhawk Formation.

The Bar X Shale is richly fossiliferous in its type area. The unit preserves a diversity of ammonites, inoceramid bivalves, and even fossil crabs and conifer fragments. Ammonites indicate it ranges from the upper lower Campanian *Baculites* sp. (smooth 1) or *Baculites* sp. (weak flank ribs) Zones up through the lower middle Campanian *Baculites maclearni* Zones correlating to the lower Pierre Shale of eastern Colorado and Wyoming (Gill and Cobban, 1966; Cobban et al., 2006, Singer et al., 2023). The Bar X contains noteworthy vertebrate fossils where it crosses Prairie Canyon, including plesiosaurs, mosasaurs, and a juvenile hadrosaur identified as being a species of *Gryposaurus* (Carter et al., 1987; Lucas et al., 2006). Its extensive middle Campanian marine vertebrate fauna is reminiscent of that preserved in the correlative Sharon Springs Member of the Pierre Shale (Gill and Cobban, 1966; Carpenter, 1996a, 1996b; Bertog, 2010), although its more diverse benthic fauna suggests a better oxygenated seafloor. Several distinct bentonites occur in the lower part of the Bar X, including 0.5 feet (16 cm) ash at 64.3 feet (19.6 m), may be correlative to the Ardmore Bentonite marker bed in the lower Sharon Springs Member of the Pierre Shale of Wyoming (Gill and Cobban, 1966). In the Piceance Basin, farther to the southeast, beyond the pinch-out of the overlying Castlegate, this stratigraphic interval between the underlying Prairie Canyon Formation and the overlying informal Lujane Point sandy shale bed, correlates to the lower Pierre Shale from the Sharon Springs Member down to its base (Noe et al., 2007; Noe 2010; Cole and Hood, 2014). This Bar X Shale has also been described as the "Castlegate condensed zone" in the subsurface within the Piceance Basin of Colorado where it is an important petroleum source rock (Schwendeman, 2011; Rogers, 2012).

Buck Shale

Fisher (Erdmann, 1934; Fisher, 1936) named the Buck Tongue from Buck Canyon to the north of Cisco, Utah, where it is 269 feet (82 m) thick. It thickens eastward to the Utah-Colorado border where it is 351 feet (107 m) thick before the Castlegate Sandstone pinches out beneath it to the east (Fisher 1936). The basal contact of the Buck Shale of the Mancos Group with the lower Castlegate below is often sharp, marked in a more proximal (northwest) position by a potential paleosol horizon of nodular hematitic mudstone and chert that stretches almost to Green River (Hettinger and Kirschbaum, 2002). The Buck Shale (Day 2, Stop 2) has *Baculites perplexus* in the lower half of the member (Gill and Hail, 1975) that are older than the mollusks of the basal *Baculites scotti* Zone in the Sego Sandstone above (Zapp and Cobban, 1960). Kirkland (herein) identified *Baculites* (smooth 2) and *Cataceramus* at the base of the Buck Shale in easternmost Utah near the state line. This indicates a Middle Campanian age spanning three to four ammonite zones, *Baculites* sp. (smooth 2) through *Baculites reduncus* (Cobban et al., 2006; Singer et al., 2023). The Buck Shale pinches out into the lower mudstone of the Price River Formation at the Beckwith Plateau northwest of Green River, Utah (Day 2, Stop 9). Witkind (1988) used the Green River in Desolation Canyon, Utah, as the cut off point for the stratigraphic nomenclature of the eastern and western Book Cliffs. To the east in Colorado, beyond the Castlegate pinch-out, the Buck Shale is recognized between the Lujane Point beds and overlying Sego Sandstone in the southern Piceance Basin until it merges eastward(?) with the Anchor Shale (Noe, 2010; Cole and Hood, 2014). Kirkland et al. (2024) suggested that from this point east, it may be best to revert to Pierre Shale terminology for the uppermost Mancos Group. Within the northern and central Piceance Basin, the Loyd Sandstone sequence is completely within the Buck Shale dividing it into a lower and upper sequence (Gill and Hail, 1975; Rogers. 2011; Schwendeman, 2011).

Anchor Mine Shale

The Anchor Mine Shale (Day 2, Stop 2) was originally named the Anchor Mine Tongue of the Mancos Group for the finer deposits splitting the sandstone beds of the Sego Sandstone (Erdman, 1934). At the Utah-Colorado state line the Anchor Mine Shale is around 100 feet (30 m) thick. The unit extends eastward until the lower parts of the Sego pinch-out north of Fruita, Colorado (Young, 1955, 1957). Farther to the east the unit merges with the underling Buck Shale. At this longitude the unit is 233 feet (71 m) thick (Hettinger and Kirschbaum, 2002). The basal contact of the Anchor Mine is sharp with an abrupt fining of grain-size (Willis and Gabel, 2003). The Anchor Mine contains pinching and swelling sand bodies with the upper contact of the unit often shown to be sharp. Locally the upper contact is gradational (Gill and Hail, 1975; Van Wagoner, 1991; Willis and Gabel, 2003). The Anchor Mine spans the middle Campanian based on *Baculites gregoryensis* to low *Baculites scotti* Zones (Young, 1983), *Didymoceras binodosum* (lower *B. scotti* Zone) in the lower parts of this unit (Kennedy and Cobban, 1991), as well as *B. scotti* within the middle and upper parts of this unit (Gill and Hail, 1975).

ROAD LOG

The road log consists of three days across central Utah (Figure 9). The first day starts in Salina and ends in Green River, Utah. The second day starts and ends in Green River. The third day starts in Green River and ends in Spanish Fork, Utah.

Day 1
Road Log Starts in Salina, Utah

Inc. Mileage	*Cum. Mileage*	*Milepost*	*Description*
0	0	MP-56.5	Enter I-70 eastbound at Exit 56 from Salina. Extensive exposures of Middle Jurassic Arapien Formation in this area are contorted by diapiric movement of salt and gypsum layers.
2.5	2.5	MP-59	Dirt frontage road ends on north side of I-70.
0.4	2.9	MP-59.4	Road cut to north side of I-70 (left) exposing Cedar Mountain Formation at base of Utah's Cretaceous section. (Figure 10). Unfortunately, given the long drive to the first day's stops, these important outcrops can only be pointed out as the trip passes by (N. 38° 56.023, W. 111° 48.060; 12S E. 430574 N. 4309726). The westernmost exposures of Cedar Mountain Formation in central Utah are in the San Pitch Mountains southeast of Nephi, and near the mouth of Salina Canyon (Figure 10). Farther to the west, it correlates to the lower part of the Canyon Range Conglomerate (Sprinkel et al., 1999). In Salina Canyon, the Cedar Mountain is dominantly pale variegated mudstone and sandstone and is 617 feet (188 m) thick (Sprinkel et al., 1999) representing the Skull Creek-Thermopolis Cyclothem. The Cedar Mountain is separated from a few tens of feet of strata tentatively assigned to the Upper Jurassic Morrison Formation at its western pinchout by a poorly exposed conglomerate

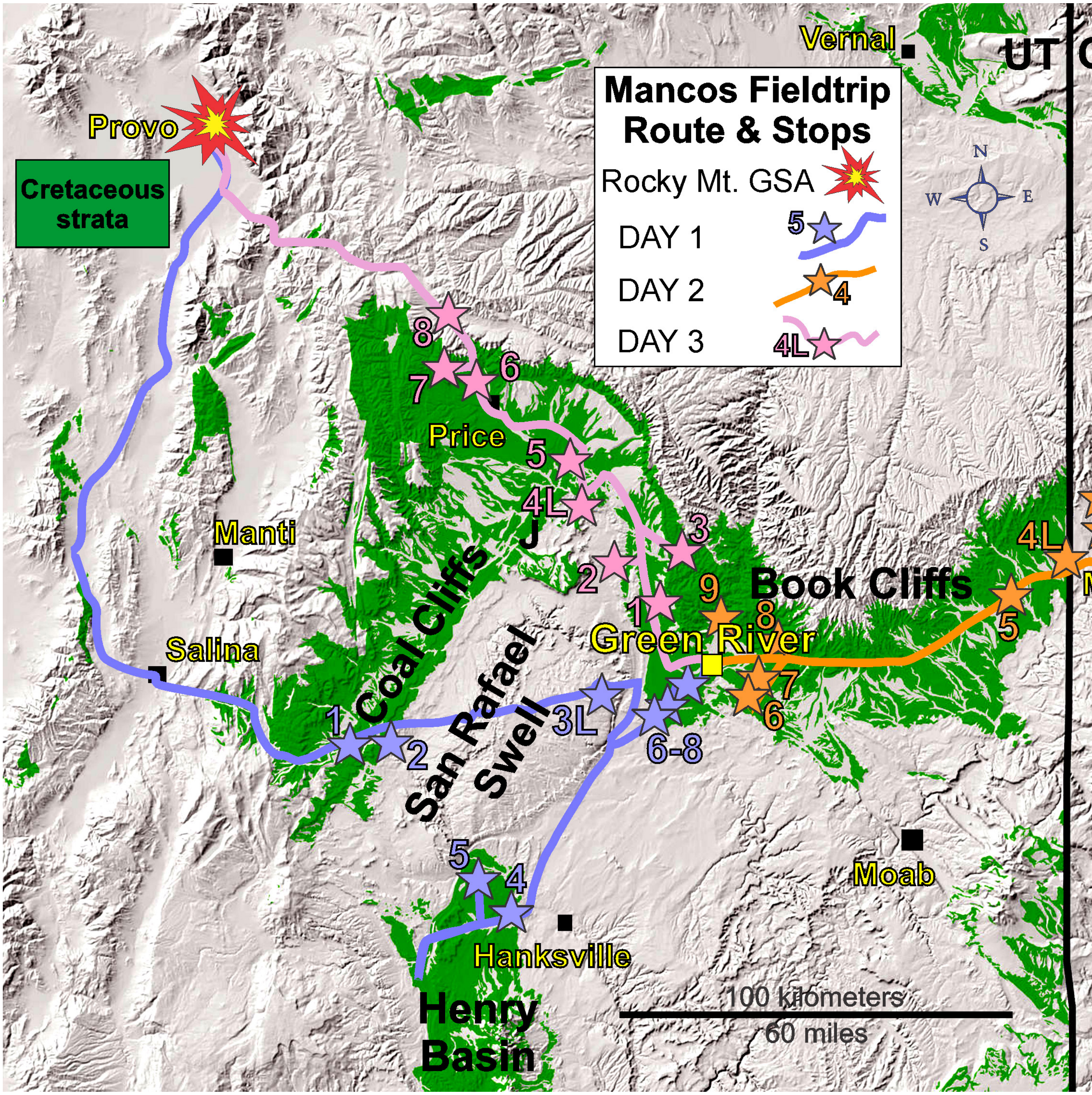

Figure 9. Cretaceous outcrops (in green) of east-central Utah with field trip route and stops. L indicates lunch stop.

that is assumed to be the Buckhorn Conglomerate Member of the Cedar Mountain Formation (D.A. Sprinkel, Utah Geological Survey, personal communication, 2004).

There is no established Morrison foredeep basin, it pinches out and the thickened pale variegated mudstone sequences to the west are representative of the Aptian-Albian Ruby Ranch Member of the Cedar Mountain Formation (Kirkland et al., 2016). The absence of Upper Jurassic strata to the west is a possible

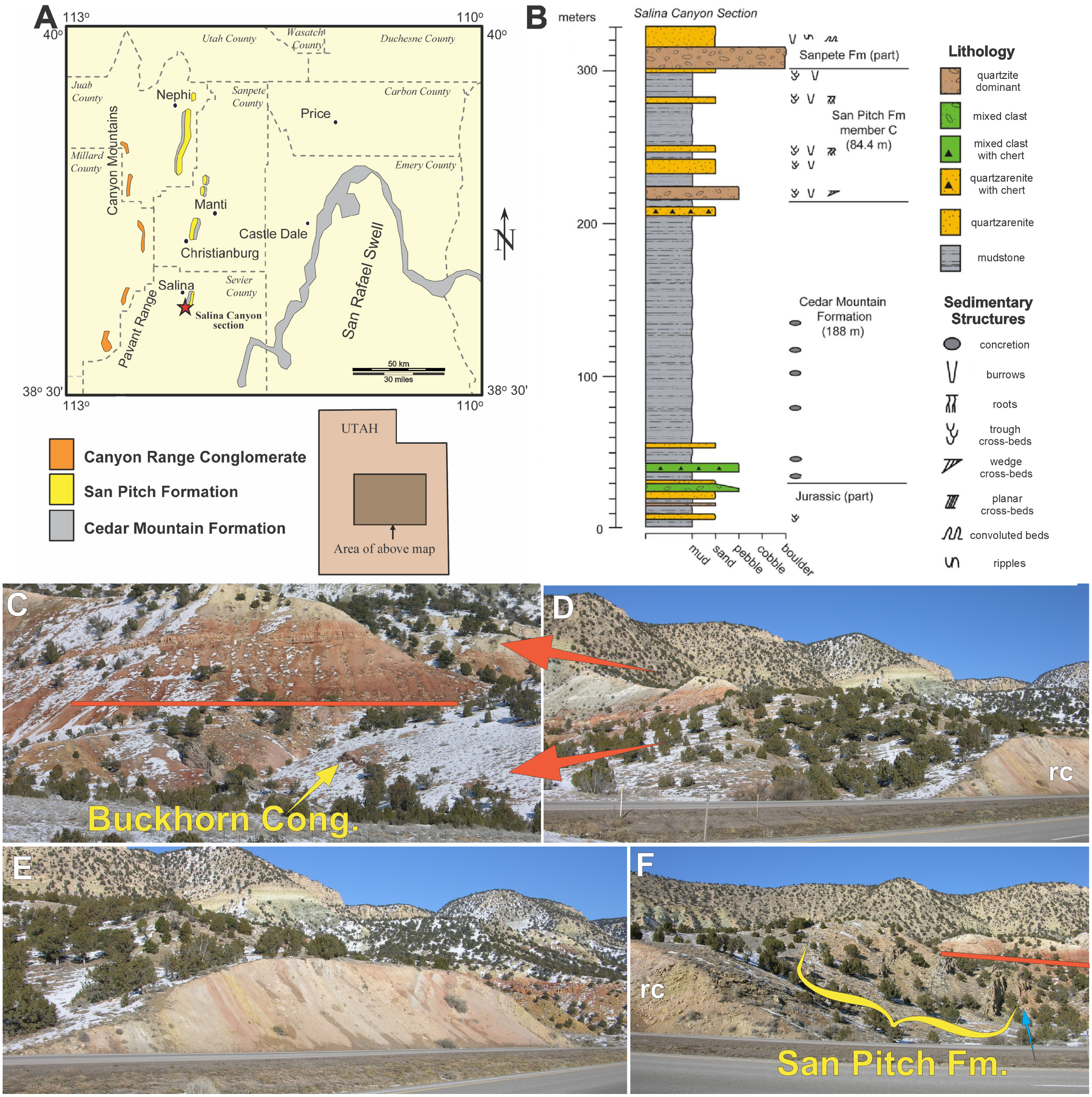

Figure 10 caption is on the next page.

result of isostatic rebound following the Middle Jurassic Elko orogeny prior to the Aptian-Albian onset of the Sevier orogeny (Thormon and Peterson, 2003; Thormon, 2011). In the San Pitch Mountains, the Cedar Mountain Formation unconformably overlies the reddish-orange sandstone beds of the Middle Jurassic Twist Gulch Formation or underlying Arapien Formation.

Figure 10 is on the previous page. Western outcrops of the Lower Cretaceous strata. (A) Distribution of Lower Cretaceous strata in central Utah. The Cedar Mountain Formation is exposed in nearly continuous outcrops at the base of the Cretaceous section around the San Rafael Swell, the north end of the Henry Mountains basin, and south of the Book Cliffs eastward to the Colorado River (Figure 9). West of the San Rafael Swell, the Cedar Mountain and San Pitch Formations are exposed in discontinuous outcrops from the San Pitch Mountains southward to Salina Canyon. Farther west, the equivalent Canyon Range Conglomerate is exposed as discontinuous outcrops from the Canyon Mountains south to the Pahvant Range. The location of the San Pitch Formation type section at Christianburg, Utah, southwest of the west end of Salina Canyon. From Sprinkel et al. (1999), courtesy of Doug Sprinkel. (B) Measured section of Cedar Mountain Formation and San Pitch Formation from north side of I-70 in Salina Canyon. From Sprinkel et al. (1999), courtesy of Doug Sprinkel. (C through F) Salina Canyon section from I-70 looking north. (C) Detail of base of section with Buckhorn Conglomerate indicated. (D) Lower part of Salina Canyon section with area of C indicated by red arrows. (E) Roadcut of Cedar Mountain Formation. (F) Upper part of Salina Canyon section with position of San Pitch Formation indicated (N. 38° 56.023, W. 111° 48.060; 12S E. 430574 N. 4309726). Blue arrow indicates position of basal conglomerate of Sanpete Formation. rc indicates east end of roadcut in E. Red line = angular unconformity at base of Flagstaff Formation.

The recognition of middle to late Albian palynomorphs in the basal Indianola Group facilitated the recognition of a Lower Cretaceous San Pitch Formation at the base of these strata. The San Pitch Formation consists of interbedded reddish-brown conglomerate, sandstone, and mudstone, and has a type section near Christianburg, at the south end of the San Pitch Mountains, where it measures 646 feet (197 m) thick and is divided into three informal members (Sprinkel et al., 1999). It is over 3000 feet (1000 m) thick to the north along the west flank of the San Pitch Mountains. Only the uppermost member is present in Salina Canyon, where it is 277 feet (84.4) m thick (Figure 10) and has been dated palynologically as late Albian (Sprinkel et al., 1999). Conglomerate beds at the base of the San Pitch Formation unconformably overlie the variegated mudstone of the Cedar Mountain Formation and are readily recognized as the first cliff above the slopes of the Cedar Mountain. Regionally, a light-colored quartzite boulder conglomerate marks the unconformity at the base of the Cenomanian Sanpete Formation overlying the San Pitch Formation (Sprinkel et al., 1999).

A detailed description of this exceptionally exposed angular unconformity separating Mesozoic strata from the overlying Paleogene strata is provided by Judge et al. (2023).

4.3	7.2	MP-63.7	Cretaceous exposures over the next 10 miles (16 km) are cut by many north-south-trending faults marking the eastern extent of the Sevier orogenic belt.
9.3	16.5	MP-73	Outcrops of the uppermost Cretaceous to Lower Paleocene North Horn Formation begin here and extend for the next 3 miles (4.8 km). Note, that there is an abundance of pedogenic carbonate nodules on these light-colored exposures. This valley formed by these less-resistant beds marking the western boundary of the Colorado Plateau.
0.7	17.2	MP-73.7	Exit 73 provides good access to extensive exposures of North Horn Formation.
2.7	19.9	MP-76.4	Exposures of carbonaceous Mesaverde Group unconformably underlie the North Horn Formation. The Campanian Mesaverde Group extends northward from the

			eastern escarpment of the Wasatch Plateau to Price. The Mesaverde is divided into the upper Price River Formation and lower coal-rich Blackhawk Formation separated by the Castlegate Sandstone, with the basal Star Point Sandstone below the Blackhawk reflecting the coastline following the final eastward regression of the Late Cretaceous Western Interior seaway in this area. Progressively younger Mesaverde sediments are exposed along the highway over next 9 miles (15 km).
8.6	28.5	MP-85	Entering the west side of Castle Valley. Exposures of Star Point Sandstone are visible capping slopes of the "Helper Formation" (formally the upper unnamed shale member of Mancos Shale of Peterson and Ryder (1975) and Ryer (1984) on the east side of Wasatch Plateau.
2.5	31.0	MP-87.5	Exposures of the upper Santonian Emery Formation of Mancos Group rise and fall near I-70 due to north-south-trending faults and folds in the Joes Valley-Paradise Valley graben (easternmost Basin and Range style faulting).
1.2	32.2	MP-88.7	Extensive cliffs formed by resistant sandstone beds in the Emery Formation overlie a thick section of Blue Gate Shale of the Mancos Group, which become visible north and south of I-70. The Blue Gate Shale, the intermediate Emery Formation, and the overlying "Helper Formation" are largely correlative to the Smoky Hill Member of Niobrara Formation (Niobrara Cyclothem) of central United States. Older Lower Coniacian age fossils correlative to the underlying Fort Hays Limestone Member are only recorded from this area in a narrow belt of basal Blue Gate Shale extending from I-70 up to Emery, Utah, and in Cretaceous strata farther to the northeast near Manti, Utah (Kennedy and Cobban, 1990; Bylund and Stephen, in press).
2.6	34.8	MP-91.3	**Exit 91**, Junction of Utah State Route 10, exit. Turn right (south) at stop sign onto the Last Chance Road.
5.6	40.4		Drive south uphill turning east after less than 1 mile (1.6 km). In 2.8 miles (4.5 km) take U-turn at intersection returning 1 to 2 miles (1.6–3.2 km) to park along road to discuss the upper Mancos Group exposed below the Mesaverde Group to the northwest. **Stop 1 (**N. 38° 45.844, W. 111° 20.088; 12S E 470913 N 4290648)**: Emery Formation in type area (Figure 11)**. The Emery Formation was described as a series of interbedded sandstone, siltstone and silty shale near base of the eastern escarpment of the Wasatch Plateau southwest of Emery, Utah, as a member of the Mancos Shale by Spieker and Reeside (1926). The most comprehensive study of these strata was by Edwards et al. (2005) documenting 17 coarsening upward parasequences that they correlated along the Coal Cliffs with a coal-bearing fluvial sequences capping some to the west in the subsurface. We propose assigning these strata to the Emery Formation because of these sedimentological complexities. The overlying slope-forming unit was initially improperly referred to the Masuk Shale of the Mancos Group (younger Campanian age Masuk Formation), before being correctly identified as a younger unit by Peterson and Ryder (1975) and Ryder (1985). These studies determined that the "Emery Sandstone" is not present in the Henry Mountains basin and

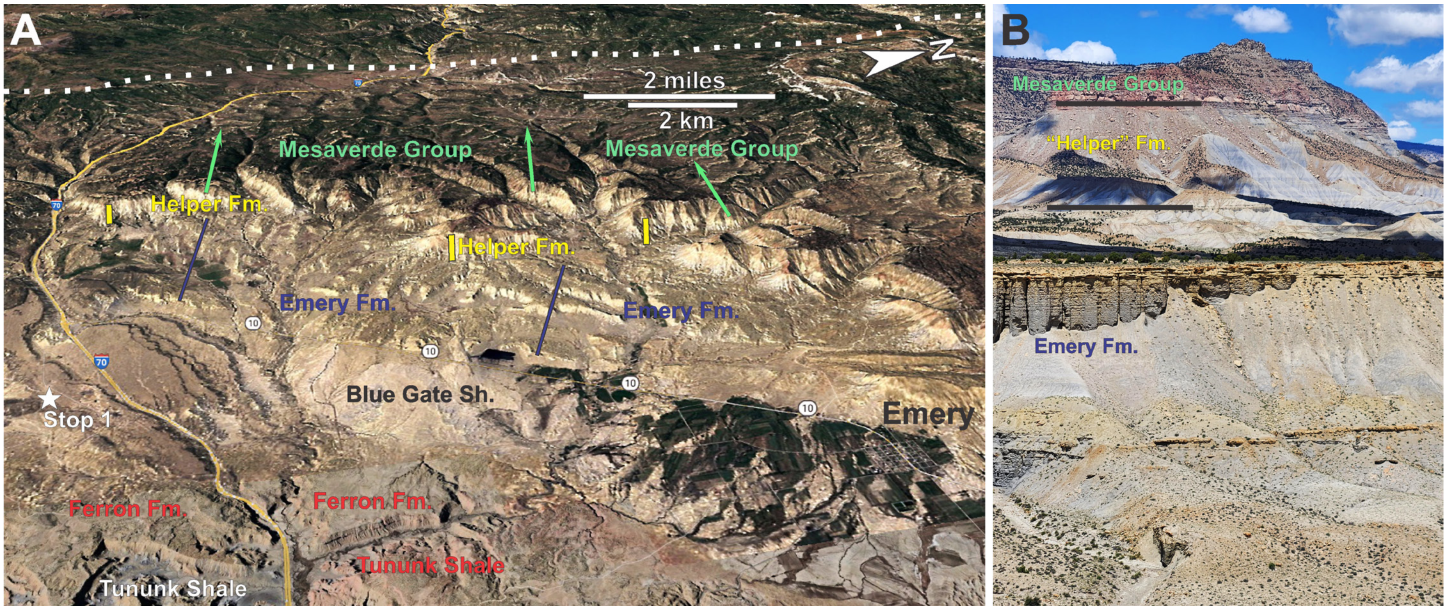

Figure 11. Upper Mancos Group underlying the Mesaverde Group to north of **Day 1, Stop 1**. (A) Outcrop north of I-70. Emery Formation (formally Emery Sandstone) interval indicated by thin blue bars. Helper Formation (formally unnamed upper shale member) indicated by yellow bar. White dotted line designates the approximate eastern boundary of the Colorado Plateau. Image from Google Earth ©2018. (B) Outcrop of Emery Formation about 17 miles (27 km) north of Emery west of Clawson.

the slope-forming unit above the Emery Formation was subsequently referred to as the "unnamed shale member" or as "upper Blue Gate Shale." The "Helper" is denoted as a formation rather than a shale, as it is dominantly a structureless mudstone with sandier zones and there are few strata that are at all well-bedded in the type area. These strata are in turn capped by the Star Point Sandstone of the Mesaverde Group. Continue back onto I-70 eastbound.

4.4 44.8 MP-95.7 The freeway cuts down through top of the upper Ferron Formation of the Mancos Group. The Ferron represents a middle to upper Turonian river- to wave-dominated delta system that formed along the west side of the San Rafael Swell and Henry Mountains basin. The capping Middle Turonian lower Ferron Formation interfingers with the underlying Tununk Shale, representing the Greenhorn Cyclothem. The upper Ferron Formation largely correlates to the Juana Lopez Formation and overlying Upper Turonian Montezuma Valley Member of the Blue Gate Shale, which represent the minor Sage Breaks Cyclothem separating the more extensive Greenhorn and overlying Niobrara Cyclothems. The Ferron Formation is highly important economically for its coal and natural gas and has been the subject of numerous scientific studies as a fluvial-deltaic reservoir analog (Lupton, 1916; Ryer, 1981; Garrison et al., 1997; Montgomery et al., 2001; Gloyn et al., 2003; Garrison and Ven den Bergh, 2004; Biber et al., 2017; Li and Zhu, 2012; Ahmend et al., 2014; Li et al., 2018; Chidsey and Anderson, 2019).

0.9 45.7 MP-96.6 The base of the Ferron Formation overlying the Tununk Shale of the Mancos

			Group is exposed on both sides of I-70.
0.8	46.5	MP-97.4	A classic example of river-dominated delta clinoforms are preserved in the Ferron Formation in the Ivie Creek area on the north side of I-70. A more detailed explanation of this outcrop is provided by Anderson et al. (2004) and Chidsey and Anderson (2019).
2.5	48.3	MP-99.1	Continue east on I-70 for 2.5 miles (3.3 km) turning south at Exit 99 to **Stop 2 (**N. 38° 48.320, W. 111° 12.374; 12S E 482093 N 4295194): **Lower Mancos – Tununk Shale and Ferron Formation.** Across most of this region the base of the Mancos Group is characterized by a transgressive unconformity characterized by a mixed chert-pebble conglomerate**—***Pycnodonte newberryi* coquina—variably overlying either the Naturita or Cedar Mountain Formations (Eaton et al., 1990; Molenaar and Cobban, 1991). At this stop, the top of the Naturita preserves the Late Cenomanian index fossils *Inoceramus pictus* and *I. flavus* and within a short distance up section there is a prominent basal Turonian bentonite bed identified as Bentonite C from which several radiometric ages are used to refine the age for the base of the Turonian stage (Obradovich, 1993; Sageman et al., 2006; Ogg et al., 2012; Gale et al., 2020; Singer et al., 2023) (Figures 12A and 12B). Additional study of this contact has been made 11.2 miles (18 km) to the northeast at the Moore Cutoff Road, where Bentonite C is sandwiched between the basal Turonian inoceramid *Mytiloides kossmati* below and the ammonite *Pseudaspidoceras flexuosum* above (Kennedy et al, 2000; Cobban et al., 2006). Below the inoceramid-bearing sandstone capping the Naturita Formation, there are a pair of ashes, each on the order of 8 inches (20 cm) thick, that are tentatively identified as representing Bentonite A (Figures 12C through 12E). Uranium-lead dating of the zircons from these two bentonite beds is still pending. The chert pebble conglomerate is interpreted to be a result of reworking of the basal conglomerate off the crest of the San Rafael Swell during sea-level rise in the latest Cenomanian with the presence of *Pycnodonte newberryi* indicating that these gravels were being reworked across the region until water depths exceeded storm wave-base (Eaton et al., 1990; Kirkland et al., 2007; Santucci and Kirkland, 2010). If the identification of Bentonite A is correct, the entire process of uplift, and reworking of these pebbles across the region would have occurred within the span of approximately 100,000 years. The upper Ferron Formation directly overlies the undivided Tununk Shale in this area, and the Clawson and Washboard Members of the lower Ferron Formation are reported to pinch out into the Tununk just to the north at Ivie Creek (Chidsey and Anderson, 2019). As noted in Kirkland et al. (2024), the nomenclature question arises, should the lower and upper Ferron be split into separate formations, as they are parts of separate marine sequences and are already mapped separately. In such a scenario, the southwestern-sourced upper Ferron would be retained as the Ferron Formation and more northern-sourced lower Ferron (Katich, 1951, 1953; Cotter, 1975), including the Clawson and overlying Washboard Members, would be designated as a separate formation.
3.9	52.2	MP-100.5	Exposures of the Cenomanian Naturita Formation at base of the Mancos Group

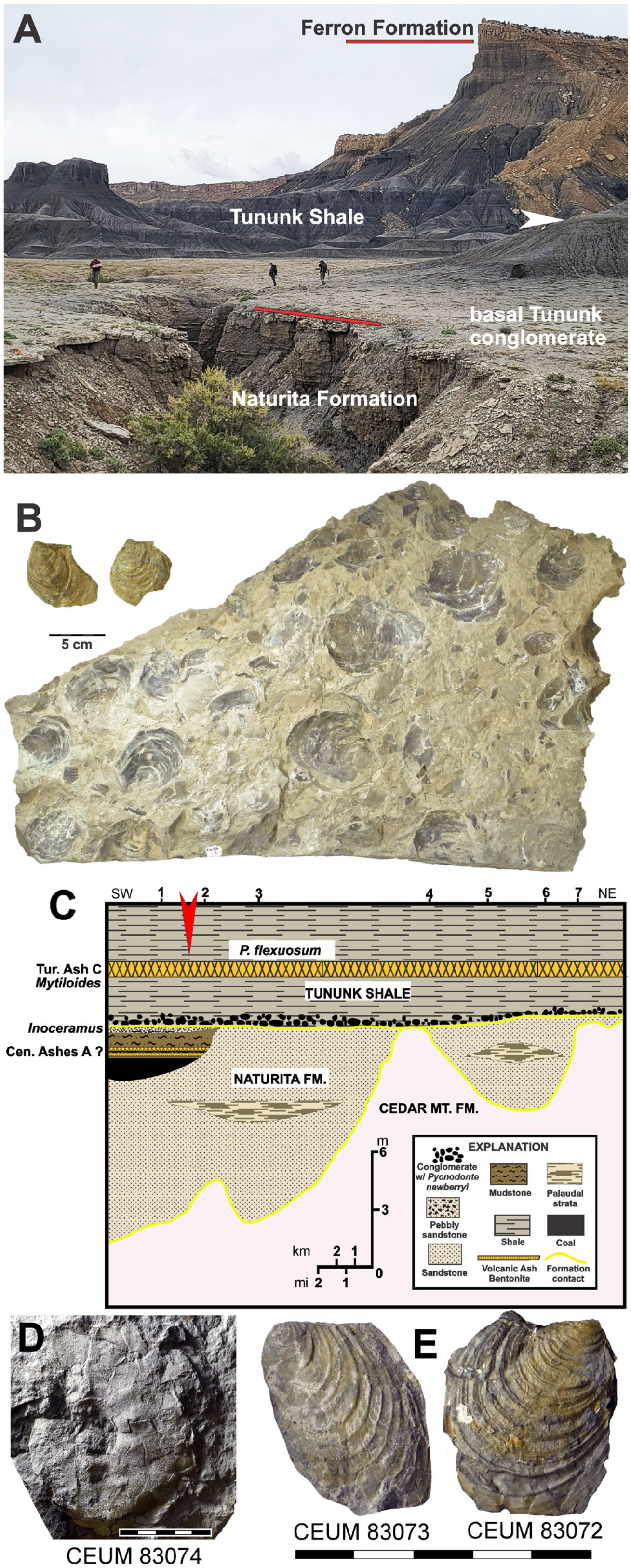

Figure 12. (A) Well-exposed Tununk Shale exposures south of I-70 at **Day 1, Stop 2**. Arrow points to Bentonite "C" of Elder (1985, 1988). (B) Examples of *Inoceramus flavus* from the upper Cenomanian *Burroceras clydense* Zone at the top of the Naturita Formation in this area. The basal gravel in this area represents the uppermost Cenomanian. (C) Simplified cross section of the basal Tununk Shale, its basal conglomerate, and its unconformable relationship with underling strata. Modified from Eaton et al., (1990). Red arrow indicates the position of the Moore Cutoff Road 11.2 miles (18 km) to the northeast. (D) *Pseudaspidoceras flexusum* from a few feet above Bentonite C. (E) Examples of *Mytiloides kossmatti* from immediately below Bentonite C. CEUM indicates that the specimen is located at the Utah State University Eastern, Prehistoric Museum.

			and overlying the Cedar Mountain Formation.
0.9	53.1	MP-101.4	Excellent exposures of both the pale-gray, smectitic Mussentuchit and the underlying pale-mauve, pedogenic, carbonate-rich Ruby Ranch Members of the Cedar Mountain Formation are on north side of I-70.
0.2	54.3	MP-101.6	The western margin of the Buckhorn Conglomerate interfingering with the Yellow Cat Member facies with the characteristic ferruginous paleosols at the base of Cedar Mountain Formation and caps the Morrison Formation on both sides of I-70 (Kirkland et al., 2016).
2.8	57.1	MP-103.4	The off ramp for the Salt Wash rest area is built on light-colored transgressive marine sandstone of the Curtis Formation. The Curtis is overlain by brownish-red shallow-marine strata of Summerville Formation, which in turn is overlain by Morrison Formation. This Middle Jurassic marine sequence lies above the regional J-3 unconformity developed on top of the Entrada Sandstone as indicated by localized lenses of small chert pebbles on this surface (Pipiringos and O'Sullivan, 1978).
4.6	61.7	MP-108	A thick section of reddish-colored Entrada Sandstone and Windsor Member of the Carmel Formation are exposed in mesas and canyons throughout area.
4.0	65.7	MP-112	Begin climbing long dip slope on west side of San Rafael Swell through exposures of lower Middle Jurassic marine Carmel Formation. Gypsum is mined in several areas in the Carmel on this side of the San Rafael Swell (Bowden et al., 2016). The road continues to cut down section until crest of San Rafael Swell.
8.4	74.1	MP-115.3	Looking across canyons from the view area are exposures of the Lower Jurassic Glen Canyon Group.
0.5	74.6	MP-115.8	Travel eastbound on I-70 and take off ramp for Exit 116—the Moore Cutoff Road.
1.8	76.4	MP-116.6	Excellent exposures of the Upper Triassic-Lower Jurassic Glen Canyon Group downward through the Lower Triassic Moenkopi Formation are present along the road across the crest of the San Rafael Swell for the next 25 miles (40 km). The San Rafael Swell is one of the most dramatic geological features in Utah. It is a doubly plunging anticline that forms a huge north-south-trending elongate "bulls-eye" that is more than 200 miles (320 km) in circumference (Figure 13). It serves as a model for the study of petroleum reservoirs such as the Navajo Sandstone, which preserves dead oil around the entire structure, and is considered to be a breached "mega"-reservoir. The San Rafael Swell exposes older rocks from the deep subsurface. These outcrops are used to model possible reservoir trends. Additionally, the San Rafael Swell was studied as a reservoir for the sequestration of carbon dioxide.
16.4	92.8	MP-133	For the next 2 miles (3.2 km) the crest of the San Rafael Swell is formed of the Permian Black Box Dolomite (Kaibab Limestone of many reports).
7.0	99.8	MP-140	Rest area. Spectacular views of the east side of the San Rafael Swell as the strata dip down the steep side of Swell forming the San Rafael Reef. The marine Sinbad

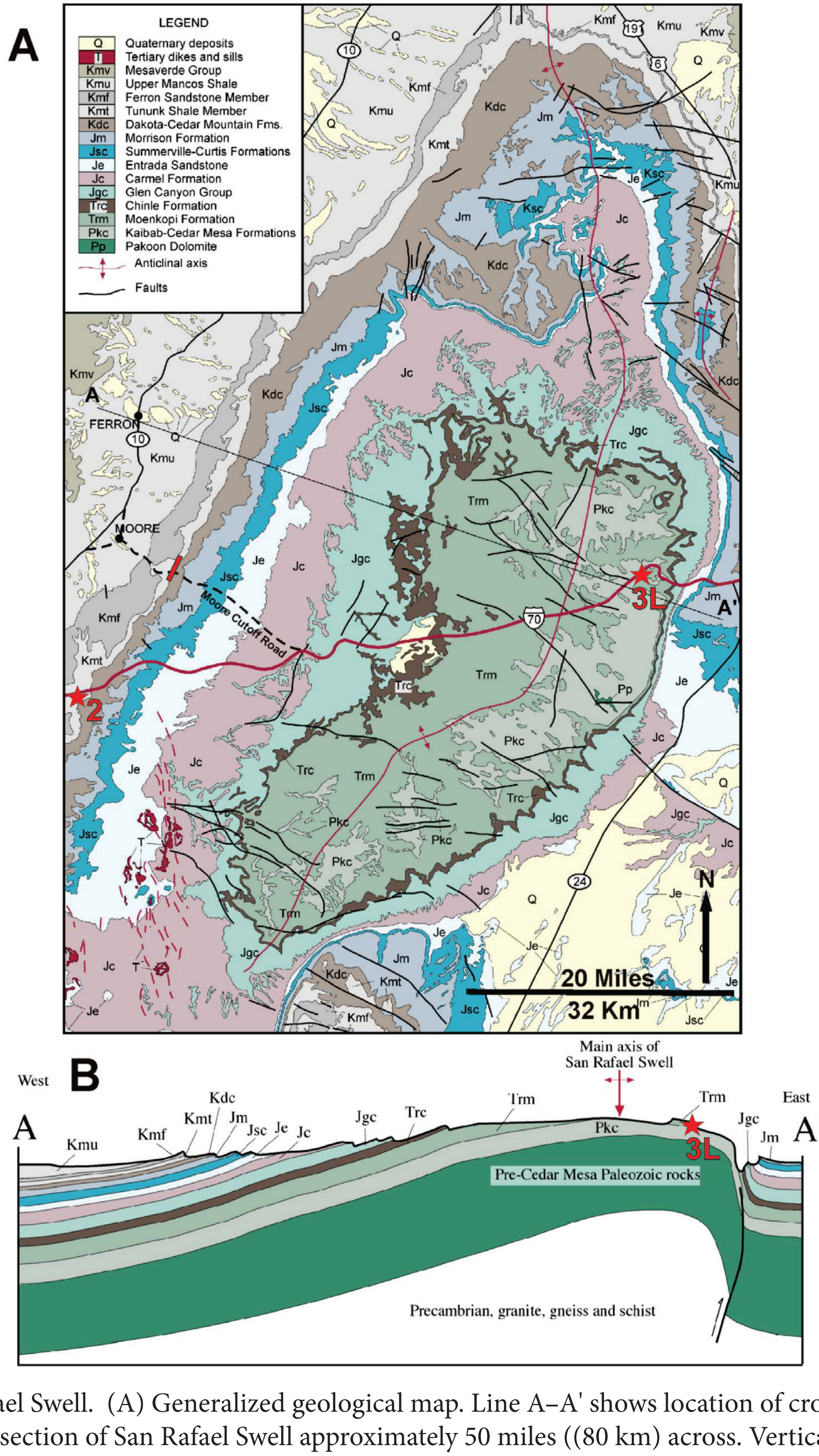

Figure 13. San Rafael Swell. (A) Generalized geological map. Line A–A' shows location of cross section. (B) West-to-east cross section of San Rafael Swell approximately 50 miles ((80 km) across. Vertical scale about 80 times horizontal scale. From Doelling and Hylland (2002). Red stars = **Day 1, Stop 2** and **Day 1, Stop 3**, lunch stop.

			Limestone Member of the Early Triassic age Moenkopi Formation is exposed on the west side of rest area. Permian White Rim Sandstone (Coconino Sandstone of many reports) is cut into by the deepest canyons. **Stop 3** (N. 38° 55.964, W. 110° 28.314; 12S E 545772 N 4309444) **for lunch** (30 minutes).
4.0	103.8	MP-144	The rest area is on Middle Jurassic Entrada Sandstone with a strike valley of Middle Jurassic Carmel Formation. To the west and below the Carmel, a dip-face of huge flatirons of the Lower Jurassic Navajo Sandstone and local outcrops of the Middle Jurassic Temple Cap Formation forms the San Rafael Reef (Sprinkel et al., 2011). To the southeast, resistant sandstone of the Salt Wash Member of the Morrison Formation hold up cliffs formed from exposures of reddish-brown Summerville Formation overlying, light-colored Curtis Formation.
5.2	109.2	MP-149.4	Exit 149. Exit for Utah State Route 24 (SR-24) southbound to Hanksville, Utah. Upper part of Salt Wash Member is exposed here. Merge right to Hanksville and begin SR-24 mileposts.
0.8	110.0	MP-160	Driving on top of the Salt Wash Member of the Morrison Formation. The Buckhorn Conglomerate caps slopes of Brushy Basin Member of the Morrison Formation on left for about next 3 miles (4.8 km). To the right, Navajo Sandstone flatirons form the San Rafael Reef.
3.1	113.1	MP-156.9	We will take the "old" SR-24 to Green River on our return. Road cuts down through the Tidwell Member of the Morrison Formation. Note white patches along right side of road; these reflect gypsum deposits in the Tidwell. The Summerville Formation forms cliffs below Tidwell Member.
0.3	113.4	MP-156.6	Crossing San Rafael River.
3.6	117.0	MP-152	Between here and Hanksville, the bedrock is discontinuously covered by a combination of active dunes and dunes stabilized by vegetation. This probably reflects an environment similar to that of the lower Campanian Djadokhta Formation in Mongolia's Gobi Desert. There are an abundance of small vertebrates (lizards, birds, and mammals) living in the high desert on the Colorado Plateau as there were in the Late Cretaceous of the Gobi Desert. Coyote and bobcat are analogous to the Cretaceous carnivores like *Velociraptor* and *Oviraptor*, whereas the pronghorn would comparable to the herbivores such as *Protoceratops* and *Pinacosaurus*.
1.7	118.7	MP-150.3	Exposures of the Middle Jurassic Entrada Sandstone.
5.6	114.3	MP-144.7	Exposures of the underlying Carmel Formation are visible in the valley on the right.
8.5	122.8	MP-136.3	Turnoff to Goblin Valley State Park on right.
4.3	127.1	MP-132	The road goes down grade into the valley of the Muddy, Fremont, and Dirty Devil Rivers. The scattered buttes along the route to Hanksville are made of Entrada Sandstone.
4.0	131.1	MP-128	Henry Mountains are seen to the south. To the west (right), light-colored sand-

			stone of Curtis Formation overlies red beds of Entrada Sandstone and in turn is overlain by brownish-red beds of Summerville Formation.
1.7	132.8	MP-126.3	Leaving Emery County and entering Wayne County.
5.9	138.7	MP-120.4	Hanksville Airport is on right.
0.7	139.4	MP-119.1	Crossing the Dirty Devil River. Muddy Creek joins the Fremont River from northwest to form Dirty Devil River just west of this bridge.
2.4	141.8	MP-116.7	At the intersection of SR-24 with SR-95 in Hanksville, Utah, turn west (right) to continue on SR-24 toward Capitol Reef National Park.
0.4	142.2	MP-116.2	Steel "dinosaur" graveyard on right.
0.2	142.4	MP-116.0	Rock shop on right.
0.6	143	MP-115.4	Crossing the Fremont River on west side of Hanksville. Outcrops of the light-colored Curtis Formation below the brownish-red Summerville Formation north of road.
1.4	144.7	MP-114.0	Passing outcrops of the Summerville Formation on right side of road with Fremont River on left side.
0.7	145.4	MP-113	Passing through exposures of the Salt Wash Member of the Morrison Formation. Note the relative thinness of this section compared to that in the Green River area as will be seen on Day 2.
2.2	147.6	MP-110.5	Exposures of Naturita Formation overlying Brushy Basin Member of the Morrison Formation on the right.
0.6	148.3	MP-109.9	Passing onto the basal Tununk Shale. Turn right on dirt track up and over Tununk before turning east to park. **Stop 4** (N. 38° 22.168, W. 110° 49.167; 12S E 515771 N 4246824): **basal unconformable Tununk Shale contact with the Naturita Formation.** In the Hanksville area, the Naturita Formation may be split into three units (Antia and Fielding, 2011): (1) a basal conglomeratic fluvial sandstone rich in quartzite, (2) a medial carbonaceous paludal sequence, and (3) an upper fossiliferous transgressive marine sandstone (Figure 14). The top of the Naturita and the base of the Tununk are characterized by thick accumulations of *Pycnodonte newberryi*, which were so thick here that it was mined to provide the roadbed for SR-24 across the Mancos Group to Capitol Reef National Park.
3.1	151.4	MP-106.8	Abandoned Giles townsite is on the left (south) side of road along the Fremont River. The Ferron Formation forms cliff above Tununk Shale.
0.7	152.1	MP-106.1	Passing up through the basal Ferron Formation. On the left side of road, a fallen block of sandstone was found to preserve shark teeth, turtle shell sections, and the sacrum of a small ornithopod dinosaur, which are now in the collections of the Burpee Museum, Rockford, Illinois.
0.4	152.5	MP-105.7	Passing up through the top of Ferron Formation. Extensive paludal facies at the

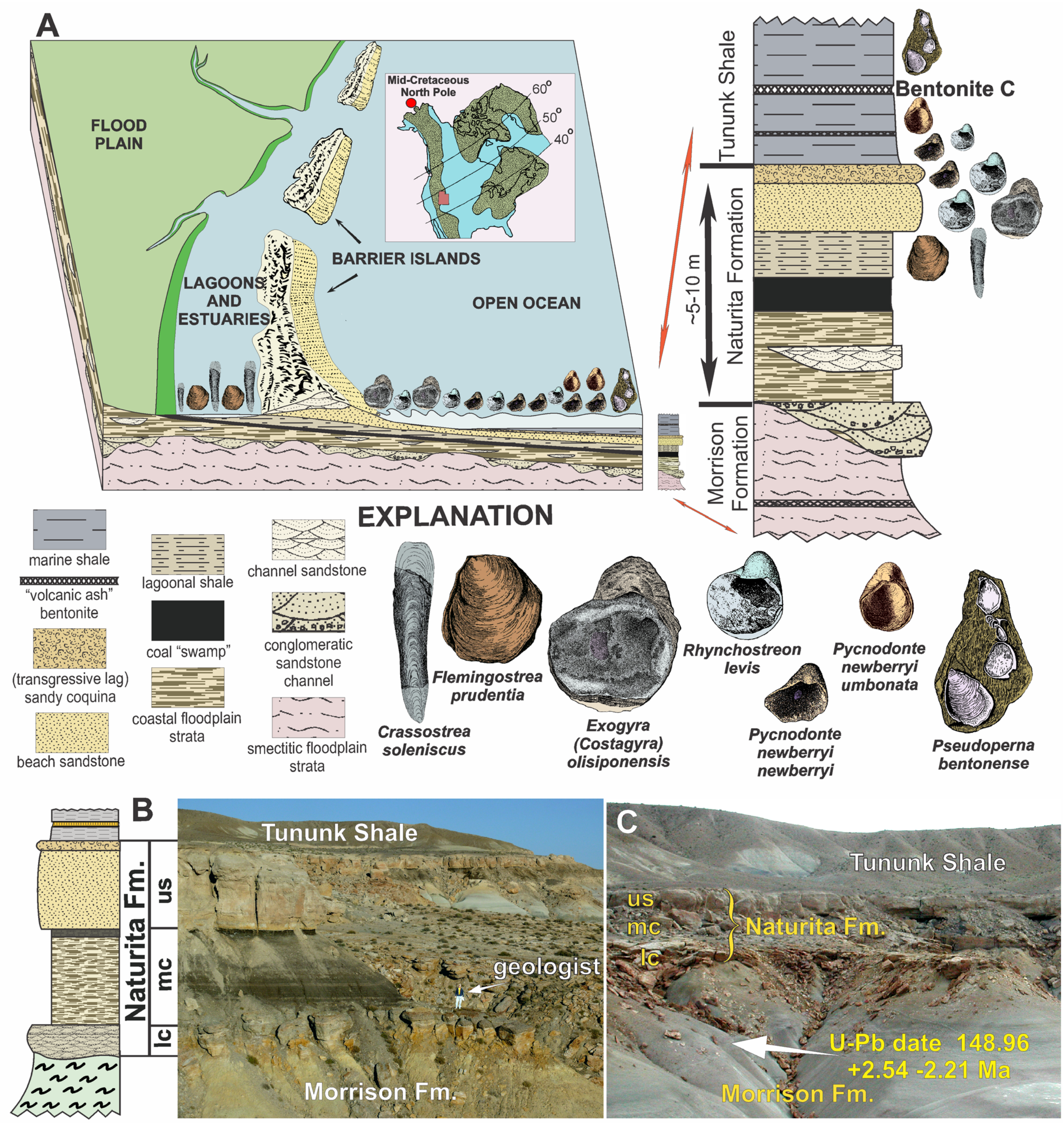

Figure 14. The Upper Cretaceous transgressive sequence in the Hanksville area. (A) Generalized Upper Cenomanian-Lower Turonian transgressive sequence largely based on the stratigraphic section preserved west of Hanksville, Utah, (**Stop 4**) showing the distribution of various oyster taxa relative to the facies in which they are preserved. Oyster figures from Stanton (1893) with ecological interpretations from Kirkland (1996). Figure updated from Santucci and Kirkland (2010). (B) The Naturita and basal Tununk section just east of **Stop 4** with the distribution of oyster species documenting the ecologic progression from freshwater environments, brackish water, beach, shallow shelf sands reworked periodically by storm processes to quiet shelf settings below storm wave base. Molluscan data following Kirkland (1990, 1991, 1996; Santucci and Kirkland, 2010). (C) The same section about 0.6 miles (1.0 km) to the east showing approximate position of Morrison laser ablation SR-Pb zircon age from Kowallis et al. (2007). Abbreviations: us = upper sandstone member, mc = middle carbonaceous member, lc = lower conglomerate member.

			top of the Ferron are well exposed across this bench.
0.5	153.0	MP-105.6	Turn off for Factory Butte on right.
5.1	158.1	MP-100.5	Continue west through blue-gray Blue Gate Shale badlands between North and South Caineville Mesas.
2.8	160.9	MP-97.6	Continue west through Caineville, Utah, and pass through the water gap formed by the Caineville Reef, where road turns south along this monoclinal structure.
5.3	162.2	MP-92.0	Continue south along the west side of the Caineville Reef to the Notom Road. The Caineville Reef is held up by sandstone of the Ferron Formation with the Tununk Shale forming the valley floor. The more resistant beds in the Lower Cretaceous Cedar Mountain Formation forms a low ridge on the western side of the road immediately below the Tununk (Figures 15A and 15B). This unconformable contact has been discussed here by Kirkland et al. (2016) and as elsewhere is represented by a lag of *Pycnodonte newberryi* shells with scattered chert pebbles. Turn left (south) onto the Notom Road and turn around to proceed back north on SR-24.
2.5	167.7	MP-94.5	Passing by the entrance to Sleepy Hollow Campground on right, just south of where SR-24 crosses the Fremont River (Figure 15B). Note: the sandy resistant beds in the Tununk Shale slope below the Caineville Reef. These beds appear to correlate with the Coon Spring Sandstone Member of the Tununk Shale (Molnaar and Cobban, 1991), but are they continuous with the Coon Spring and are they also sourced from the north? There have been no stratigraphic studies on the Tununk in this area.
9.1	176.8	MP-105,6	Drive north on Factory Butte Road for 13 miles (21 km) where we will turn around and park for **Stop 5** (N. 38° 28.060, W. 110° 54.130; 12S E 508534 N 4257710): **Factory Butte.** Factory Butte consists of a thick section of Blue Gate Shale of the Mancos Group capped by the Muley Canyon Sandstone (Figure 15C). Superficially, the Muley Canyon Sandstone would appear to be correlative with the Emery Formation of the Mancos Group, except that it is early Campanian in age and underlies the terrestrially deposited middle Campanian Masuk Formation. Additionally, the Emery Formation is late Santonian in age and underlies the Helper Formation of the Mancos Group (Eaton, 1990; Titus et al., 2016; Kirkland et al., 2024). Along the sides of the road, we can examine the disconformity between the top of the Ferron Formation and the base of the Blue Gate Shale, where we can collect *Pycnodonte aucella* and fragments of *Volviceramus involutus* (Figure 15D) indicating that the basal Blue Gate is no younger than upper middle Coniacian in this area. Return to SR-24.
26.0	202.8	MP-105	Turn east on SR-24 for 10.8 miles (17.4 km) to Hanksville. Bear left to continue north for 52.1 miles (83.9 km) across the San Rafael River, then turn right on the old abandoned SR-24. The bench is formed by the Salt Wash Member of the Morrison Formation
62.9	265.7	MP-156.9	Cattleguard. We will take the "old" SR-24 (Bureau of Land Management [BLM] Road 9102) toward Green River, Utah.

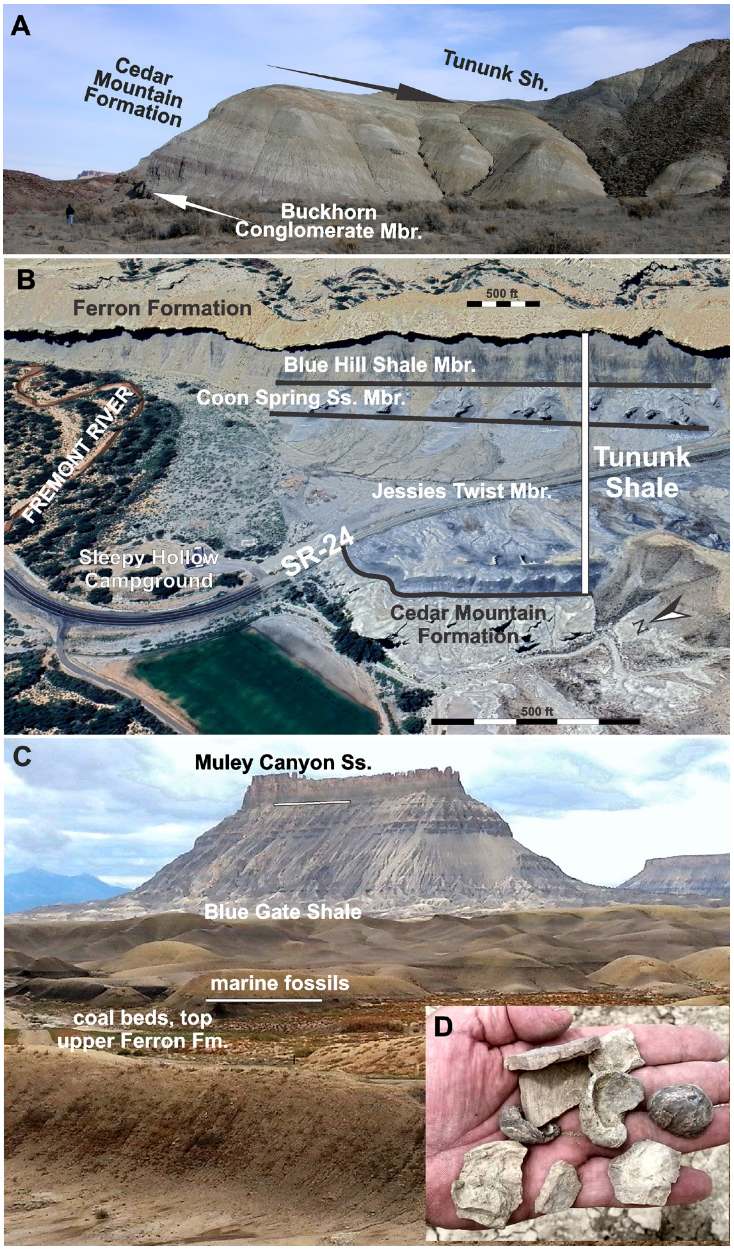

Figure 15. Mancos Group around north end of Henry Mountains basin. (A) Basal contact of Tununk Shale with Cedar Mountain Formation at the south end of Caineville Reef (38°16'27.56"N., 111° 3'58.48"W.). (B) Oblique view from west of Tununk Shale along Caineville Reef south of Fremont River. Google Earth ©2024. (C) Exposures to the northeast of Factory Butte just to the east of the type area for the Blue Gate Shale at **Stop 5**. (D) Examples of the common fragments of the inoceramid *Volviceramus* and the oyster *Pycnodonte aucella* from the base of the Blue Gate Shale.

1.1	266.8	There are no mile posts along the abandoned SR-24 route. Cross the clay-change from illitic to smectitic mudstone beds marking the transition from Salt Wash to the Brushy Basin Member of the Morrison Formation.
0.7	267.5	Entering Jessies Twist; an important accessible exposure of the upper Morrison Formation and the Yellow Cat and Poison Strip Members of the Cedar Mountain Formation.
0.3	267.8	Note the iron-stained ferruginous paleosols marking the basal beds of the Yellow Cat Member, documenting an exceedingly wetter climatic interval at the beginning of the Cretaceous before a return to dryer conditions in the middle of the Yellow Cat (Kirkland et al., 2016; Kirkland and DeBlieux, 2024). Also useful to note that the mudstone beds in the Lower Cretaceous of the Paradox Basin are

nonsmectitic, such that the change in the weathering profile is a useful way to map the contact between the convexly weathering Morrison Formation and the flat to concave weathering profile of the Yellow Cat Member of the Cedar Mountain Formation. The Yellow Cat Member has been dated as ranging from the Berriasian through Valanginian using a combination of biostratigraphy of microfossils (palynology, charophytes, and ostracodes), and chemostratigraphy calibrated with detrital U/Pb ages from paleosols (Joeckel et al., 2019, 2023).

0.3 268.1 Cross onto bench formed by sandstone within the Poison Strip Member of the Cedar Mountain Formation. Within 30 feet (10 m) of this bed—1.5 miles (2.4 km) to the northwest—Warren and Carpenter (2004) collected a large nodosaurid curated at the Denver Museum of Nature and Science that is similar to *Sauropelta* and represents the lowest record of an Aptian-age dinosaur in the Paradox Basin (Kirkland et al., 2016).

0.7 268.8 The largely vegetated bench is composed of poorly exposed Ruby Ranch Member of the Cedar Mountain Formation. Turn left (northwest) onto BLM Road 9130.

0.5 269.3 Follow the dirt track past borrow pits exposing pale-green mudstone of the upper Ruby Ranch Member of the Cedar Mountain Formation. After S-curve in track turn around and park. **Stop 6** (N. 38° 54.624, W. 110° 19.486; 12S E 558543 N 4307050): **Basal Tununk unconformity.** Mixed chert pebble conglomerate and coquina of *Pycnodonte newberryi subundata* (Figure 16) indicating the unconformable base of the Tununk in this area is basal Turonian in age. This is the type area of the proposed Jessies Twist Member of the Tununk Shale. The Jesse Twist extends from the basal conglomeratic lag up to the base of the Coon Spring Sandstone Member. A type section has been measured approximately 2 miles (3.2 km) farther northwest. This stratigraphic interval is composed of dark olive-gray, calcareous, silty to sandy shale with numerous, thin fine-grained sandstone layers less than 0.2 inches (0.5 cm) thick individually. This unit is remarkably unfossiliferous, without a single inoceramid bivalve or ammonite encountered until the basal sandstone layers beneath the main Coon Spring Sandstone concretion level, which preserved the ammonite *Collignoniceras woollgari*.

0.4 269.7 Return to “old” SR-24 and take the left fork onto BLM Road 9137.

0.8 270.5 Stop alongside of road. **Stop 7** (N. 38° 55.092, W. 110° 18.609; 12S E 559804 N 4307925): **Coon Spring Sandstone concretion level.** These sandstone beds are interpreted to have been sourced from the north across the Uinta Basin region (Cotter,1975; Riemersma, 1989; Molenaar and Cobban, 1993), where only the uppermost Middle Turonian Tununk Shale is exposed beneath the sandstone beds of the Frontier Formation (Ryer and Lovekin, 1986; Molenaar and Wilson, 1990). These sandstone concretions preserve a shallow water molluscan fauna (Figure 17). We have proposed designating the shale interval between the Coon Spring Sandstone and Juana Lopez Formation as the Blue Hill Shale Member of the Tununk Shale. In this area, these unfossiliferous, dark, noncalcareous beds include many thin sandstone beds.

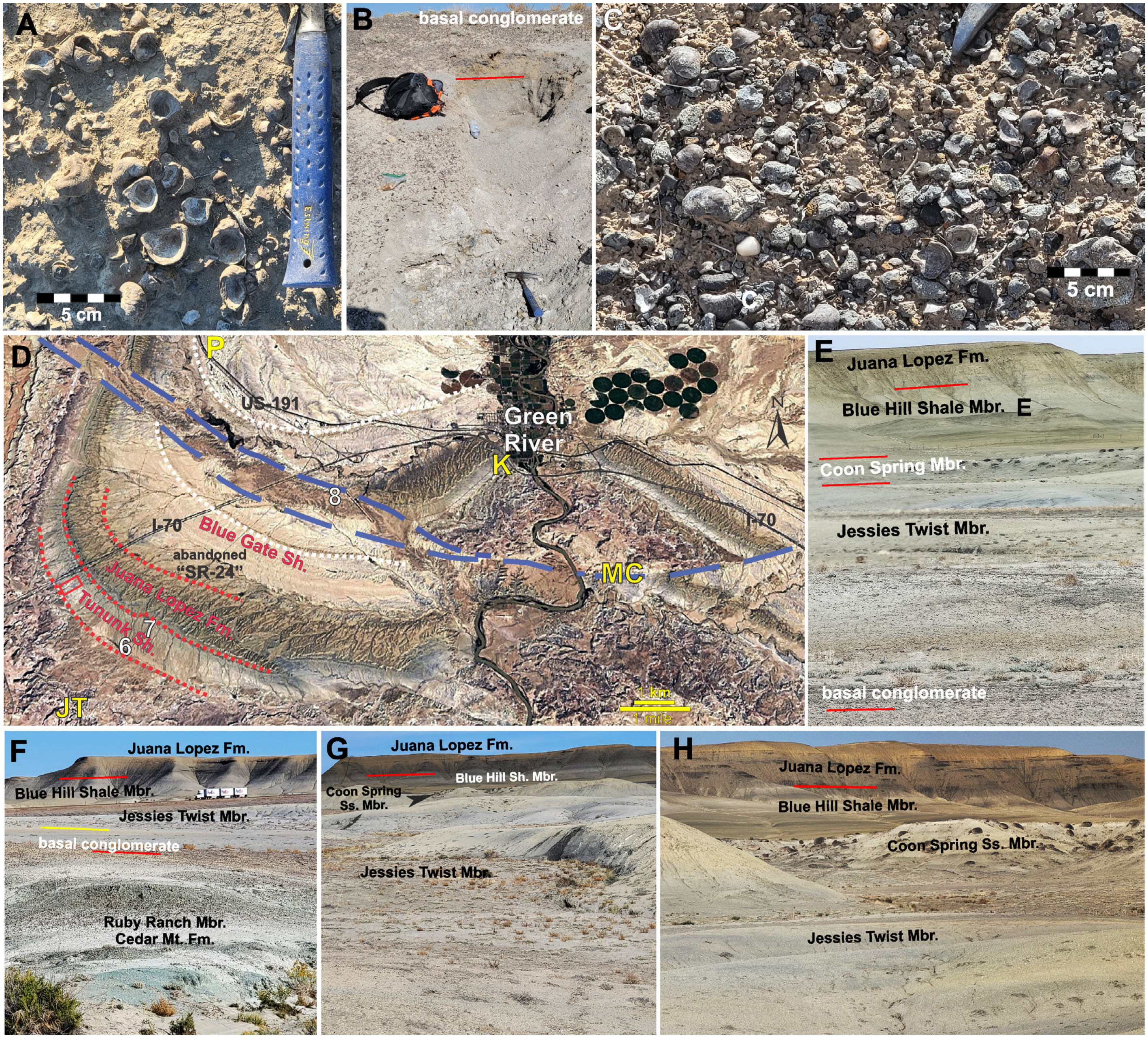

Figure 16. Jessie Twist Member in Green River area. (A) *Pycnodonte newberryi* at **Day 1, Stop 7**. (B) contact of Ruby Ranch Member of Cedar Mountain Formation, with conglomeratic coquina at the base of the Jessies Twist Member at its proposed type section. (C) Carbonate-cemented conglomeratic coquina at the base of the Jessies Twist Member north of BLM Road 1043, 2.1 miles (3.4 km) east of "old" SR-24. (D) Lower Mancos Group in the Green River area. JT = Jessies Twist, K = Tununk Shale section of Katich (1951), MC = Tununk Shale section south of fault of Molenaar and Cobban (1991), P = "Platyceramus Hills," an area preserving abundant large specimens of *Platyceramus cycloides*. Red square = type area for the Jessies Twist Member of the Tununk Shale south of I-70. Dashed red lines = approximate positions of formational boundaries in the lower Mancos Group. White numbers refer to Stops 6, 7, and 8 on Day 1. Dotted white line indicates occurrence of sandy bluff preserving *Scaphites depressus* fauna ("Floy Wash Sandstone" marker bed). Note the repetition of this marker bed across the arcuate Little Grand Wash fault zone (blue dashed line) south of Green River. Image from Google Earth ©2023. (E) Tununk Shale section 2 miles (3 km) east of "old" SR-24. (F through H) Type section of Jessies Twist Member of Tununk Shale 2.5 miles (4 km) northwest of "old" SR-24 parallel to I-70; (F) lower part, (G) middle part, and (H) upper part. Yellow bar marks position of Bentonite C.

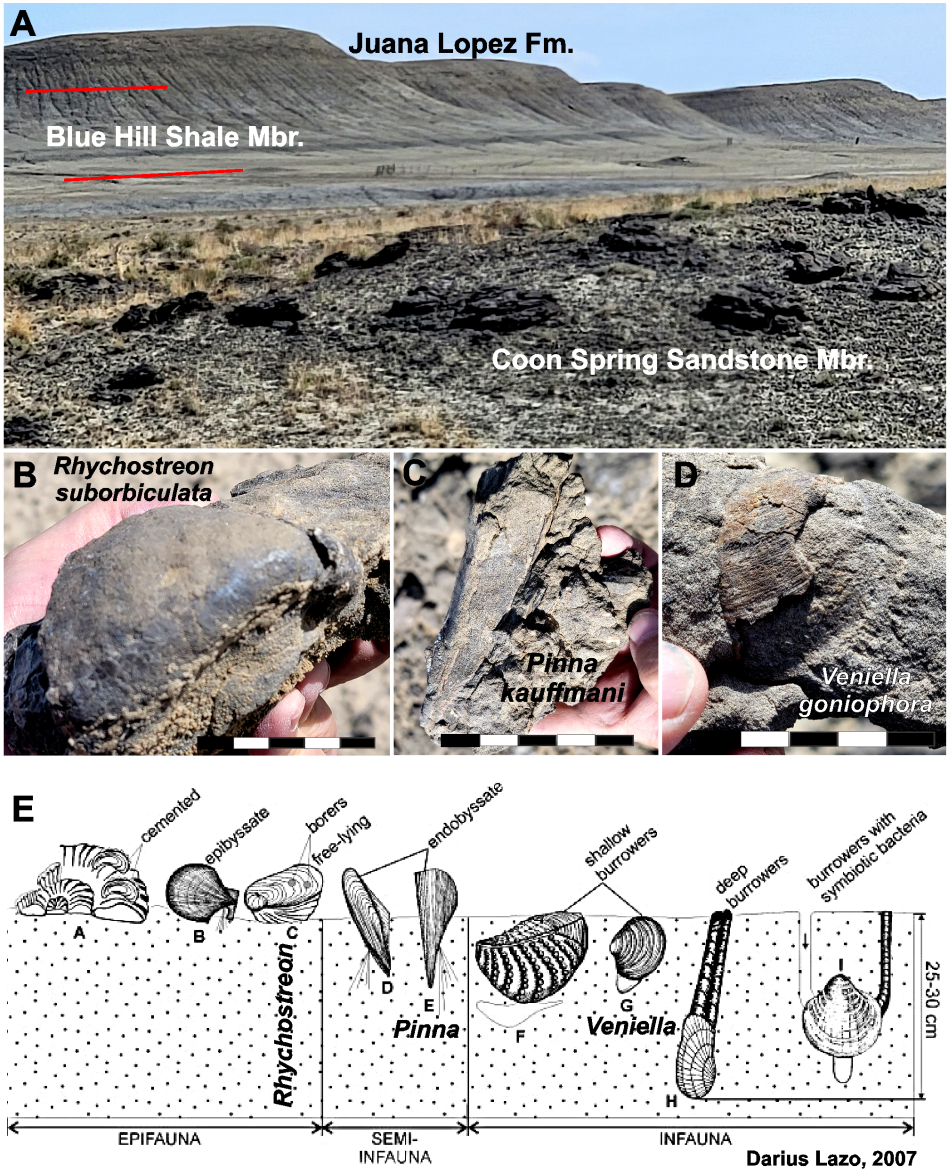

Figure 17. Upper Tununk Shale and lower Juana Lopez Formation east along "old" SR-24. (A) Overview of section at **Day 1, Stop 7**. (B through D) Most common bivalves in Coon Spring Sandstone Member near Green River, Utah. (E) Typical Cretaceous bivalve paleoecosystem in a healthy shallow marine shelf sandstone. Modified from Lazo (2007).

0.3	270.8	Passing up through the Juana Lopez Formation. The base of the formation is marked by a 8- to 12-inch-thick (20–30 cm) sandstone with common scattered chert pebbles and shark teeth marking a transgressive unconformity. The crest of the ridge is marked by numerous fossiliferous, thin sandstone and calcarenite beds preserving a latest middle Turonian *Prionocyclus wyomingensis* fauna including *Scaphites ferronensis*, *Inoceramus perplexus*, and *Cameleolopha lugubris* (Cobban et al., 2006; Hook and Cobban, 2012).
0.5	271.3	For approximately the next 0.5 miles (0.8 km), the road gradually descends the

			back slope of the Juana Lopez Formation preserving a basal upper Turonian ammonite fauna including *Prionocyclus novimexicanus* and *Scaphites whitfieldi*. From this point, the lower Blue Gate Shale is poorly exposed and, whereas the upper Turonian Montezuma Valley Member is recognized to the north and east, it has not yet been differentiated from the lower Smoky Hill Member of the Blue Gate Shale in this area.
3.8	275.1		Continue across large culvert to the northeast on "old" SR-24 for nearly 4 miles (6 km) before turning a sharp right (east) off the abandoned SR-24 onto BLM Road 9100.
1.1	276.2		Continue east for a little more than 1 mile (1.6 km) and pull over to the side of the road. **Stop 8** (N. 38° 57.925, W. 110° 14.235; 12S E 566080 N 4313215): **Blue Gate Shale and the Book Cliffs**. We will stroll over to the edge of the ravine for an overview of the Blue Gate Shale and the Book Cliffs above Green River, Utah (Figure 18). Given enough time, participants can wander down the slope a bit to examine examples of the lower Santonian index fossil *Platyceramus cycloides*.
1.4	277.6		Continue southeast along southside of the Green River Airport and bear left (north) at fork south of the end of the runway.
0.9	278.5		Continue north and bear right onto the paved Airport Road.
3.2	281.7		Continue north along the bluff formed by the Juana Lopez Formation on left, beneath I-70 overpass and across railroad tracks to the stop sign on Green River Road, and turn left.
0.1	281.8		Turn right on Long Street.
0.3	282.1		Drive past Pearl Baker Park on left to the Market Street (I-70 Business Loop). Turn right (east) onto Market Street.
1.6	283.7		Drive east across the Green River, past the John Wesley Powell River History Museum on the left and up the hill. The Super 8 Hotel is on the right. Check in!

Day 2

Road Log Starts in Green River, Utah

Inc. Mileage	*Cum. Mileage*	*Milepost*	*Description*
0	0		Leave the Super 8 Hotel on I-70 Business Loop.
1.3	1.3	MP-164.4	Drive southeast on I-70 Business Loop to I-70, Exit 164, interchange crossing highway and turning left (east) onto I-70.
78.0	79.3	MP-11	Travel east on I-70 to Exit 11 at Mack, Colorado.

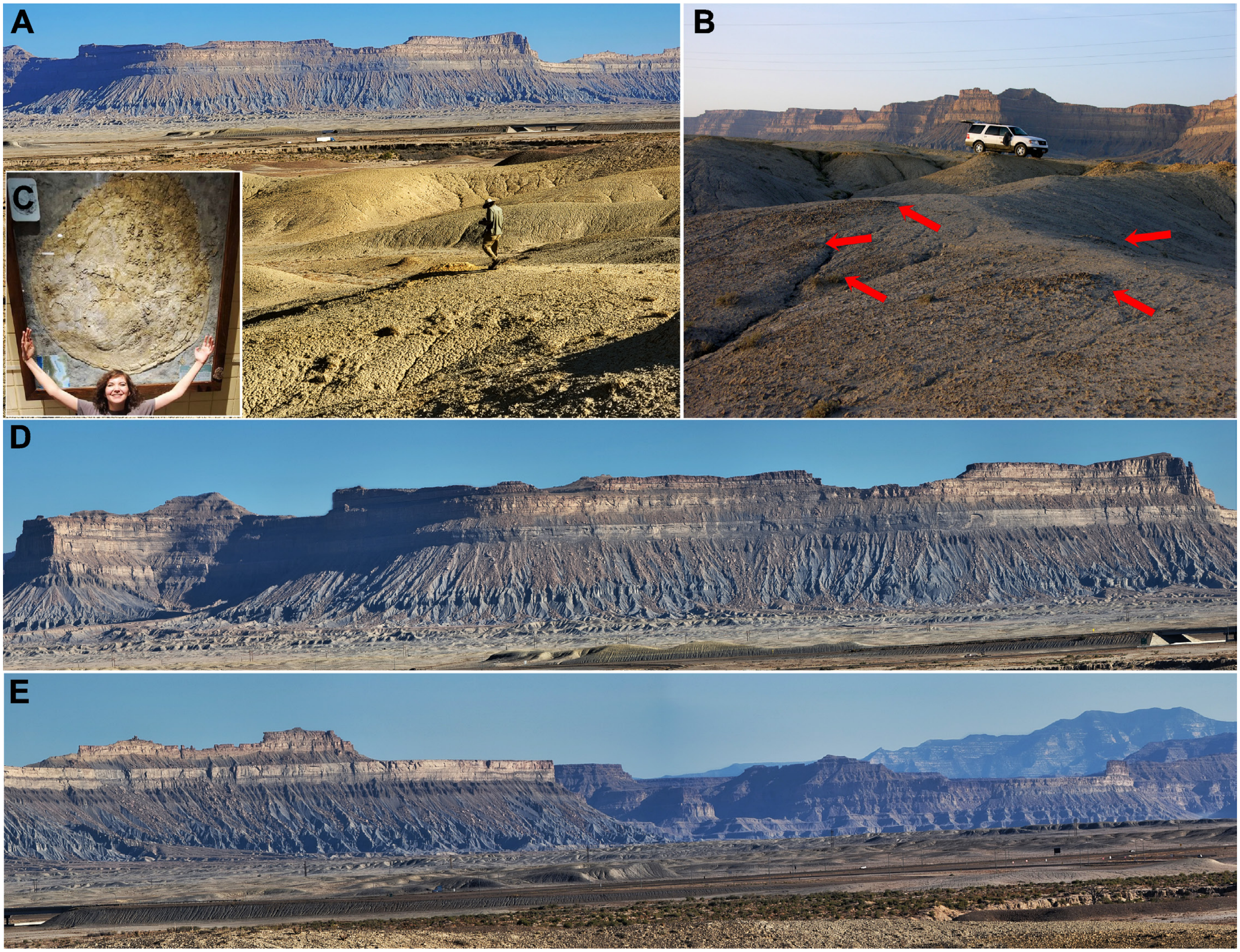

Figure 18. Upper Mancos and lower Mesaverde near Green River. (A) Mancos Group at **Day 1, Stop 8**, large examples of *Platyceramus cycloides* weathering out on slope in foreground. (B) Red arrows point to examples of P. *cycloides* weathering out in the "*Platyceramus* Hills" northwest of Green River (P in Figure 16D). (C) *Platyceramus cycloides* from the "*Platyceramus* Hills" on exhibit in the Utah State University Eastern, Prehistoric Museum in Price. Photograph courtesy of Hannah Pettijohn. (D) Upper Mancos and lower Mesaverde northwest of Green River. (E) Upper Mancos and lower Mesaverde north of Green River.

0.1	79.4	Turn right and then left onto the south frontage road.
4.3	83.7	Follow frontage road to the east, notice that the low ridge to south is held up by the Juana Lopez Formation. Merewether et al. (2006) measured their section of the lower Mancos up through the Montezuma Valley Member by the conical hill about 2 miles (3.2 km) along this road. (Figure 19A). Continue past the Colorado entrance Station and cross I-70 at Exit 15. Note the yellow band on the bluff on northeast side of the Exit 15 interchange (Figure 19). **Stop 1** (N. 39° 10.783, W. 108° 48.774; 12S E 688914 N 4338998): **disconformity between the Montezuma Valley and the Smoky Hill Members of the Blue Gate Shale.**

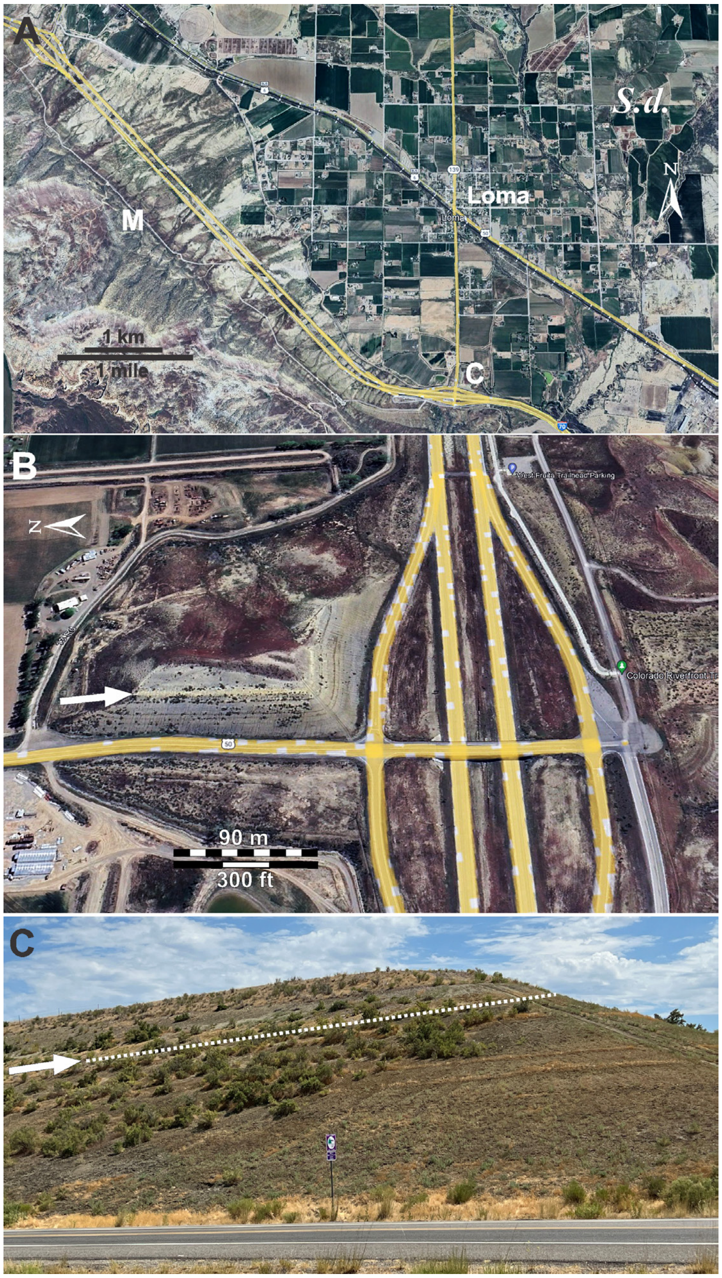

Figure 19. Lower Mancos Group in the western Grand Valley area, Colorado. (A) Mack and Loma, Colorado, area. C = contact between the Montezuma Valley and Smoky Hill Members of the Blue Gate Shale. M = approximate location of Merewether et al.'s (2006) Mack village section of Tununk Shale and Juana Lopez Formation. *S.d.* = location of carbonate unit preserving *Scaphites depressus*, *Baculites codyensis,* and wood fragments. (B) Oblique Google Earth view from west of I-70, Loma, Exit 11. Image from Google Earth ©2009. (C) Exposure from the west illustrating the amount of revegetation on this road cut (**Day 2, Stop 1**). White arrow points to glauconitic sandy unit contact between the Montezuma Valley and Smoky Hill Members of the Blue Gate Shale. Dotted white line indicates basal contact of the Smoky Hill Member with the underlying Montezuma Valley Member of the Blue Gate Shale.

1.3	85.0	Continue north and turn left onto the "old" U.S. Highway 6 and 50 (US-6 & 50).
5.8	90.8	Continue northwest on old US-6 & 50 about 2 miles (3.2 km) past Mack, Colorado, and turn right onto 8 Road heading north.
3.5	94.3	Turn left (west) on S Road.
3.0	97.3	Bear right (north) onto 4 Road.
6.2	103.8	Take west fork northward on the Prairie Canyon Road (U-1 5/10 Road) for 4.7 miles (7.6 km) to the top of the Mancos Group. Turn around. **Stop 2** (N. 39° 22.052, W. 109° 2.5930; 12S E 668568 N 4359389): **top of the Mancos Group.** To

the northeast, the upper cliff face represents the Sego Sandstone, which is split into upper and lower units by the less resistant Anchor Mine Shale in this area (s 20A through 20C). Below the Sego Sandstone lies the mudstone beds of the Buck Shale and a sandy bench of the "lower" Castlegate Sandstone, which is within the *Baculites asperiformis* Zone in the middle Campanian (Cobban et al., 2006; Singer et al., 2023). To the west, the organic-rich, volcanic ash-bearing shale below is the Bar X Shale (Figures 20D and 20E; Kirkland et al., 2024), containing upper lower Campanian *Baculites* sp. (smooth 1) or *Baculites* sp. (weak flank ribs) Zones to lower middle Campanian *Baculites maclearni* Zones at the top correlating to the lower Pierre Shale of eastern Colorado and Wyoming (Gill and Cobban, 1966;

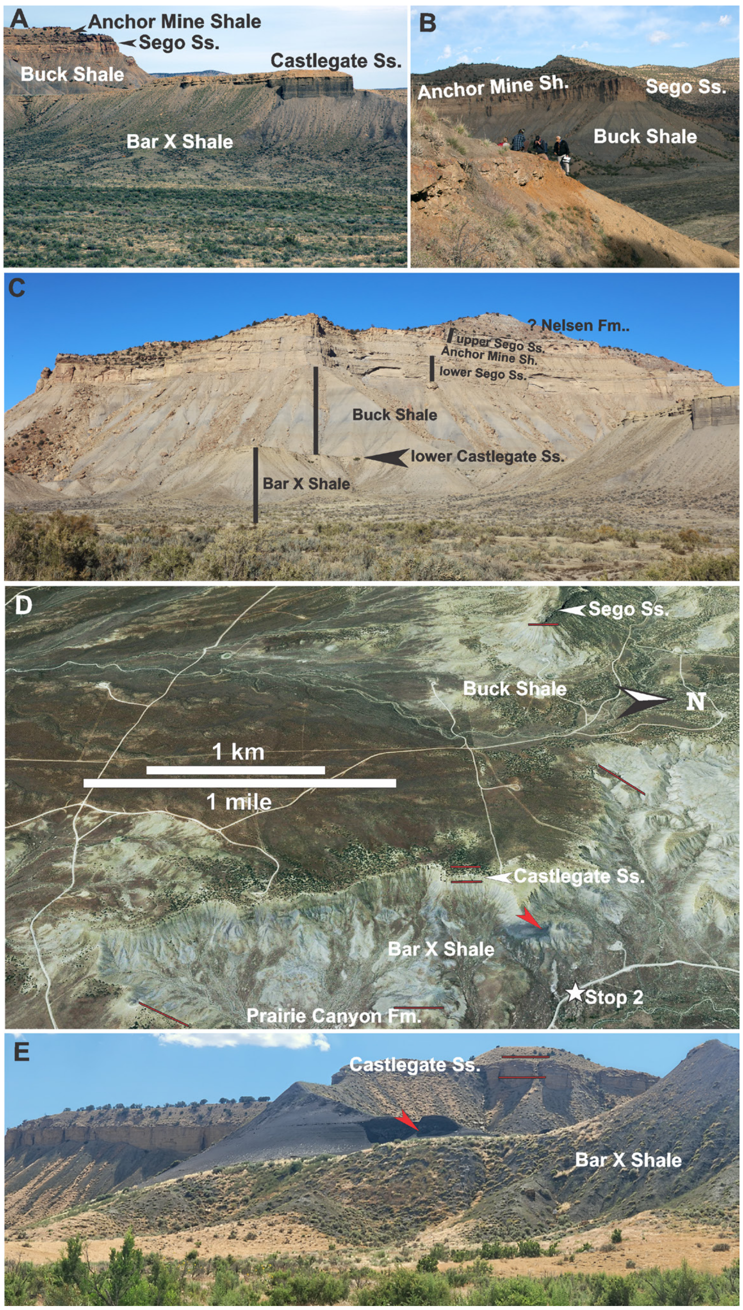

Figure 20. Uppermost Manco Group in Prairie Canyon area. (A) View of Mancos-Mesaverde Group transition north of **Day 2, Stop 2** on east side of Prairie Canyon. (B) West Salt Creek facing west. (C) View to east of **Day 2, Stop 2** of uppermost Mancos Group based on Young (1955) and Willis and Gabel (2003). (D) Oblique view across west side of Prairie Canyon at type section of Bar X Shale. Image from Google Earth ©2023. (D) West side of Prairie Canyon Section at **Day 2, Stop 2**, upper type section of Bar X Shale. Red arrowhead indicates hadrosaur site reported in Lucas et al. (2006).

Cobban et al., 2006, Singer et al., 2023).

1.1 104.9 Backtrack to base of the Bar X Shale**.** The base of the Bar X and top of the Prairie Canyon Formation is marked by a slight fining of the sediment associated with a gradational color change (Figure 21A), some large nodule horizons below the boundary, and may be more easily distinguished with geophysical tools such as gamma ray (Cole et al., 1997; Kirkland et al., 2024).

1.6 106.5 Continue backtracking to the south. After about 1.6 miles (2.6 km) note the exposures of the Prairie Canyon Formation, especially on the left (east) side of the road (Figure 21B). **Stop 3** (N. 39° 19.269, W. 108° 59.223; 12S E 673521 N 4354348): **exposures of the middle Prairie Canyon in the type area close to the road.** The upper Prairie Canyon is composed of silty shale, whereas the middle member is a series of sandy coarsening upward cycles, with the contact between the middle and upper representing a major flooding surface (Cole et al., 1997).

1.7 108.2 Farther south, channelized deposits occur in the lower Prairie Canyon Formation (Figure 21C). The lower Prairie Canyon here likely correlates to the Beckwith sandstone bed (proposed herein) near Woodside, which are latest Santonian,

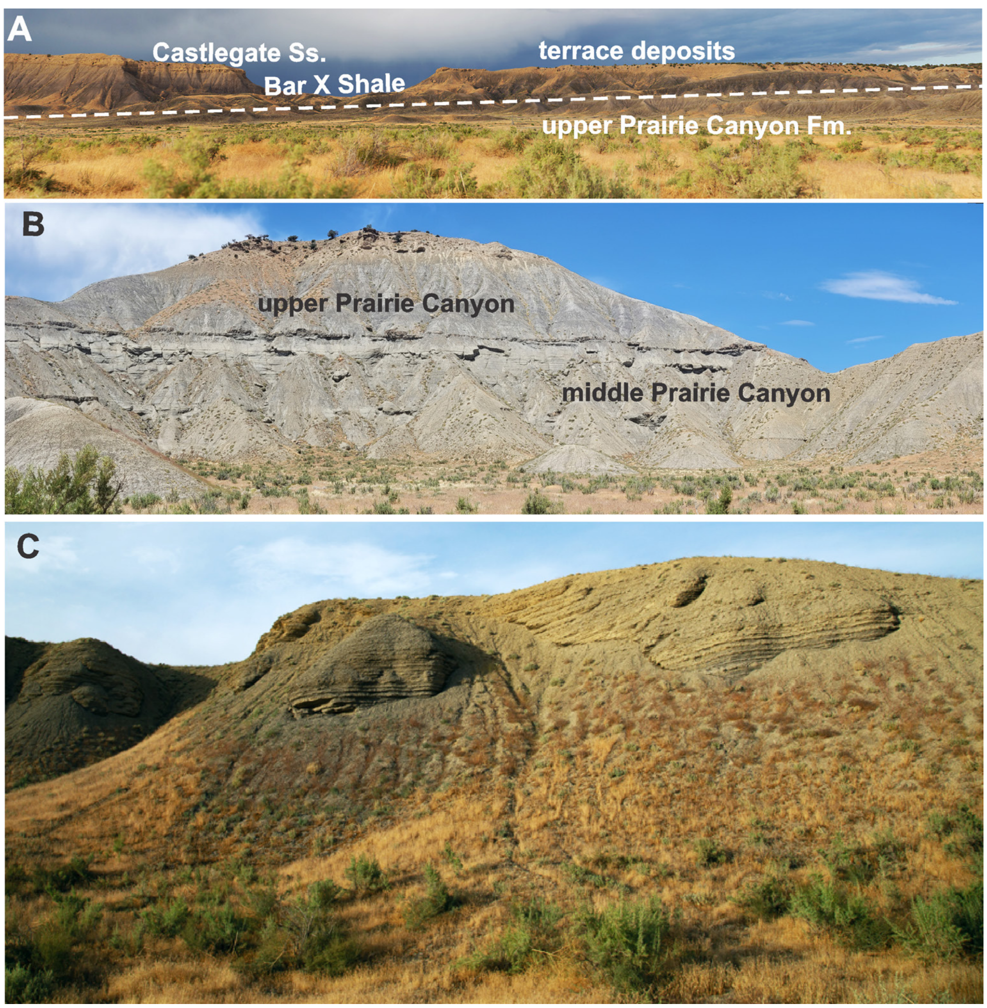

Figure 21. Prairie Canyon Formation at Prairie Canyon. (A) Upper contact of the Prairie Canyon Formation with the overlying Bar X Shale at color change from olive-gray to dark olive-gray. Photograph taken after a rain when the color contrast is more apparent. (B) Upper Prairie Canyon overlying middle Prairie Canyon on the east side of Prairie Canyon (**Day 2, Stop 3**). (C) Lower Prairie Canyon Formation facing east at the southern mouth of Prairie Canyon.

			based on *Desmoscaphites bassleri* locations (Fouch et al., 1983; Chan et al., 1991), and potentially linked to marine flooding at the top of the Emery Formation main body (Cole et al., 1997).
0.3	108.5		Return to 4 Road, take right toward the south.
10.3	118.8		Return to old US-6 & 50, turn left.
2.0	120.8	MP-11	In Mack, turn right on "old" US-50 and proceed to westbound ramp of I-70. Proceed on I-70 to Exit 2.
9.0	129.8	MP-2	Take Exit 2, Rabbit Valley. **Lunch and Stop 4** (N. 39° 11.716, W. 109° 1.2360; 12S E 670934 N 4340312): **the Mygatt-Moore Dinosaur Quarry and the beginning of the Trail Though Time.** These sites are in the Brushy Basin Member of the Morrison Formation. The bluff to the west is held up by the Naturita Formation overlying a short section of the Cedar Mountain Formation. This Morrison dinosaur site is one of the most significant ongoing excavations in western Colorado (Figure 22) For recent descriptions of this site see Foster et al. (2016, 2018). Note: one of your trip leaders (Kirkland) discovered the first and most complete ankylosaur, *Mymoorapelta maysi*, ever found in the Jurassic of North America (Kirkland and Carpenter, 1994; Kirkland et al., 1998) at this site.
6.5	126.3	MP 227.3	Continue west on I-70 into Utah at 3.8 miles (6.1 km), MP-229.8, cross up and over the Juana Lopez Formation. Turn left (south) under I-70 at Exit 227, at Westwater.
0.2	126.5		Turn south on BLM 192, down to Harley dome.
5.2	131.7		Proceed southwest turning more to south at about 1.5 miles (2.4 km) with exposures of the Naturita Formation on the right. Turn right (northwest) onto BLM Road 191.
1.0	132.7		Follow the road as it loops around the south end of bluff held up by the Naturita Formation. As the road runs north, it parallels an important reference section (Figure 23) of the Tununk Shale and overlying Juana Lopez Formation described by Anderson and Harris (2006). **Stop 5** (N. 39° 6.6390, W. 109° 9.5300; 12S E 659187 N 4330669): **lower Mancos Group at Westwater.** Important to note at this section is that large fossiliferous sandstone concretions of the medial Coon Spring Sandstone Member of the Tununk Shale are well-developed in this area. A tonstein in the underlying Naturita Formation preserves a diverse, well-preserved flora that has been dated using U-Pb from zircons extracted from multiple volcanic ash layers as Middle Cenomanian (97.5 to 98.0 Ma) by Barclay et al. (2015).
1.5	134.2		Continue to follow BLM Road 191 north along Tununk and Juana Lopez section turning left (northwest) at about 0.8 miles (about 1.3 km) toward I-70. As road approaches I-70, it turns southwest and then northwest going beneath I-70. The road circles back to the north to join frontage road. Note: on the geological map (Figure 23F) of the Agate quadrangle, Willis et al. (1996) mapped in the lower Blue Gate Shale two marker beds that have subsequently been recognized throughout

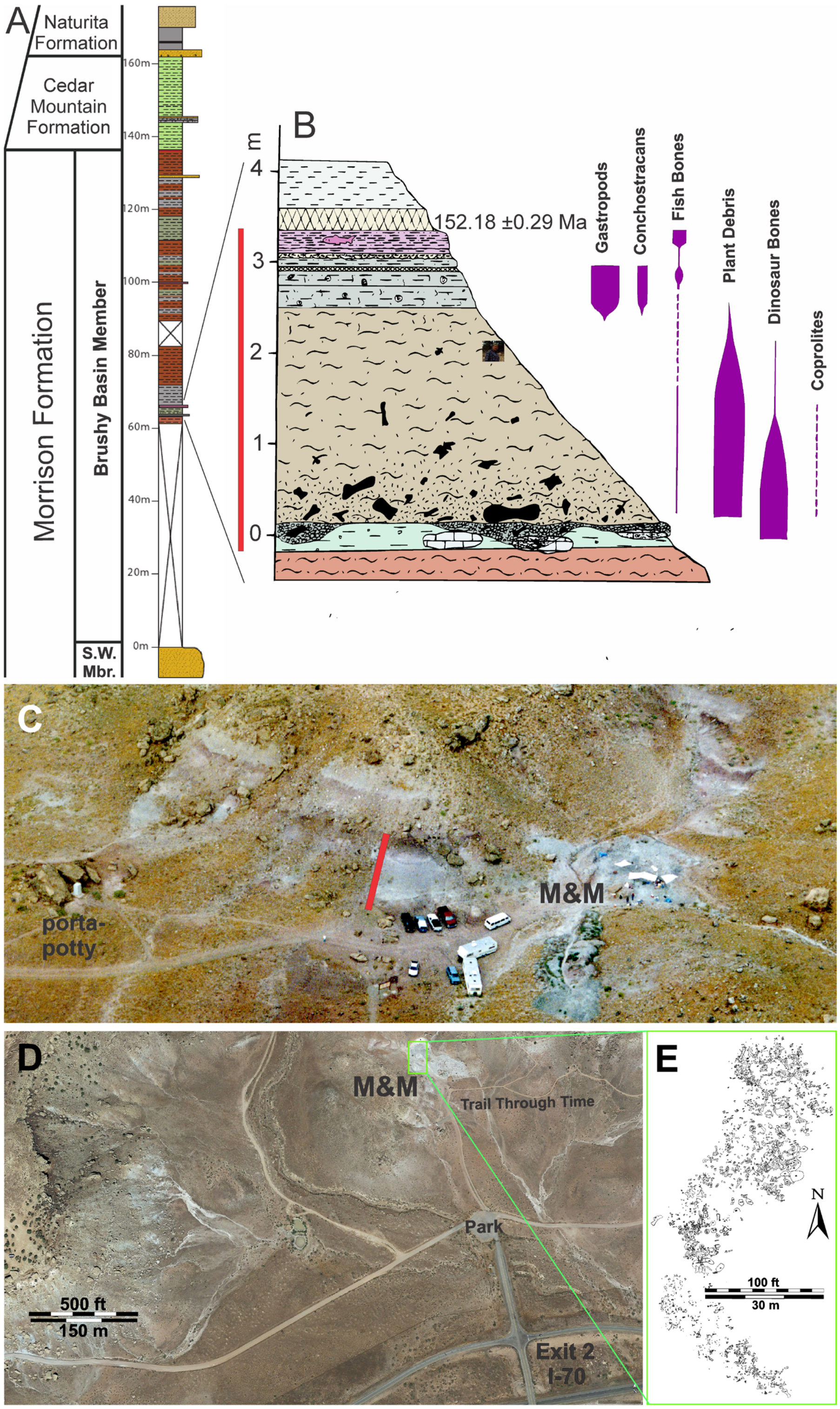

Figure 22. Mygatt-Moore Quarry Area (**Day 2, Stop 4**). (A) Brushy Basin Member of Morrison Formation in Rabbit Valley with the position of the Mygatt-Moore Quarry indicated. After Foster et al. (2018). (B) Detailed section through Mygatt-Moore Quarry. From Chin and Kirkland (1998). (C) Oblique air photograph of Mygatt-Moore Quarry. Red bar = site of detailed stratigraphic section in B. (D) Overview of northwest side of Rabbit Valley showing relation of Mygatt-Moore Quarry with Colorado Exit 2, I- 70. Image from Google Earth ©2023. (E) Mygatt-Moore Quarry bone map. From Foster et al. (2018). M&M = Mygatt-Moore Quarry.

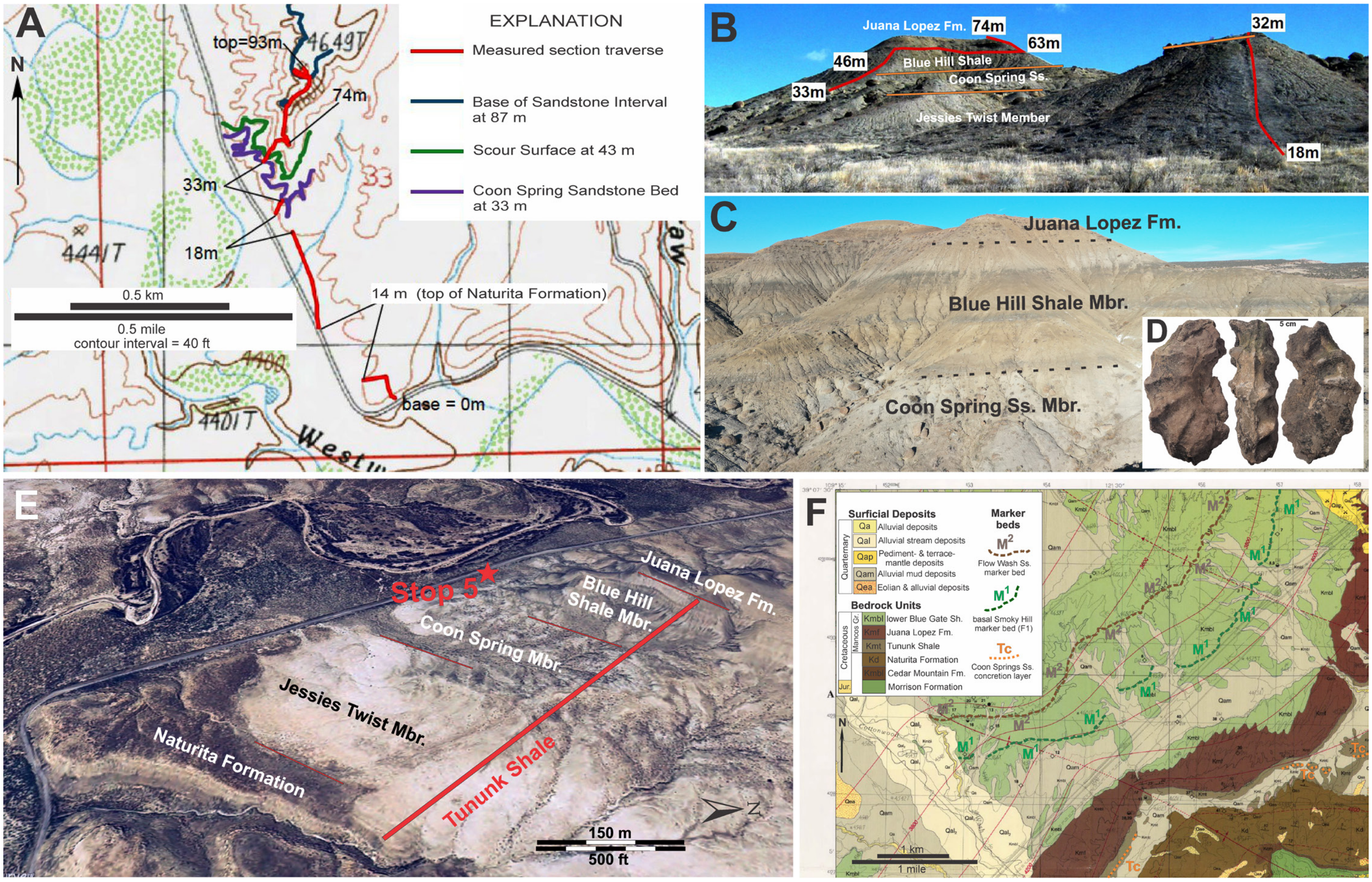

Figure 23. Lower Mancos Group in Westwater area. (A) Line of Anderson and Harris' (2006) stratigraphic section with prominent marker beds. Modified from Anderson and Harris' Figure 4A. (B) Outcrop of Tununk Shale from west (**Day 2, Stop 5**). From Anderson and Harris' (2006) Figure 4B. (C) Same area from more to west (**Day 2, Stop 6**). (D) An example of *Collignoniceras woollgari regulare* (CEUM 86875) from the Coon Spring Sandstone concretion level in this immediate area. (E) Oblique view of Anderson and Harris's (2006) research area from the east. Image from Google Earth ©2009. (F) Northeastern portion of the geological map Agate, Utah 7.5' quadrangle (Willis et al., 1996) emphasizing the distribution of laterally traceable marker beds. M^1 = glauconitic sandstone marking the disconformable base of the Smoky Hill Member of the Blue Gate Shale (Leckie et al., 1997; Nelsen and Sonnenberg, 2001; Ressetar et al., 2014; Kirkland et al., 2024), F1 glauconitic marker bed of Anderson and Harris (2006). M2 = Blue Gate Silt (Fisher, 2007; Ressetar et al., 2014) and is being designated the "Floy Wash Sandstone Beds" by Kirkland et al. (2024).

the southern Uinta Basin (Ressetar et al., 2014; Kirkland et al., 2024). M1 (F1 of Anderson and Harris, 2006) marks the disconformable contact between the upper Turonian Montezuma Valley Member and the middle Coniacian through Santonian Smoky Hill Member of the Blue Hill Shale throughout the southern Uinta Basin.

1.2	135.4	MP-222.1	Follow the frontage road one mile before turning left to I-70, Exit 222, Dutch Flat. South of Exit 222 is the new Grand Junction Terminal that serves as a hub for supplying gasoline and diesel fuel to gas stations in the region.
34.5	169.9	MP -187.6	Drive west on I-70. Over the next 44 miles (71 km) the highway follows the broad

bench formed by erosion of the thick Blue Gate Shale. To the south, the Juana Lopez Formation forms a low escarpment that dips a few degrees to the north forming the southern margin of the Uinta Basin. Typically, the upper Juana Lopez Formation and the overlying Montezuma Valley Member are poorly exposed on this dip slope. This region is largely covered by a high desert scrubland, which replaced the high desert grasslands due to continued grazing pressure during the near continent-wide drought of the 1930s Dust Bowl interval. As shown by Ressetar et al. (2014), the marker beds in the lower Blue Gate Member are not well exposed on the Juana Lopez Formation dip slope, but easily identified in the subsurface across the southern Uinta Basin (Figure 24). Exposures of the upper Mancos Group occur in the lower slopes of the Book Cliffs below the Mesaverde Group. A great deal of research has been ongoing on this regressive Cretaceous coastline largely

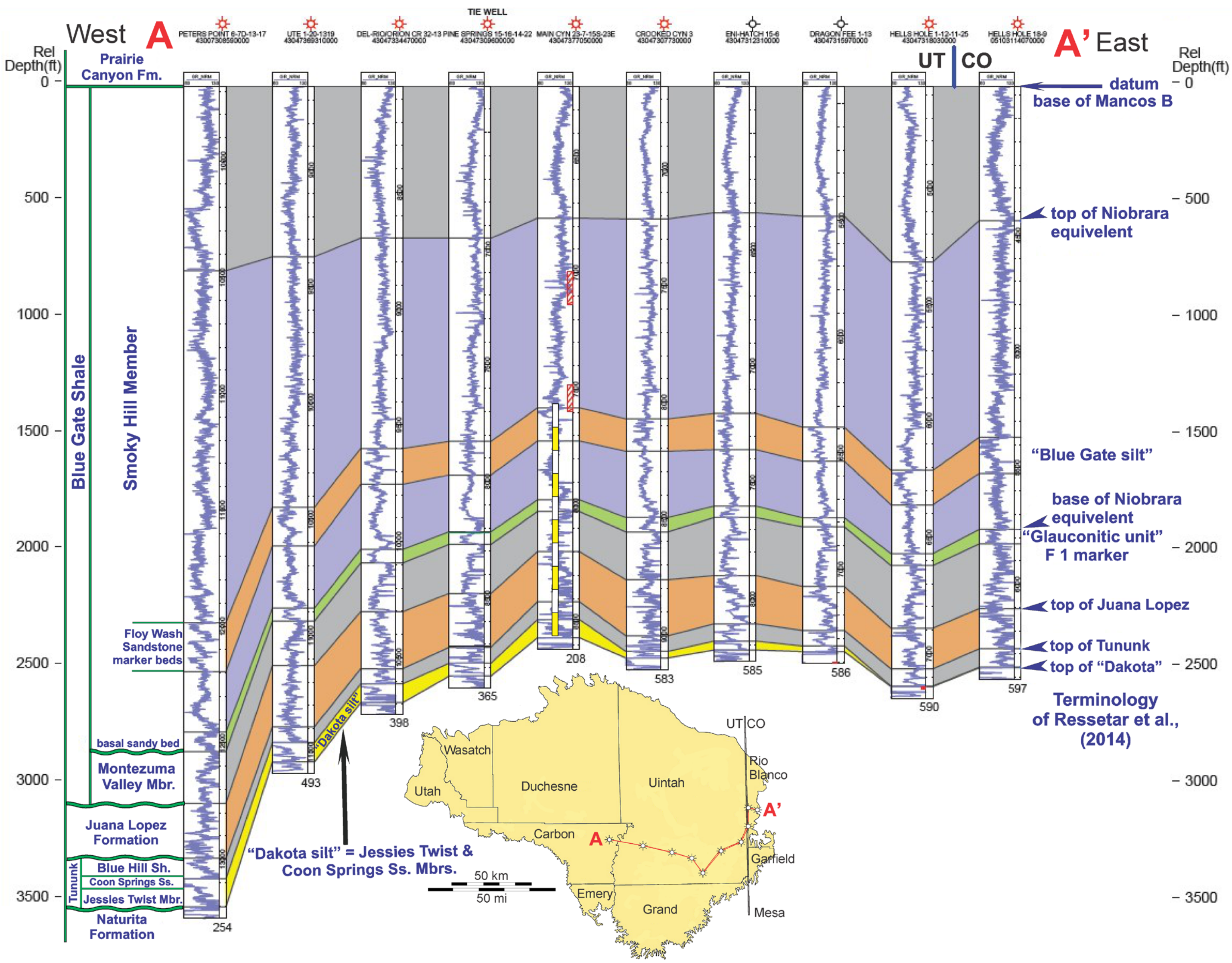

Figure 24. Subsurface correlation of lower Mancos Group west to east across southern Uinta Basin. Nomenclature proposed herein on west side and original subsurface nomenclature on the east side of cross section. Modified from Ressetar et al. (2014).

within the canyons cutting through the Book Cliffs as the strata help to interpret subsurface data farther to the north in the Uinta Basin. These strata also serve as an important model in understanding the depositional environments along the coasts of stable continental shelves. Passing the Thompson, Exit 187; the hopeful future north entrance to Arches National Park.

11.8 181.7 MP-175.8 Over the next 12 miles (19 km) to the south and southeast, the Salt Valley anticline that forms the core of Arches National Park is visible. This structure was formed by a salt-wall rising in the Paradox Basin during the late Paleozoic and Mesozoic from the thick beds of salts that accumulated in this foreland basin formed on the west side of the Ancestral Rockies during the Pennsylvanian (Doelling, 2024). Passing Crescent Junction, Exit 182; the turnoff for Arches and Canyonlands National Parks, Moab, and points south. Continue west to the Floy Wash, Exit 175, and turn left (south).

4.5 186.2 Drive south on Ruby Ranch Road down section through the Blue Gate Shale and Juana Lopez Formation and turn around for **Stop 6** (N. 38° 51.838, W. 109° 57.666; 12S E 590133 N 4302194): **lower Mancos Group on Ruby Ranch Road.** Note that the Tununk Shale is poorly exposed in this area. However, 0.5 miles (0.8 km) farther south on the Ruby Ranch Road, there is an open dirt track on the right (west) that crosses a pipeline and leads to extensive well-exposed Tununk outcrops over an interval of 2 to 5 miles (3.2–8.1 km) for which a high clearance vehicle is required (Figure 25). Scramble up the slope to examine the conglomeratic sandstone at the base of the Juana Lopez Formation. The trip leaders have not traced this bed east of the Salt Valley anticline; however, this bed is well expressed on the southeastern side of the axis of the San Rafael Swell along Farnham Dome at Mounds. This bed is derived by the erosion of the eastern margin of the lower Ferron Formation and its reworking across the southern Uinta Basin during an upper Turonian sea level rise. The extra-basinal pebbles are derived from reworking of units in the upper part of the Washboard Member of the lower Ferron Formation (Kirkland et al., 2024). Shark teeth (Figure 25F) are also abundant in this bed (Becker et al., 2010, 2012).

1.5 187.7 Drive north on Ruby Ranch Road. At 0.4 miles (0.6 km), cross the top of the Juana Lopez Formation on the back slope of ridge formed by more resistant beds in the basal upper Turonian *Prionocyclus wyomingensis* Zone with *Scaphites ferronensis*, *Inoceramus perplexus*, and *Cameleolopha lugubris*. As we drive through the medium olive-gray shale beds of the Montezuma Valley Member of the Blue Gate Shale look for concretions characteristic of these strata. The *Prionocyclus novimexicanus* Zone spans the contact with the underlying Juana Lopez and the *Prionocyclus quadratus* Zone is at the top of these strata. A superficial examination of these rocks west of the road yield ammonites only identifiable as *Prionocyclus* sp. and *Mytiloides incertus* (Figures 25G and 25H). About 0.3 to 0.4 miles (0.5–0.6 km) farther the basal disconformable contact is marked by a pale olive-yellow band on the tops of low hills along the east side of road and broken fragments of *Volviceramus involutus* probably marking the upper part of the middle Coniacian *Scaphites*

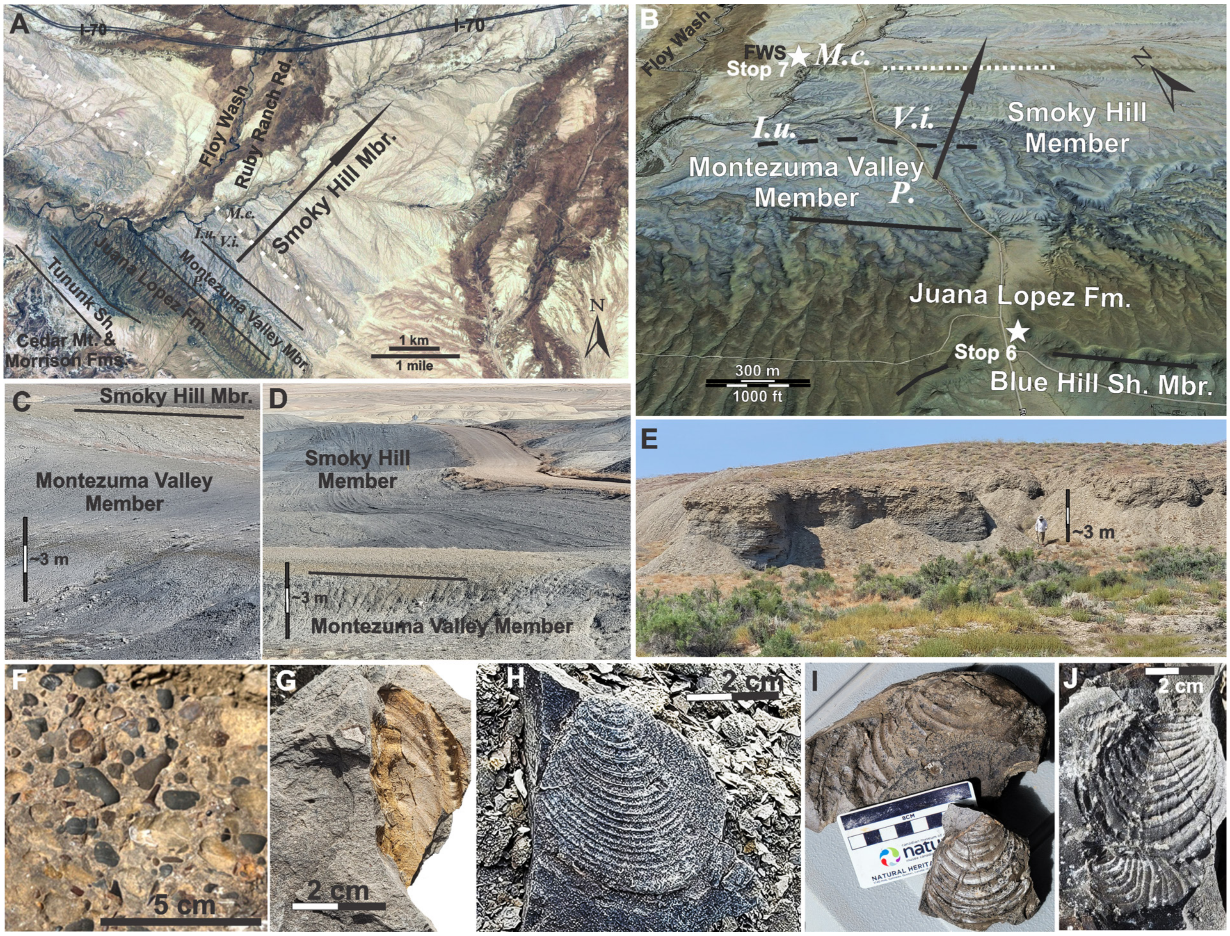

Figure 25. Blue Gate Shale along the Ruby Ranch Road. (A) Google Earth view of exposures of the Blue Gate Shale and bounding strata in the area of the Ruby Ranch Road. Image from Google Earth ©2023. (B) Oblique view of the Juana Lopez Formation and the lower Blue Gate Shale along the Ruby Ranch Road. Image from Google Earth ©2023. White stars designate **Day 2, Stops 6 and 7**. (C) Montezuma Valley Member. (D) Upper Montezuma Valley Member and basal Smoky Hill Member, view to north. External mold of venter of *Prionocyclus* sp. from locality P. in A and B. (E) "Floy Wash Sandstone" type area. West of Ruby Ranch Road looking south (**Day 2, Stop 7**). FWS in B. (F) Basal conglomeratic sandstone of Juana Lopez Formation. Note extra-basinal and Ferron pebble-sized clasts with a diversity of shark teeth in this transgressive marker bed. (G) *Prionocyclus* sp. (H) *Inoceramus incertus* also from locality ***P.*** in A and B. (I) *Inoceramus undabundus* from middle Coniacian locality ***I.u.*** in A and B. (J) *Magadiceramus crenulatus* from upper Coniacian locality ***M.c.*** in A and B. Solid black lines indicate approximate stratigraphic boundaries. Dashed black line indicates occurrence of sandy bluff preserving lowest fragments of V*olviceramus*. ***V.i.*** = Locality yielding fragments of *Volviceramus involutus*. Dotted white line indicates low sandstone bluff associated with an upper Coniacian *Scaphites depressus-Magadiceramus crenulatus* fauna (Floy Wash Sandstone marker bed). FWS = type area for Flow Wash Sandstone Bed.

ventricosus Zone. After crossing a deep dry wash turn left (west) into parking area. **Stop 7** (N. 38° 53.125, W. 109° 57.321; 12S E 590605 N 4304580): **Floy Wash Sandstone Bed**. To the southwest is an excellent exposure of the Floy Wash Sandstone Bed (Figure 25E) in its type area just east of Floy Wash. This prominent maker bed angles to the southeast such that the medium olive-gray calcareous shale exposed here has yielded good specimens of the Upper Coniacian inoceramid *Magadiceramus crenulatus* (Figure 25J). The Floy Wash area would be an excellent area to establish a refined reference section of the entire Mancos Group such as that of Leckie et al. (1997) for the type section of the Mancos Group. From this point the section would need to veer to the northeast away from the Ruby Ranch Road (Figure 25A). Some effort would also need to be made to trace a marker bed across I-70 into the basal Prairie Canyon Formation below Hatch Mesa.

3.2	190.9		Drive back north across the Floy Wash, Exit 175, bearing left (west) on the northern frontage road, the Old Elgin Highway.
0.3	193.2		Turn right north onto BLM Road 225.
2.0	195.2		Drive north across railroad tracks. In about 2 miles (3.2 km), we will turn around and return south for about 1 mile (1.6 km) and stop along the road for **Stop 8** (N. 38° 55.906, W. 109° 55.845; 12S E 592678 N 4309748): **Prairie Canyon Formation.** The Prairie Canyon Formation below Hatch Mesa (Figure 26) has been the focus of many research projects over the years (Riemersma et al., 1992; Chaiwongsaen, 2007; Casaleggio, 2009). However, Stevens (2004) conducted the most focused study of this important stratigraphic section (Figures 26B and 26C). Stevens split the section into three distinctive sedimentological packages. (1) A lower unit consisting of isolated scour-filled units of sandstone, oolitic ironstone, and dolomicrite reported to preserve ammonites marking the Santonian-Campanian boundary. (2) The medial "Hatch Mesa sandstones" further divided into eight sandstone-mudstone sequences interpreted to be deposited sediment gravity flows. (3) The uppermost beds, which are the offshore facies of the Kenilworth, Sunnyside, and Grassy Members of the Blackhawk Formation. We (Kirkland et al., 2024) interpret the Sunnyside Member as pinching out into the "Bar X Shale" here and that the Kenilworth Member forms the top of the Prairie Canyon Formation where the "Bar X Shale" can be recognized (Figure 26A). An important nomenclatural question that needs to be more rigorously examined, is if the Beckwith sandstone bed, examined Day 3, Stop 3, correlates to Stevens (2004) Hatch Mesa sandstones?
2.0	197.2	MP -175.8	Return to I-70 turning right to head westbound toward Green River.
10.8	208.0	MP-165.0	Exit right at Exit 164 onto Green River Business Loop.
1.5	209.5		Turn right (north) onto Hastings Road.
18.0	227.5		At 7 miles (11 km) driving on the east bank of the Green River. Note the exposures to the northeast and southwest of the transition between the Prairie Canyon Formation and the members of the Blackhawk Formation. The Bar X Shale continues to thin and is sandwiched here between the Kenilworth and Sunnyside Members of the Blackhawk (Figures 27B and 27C). At 9 miles (15 km), the road enters Desolation Canyon. At 9.5 miles (15.3 km), pass the popular Swasey's Beach. At 18 miles 29 km), turn in at Nefertiti. **Stop 9** (N. 39° 11.720; W. 110° 4.629; 12S E 579692 N 4338858): **examine the pinch out of the Buck Shale in the cliffs above (Figure 27A).**
18.0	245.5		Return to the Green River Business Loop and turn left to hotel.

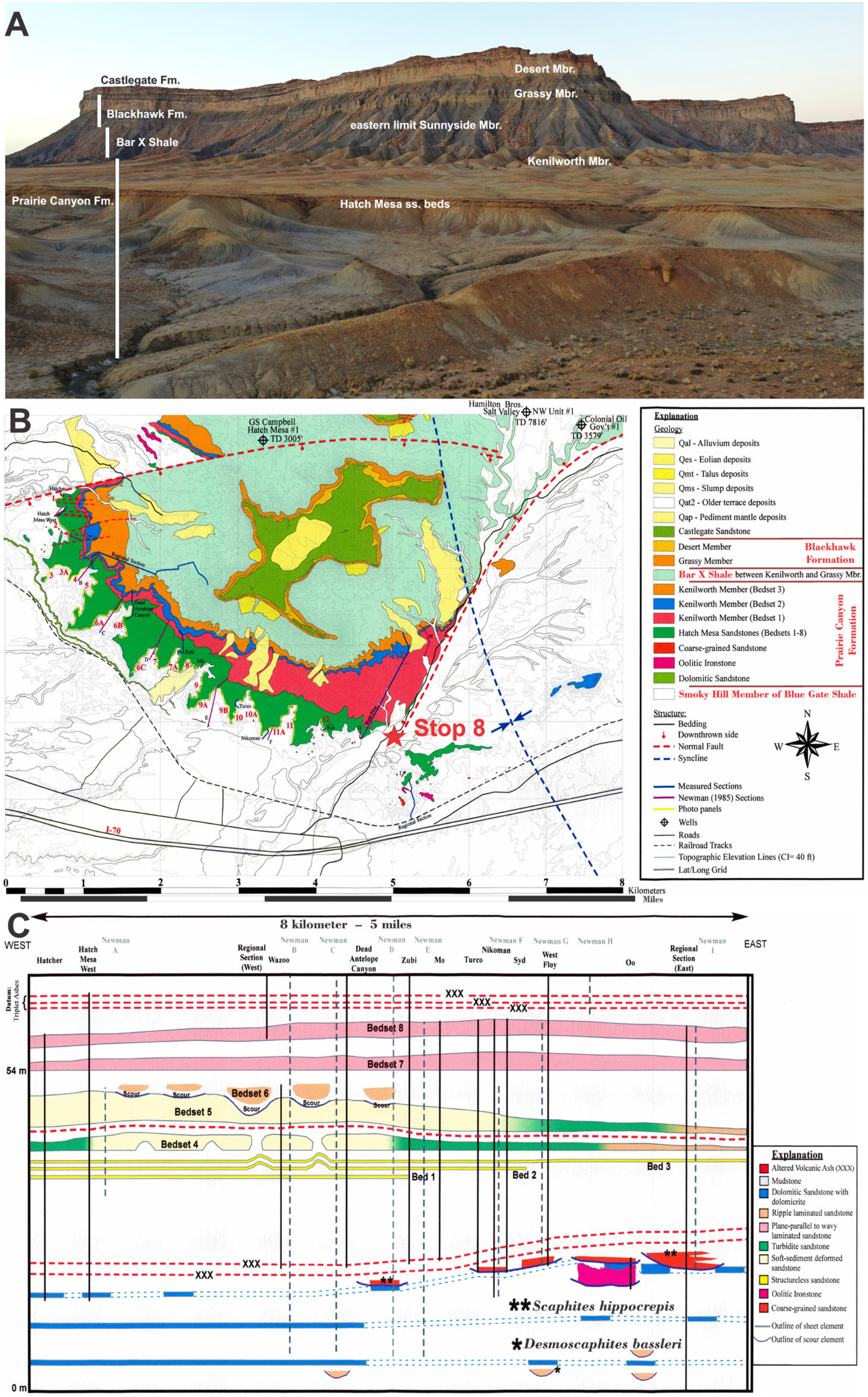

Figure 26. Geology of the Hatch Mesa area. (A) View of southeastern Hatch Mesa from **Day 2, Stop 8**. (B) Facies map of upper Mancos Group at Hatch Mesa with location of sections. Note: our stratigraphic interpretations are highlighted in red. We would propose that the Kenilworth correlates with the upper Prairie Canyon Formation. (C) Detailed stratigraphic cross section of lower Prairie Canyon strata (lower dolomitic sandstone beds up through Hatch Mesa sandstones) exposed at base of slope south of Hatch Mesa. Note occurrence of the ammonite *Desmoscaphites bassleri* in scours at base of sequence. Figures B and C modified from Stevens (2004).

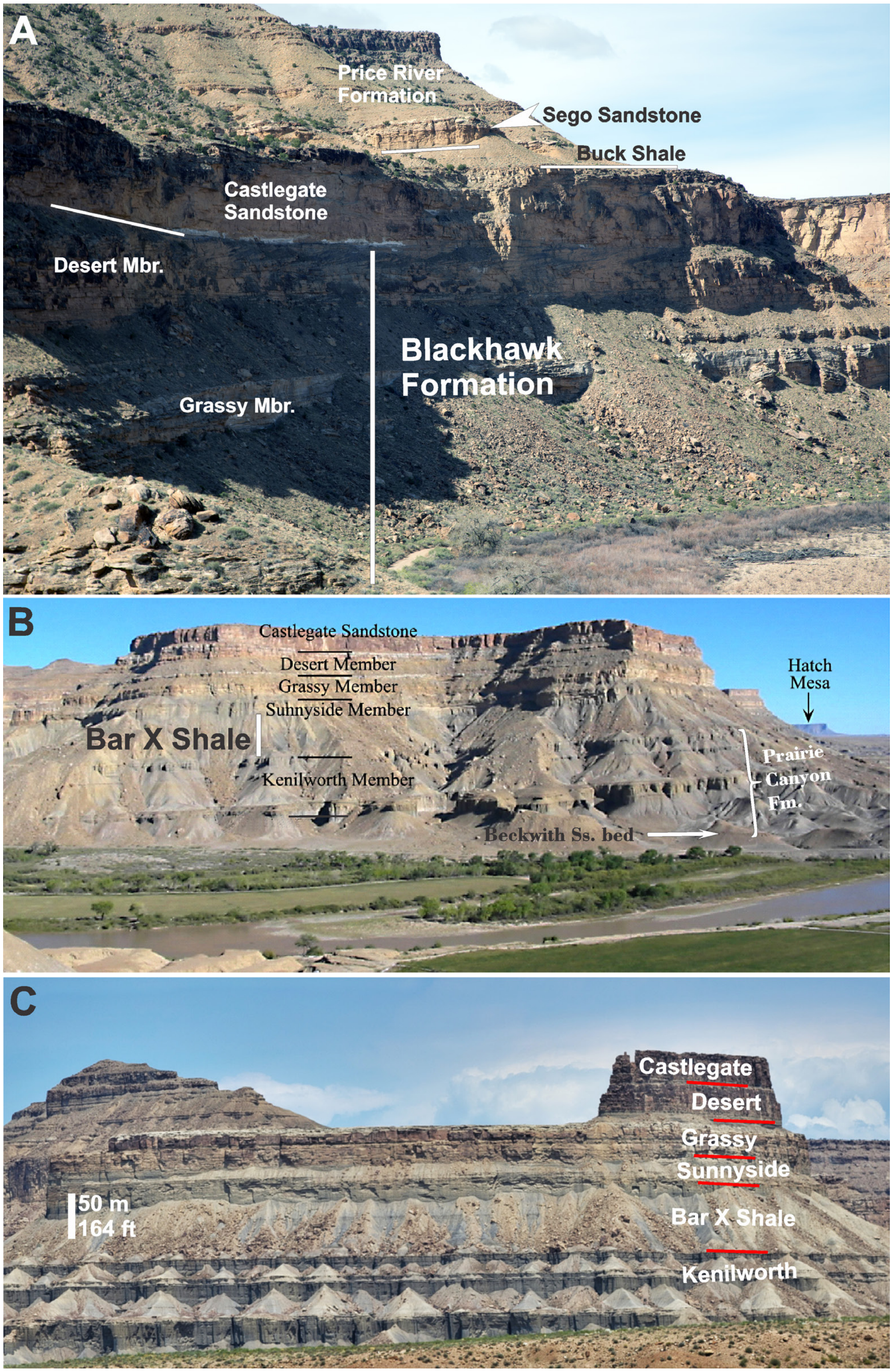

Figure 27. The Mancos Group to Mesaverde Group transition north of Green River, Utah. (A) View to southeast from near end of Hastings Road on the Green River near Nefertiti rock at the pinchout of the Buck Shale; **Day 2, Stop 9.** (B) Blackhawk Formation east of the Green River. Note that between here and Hatch Mesa the Sunnyside Member of the Blackhawk Formation grades into the Bar X Shale (Figure 26A). (C) Blackhawk Formation and overlying lower Castlegate Sandstone west of the Green River.

Day 3

Road Log Starts in Green River, Utah

Inc. Mileage	*Cum. Mileage*	*Milepost*	*Description*
0	0		Leave the Super 8 Hotel on I-70 Business Loop.
3.2	3.2	160.5	Drive west across the Green River, past the John Wesley Powell River History Museum on the left and up the hill. Turn right onto I-70 west bound at Exit 160.
2.0	5.2	158.5	Take Exit 157 off I-70 and bear right (north) onto US 6/191 toward Price, Utah.
5.0	10.2	297.2.	Off to right of road on the other side of the railroad tracks the low hills have been informally been nick-named the *Platyceramus* Hills for the large numbers of the large lower Santonian inoceramid *Platyceramus* cycloides weathering out of the Smoky Hill Member of the Blue Gate Shale (Figures 16D, 18B, and 18C).
10.0	20.2	287.2	Continuing north, US 6/191 crosses over Union Pacific railroad tracks near the former Grassy Siding. Turn to right in 0.3 miles (0.5 km) for **Stop 1** (N. 39° 8.416, W. 110° 20.126; 12S E 557432 N 4332552): **overview of the Floy Wash sandstone beds**. In this area, the upper Coniacian ammonite *Scaphites depressus* has been recovered in the main sandstone marker bed and with the middle Coniacian ammonite *Scaphites ventricosus* recovered in discontinuous concretionary sandstone about 30 feet (10 m) lower (Figure 28). Fragmentary *Volviceramus involutus* are present on the surface throughout this area indicating that the Smoky Hill Member exposed in this area is upper middle into upper Coniacian. West of the US 191, Forster et al. (2020) described the upper Turonian biostratigraphy and as a result documented the presence of the Montezuma Valley Member at the base of Blue Gate Shale in this area (Figures 28A and 28E).
0.1	20.3	287.3	Return to US 6/191 and turn right continuing north.
13.8	33.4	283.5	Turn left across US 6/191 onto the Green River Cutoff Road.
3.1	36. 6		The first few miles of the Green River Cutoff Road (BLM Road 409) zigzags on the way to the steeply dipping strata on the east side of the Woodside anticline. Driving northwest in 1 mile (1.6 km), turn left to southwest, in 0.5 miles (0.8 km) after crossing under railroad overpass turn left. In another 1.0 miles (1.6 km) the road turns west through the hogback formed by the Juana Lopez Formation and turns west, in 0.4 miles (0.6 km) the road turns south along valley floor formed by poorly exposed Jessie Twist Member of Tununk Shale east of the dip slope formed by the Naturita Formation in this area. After 0.7 miles (1.1 km) Stop 2 is on a side road to left where we will turn around for the return to US 6/191. **Stop 2** (N. 39° 12.490, W. 110° 22.178; 12S E 554424 N 4340066): **examine the sandstone bench formed by the Coon Spring Sandstone Member of the Tununk Shale in its type area (Figure 29)**. The type section of the Coon Spring is 8.2 miles (13.2

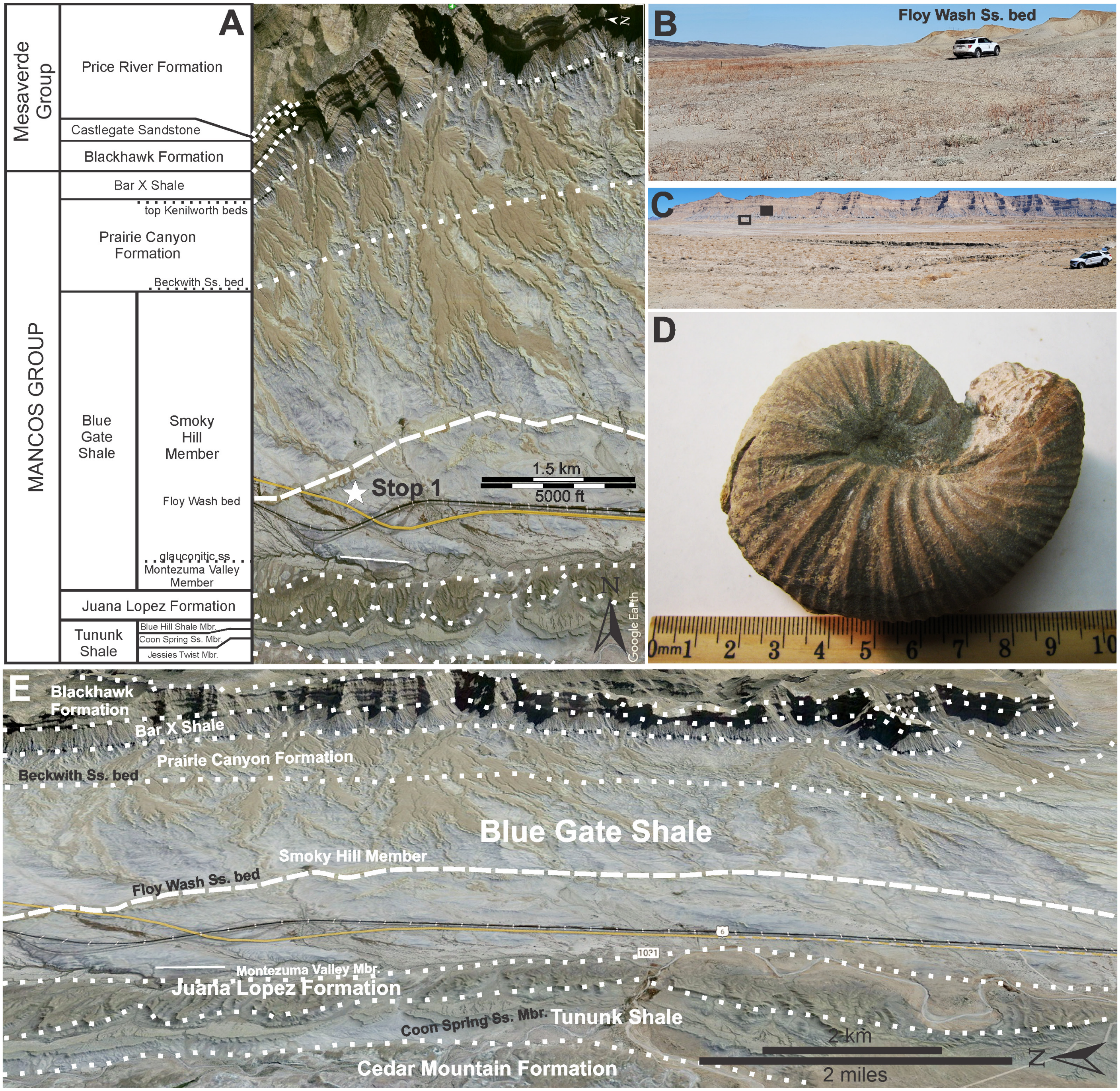

Figure 28. Mancos Group on southwest side of Uinta Basin. (A) Oblique view to east of Mancos Group across US-191 with stratigraphic interpretation. Image from Google Earth ©2009. (B) View to northwest along Floy Wash Sandstone at **Day 3, Stop 1** in lower Smoky Hill Member of Blue Gate Shale. From Kennedy and Cobban's (1991) U.S. Geological Survey Mesozoic locality D12987. Fragments of *Volviceramus involutus* are common on lower slope at base of upper Coniacian *Scaphites depressus* Zone. (C) View down back slope of sandy bluff toward Book Cliffs. Open rectangle = Prairie Canyon Formation; solid rectangle = Bar X Shale. (D) *Scaphites depressus* from top of Floy Wash Sandstone bed at **Day 3, Stop 1**. Photograph courtesy of Kevin Bylund. (E) Oblique view of Cretaceous exposures from the west across US-191 north of I-70. Dotted white lines indicate approximate formational and member boundaries. Dashed white line indicates occurrence of sandy bluff (Floy Wash Sandstone marker bed) preserving *Scaphites depressus* fauna. Thin white bar indicates glauconitic sandstone bed at base of Smoky Hill Member of the Blue Gate Shale. Image from Google Earth ©2009.

			km) north of the stop (Figures 29E and 29F) just across the Price River (Molenaar and Cobban, 1991), whereas this is the type area of the Woodside Sandstone of Cotter (1975). Cotter linked this bed to the Ferron Formation to north, correctly indicating it was sourced from the north. However, Molenaar and Cobban (1991) abandoned the name "Woodside" and named these sandstone beds, together with the sandstone concretion zone along the southern Book Cliffs, the Coon Spring Sandstone Bed.
3.2	39.8	283.4	Return to US 6/191 and turn left (north).
5.1	44.9	278.3	Continue north crossing the Price River in 4.8 miles (7.7 km). In another 0.3 miles (0.5 km), turn right (east) across from Woodside, Utah, on to the Price River Campground Road (BLM Road 129).
3.6	48.5		Follow the road southeast to Price River Campground, where we will turn around before proceeding down section. Note the well exposed Upper Mancos Group transition with Mesaverde Group in this area (Figure 30B).
1.6	50.1		Outcrop of Beckwith sandstone bed is on northeast side of road (Figure 30E). **Stop 3** (N. 39° 15.356, W. 110° 18.826; 12S E 559207 N 4345402): **discussion of the Beckwith sandstone bed**. Biostratigraphically, the reported occurrence of *Desmoscaphites bassleri* (Spieker and Reeside, 1926; Katich, 1951; Cobban 1976) with *Cataceramus balticus* (Figures 30C and 30D) is in this extensively outcropping marker bed along the west site of the Book Cliffs, which suggests it correlates to the base of the Prairie Canyon Formation. But is it contiguous?
2.0	52.1	278.3	Continue northwest along road, look toward the northeast over the next mile to get a sense of the lateral continuity of the proposed Beckwith sandstone bed (Figure 30A). On returning to US 6/191 turn right (north).
9.8	61.9	268.5	Drive north through rolling hills in the Smoky Hill Member of the Blue Gate Shale. At 7.4 miles (12 km) north of Woodside, turnoff to the right to the Lila Canyon Coal Mine providing a paved access through the upper Mancos Group into the basal Mesaverde Group as an alternative to Stop 3 in case of rain. Start up a 0.5-mile (0.8 km) grade up through a prominent Pleistocene terrace.
0.8	62.7	267.3	Rest area and road to Horse Canyon, the canyon through the Book Cliffs that is the source of this boulder terrace.
10.5	71.3	253.2.	Turn left across US 6/191 onto the Mounds Road.
2.8	74.1		Following Mounds Road south along bench, turn onto track right to edge of bench formed by the shallow marine sandstone of the lower Ferron Formation overlooking the lower Cretaceous Cedar Mountain Formation at the center of Farnham Dome (Figure 31C). **Stop 4** (N. 39° 29.122, W. 110° 37.483; 12S E 532273 N 4370708): **lunch in this area**. Cotter (1977) emphasized the separation of his upper and lower Ferron Sandstone. However, we could not distinguish separate Clawson and Washboard Members at Farnham Dome (Figures 31A and 31B).

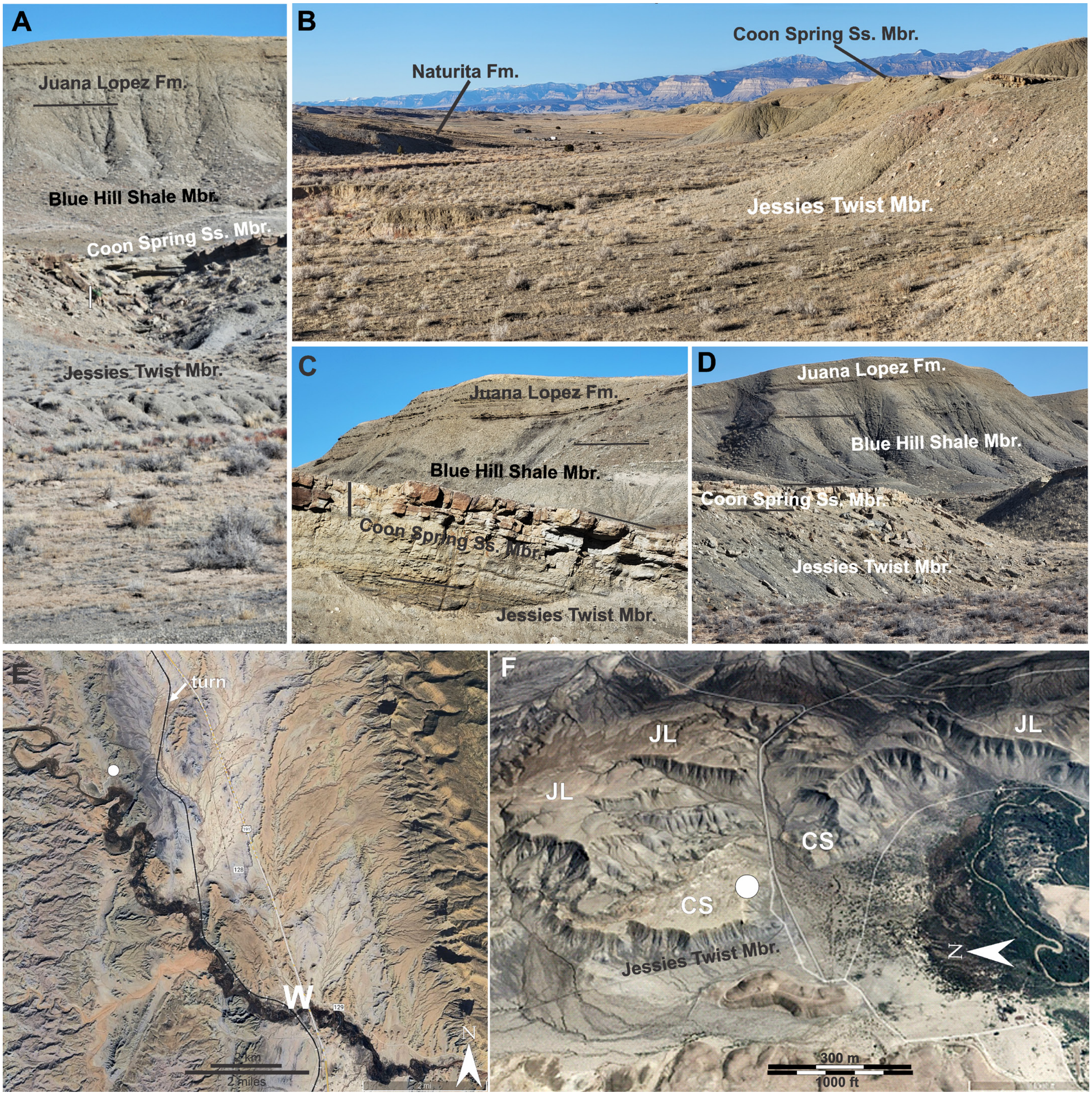

Figure 29. Tununk Shale and Juana Lopez Formation east side of US-191. (A) Overview of section east of Green River Cut-off Road (**Day 3, Stop 2**); east side of Woodside anticline. (B) Looking south along valley formed by Jessies Twist Member. demonstrating the poor quality of exposures of the lower Mancos Group along much of the Book Cliffs. (C) Vertical exposure of the Coon Spring Sandstone Member (scale bar = ~ 2 m). The well-cemented, capping sandstone in this area was named the Woodside Sandstone bed by Cotter (1976). The sequence is very similar to the type section of the Coon Spring Sandstone Member north of Price (Molenaar and Cobban, 1991). (D) A view of the Blue Hill Shale Member. (E) Overview of location of Coon Spring type section with the west turn from US-191 onto East Silvagani Ranch Road. W = Woodside, Utah. (F) Oblique view from west of the Coon Spring type area. CS = bench formed on carbonate-cemented sandstone at top of the Coon Spring. JL = bench formed of main concentration of calcarenitic sandstone layers within the Juana Lopez Formation. White dot indicates approximate location of type section (Molenaar and Cobban, 1991). Both images Google Earth ©2023.

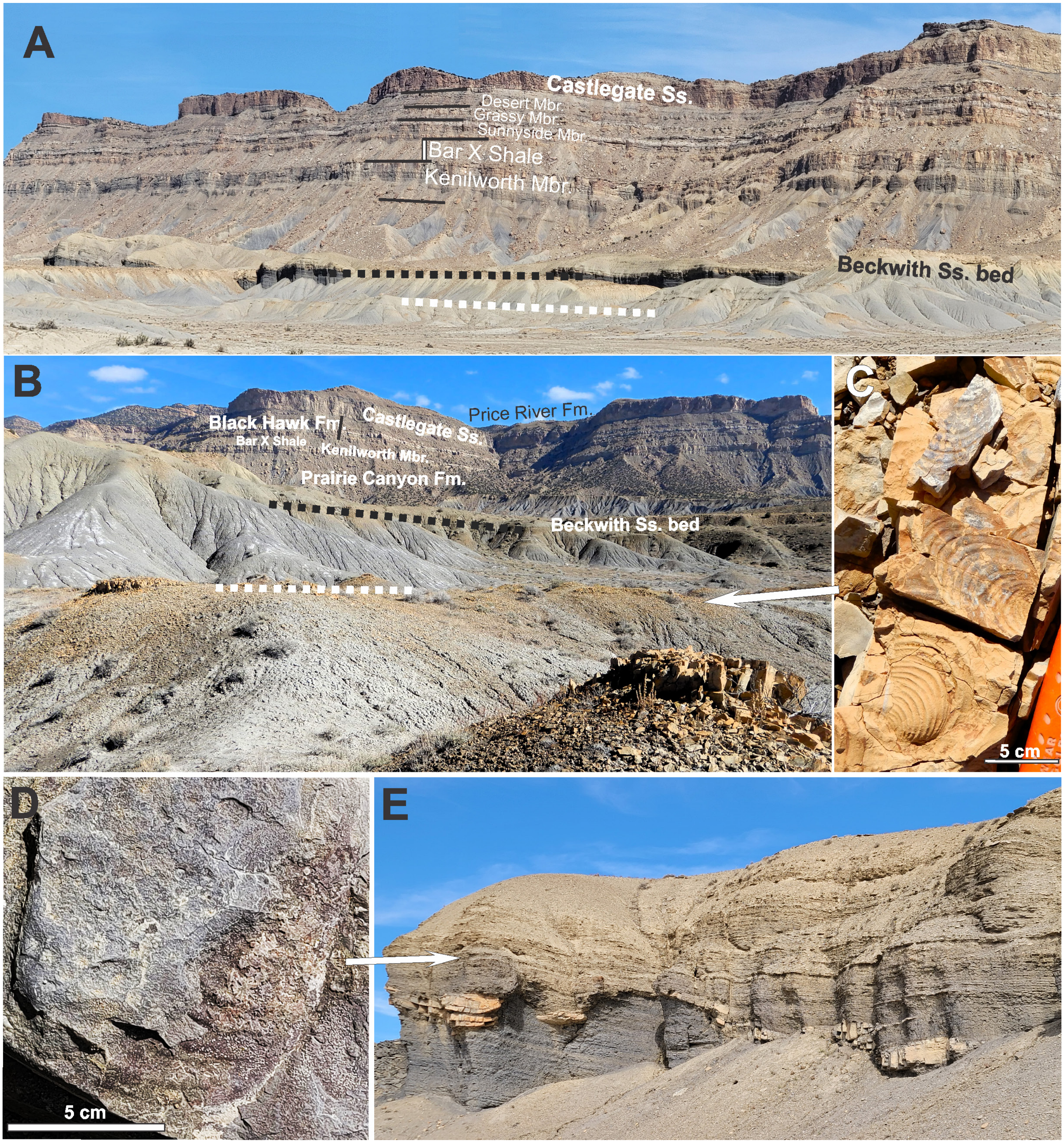

Figure 30. Exposures of Upper Mancos Group along northeast side of the Woodside Road, BLM Road 129. (A) Overview of section looking northeast. (B) View across Woodside Road Sandstone beds to southeast. (C) *Cataceramus balticus* from underling concretionary horizon. (D) Example of a *Cataceramus* from Woodside Road Sandstone. (E) Exposure of the Beckwith sandstone bed close to the Woodside Road, **Day 3, Stop 3**. Note, the internal scoured surfaces. Black dotted line represents line of main Beckwith sandstone bed; white dotted line represents line of underlying concretion horizon.

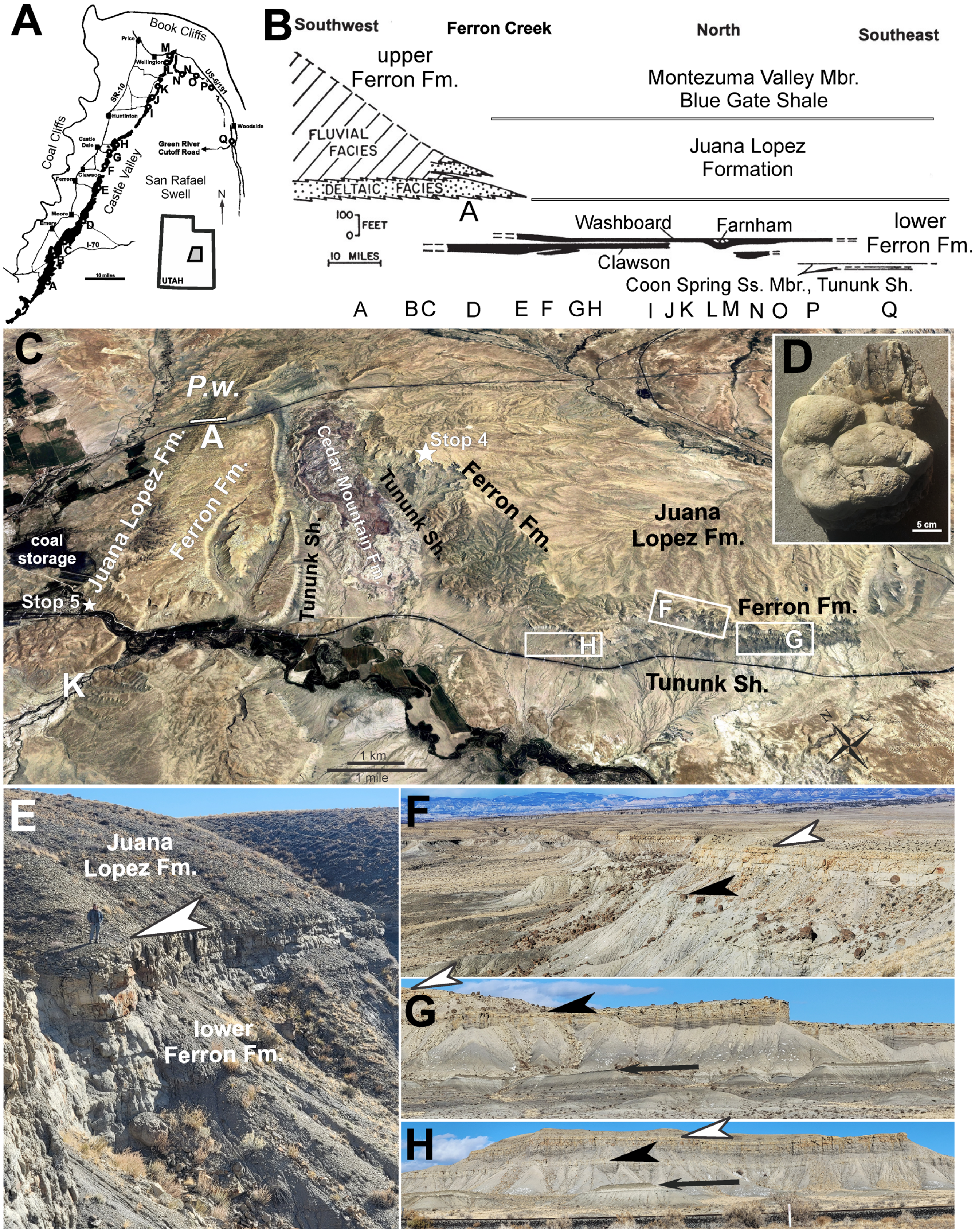

Figure 31 caption is on the following page.

Figure 31 is on the previous page. Farnham Dome area. (A) Index map of section sites from Cotter (1975, Figure 1). (B) Simplified section modified from Cotter (1977, Figure 2) emphasizing the separation of his upper and lower Ferron Sandstone. Note, we cannot distinguish separate Clawson and Washboard Members at Farnham Dome. (C) Oblique overview of Farnham Dome area from the southwest indicating locations of Stops 4 and 5. Image from Google Earth ©2023. ***P.w.*** = location of molluscan fauna from the basal upper Turonian *Prionocyclus wyomingensis* Zone north of US-191. White bar labeled A = Edwards' (2005) section A on the northwest side of US 6/191. K = approximate site of Katich's (1951) Figure 13 image of the fossiliferous basal Blue Gate on the south side of Miller Creek. White rectangles indicate approximate areas of F through H. (D) Large example of the latest middle Turonian index fossil *Prionocyclus macombi* protruding from a concretion from the lower Juana Lopez Formation at Mounds. (E) Contact between lower Ferron Formation and overlying Juana Lopez Formation. (F) View from West Mounds Road to northwest along escarpment formed by lower Ferron Formation. (G) View of the eastern end of escarpment below mounds from Farnham Road. (H) View of the western end of escarpment below mounds from Farnham Road. White arrowhead indicates position of pebbly, shark tooth lag marking sequence boundary at base of Juana Lopez Formation and top of upper coarsening upward sandstone sequence of lower Ferron Formation. Black arrowhead marks top of lower coarsening upward sandstone sequence of lower Ferron Formation. Black arrow marks the Coon Spring Sandstone Member of the Tununk Shale.

5.4	79.5	Continue south along the Mounds Road, which at 2 miles (3 km) we will turn east following the escarpment through these popular fossil collecting areas in the basal Juana Lopez Formation. Along this entire area a course sandstone lag with chert pebbles and shark teeth forms the base of the Juana Lopez Formation (Figure 31E) as described by Becker et al. (2010, 2012). Carbonate concretions in the lower Juana Lopez Formation are known to preserve large specimens of *Prionocyclus macombi* (Figure 31D) marking the top of the middle Turonian (Cobban et al., 2006). At 4.5 miles (7.3 km) the road winds south through the lower Ferron Formation dropping to the south. After crossing over the railroad tracks turn right (west) onto the Farnham Road to the west.
3.8	83.3	Continue northwest along the south side of rail line. Note, the lower sandstone bluff formed by the Coon Spring Sandstone Member of the Tununk Shale below the escarpment formed by the lower Ferron Formation over the next 3 miles (5 km) (Figures 31F through 31H) before the road crosses the axis of the San Rafael Swell. The lower Cedar Mountain Formation is exposed in the center of Farnham Dome up slope north of rail line.
2.2	85.5	In 0.4 miles (0.6 km), Farnham Road turns north crossing the railroad track and continues northwest along rail line. In another 1.8 miles (2.9 km) to the southwest, Miller Creek enters Soldier Wash from the west. Katich (1951, Figure 13) documented the presence of a distinct lithofacies and upper Turonian fossils as the Sage Breaks fauna in the basal Blue Gate Shale reflecting the presence of the Montezuma Valley Member in this area above the Juana Lopez Formation west of the axis of the San Rafael Swell.
0.7	86.2	Continuing northwest as the Farnham Road curves to the north, where we take a sharp right onto a short road leading into a sandstone quarry in the lower Ferron Formation. **Stop 5** (N. 39° 30.967, W. 110° 40.963; 12S E 527273 N 4374101): **marine sandstone beds of the lower Ferron Formation**. At this site, the marine sandstone beds of the lower Ferron Formation are overlain by the shallow marine heterolithics beds of Edwards' (2005a) 3rd transgressive systems track (TST3) (Fig-

			ure 32). Within TST3, dispersed chert pebbles are present (Figure 33F) and almost certainly represent the source of the pebbles in the conglomeratic shark tooth lag at the base of the overlying Juana Lopez Formation at Mounds (Becker, 2010), as well as farther to the south and east (Figure 25F). There needs to be a closer examination of the transition of facies across the axis of the San Rafael Swell in outcrop at Farnham Dome and in the subsurface.
1.7	87.9		Continue north on the Farnham Road. Turn right on Ridge Road at Wellington, Utah.
0.3	88.2	249.3	Turn left (west) onto US 6/191 on the east side of Wellington, Utah.
11.8	100.0	237.5	Drive northwest on US 6/191 that curves around the west side of Price, Utah, home of Utah State University Eastern and its Prehistoric Museum. Pull off to right into the northbound Utah port of entry at mile marker 238 and proceed to the north end. **Stop 6** (N. 39° 37.564, W. 110° 51.550; 12S E 512086 N 4386265): **discuss the basal Garley Canyon Member of the Emery Formation of the Mancos Group**. The basal Garley Canyon Member forms a distinct double sandstone bench along both sides of US 191 starting here (Figure 33).
1.9	101.9	235.6	Continue north on US-6/191 before turning left onto Consumers Road heading east.
6.8	108.7		Drive west to **Stop 7** (N. 39° 39.249, W. 110° 58.826; 12S E 501678 N 4389372): **overview the type section of the Helper Formation (Figure 34).** Formally referred to as the unnamed shale tongue of the Blue Gate Shale, this slope-forming interval separates the Emery Formation from the overlying Star Point Sandstone at the base of the Mesaverde Group and extends along the entire west site of the San Rafael Swell south of I-70. This section consists almost exclusively of mudstone and sandy mudstone with numerous muddy sandstone beds, lacking any finely bedded units. For this reason, it is considered more appropriate to refer to these strata as a formation rather than a shale (Kirkland et al., 2024).
6.8	115.5	235.6	Return to US 6/191 and turn left (north) toward Price Canyon.
5.9	121.4	229.7	At MP 233 drive through Helper, Utah. The escarpment directly ahead to north of road consists of the Helper Formation overlain by the Panther Tongue Member of the Star Point Sandstone, which pinches out into the Helper Formation within 10 miles (16 km) to the east. The road winds through the Blackhawk Formation and at MP 230.1 continue straight north on US 6 as US 191 splits off to northeast. Cuts on either side of road provide excellent exposures of coal-bearing strata in the lower Blackhawk Formation. Pull into north end of long pullout on right by block preserving dinosaur track at **Stop 8** (N. 39° 43.933, W. 110° 52.253; 12S E 511093 N 4397994): **overview of Blackhawk Formation and Castlegate Sandstone (Figures 35 and 36)**. Note that all of these strata interfinger into the upper Mancos Group in western Colorado.
7.0	128.4	222.7	Continue up Price Canyon. On the west side of the last long sweeping curve near the top of the canyon, note the color change in the North Horn Formation from

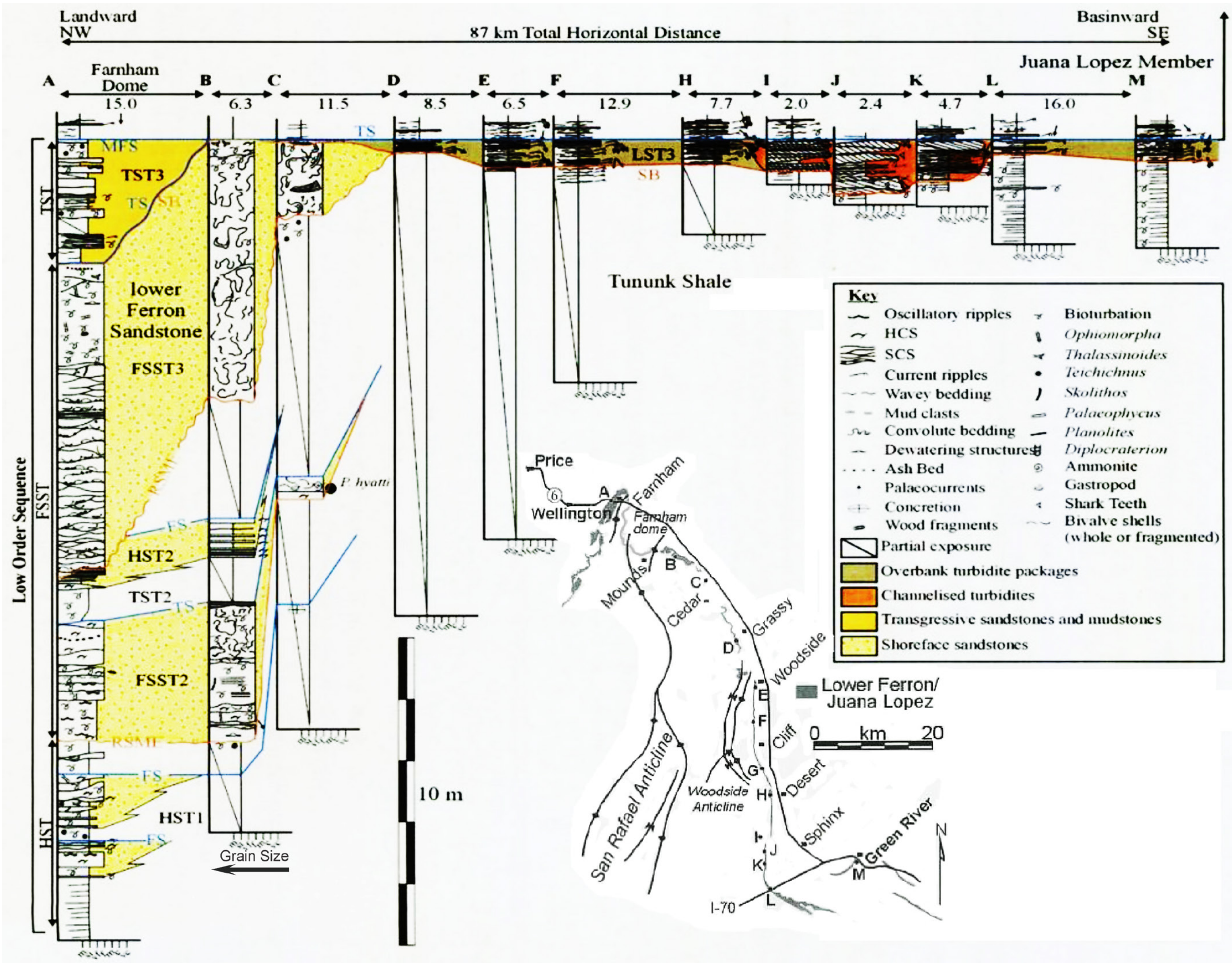

Figure 32. Stratigraphic correlation panel of the lower Ferron Sandstone. Edwards' (2005a) captions this figure as follows; "The lower Ferron contains 2 constituent higher-order sequences within a lower-order sequence. The lower-order sequence is dominated by a falling stage systems tract that contains three higher-order component sequences, characterized in sequences 2 and 3 by sharp-based shoreface successions bound by regressive surfaces of marine erosion (RSME), capped by transgressive surfaces (TS) and deposited during higher-order falls in relative sea-level (FSST2 and FSST3). The lowermost shoreface units appear to consist of 'normal' parasequences deposited during a highstand systems tract (HST1). The oldest sharp-based shoreface package is bound at its base by a regressive surface of erosion and is capped by an abrupt transgressive surface. Relative sea-level rise at this time was too rapid to preserve lowstand systems tract deposits. Falling sea level during the deposition of sequence 3 (FSST3) is recorded by sharp-based shoreface deposits bounded by a regressive surface of erosion at section A that correlates basinwards to slumped sandstones. The lowstand systems tract of this sequence (LST3), and indeed of the lower-order sequence too, is represented by turbidite deposition basinward of the preceding sharp-based shoreface package at section A and corresponds chronostratigraphically with a gravely bypass lag surface at section C. There is no evidence for subaerial exposure during this time of reduced accommodation. The transgressive surface that separates LST3 from the overlying transgressive systems tract (TST3) is denoted by an abrupt increase in water depth and intensely bioturbated crests of the FSST3 deposits at sections A and B and corresponds to a cessation of lowstand deposition. A thin, distal shoreface succession above the FSST3 at section A represents transgressive systems tract deposition, the top of which marks maximum flooding at both low and higher-order levels." We interpret his LST3 sequence as a transgressive unconformity at the base of the Juana Lopez Formation and not as turbidites and that the Juana Lopez strata preserving the *Prionocyclus wyomingensis* fauna extents west across top of the TST3 systems track on the west side of Farnham Dome.

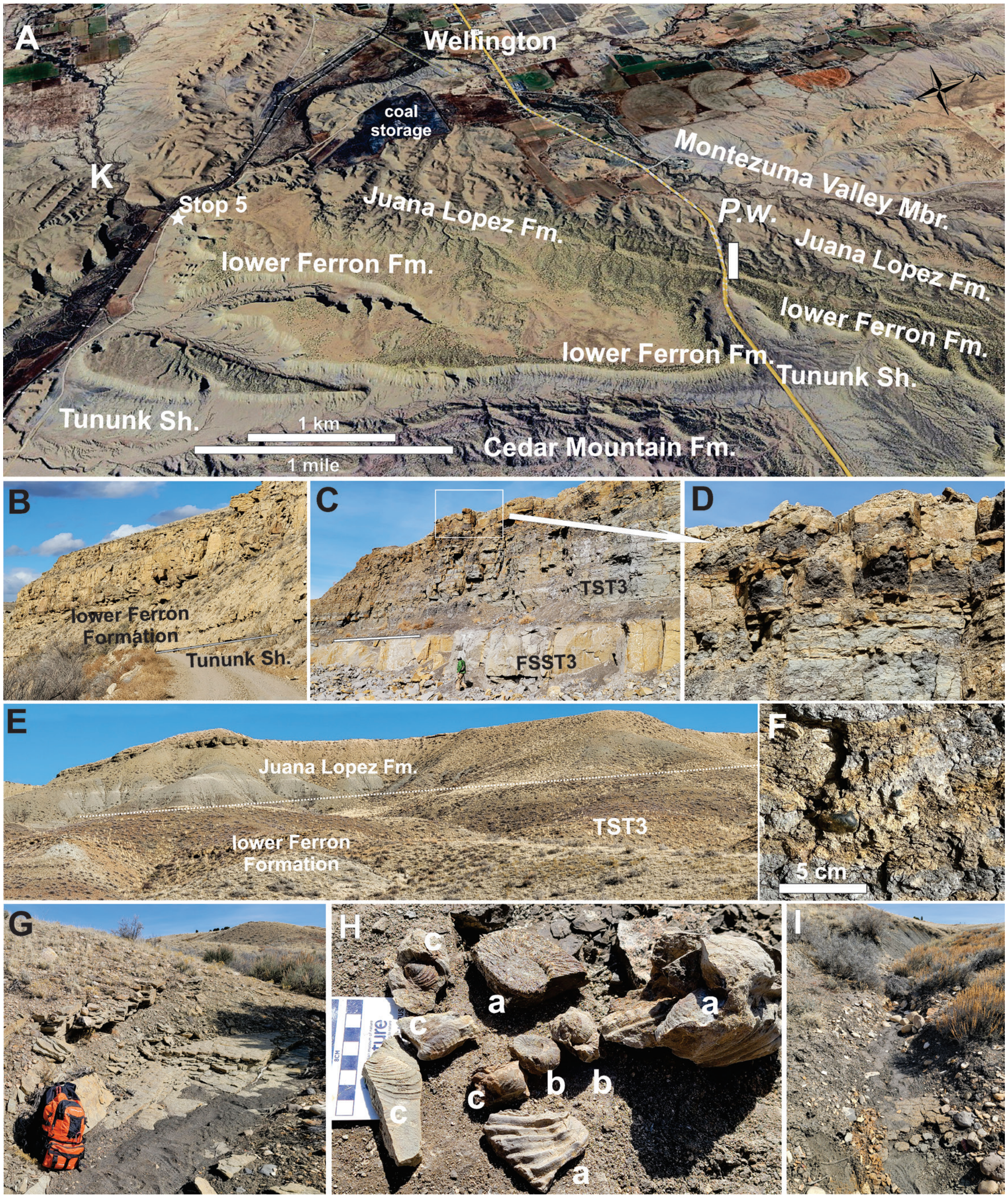

Figure 33. Northwest side of Farnham Dome and lower Ferron and Juana Lopez Formations. (A) Oblique view of strata on west side of Farnham Dome. White bar = Edwards' (2005) section A on the northwest side of US-6/192. ***P.w.*** = Juana Lopez exposures preserving a *Prionocyclus wyomingensis* fauna in F through H. Image from Google Earth ©2023. (B) Lower Ferron Formation on Farnham Road just south of turn into **Day 3, Stop 5**. (C) Lower Ferron Formation exposure of the contact between sandstone-dominated falling sea-level system's track 3 (FSST3) and overlying carbonaceous transgressive system's track 3 (TRT3) as expressed at **Day 3, Stop 5**. (D) Detail of the carbonaceous TST3 strata at **Day 3, Stop 5**. (E) TST3 at top of lower Ferron Formation overlain by Juana Lopez Formation north of turn into **Day 3, Stop 5.** (F) Dispersed pebbles in mudstone beds of TST3 at **Day 3, Stop 5**. (G) Interbedded rippled sandstone and mudstone in the lower Juana Lopez Formation. (H) Typical fossils from lower Juana Lopez Formation at this site, a, *Prionocyclus wyomingensis*, b, *Scaphites ferronensis*, and c, I*noceramus dimidius*. (I) Upper Juana Lopez is dominated by dark organic-rich shale with prionocyclid ammonites and inoceramid bivalves. Systems tracks after Edwards (2005) (see Figure 32).

Figure 34. Garley Canyon Member of Emery Formation. (A) Exposures of Garley Canyon to the northeast of **Day 3, Stop 6**. (B) Transition between the Blue Gate Shale and base of the Garley Canyon Member to the northwest of **Day 3, Stop 6**.

drab medium-gray to pinkish-gray marking the Cretaceous-Paleogene contact. In the canyon this contact is thought to be represented by a slight disconformity. The limestone beds up slope capping the rim of the canyon are the Paleocene Flagstaff Formation.

11.7 126.9 211.0 At the top of the Price Canyon, US 6 turns west. Along the north and east side of road extensive outcrops of the pale-red flood plain deposits of the lower Eocene Colton Formation overlain by the thick lacustrine beds of the Middle Eocene Green River Formation over the next 12 miles (19 km) to the crest of Soldier Summit.

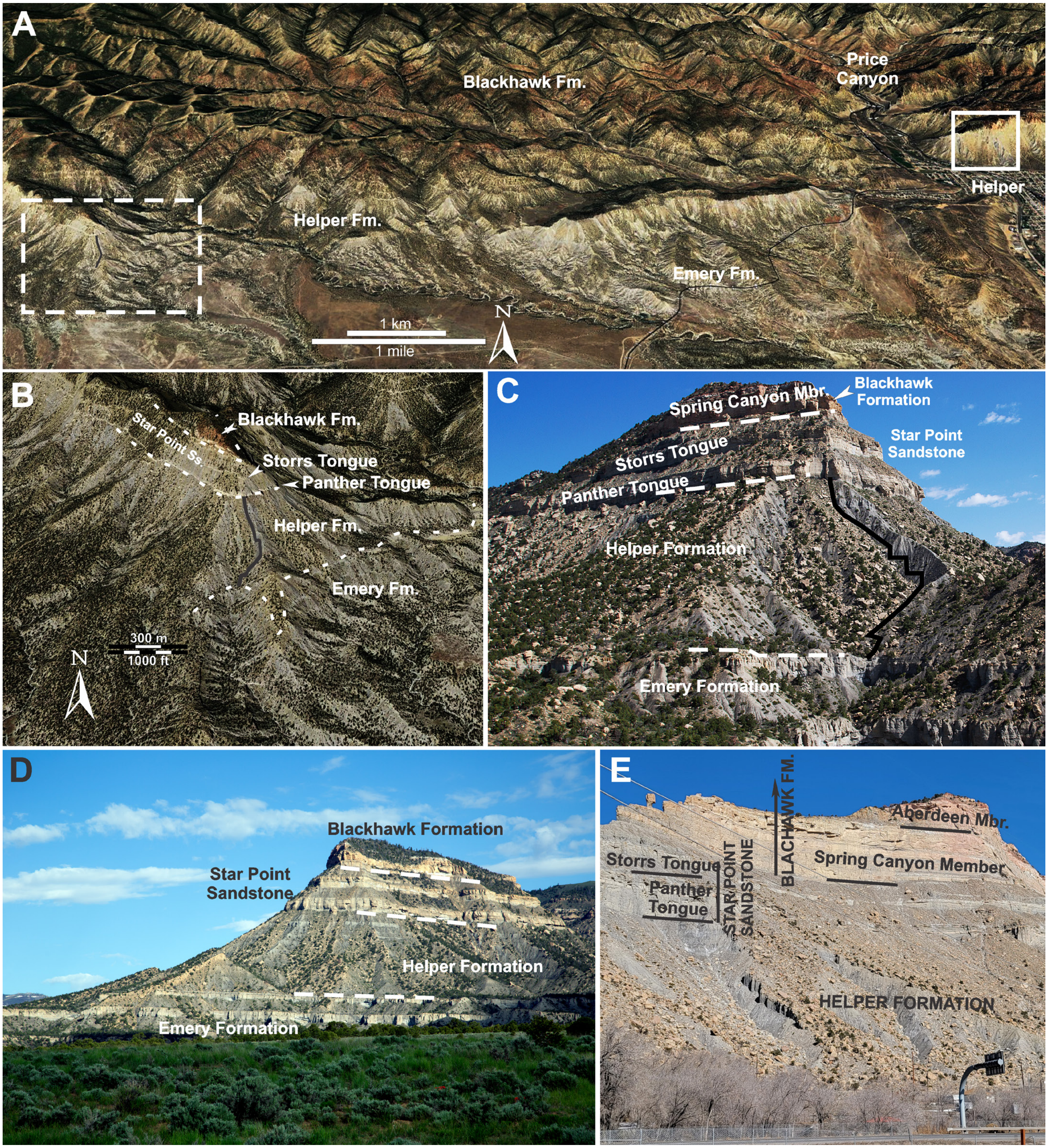

Figure 35. Helper Formation and the transition between the Mancos Group and the Mesaverde Group. (A) Overview of transition between upper Mancos Group and Mesaverde Group across mouth of Price Canyon. Dashed white box = area in B. White box = area in E. (B) Oblique view of Bull Point. Line of type section of Helper Formation in black from **Day 3, Stop 7**. (C) Detailed route of Helper Formation type section (in black) up southwest end of Bull Point. (D) Bull Point from the southeast. (E) Helper Formation northeast of US-191 at Helper, Utah. Dashed white lines indicate formation boundaries. Images from Google Earth ©2023.

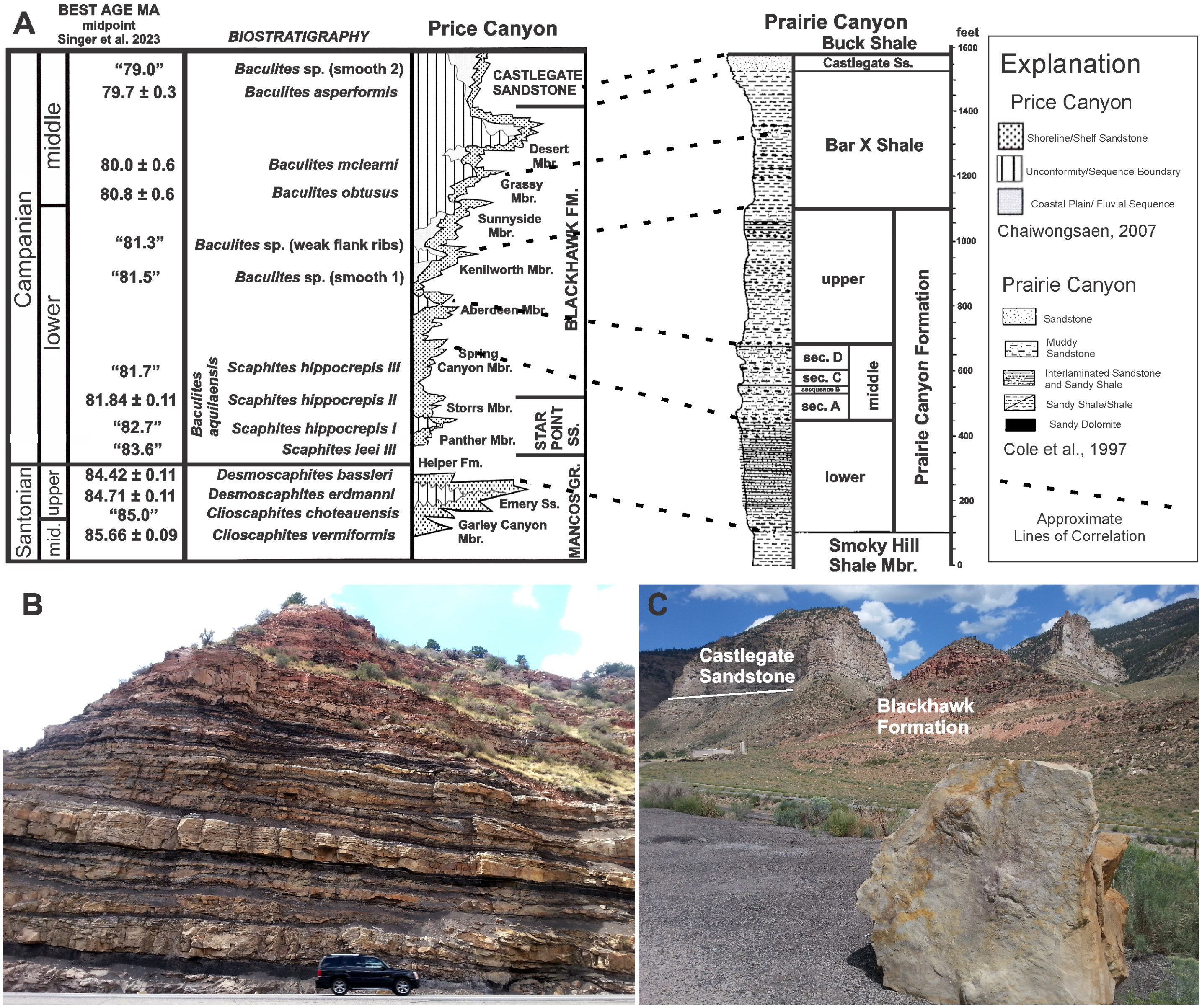

Figure 36. Price Canyon. (A) Correlation of Blackhawk Formation with upper Mancos Group. Modified after Cole et al. (1997), Stevens (2004), and Chaiwongsaen (2007). Ages taken from Singer et al. (2023). (B) Coal-bearing Blackhawk Formation exposed in roadcut on west side of US-6 at MP 229.9. (C) Blackhawk and Castlegate Formations to northeast of pull out at **Day 3, Stop 8**. Note: natural casts of ceratopsian tracks in fallen sandstone block from Blackhawk Formation.

18.0 144.9 193.0 Driving down the western slope of Soldier Summit, exposures of the Eocene lacustrine Green River Formation are present over the next 17 miles (27 km). A structurally complex interval between mile markers 194 and 193 marks the boundary between the Colorado Plateau and the Basin and Range Province with the Cretaceous Rede Narrows Conglomerate superimposed on the Eocene Green River Formation.

4.0 148.9 189.0 Tabular boulder conglomerate and mudstone of the Red Narrows Conglomerate (Young, 1976) are the result of the alluvial fans formed proximal to the Sevier oro-

			genic belt (Figure 37). Strikingly, the correlative coastal strata in Price Canyon includes barely any pebbles within its fluvial sequences across the narrow floodplain 30 miles (48 km) to the southeast. This reflects the rapid subsidence of the narrow Cretaceous foredeep basin of northern Utah.
3.5	152.4	185.5	Traversing west for the next 3 miles (5 km), lower Cretaceous strata of the Kelvin Formation (Granger, 1953) that outcrops along the north side of the road appears gradational with the overlying Red Narrows Conglomerate due to its isolated sheet conglomerate in its upper part documenting the early phases of the Sevier orogeny. A short northward curve in the road is bounded by marine Middle Jurassic Arapien Formation (Sprinkel et al., 2024). As the road starts down slope to the north, the extensive scar of the 1980s Thistle landside is visible to the west across the deep valley.
6.6	158.0	179.0	The road continues to drop down through the Mesozoic section for the next 1.5 miles (2.4 km) through the Early Triassic Thaynes Formation as the road turns west again just past the Diamond Fork turnoff on the right. The road continues to cut down section through the upper Paleozoic to the small windfarm at the mouth of the canyon on the east side of Spanish Fork, Utah.
5.5	163.5	173.5	Continue on US-6 northwest across Spanish Fork and merge onto I-15 northbound to Provo.

Road Log Ends in Spanish Fork, Utah

Figure 37. Red Narrows Conglomerate. Tabular-bedded boulder conglomerate of the Red Narrows Conglomerate represent alluvial fans adjacent the Upper Cretaceous Sevier orogenic belt (N. 39° 59.603, W. 111° 23.927; 12S E 465956 N 4427099).

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