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EDITED BY PAUL KARL LINK AND BART J. KOWALLIS

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MESOZOIC TO RECENT GEOLOGY OF UTAH

Edited by

Paul Karl Link and Bart J. Kowallis

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CONTENTS

Triassic and Jurassic Macroinvertebrate Faunas of Utah: Field Relationships and Paleobiologic Significance . . . . Carol M. Tang and David J. Bottjer 1

Part 2: Trace fossils, hardgrounds and ostreoliths in the Carmel Formation (Middle Jurassic) of southwestern Utah . . . . Mark A. Wilson 6

Part 3: Low-diversity faunas of the Middle Jurassic Carmel Formation and their paleobiological implications . . . . Carol M. Tang and David J. Bottjer 10

Part 4: Paleoecology of Lower Triassic marine carbonates in the southwestern USA . . . . David J. Bottjer and Jennifer K. Schubert 15

Structure and Kinematics of a Complex Impact Crater, Upheaval Dome, Southeast Utah . . . . Bryan J. Kriens, Eugene M. Shoemaker, and Ken E. Herkenhoff 19

Stratigraphy, and structure of the Sevier thrust belt, and proximal foreland-basin system in central Utah: A transect from the Sevier Desert to the Wasatch Plateau . . . . T. F. Lawton, D. A. Sprinkel, P. G. DeCelles, G. Mitra, A. J. Sussman,, and M. P. Weiss 33

Lower to Middle Cretaceous Dinosaur Faunas of the Central Colorado Plateau: A Key to Understanding 35 Million Years of Tectonics, Sedimentology, Evolution, and Biogeography . . . . James I. Kirkland, Brooks Britt, Donald L. Burge, Ken Carpenter, Richard Cifelli, Frank DeCourten, Jeffrey Eaton, Steve Hasiotis, and Tim Lawton 69

Sequence Architecture, and Stacking Patterns in the Cretaceous Foreland Basin, Utah: Tectonism versus Eustasy . . . . P. Schwans, K. M. Campion 105

Fluvial-Deltaic Sedimentation, and Stratigraphy of the Ferron Sandstone . . . . Paul B. Anderson, Thomas C. Chidsey, Jr., and Thomas A. Ryer 135

Depositional Sequence Stratigraphy and Architecture of the Cretaceous Ferron Sandstone: Implications for Coal and Coalbed Methane Resources—A Field Excursion . . . . James R. Garrison Jr., T. C. V. van den Bergh, Charles E. Barker, and David E. Tabet 155

Extensional Faulting, Footwall Deformation and Plutonism in the Mineral Mountains,
Southern Sevier Desert . . . . Drew S. Coleman, John M. Bartley,
J. Douglas Walker, David E. Price, and Anke M. Friedrich 203

Neotectonics, Fault segmentation, and seismic hazards along the Hurricane fault in
Utah and Arizona: An overview of environmental factors . . . . Meg E. Stewart, Wanda J. Taylor,
Philip A. Pearthree, Barry J. Solomon, and Hugh A. Hurlow 235

Part 2: Geologic hazards in the region of the Hurricane fault . . . . William R. Lund 255

Part 3: Field Guide to Neotectonics, fault segmentation, and seismic hazards along
the Hurricane fault in southwestern Utah and northwestern Arizona . . . . Meg E. Stewart,
Wanda J. Taylor, Philip A. Pearthree, Barry J. Solomon, and Hugh A. Hurlow 261

Fault-Related Rocks of the Wasatch Normal Fault . . . . James P. Evans, W. Adolph Yonkee,
William T. Parry, and Ronald L. Bruhn 279

Geologic Hazards of the Wasatch Front, Utah . . . . Michael D. Hylland, Bill D. Black, and Mike Lowe 299

Bedrock Geology of Snyderville Basin: Structural Geology Techniques Applied to
Understanding the Hydrogeology of a Rapidly Developing Region,
Summit County, Utah . . . . Kelly E. Keighley, W. Adolph Yonkee, Frank X. Ashland, and James P. Evans 325

New explorations along the northern shores of Lake Bonneville . . . . Charles G. (Jack) Oviatt,
David M. Miller, Dorothy Sack, and Darrell Kaufman 345

Quaternary Geology and Geomorphology, Northern Henry Mountains Region . . . .
. . . . Benjamin L. Everitt, Andrew F. Godfrey, Robert S. Anderson, and Alan D. Howard 373

Part 2: Wind Erosion of Mancos Shale Badlands . . . . Andrew E. Godfrey 384

Part 3: Long-Term Measurements of Soil Creep Rates on Mancos Shale
Badland Slopes . . . . Andrew E. Godfrey 386

Part 4: Vegetation and Geomorphology on the Fremont River . . . . Ben Everitt 388

Part 5: Gravel Deposits North of Mount Ellen, Henry Mountains, Utah . . . . Andrew E. Godfrey 390

Part 6: Monitoring flash floods in the Upper Blue Hills badlands, southern Utah . . . . Gregory S. Dick,
Robert S. Anderson, and Daniel E. Sampson 392

Part 7: Dating the Fremont River Terraces . . . . James L. Repka,
Robert S. Anderson, Greg S. Dick, and Robert C. Finkel 398

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Cover photos taken by Paul Karl Link.

Top: Upheaval Dome, southeastern Utah.

Middle: Lake Bonneville shorelines west of Brigham City, Utah.

Bottom: Bryce Canyon National Park, Utah.

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Preface

Guidebooks have been part of the exploration of the American West since Oregon Trail days. Geologic guidebooks with maps and photographs are an especially graphic tool for school teachers, University classes, and visiting geologists to become familiar with the territory, the geologic issues and the available references.

It was in this spirit that we set out to compile this two-volume set of field trip descriptions for the Annual Meeting of the Geological Society of America in Salt Lake City in October 1997. We were seeking to produce a quality product, with fully peer-reviewed papers, and user-friendly field trip logs. We found we were bucking a tide in our profession which de-emphasizes guidebooks and paper products. If this tide continues we wish to be on record as producing "The Last Best Geologic Guidebook."

We thank all the authors who met our strict deadlines and contributed this outstanding set of papers. We hope this work will stand for years to come as a lasting introduction to the complex geology of the Colorado Plateau, Basin and Range, Wasatch Front, and Snake River Plain in the vicinity of Salt Lake City. Index maps to the field trips contained in each volume are on the back covers.

Part 1 "Proterozoic to Recent Stratigraphy, Tectonics and Volcanology: Utah, Nevada, Southern Idaho and Central Mexico" contains a number of papers of exceptional interest for their geologic synthesis. Part 2 "Mesozoic to Recent Geology of Utah" concentrates on the Colorado Plateau and the Wasatch Front.

Paul Link read all the papers and coordinated the review process. Bart Kowallis copy edited the manuscripts and coordinated the publication via Brigham Young University Geology Studies. We would like to thank all the reviewers, who were generally prompt and helpful in meeting our tight schedule. These included: Lee Allison, Genevieve Atwood, Gary Axen, Jim Beget, Myron Best, David Bice, Phyllis Camilleri, Marjorie Chan, Nick Christie-Blick, Gary Christenson, Dan Chure, Mary Droser, Ernie Duebendorfer, Tony Ekdale, Todd Ehlers, Ben Everitt, Geoff Freethey, Hugh Hurlow, Jim Garrison, Denny Geist, Jeff Geslin, Ron Greeley, Gus Gustason, Bill Hackett, Kimm Harty, Grant Heiken, Lehi Hintze, Peter Huntoon, Peter Isaacson, Jeff Keaton, Keith Ketner, Guy King, Mel Kuntz, Tim Lawton, Spencer Lucas, Lon McCarley, Meghan Miller, Gautam Mitra, Kathy Nichols, Robert Q. Oaks, Susan Olig, Jack Oviatt, Bill Perry, Andy Pulham, Dick Robison, Rube Ross, Rich Schweickert, Peter Sheehan, Norm Silberling, Dick Smith, Barry Solomon, K.O. Stanley, Kevin Stewart, Wanda Taylor, Glenn Thackray and Adolph Yonkee. In addition, we wish to thank all the dedicated workers at Brigham Young University Print Services and in the Department of Geology who contributed many long hours of work to these volumes.

Paul Karl Link and Bart J. Kowallis, Editors

Lower to Middle Cretaceous Dinosaur Faunas of the Central Colorado Plateau: A Key to Understanding 35 Million Years of Tectonics, Sedimentology, Evolution and Biogeography

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ABSTRACT

Three distinct dinosaur faunas separated by unconformities representing about 10 my each are present in the Cedar Mountain Formation of east-central Utah. These biostratigraphic relationships compliment the lithostratigraphic relationships present in the Cedar Mountain Formation resulting in the recognition of five members to be recognized. These members are a basal Buckhorn Conglomerate and four new members defined herein. In ascending order these are the Yellow Cat Member, Poison Strip Sandstone, Ruby Ranch Member, and Mussentuchit Member.

The Buckhorn Conglomerate is a trough cross-bedded pebble conglomerate present at the base of the Cedar Mountain Formation on the west and north sides of the San Rafael Swell. It is unfossiliferous. The oldest fauna preserved is in the largely fine grained deposits of basal Yellow Cat Member east of the San Rafael Swell. The dinosaurs include abundant polacanthids, cf. *Polacanthus* n. gen., *Iguanodon ottingeri,* a sail-backed iguanodontid (= *I. ottingeri* ?), camarasaurid and titanosaurid sauropods, a small maniraptoran theropod, cf. *Ornitholestes* n. gen., and the giant dromaeosaurid *Utahraptor ostrommaysorum.* The ankylosaurs, iguanodontids, and sauropods indicate close temporal and geographic ties to the Barremian of Europe.

The cliff forming Poison Strip Sandstone outcrops across central Utah east of the San Rafael Swell. Dinosaurs present in this member are limited to the nodosaurid ankylosaur *Sauropelta,* and isolated theropod and sauropod bones. The overlying Ruby Ranch Member is characterized by largely illitic mudstones and an abundance of calcareous nodules. It preserves a dinosaur fauna including the nodosaurid *Sauropelta,* the primitive iguanodontian *Tenontosaurus*?, sauropods assigned to *Pleurocoelus,* dromaeosaurid teeth, an unidentified large theropod, and *Acrocanthosaurus.* This fauna compares well with those documented from the Cloverly Formation, Arundel Formation, and Trinity Group characteristic of North American's apparently endemic Aptian-Albian dinosaur fauna.

A sharp break from carbonate nodule bearing, non-smectitic strata to carbonaceous, highly smectitic strata marks the base of the Mussentuchit Member in the western San Rafael Swell region. It is dated as spanning the Albian/Cenomanian boundary based on palynology and radiometric dates. This youngest dinosaur fauna includes a small nodosaurid, cf. *Pawpawsaurus* n. gen., a small ornithopod, a primitive lambeosaurid hadrosaur, ceratopsian teeth, pachycephalosaur teeth, tiny sauropod teeth, a dromaeosaurid, cf. *Richardoestesia* teeth, cf. *Paronychodon* teeth, and an early tyrannosaurid. This dinosaur fauna is remarkably similar to those of the Campanian and Maastrichtian of western North America. As the most likely ancestors of the tyrannosaurid, hadrosaur and ceratopsian are from the Early Cretaceous of Asia, the dramatic shift to faunas typical of the North American Late Cretaceous is interpreted to result from opening migration corridors to and from Asia through Alaska at the end of the Early Cretaceous, when migration to eastern North America was still possible. The middle to upper Cenomanian Dakota Formation preserves a dinosaur fauna much like that of the Mussentuchit fauna with the notable absence of sauropods.

The fossil record in east-central Utah indicates that a Barremian iguanodont-polacanthid fauna with European affinities predating common flowering plants was replaced by an Aptian-middle Albian *Tenontosaurus-Pleurocoelus* fauna, perhaps representing an impoverished recovery fauna following a Early Cretaceous extinction event (endemic to North America). In turn, this was followed by a latest Albian-earliest Cenomanian hadrosaur dominated fauna with Asian affinities when flowering plants were co-dominant, which continued until the end of the Cretaceous.

INTRODUCTION

Approximately 50 million years of Earth's history is represented between the final deposition of the Late Jurassic Morrison Formation and the first transgression of the Late Cretaceous Western Interior Seaway across the Colorado Plateau. The Cedar Mountain and Dakota Formations record part of this history. Historically, these terrestrial strata have been considered to be largely unfossiliferous (Stokes, 1944, 1952; Young, 1960). Age relationships of the terrestrial Dakota Formation have been based on overlying latest Cenomanian marine fossils (Cobban, 1976; Eaton, Kirkland, and Kauffman, 1990). The uppermost Cedar Mountain Formation in the western San Rafael Swell had been dated as late Albian based on palynomorphs by Tschudy and others (1984). Dates based on freshwater bivalves, ostracodes, charophytes, and plants, while not as accurate, are compatible (Mitchell, 1956; Stokes, 1952; Young, 1960). Thus, it has been accepted that a broadly Albian Cedar Mountain Formation was overlain by a largely Cenomanian Dakota Formation. The Cedar Mountain Formation has subsequently been considered as a homogenous Aptian-Albian unit in most regional studies (ex. Lawton, 1985; 1986; Heller, et al., 1986; Baars, 1988).

Additionally, the North American terrestrial vertebrate record is very poor overall for the "middle" Cretaceous; a the notable exception being the Aptian-Albian fauna from the Cloverly Formation of northern Wyoming and southern Montana (Ostrom, 1970). Largely correlative faunas are known from the Antlers Formation of Oklahoma, Arkansas, and west Texas (Stovall and Langston, 1950; Langston, 1974), the Pauluxy and Twin Mountains formations of central Texas (Langston, 1974; Winkler et al., 1989; 1990), and the

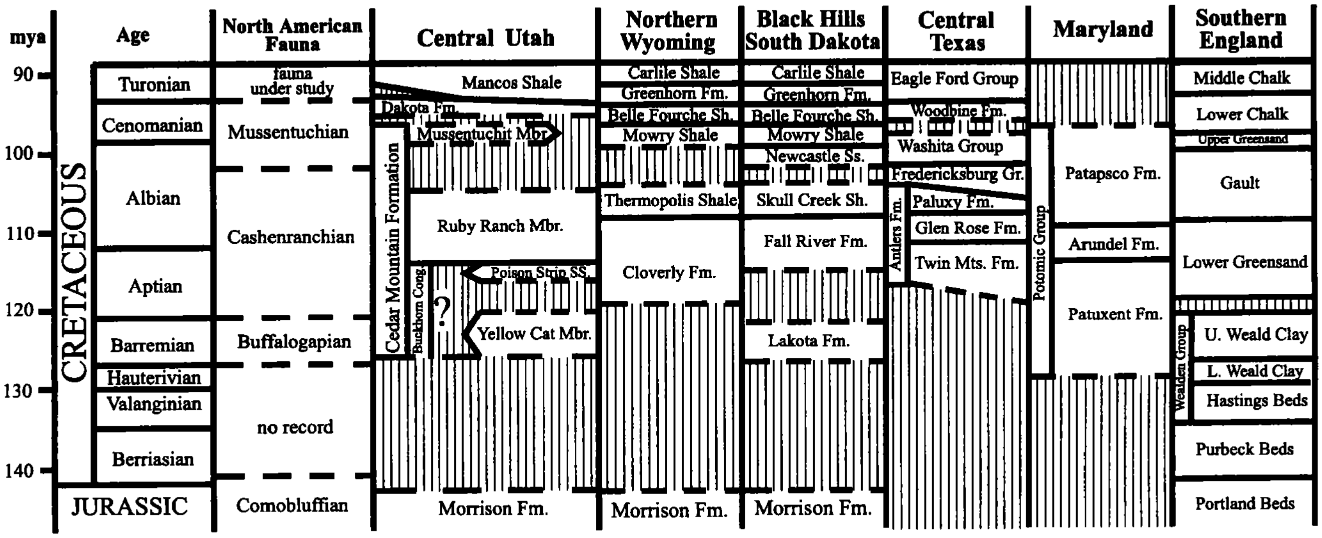

Figure 1. Correlation chart showing age relationships of stratigraphic units dicussed in text. Vertical lines denote unconformites. Time scale from Obradovich (1993). North American faunas ages after Lucas (1993) and this paper. Data from Dyman et al., (1994), Winkler et al., (1995), Hancock et al., (1993), Kranz (1989), and Benton and Spencer (1995).

Arundel Formation of Maryland (Gilmore, 1921; Kranz, 1989, 1996) (Fig. 1).

Recent research has indicated that there are three distinct dinosaur faunas separated by unconformities representing about 10 my each in the Cedar Mountain Fm. of east-central Utah (ex. Kirkland, 1996b). In addition to the well known Aptian-Albian fauna, there are distinct earlier and later faunas preserved in the Cedar Mountain Formation. A diverse fauna has also been recovered from the overlying Dakota Formation in southern Utah and from a small site in the western San Rafael Swell (Eaton, 1987, 1993a, b; Eaton et al., 1997). Improved biostratigraphic resolution within this time interval indicates a more complex regional history during the Early to "middle" Cretaceous and will lead to refinements in our geological interpretations.

Significant localities demonstrating this three-fold division of the Cedar Mountain Formation will be visited, as will a pertinent outcrop of the Dakota Formation during the course of this field trip (Fig. 2). Additionally, each of the proposed members of the Cedar Mountain Formation will be examined.

Detailed descriptions as to how to get to the fossil localities described in this guidebook are not provided as these are sensitive sites of ongoing research by many institutions. This information is on file at these institutions (listed below) and will be provided to qualified researchers. It is hoped that this field trip and guidebook will provide ample explanation as to why our fossil resources should be protected so that they can continue provide data to better understand the Earth's geological, biological and climatic history.

Lower Cretaceous Strata in the Thrust Belt.

Lower Cretaceous strata of the central Utah thrust belt were deposited near the tip of the advancing thrust wedge west of the Wasatch Plateau in the axis of a foreland basin created by the load of the thrust faults. The section thickens very rapidly to the northwest from the vicinity of Salina, Utah, achieving a maximum thickness of 1160 m at Chicken Creek in the west central San Pitch Mountains (Sprinkel et al., written commun., 1996). From that point westward, correlative strata thin by onlap onto the hanging wall of the Pavant thrust. Clasts in conglomerate of the Lower Cretaceous section were derived from hanging wall rocks of both the Canyon Range and Pavant thrusts, coeval with movement of the Pavant Thrust (Lawton, 1985; DeCelles, et al., 1995). Paleocurrent data and clast composition trends indicate that the conglomeratic part of the section was at times distributed southeastward away from the thrust belt, reaching the latitude of Salina as toes of large fans, and at other times dispersed northeast longitudinally along the axis of foredeep of the foreland basin by large braided rivers. The robust river systems that occupied the rapidly subsiding axis of the basin were probably poorly represented or even completely absent from equivalent depositional systems of more slowly subsiding regions further from the thrust belt. It is not surprising that correlation of this interval through the subsurface of the Wasatch Plateau has proven challenging. The Lower Cretaceous section in the central Utah part of the thrust belt is characterized by a quartzite-cobble and boulder conglomerate that is generally regarded as correlative with the base of the Dakota Formation (Schwans, 1995; Lawton et al., in press; Sprinkel et al., written commun., 1996).

Strata in the central Utah part of the Sevier orogenic belt equivalent to the Cedar Mountain Formation of the Colorado Plateau have a varied history of nomenclature (Fig. 3). They were tentatively identified as Morrison Formation based on stratigraphic position (Spieker and Reeside, 1926). Spieker (1946, 1949) later hedged his correlation with a query as he learned more about regional relations of the continental interval above the San Rafael Group. Although Stokes (1972) questioned the Morrison assignment on the basis of polished chert pebbles or gastroliths in the beds of the thrustbelt, it was not until a succession of studies in the 1980's that the Early Cretaceous age of these strata was established. Standlee (1982), Witkind et al., (1986), and Weiss and Roche (1988) recommended use of the term Cedar Mountain for redbeds exposed in the San Pitch Mountains, although there was some confusion among some workers about how to handle an interval of red conglomerate lying above the gastrolith shales and beneath the Indianola Group. Schwans (1988a, b) reassigned the Lower Cretaceous section to the Pigeon Creek Formation, assigning the lower shale-rich part to a lower member and about a kilometer of conglomerate on the west side of the San Pitch Mountains to an upper member. Weiss (1994) included the lower mudstone interval in the Cedar Mountain Formation and overlying conglomerate in an unnamed basal formation of the Indianola Group. Based on ongoing, detailed biostratigraphic and structural studies Sprinkel et al., (1992; written commun., 1996) recommended assignment of the lower shale-rich interval to the Cedar Mountain Formation, and the upper conglomeratic interval to a new formation, the "San Pitch Formation," to be included in the Indianola Group.

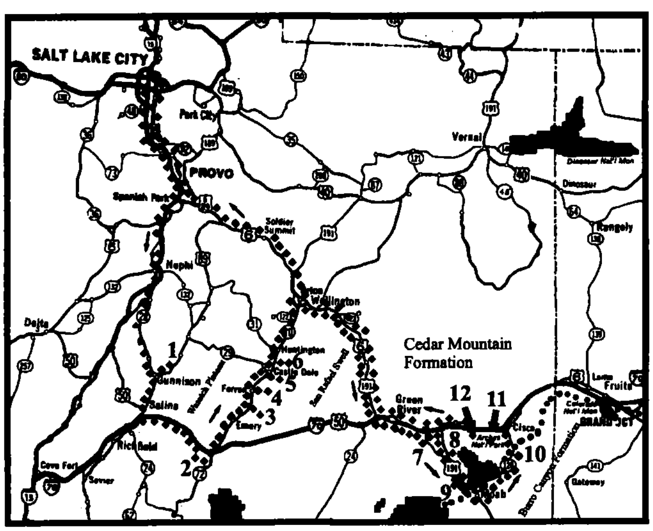

Figure 2. Map showing route of field trip (diamonds). Field trip stops listed by number. Line of dots indicates geographic boundary between Cedar Mountain and Burro Canyon Formations.

Palynomorph biostratigraphy indicates that both the shale-rich and conglomerate rich intervals of the thrust belt correlate with the Cedar Mountain Formation exposed east of the Wasatch Plateau. The base of the conglomerate is middle to late Albian in the San Pitch Mountains based on concurrent range zones of palynomorph collections (Sprinkel et al., written commun., 1996). The Cedar Mountain Formation of the San Pitch Mountains is probably Aptian-lower Albian by comparison with similar lithologies rich in carbonate nodules associated with the Ruby Ranch Member of the Cedar Mountain on the Colorado Plateau. Both the Cedar Mountain and the overlying conglomerate beds are therefore equivalent to the Cedar Mountain of the Colorado Plateau, although the conglomerate beds appears rather inconveniently to correspond to an unconformity between the Ruby Ranch and Mussentuchit members of the plateau.

The Cedar Mountain Formation.

The term Cedar Mountain Shale was designated by Stokes (1944) for the drab variegated slope-forming sediments lying between the Buckhorn Conglomerate and the Dakota Formation (Fig. 4); the type section lies on the southwest flank of Cedar Mountain, Emery County, Utah. It was characterized as having slopes covered with abundant carbonate nodules that were often septarized with agate, barite, and other fillings. Stokes noted an abundance of elongate sandstone lenses (ribbon sandstones) that represented abandoned river channels. The presence of polished chert pebbles "gastroliths" was also noted.

Stokes (1952) renamed the unit the Cedar Mountain Formation and included the Buckhorn Conglomerate as its basal member (Fig. 4). His measured type section (Sec. 9, T18S, R10E) is 123.6 meters thick. He recognized that the Burro Canyon Formation of western Colorado (Stokes and Phoenix, 1948) is largely equivalent to the Cedar Mountain Formation and recommended using the Colorado River as the dividing line between these formations (Stokes, 1952).

Young (1960), recognizing the continuity of the two formations, proposed that the term Burro Canyon be abandoned in favor of Cedar Mountain Formation. This proposal has been ignored by subsequent authors (ex. Craig, 1981). Young (1960) recognized several regionally extensive sandstones in the Cedar Mountain that were useful for correlation (Fig. 4).

Based on correlations of regionally persistent sandstone units, Young (1960) proposed that, toward the east, calcareous mudstones assigned to the Cedar Mountain passed into

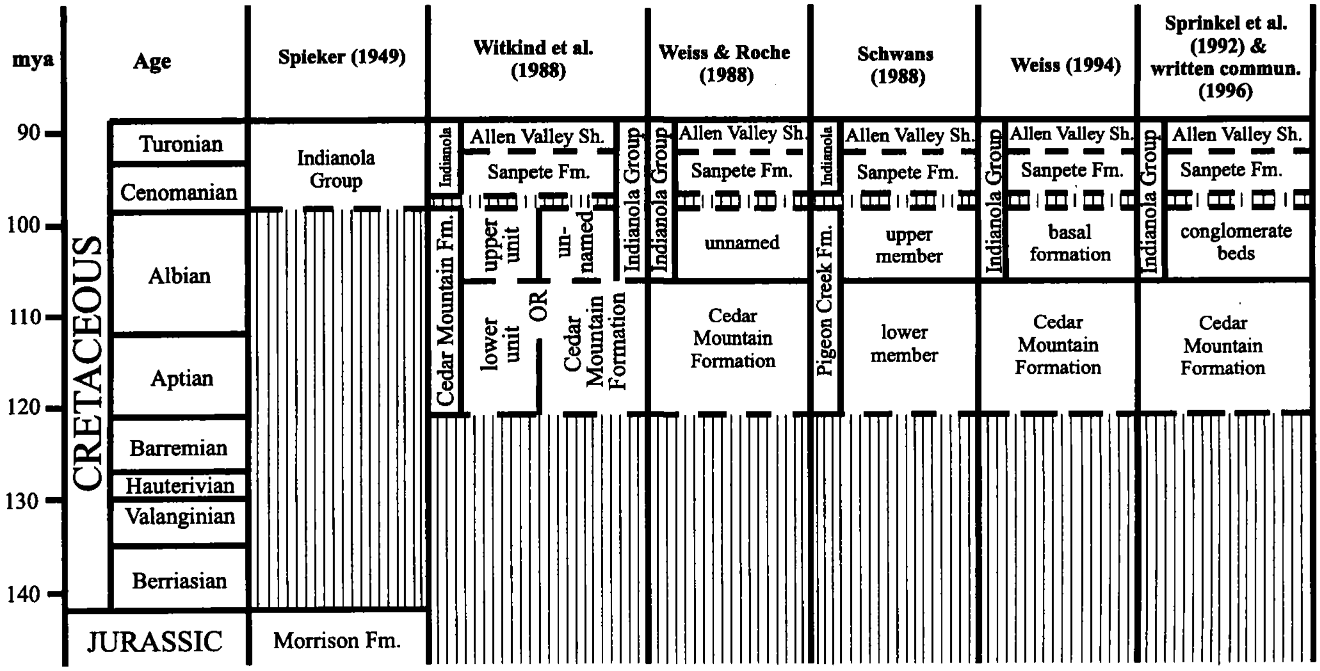

Figure 3. History of nomenclature for "middle" Cretaceous strata in the San Pete Valley. Time scale from Obradovich (1993).

the carbonaceous sandstones and shales of his Naturita Formation (Fig. 4). Although the more refined biostratigraphy developed herein precludes such a rapid facies change, Molenaar and Cobban (1991) and correlations presented here indicate that the upper Cedar Mountain Formation correlates with the upper Dakota Formation northwestward across the Uinta Basin. Young's (1960) sandstone correlations suffered from this lack of biostratigraphic control, but these units mark major breaks in sedimentation as indicated by the dramatic faunal changes documented herein. Thus Young's (1960) recognition of these units represented a significant, if belatedly utilized, breakthrough in our understanding of the Cedar Mountain Formation.

In addition to the basal Buckhorn Conglomerate of the western San Rafael Swell, four additional members are newly proposed herein. In ascending order, based on stratigraphic and biostratigraphic relationships, these are; Yellow Cat Member, Poison Strip Sandstone, Ruby Ranch Member, and Mussentuchit Member (Figs. 1, 3).

The Buckhorn Conglomerate.

The Buckhorn Conglomerate was defined by Stokes (1944) for exposures below the dam at Buckhorn Reservoir on the southwest flank of Cedar Mountain, where its exposed thickness is 7.5 m. At the type locality, the pebbles have an average diameter of 3 cm and are composed mostly of black chert. Trough crossbedding indicate flow directions to the northeast. It is best developed in the northern San Rafael Swell area (Fig. 5). Because of its discontinuous nature, Stokes (1952) subsequently included it as the lower member of the Cedar Mountain Formation. Young (1960) also noted that the member was discontinuous and found that it could not be correlated with any specific sandstone east of the San Rafael Swell. Aubrey (1996, in press) has proposed that the Buckhorn intertongues with the Morrison Formation and should be considered Late Jurassic (Fig. 4). Beyond reworked late Paleozoic invertebrates, no primary fossils have been recovered from the Buckhorn Conglomerate.

The Yellow Cat Member.

We propose that the mudstone interval at the base of the Cedar Mountain Formation in the region around Arches National Park be designated the Yellow Cat Member of the Cedar Mountain Formation, with its type section near the Gaston Quarry west of the Yellow Cat Road (Fig. 6, Stop 12). At this site (NE1/4, SE1/4, NE1/4, SW1/4, Sec. 35, T22S, R21E on the Mollie Hogans, Utah, U.S.G.S. 1:24,000 Quad.), the member measures 24 m thick. It begins at the top of a 2–3 meter thick calcrete marking the top of the Morrison Formation and consists primarily of mauve mudstone with thin (5–30 cm thick) sandstone beds. At 17.3 m above the base, there is an interval of interbedded limestone and shale that preserves mudcracks, dinosaur tracks,

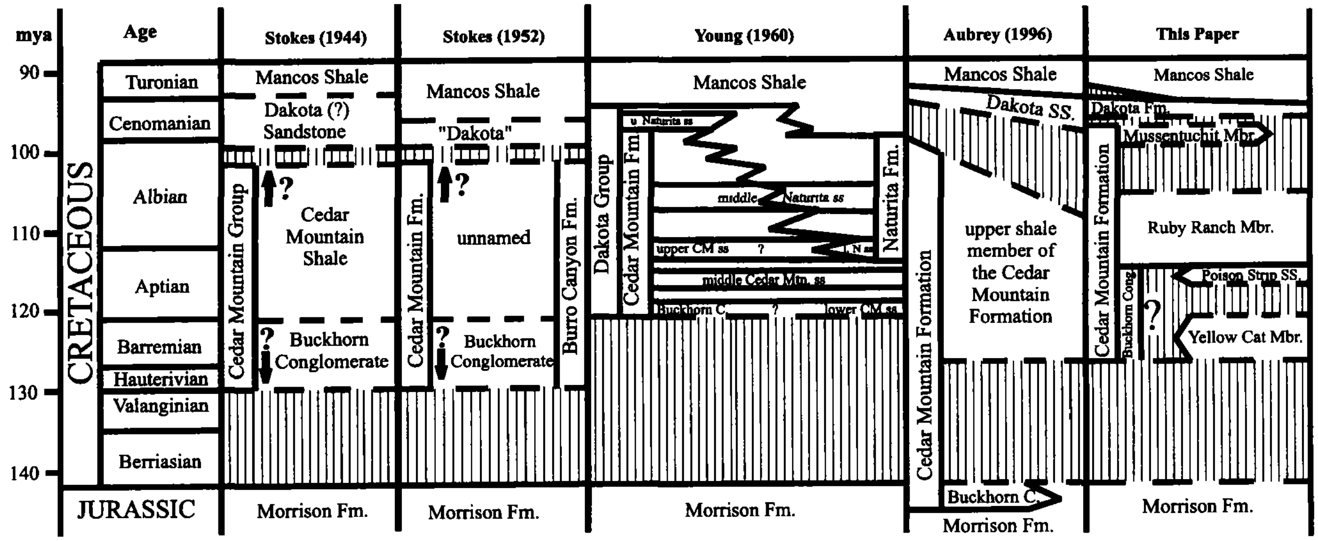

Figure 4. History of nomenclature for "middle" Cretaceous strata on the central Colorado Plateau. Time scale from Obradovich (1993).

and barite crystal clusters. The sharp upper contact with this slope forming unit is at the base of the sandstone ledge formed by the Poison Strip Sandstone.

The interval of interbedded limestone and shale toward the top of the member in the type section marks the base of the Cedar Mountain Formation in this area as described by Young (1960, Fig. 6, sec. 37). Thus, the Cedar Mountain Formation properly includes strata older than was recognized by Young (1960) in region around Arches National Park.

The newly proposed Yellow Cat Member is known to occur in a belt extending from the west side of the ancestral Uncompahgre Uplift west of Dewey Bridge, Utah, to the east side of the San Rafael Swell (Fig. 5). At most exposures, it extends from a basal calcrete (Aubrey, 1996; in press) up to the base of a regionally extensive sandstone ledge, (middle sandstone of Young, 1960; Poison Strip Sandstone, herein). Typically the member is 20–30 meters thick, but locally may thicken to 50–100 meters thick. To both the east and west the member pinches out between the Morrison Formation and the overlying sandstone. These thickness variations, together with the observed differences in its basal contact, may reflect the topography of the early Cretaceous erosional surface formed on the upper Jurassic strata. It is probable that as much as 20 million years of geological time may not be represented by sediments between Morrison and Cedar Mountain deposition (Obradovich, 1993; Kowallis et al., in press).

These sediments consist mostly of interbedded mudstone, with interbeds of sandstone and limestone. These mudstones tend to be mauve toward the base and pale green toward the top. They differ from those of the Morrison Formation in being drabber and less strongly variegated. In addition, the mudstones in the Yellow Cat Member do not appear to be smectitic based on weathering expression, in stark contrast to the underlying mudstones in the Brushy Basin Member the Morrison Formation.

The basal calcrete is not always present, and at some sites there is a shale on shale contact, although common polished chert pebbles (referred to as "gastroliths") are generally found at the probable contact (Stokes, 1944, 1952) suggesting a deflation surface. At other sites, there may be several calcretes and the contact is picked at the top of the lowest calcrete above smectitic mudstones of the Brushy Basin Member of the Morrison Formation. Examination of the basal calcrete indicates that locally it is a complex of superimposed calcretes. Aubrey (1996, in press) utilized the base of the calcrete as the base of the Cedar Mountain; however, the basal surface is often gradational. It is assumed that this calcrete represents a soil horizon developed on the Morrison paleosurface. The uppermost Morrison below the calcrete is often nonsmectitic, rooted, and a brick red color, perhaps reflecting a long period of exposure and oxidation between deposition of the Morrison Formation and the onset of Cedar Mountain deposition.

The distribution of these sediments provides an important constraint on the beginning of Sevier thrusting. Aubrey (1996, in press) has postulated that thrusting may have begun in the Barremian, based on the recognition of this basal Cedar Mountain fauna (Kirkland, 1992). However, as these sediments pinch out to the west, they would seem to preclude the onset of Sevier thrusting until at least the Aptian as there is no evidence the development of a foreland basin proximal to the thrust belt. These data provide

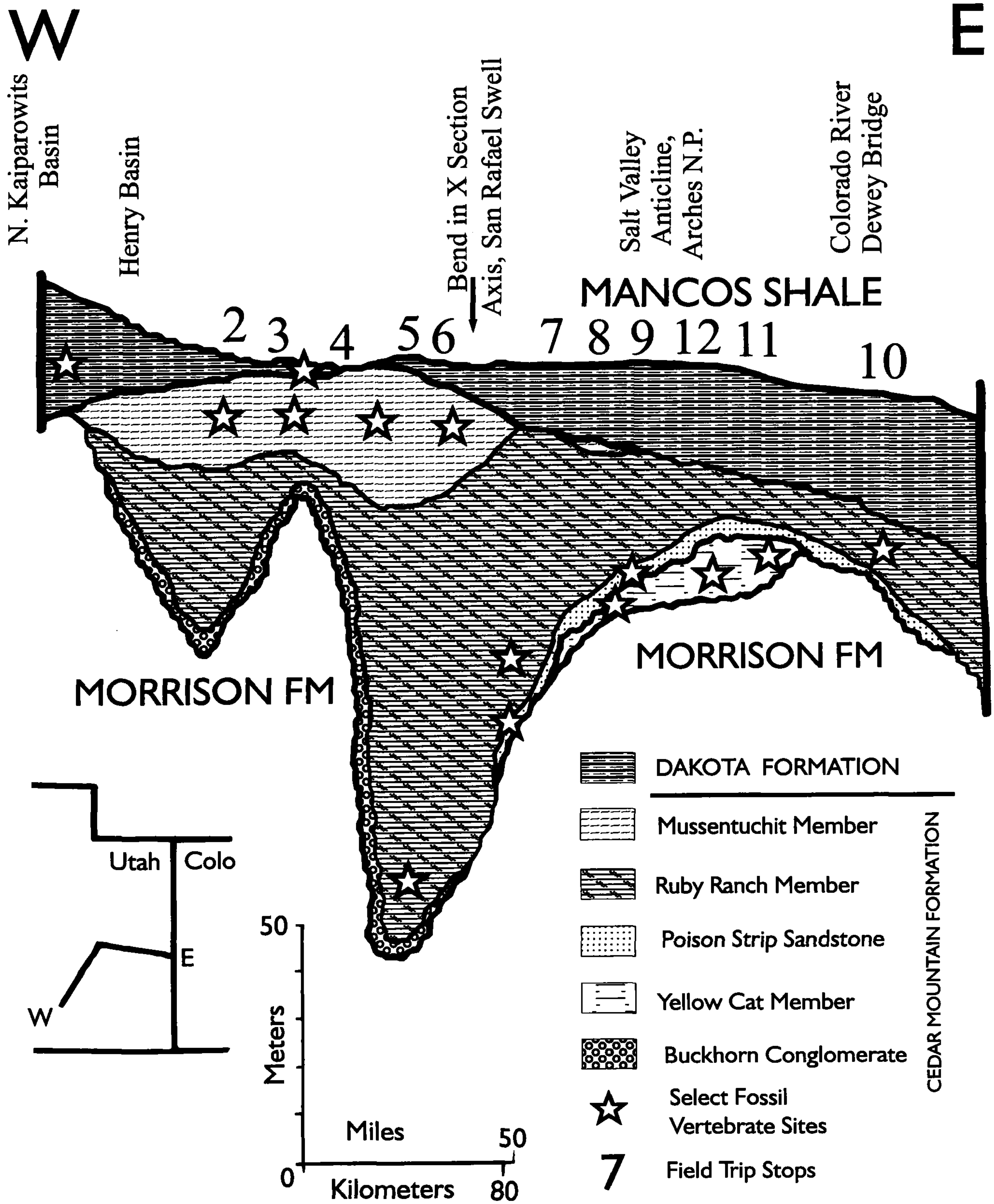

Figure 5. Cross-section showing the distribution of "middle" Cretaceous units discussed in text. Field trip stops are numbered (Fig. 2).

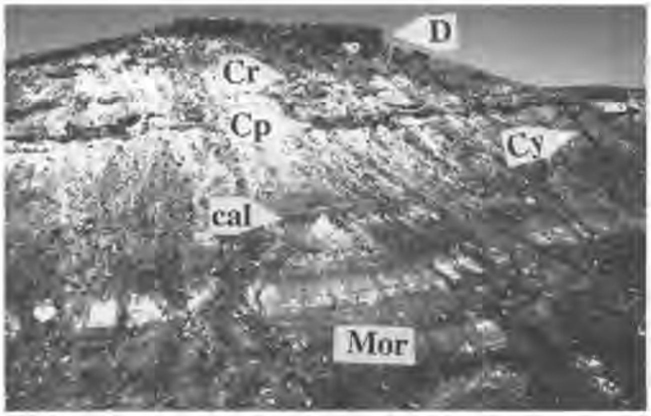

Figure 6. Type section of Yellow Cat Member of the Cedar Mountain Formation above Yellow Cat Flat near the Gaston Quarry. Arrow points to position of Gaston Quarry. Abbr. cal = calcrete; Cp = Poison Strip Sandstone; Cr = Ruby Ranch Member; Cy = Yellow Cat Member; D = Dakota Formation; Mor = Morrison Formation.

Table 1. Yellow Cat Fauna

Class Chondrichthyes
- Order Hybodontoidea
  - *Hybodus* sp.

Class Osteichthyes
- Subclass Dipnoi
  - *Ceratodus* n. sp.
- Subclass Actinopterigia
  - cf. *Semionotus* ? sp.
  - cf. *Amia* sp.

Class Reptilia
- Order Chelonia
  - cf. *Glyptops* sp.
- Order Rhynchocephalia
  - cf. *Toxolophosaurus* sp.
- Order Crocodilia
  - indet. teeth
- Order Theropoda
  - Family Dromaeosauridae
    - *Utahraptor ostrommaysorum*
  - ? Family
    - small maniraptoran n. gen.
- Order Sauropoda
  - Family Camarasauridae
    - n. gen.
  - Family Titanosauridae
    - n. gen.
- Order Ornithopoda
  - Family Iguanodontidae
    - *Iguanodon ottingeri*
    - n. gen. "with very high neural spines" (= *I. ottingeri*?)
- Order Ankylosauria
  - Family "Polacanthidae"
    - n. gen. cf. *Polacanthus* sp.

additional support to previously published Aptian-Albian dates for the onset of thrusting (Lawton, 1985, 1986; Heller et al., 1986).

The distribution of the Yellow Cat Member from the Uncompahgre Uplift to the San Rafael Swell is compatible with the proposal by Doelling (1988) and Aubrey (1996); that the distribution of Barremian age sediments in eastern Utah was controlled by salt tectonics during the Early Cretaceous. This might help explain the rapid thinning and thickening of the Yellow Cat Member in this region.

The Yellow Cat fauna as preserved at numerous sites (Stops 8, 9, 11, 12) includes abundant polacanthid specimens cf. *Polacanthus* n. gen., *Iguanodon ottingeri* (Galton and Jensen, 1979), perhaps a distinct sail-backed iguanodontid (= *I. ottingeri*, Britt and Scheetz, personal commun., 1997), titanosaurid and camarasaurid sauropods, a small maniratoran theropod cf. *Ornitholestes* n. gen., and the giant dromaeosaurid *Utahraptor ostrommaysorum* (Kirkland et al., 1993a, 1993b, 1995; Britt et al., 1996). In addition, fish, turtles, crocodilians, and a sphenodontid have been recognized (Table 1). Significant collections of these fossils are housed at the Earth Science Museum, Brigham Young University, College of Eastern Utah (CEU) Prehistoric Museum, Denver Museum of Natural History, and the Oklahoma Museum, of Natural History. The polacanthid ankylosaur, iguanodontids, and sauropods indicate close temporal and geographic ties to the Barremian of Europe (Blows, 1993; Norman, 1988). This correlation is also supported by charophyte data (Shudack, written commun., 1997). Furthermore, they indicate a close correlation with the Lakota Formation at Buffalo Gap, South Dakota (Fig. 1) (Kirkland, 1992; Kirkland et al., 1993; Lucas, 1993). Lucas (1993) has proposed that faunas of this composition be referred to as Buffalogapian for Buffalo Gap, South Dakota, where this fauna is relatively well developed in the Lakota Formation.

The presence of numerous calcareous nodules representing paleosols indicates that the Yellow Cat Member was deposited under a semiarid, monsoonal climate similar to that interpreted for the underlying Morrison Formation (Dodson et al., 1980; Wing and Sues, 1992). The widespread occurrence of fish, freshwater turtles, and crocodilians suggest it may have been somewhat wetter than indicated for the Late Jurassic of the Colorado Plateau. The floras recorded for the Barremian are generally devoid of angiosperms, suggesting a flora much like that of the Jurassic (Wing and Sues, 1992).

The Poison Strip Sandstone

We propose the Poison Strip Sandstone as the official designation for the middle sandstone unit of Young (1960) at the top of the Yellow Cat Member in eastern Utah (Fig. 4). The name comes the typical exposures of this unit along the Poison Strip. The type section forms the sandstone cliff holding up the escarpment on the southwest end of the Poison Strip (SW1/4, NE1/4, NW1/4, Sec. 31, T22S, R22E on the Mollie Hogans, Utah, U.S.G.S. 1:24,000 Quad.) east northeast of the Ringtail Mine (Fig. 7). The type section measures 5.4 m thick and is fine to medium grained with floating black, gray, and white chert pebbles. It is trough crossbedded and becoming slabby, with pale greenish mudstone partings toward the top.

Laterally, the Poison Strip Sandtone contains minor conglomeratic lenses and stringers of gray and white chert pebbles. In places there are as many as three crossbedded sandstones that are probably genetically related, and locally there is only a thin crevasse splay or no sandstone at all. This persistent sandstone interval holds up the escarpment exposing the upper Morrison Formation throughout the area from Green River to the Utah/Colorado border. It forms one of the most persistent and distinctive stratigraphic intervals in the entire Cedar Mountain Formation of eastern Utah. At some sites along the Poison Strip escarpment (Stop 11), large scale (5 m +) epsilon cross-bedding indicates that a large meandering river system was mostly responsible for its deposition. Sedimentologically, the sandstone is clearly distinct from the trough-crossbedded conglomerate of the Buckhorn Member of the Cedar Mountain Formation in the San Rafael Swell area. The middle sandstone unit as used by Young (1960) in the western San Rafael Swell area is well up within the Aptian-Lower Albian portion of the Cedar Mountain and appears to be an unrelated sandstone of more limited extent.

Although both the Buckhorn Conglomerate and the Poison Strip Sandstone lie below the Ruby Ranch Member (Fig. 5), there is no means of correlation between these two units and areas (Young, 1960). In the western San Rafael Swell area, no fossils have been found in the Buckhorn Conglomerate at the base of the Cedar Mountain Formation, so it impossible as yet to date the Buckhorn. However, DeCourten (1991) has recognized an Aptian-Albian fauna from just above the base of the Cedar Mountain Formation in one of the thickest sections near Castledale, Utah (Stop 5).

On the northeast side of Arches (Stop 8) Bodily (1969) described a large ankylosaur from the Poison Strip Sandstone. Coombs (1969) referred the taxon to the Cloverly Formation nodosaurid ankylosaur, *Sauropelta*. Just north of this site a second specimen of *Sauropelta* was recently discovered by researchers from the Denver Museum of Natural History. These fossils indicated the Poison Strip Sandstone is close to the same age as the overlying Ruby Ranch Member. The CEU Prehistoric Museum has recovered parts of an ornithopod from a conglomeratic sandstone at the base of the Cedar Mountain Formation, southeast of Wellington, Utah (Burge, 1996). This specimen appears to represent *Tenontosaurus* (also characteristic of the Cloverly Formation) and suggests this sandstone may approximately correlate to the Poison Strip Sandstone. The sparse, small, black, gray, and white chert pebbles are similar to those in the Poison Strip Sandstone. Large conifer logs and cycads are present locally within this sandstone in the area around Arches National Park.

Figure 7. Type section of Poison Strip Sandstone Member of the Cedar Mountain Formation on the west end of the Poison Strip. Abbr. Cp = Poison Strip Sandstone; Cy = Yellow Cat Member; Mor = Morrison Formation

The Ruby Ranch Member

We propose a type section (Fig. 5) for the Ruby Ranch Member north of the Ruby Ranch site (NW1/4, NW1/4, SW1/4, Sec. 31, T22S, R18E on the Dee Pass, Utah, U.S.G.S. 1:24,000 Quad.). The basal contact is with the Poison Strip Sandstone, and the upper contact is at the base of the Dakota Formation. The type section is 33.1 m thick and consists primarily of drab green and mauve varigated mudstone with abundant irregular carbonate nodules that literally cover the slope. At 2.1, 14, and 16.6 m above the base there are ribbon sandstones 2–3 meters thick, whose thalweg and crossbed directions indicate that they represent eastward flowing rivers. Overall the drab variegated mudstones have a pale mauve surface expression. The upper 8.5 m is a pale greenish gray with fewer, but larger carbonate nodules.

The Ruby Ranch Member extends across the entire outcrop belt of the Cedar Mountain Formation and eastward into sediments currently assigned to the Burro Canyon

Formation east of the Colorado River. Its basal contact is with the Poison Strip Member of the Cedar Mountain Formation from at least the Utah/Colorado border region westward to the eastern San Rafael Swell. The upper contact of the Ruby Ranch is clearly with the base of the coals, carbonaceous shales, and sandstones of the Dakota Formation from Colorado westward to the eastern San Rafael Swell. On the west side of the San Rafael Swell, a sharp break from carbonate-nodule-bearing, non-smectitic strata to carbonaceous, highly smectitic strata marks the upper contact. A conglomerate unit rich in quartzite pebbles, that is equivalent for the most part to Young's (1960) middle Naturita sandstone, lies at this position along the northeastern side of the San Rafael Swell (Kirschbaum, written commun., 1997).

Locally, on the west side of Arches National Park a smectitic interval is present at the top of the Cedar Mountain Formation. Potentially, this interval correlates with the Mussentuchit Member of the western San Rafael Swell. The report of a hadrosaur femur from this area may lend support to that correlation (Galton and Jensen, 1979). In this area and to the east, weathering profiles of the Ruby Ranch Member indicated the some of the clays may be partially smectitic, but not to the degree observed in smectitic interval at the top of the Cedar Mountain Formation.

Throughout its extent, the Ruby Ranch Member consists of drab, variegated mudstones with minor sandstone and limestone layers. Perhaps most characteristic of this member are the abundant carbonate nodules that often are so abundant as to form a pavement covering the exposed slopes. The abundance of these nodules makes prospecting for fossils in this interval difficult. The Ruby Ranch Member contains ribbon sandstone bodies that often hold up ridges that may extend for a mile or more (ex. Young, 1960, DeCourten, 1991). A good portion of the northwestward thickening observed in the Cedar Mountain across the San Rafael Swell (ex. Stokes, 1952, Young, 1960) is represented by the Ruby Ranch Member. There is also a good deal of rapid thinning and thickening of this interval south to north along the west side of the San Rafael Swell.

The Ruby Ranch fauna (Table 2) includes the primitive iguanodontid *Tenontosaurus*?, the large nodosaurid *Sauropelta*, sauropods assigned to *Pleurocoelus* (= *Astrodon*), dromaeosaurid teeth, an unidentified large theropod, and *Acrocanthosaurus* (Weishampel and Weishampel, 1983; DeCourten, 1991; Kirkland, 1996b). This is the least well known of the Cedar Mountain faunas. Important collections of these fossils are housed at the University of Utah, CEU Prehistoric Museum, and the Oklahoma Museum of Natural History. This fauna compares well with those documented from the Cloverly Formation, Arundel Formation, and Trinity Group characteristic of North American's apparently endemic Aptian-Lower Albian dinosaur fauna (Kirkland, 1996b). Lucas (1993) has proposed referring to faunas with these characteristic taxa as Cashenranchian for the Cashen Ranch, in southern Montana, where this fauna is well developed in the Cloverly Formation (Fig. 1).

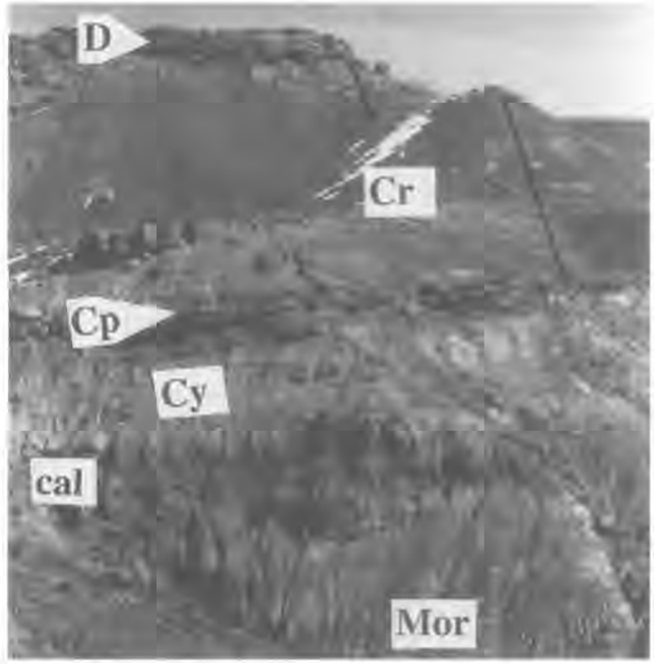

Figure 8. Type section of Ruby Ranch Member of the Cedar Mountain Formation north of the Ruby Ranch homestead site; Abbr. cal = calcrete; Cp = Poison Strip Sandstone; Cr = Ruby Ranch Member; Cy = Yellow Cat Member; D = Dakota Formation; Mor = Morrison Formation.

The presence of very abundant calcareous nodules representing paleosols indicate that the Ruby Ranch Member was deposited under a semiarid monsoonal climate similar to that interpreted for the underlying Morrison Formation (Dodson et al., 1980, Wing and Sues, 1992). The abundance of paleosols suggests the time involved in deposition of the entire Ruby Ranch Member was significant, as each paleosol represents a hiatus in deposition (Kraus and Bown, 1986). The pollen record indicates that angiosperms were becoming a part of Western Interior floras at this time (Wing and Sues, 1992).

The Mussentuchit Member.

We proposed that upper Cedar Mountain Formation along the west side of the San Rafael Swell be designated the Mussentuchit Member (Fig. 9, Stop 2), with its type section south of Mussentuchit Wash (SW1/4, NW1/4, SE1/4, Sec. 4, T25S, R6E on the Willow Springs, Utah, U.S.G.S. 1:24,000 Quad). At the type section, the member measures 25 m thick and is predominantly composed of drab, gray highly smectitic mudstone. A thin discontinuous sandstone

Table 2. Ruby Ranch Fauna

Class Chondrichthyes
- Order Hybodontoidea
  - *Hybodus* sp.

Class Reptilia
- Order Crocodilia
  - very large blunt teeth and small teeth
- Order Theropoda
  - Family Dromaeosauridae
    - cf. *Deinonychus* sp.
  - Family Allosauridae ?
    - new large theropod
    - cf. *Acrocanthosaurus* sp.
- Order Sauropoda
  - Family Brachiosauridae
    - *Pleurocoelus* sp. = *Astrodon* sp.
- Order Ornithopoda
  - Family Iguanodontidae
    - *Tenontosaurus* sp.
- Order Ankylosauria
  - Family Nodosauridae
    - cf. *Sauropelta* sp.

marks, the base, where the nonsmectitic mudstone rich in carbonate nodules is replaced by smectitic mudstone as determined by its characteristic "popcorn" weathering. Several thin lenticular sandstones and lignitic horizons are present. It is dated as straddling the Albian-Cenomanian boundary on palynology (Nichols and Sweet, 1993) and subsurface correlations (Molenaar and Cobban, 1994). The top of the member is marked by a thick buff sandstone representing the base of the Dakota Formation.

This member clearly was intended to be included by Stokes (1944, pl. 4., Fig. 2; 1952, p. 1773) in the Cedar Mountain Shale as is illustrated by his picture of the type section capped by a laterally extensive ledge of sandstone at the base of the Dakota Formation. However, he described the Cedar Mountain as having abundant carbonate nodules and does not mention that at the top it may lack such nodules. Locally, in the area of the southwestern San Rafael Swell south of Interstate 70, sandstone lenses near the top of this interval compare well with the more extensive sandstone ledge typically used to define the base of the Dakota Formation (ex. Stokes, 1944). This suggests that this interval may represent nearly continuous sedimentation with the more carbonaceous overlying Dakota Formation. In fact, Young (1960) included this interval in the Dakota Formation. The dramatic shift in the sedimentology and paleontology at the base of this interval suggests that perhaps this interval would be better included as a basal member of the

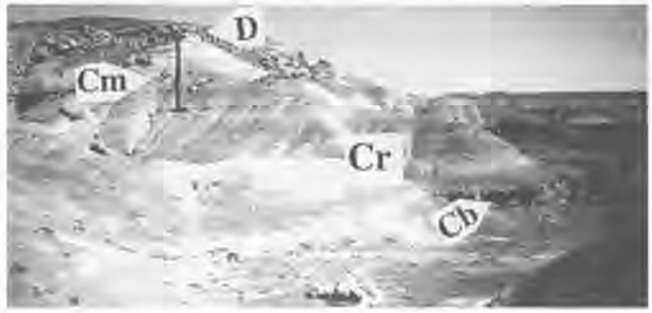

Figure 9. Type Section of Mussentuchit Member of the Cedar Mountain Formation near Mussentuchit Wash. Abbr. Cb = Buckhorn Conglomerate; Cm = Mussentuchit Member; Cr = Ruby Ranch Member; D = Dakota Formation.

Dakota Formation. This would mean, however, that nearly every fossiliferous horizon in the area of the western San Rafael Swell attributed to the Cedar Mountain Formation would have to placed in to the Dakota Formation (Katich, 1951; Stokes, 1952; Thayn, et al., 1983; 1985; Thayn and Tidwell, 1984; Tidwell and Thayn, 1985; Jensen, 1970; Eaton and Nelson, 1991; Cifelli, 1993; Kirkland and Burge, 1994; Cifelli et al., in press a, b).

The preserved dinosaur fauna (Table 3) includes a small nodosaurid cf. *Pawpawsaurus* (= *Texasetes*) n. sp., a small iguanodontian grade ornithopod, a primitive lambeosaurine hadrosaur, ceratopsian teeth, pachycephalosaur teeth, tiny sauropod teeth, a dromaeosaurid, cf. *Richardoestesia* teeth, cf. *Paronychodon* teeth, and an early tyrannosaurid (Kirkland and Burge, 1994; Kirkland and Parrish, 1995; Burge, 1996). Teeth of a very small sauropod similar in morphology to those described as *Astrodon* are also present marking the last occurrence of sauropods in North America prior to their reintroduction from South America in the Late Maastrichtian (Lucas and Hunt, 1989). At the family level, this fauna is remarkably similar to those of the Campanian and Maastrichtian of western North America (Kirkland, 1996b). Important collections of these fossils are housed at the Oklahoma Museum of Natural History and the CEU Prehistoric Museum.

As the only likely ancestors of the hadrosaur, ceratopsian, and perhaps the tyrannosaurid are from the Early Cretaceous of Asia, the dramatic shift to faunas typical of the North American Late Cretaceous is interpreted to be the result of opening migration corridors to and from Asia through Alaska at the end of the Early Cretaceous, when migration to eastern North America was still possible (Kirkland, 1996b; Cifelli et al., in press a). Following an extensive screen washing operation by the University of Oklahoma, that resulted in thousands of catalogued specimens representing nearly 80 vertebrate taxa, Cifelli et al., (in press b) characterized this fauna as the Mussentuchit Local Fauna

Table 3. Mussentuchit Fauna
(after Cifelli et al., in press a, b)

Class Chondrichthyes
- Order Hybodontoidea
  - *Polyacrodus* sp.
  - *Lissodus* sp.
- Order Orectolobiformes
  - 2 genera
- Order Batoidea
  - cf. *Baibisha* n. sp.
  - *Rhinobatus* sp.
  - *Ischyrhiza* sp.

Class Osteichthyes
- Subclass Dipnoi
  - *Ceratodus* sp.
- Subclass Actinopterigia
  - cf. *Semionotus* 2 n. gen.
  - Lepisosteiformes
  - Pycnondontiformes
  - Amiiformes

Class Amphibia
- Inc. sedis
  - Albanerpetodontidae
    - 2 genera
- Order Caudata
  - 2 genera
- Order Anura
  - 4 genera

Class Reptilia
- Order Chelonia
  - *Naomichelys* sp.
  - *Glyptops* sp.
  - ident. gen. & sp.
- Order Squamata
  - cf. *Peneteius* sp.
  - 6 n. gen. n. sp.
- Order Serpentes
  - *Coniophis* sp.
- Order Crocodillia
  - *Bernissartia* sp.
  - cf. *Dakotasuchus* sp.
  - *Polydectes* sp.
  - *Machimosaurus* sp.
  - 3 indet. gen. sp.
- Order Theropoda
  - Family Dromaeosauridae
    - new cf. *Deinonychus* sp. large
  - Family Troodontidae
    - cf. *Troodon* sp.
  - Family Tyrannosauridae
    - cf. *Alectrosaurus* sp.
  - Family indet.
    - cf. *Paronychodon* sp.
    - cf. *Richardoestesia* sp.
- Order Sauropoda
  - Family Brachiosauridae
    - ? cf. *Astrodon* sp.
- Order Ornithopoda
  - Family Hypsilophodontidae
    - cf. *Zephrosaurus* sp.
    - 2 indet. gen. sp.
  - Family Iguanodontidae ?
    - cf. *Tenontosaurus* sp.
  - Family Hadrosauridae
    - n. gen. n. sp.
- Order Ankylosauria
  - Family Nodosauridae
    - cf. *Pawpawsaurus* n. sp.
- Order Pachcephalosauria
  - indet. gen. sp.
- Order Ceratopsia
  - indet. gen. sp.

Class Aves
- Order Hesperornithiformes
  - sp. indet.
- Order indet.

Class Mammalia
- Order Triconodonta
  - *Astroconodon* n. sp.
  - 2 n. gen. sp.
- Order Docodonta
  - indet. gen. sp.
- Order Multituberculata
  - *Paracimexomys robisoni*
  - ? *Paracimexomys bestia*
  - 2 *P.* n. sp.
  - 2 ? *p.* n. sp..
  - 2 n. gen. sp.
- Order Symmetrodontia
  - *Spalacotheroides* sp.
  - *Spalacotheridium* n. sp.
  - n. gen. sp.
- Order Tribotheria
  - indet. gen. sp.
  - 3 n. gen. sp.
- Order Marsupialia
  - *Kokopellia juddi*
  - 2 n. gen.

for Mussentuchit Wash, where many of the best vertebrate sites are located. Perhaps following traditional land-animal ages begun in the middle Mesozoic by Lucas (1993), faunas preserving these taxa should be referred to as Mussentuchitian.

The most common animal from the upper fauna is a primitive hadrosaur (Kirkland and Burge, 1994). Common hadrosaur teeth from Cedar Mountain sites on the west side of the San Rafael Swell were first noted by Parrish (1991). At present, the Cedar Mountain hadrosaur has been determined to be a primitive hadrosaur somewhat like *Telmatosaurus* (Weishampel et al., 1993) from the Upper Cretaceous of eastern Europe and a bit more advanced than the iguanodont *Probactrosaurus* (Rozhdestvensky, 1967; Norman, 1990) from the Lower Cretaceous of central Asia. More research is needed to determine its systematic position relative to the Hadrosaurinae and Lambeosaurinae (Sereno, 1986; Horner, 1990; Weishampel and Horner, 1990). However, the material discovered to date suggest lambeosaur affinities. Further research will be needed to see if this determination is based on primitive characters lost in later mainline hadrosaurines.

It is important to note that Molenaar and Cobban (1991) have concluded that subsurface relationships indicate the uppermost Cedar Mountain Formation may correlate to the Mowry Shale to the northeast and thus be of basal Cenomanian age. The Albian-Cenomanian boundary on the basis of non-marine palynomorphs has been placed at the first occurrence of tricolporates (ie. *Nyssapollenites,* rare in marine rocks) and obligate tetrads (Singh, 1975; Nichols and Sweet, 1993). Tschudy et al., (1984) did not encounter these palynomorphs in their samples from the upper Cedar Mountain Formation near Castledale, Utah. Their occurrence is diachronous across Alberta (Nichols and Sweet, 1993, p. 559). In addition, with the older placement of the Albian-Cenomanian boundary by Cobban and Kennedy (1989, by ammonite correlations to the type areas in Europe), it is likely that this datum is above the base of the Cenomanian (Nichols and Sweet, 1993, p. 578).

The critical thing is that the palynology and lithostratigraphy support a correlation with the Latest Albian-Basal Cenomanian Mowry Shale to the northeast (Nichols and Sweet, 1993; Molenaar and Cobban, 1991). The classic Cloverly-Pauluxy fauna occurs at the beginning of the Kiowa-Skull Creek second order cyclothem (ex. Kauffman and Caldwell, 1993). The thin sandy interval below the Mussentuchit Member probably correlates to the base level draw down (i.e. unconformity) that occurs between these two cyclothems. Many geologists would prefer to see the unconformity at the base of the Dakota Formation to represent this unconformity and the authors of this volume are not in agreement relative to retaining the Mussentuchit Member at part of the Cedar Mountain Formation. A compromise view is to retain it as part of the Cedar Mountain Formation following Stokes' (1944, 1952) original definition.

The absence of calcareous nodules representing paleosols indicates that the Mussentuchit Member was deposited under a significantly wetter environment than were the lower members of the Cedar Mountain Formation, in part due to the transgression of the Mowry Sea into the area of the northwestern Uinta Basin (Wing and Sues, 1992). The plant record indicates that angiosperms were becoming a more important part of Western Interior floras at this time (Wing and Sues, 1992) and some of the earliest records of some angiosperm wood types are from this member (Thayne et al., 1983, 1985; Tidwell, 1996). Finally, the dramatic increase in the volume of volcanic ash preserved in the Mussentuchit Member indicates a significant increase in volcanic activity to west.

A dramatic shift in faunal composition between Albian and middle Cenomanian has been noted in Texas (Lee, 1995; Winkler et al., 1995). The new dates for the Mussentuchit Member indicate that this faunal turnover was even more dramatic than was previously thought, with a nearly complete turnover of the dinosaur fauna during the late Albian. Recognition of the Mussentuchit Local Fauna indicates that instead of a two fold zonation of Cedar Mountain Formation based on dinosaurs (Kirkland, 1992; Lucas, 1993) there are three distinct faunas (Kirkland, 1996b). These are: (1) a basal Barremian iguanodont-polacanthid fauna with European affinities predating common flowering plants found in the Yellow Cat Member, (2) a middle Aptian-middle Albian *Tenontosaurus-Pleurocoelus* fauna perhaps representing an impoverished recovery fauna following a major Lower Cretaceous extinction event (endemic to North America) found in the Poison Strip Sandstone and Ruby Ranch Member, and (3) an upper latest Albian-lowest Cenomanian hadrosaur fauna with Asian affinities when flowering plants were co-dominant found in the Mussentuchit Member. The replacement of North American taxa by taxa with Asia origins indicates that biogeography rather than the rise of angiosperms account for most of the extinction of dinosaurs recorded within the upper Cedar Mountain Formation (Kirkland, 1996b; Cifelli et al., in press b).

The Dakota Formation.

The carbonaceous strata between the Cedar Mountain and Burro Canyon Formations and the overlying Mancos Shale have been called the Dakota Sandstone or Dakota Formation. The term "Dakota (?)" has also been used (Fig. 4) because of the uncertainty of the relationship of these rocks on the Colorado Plateau with the type area of the

Table 4. Dakota Fauna
(after Eaton et al., 1997)

- Order Hybodontoidea
- Class Chondrichthyes
  - Order Hybodontoidea
    - *Hybodus* sp.
    - *Lissodus* sp.
  - Order Batoidea
    - n. gen. sp. cf. *Myledaphus*
    - Ischyrhiza sp. cf. *I. avonicola*
- Class Osteichthyes
  - Subclass Dipnoi
    - *Ceratodus gustasoni*
  - Subclass Actinopterigia
    - cf. *Semionotus* 2 n. gen.
    - *Lepidotes* sp.
    - cf. *Dapedius* sp.
    - Pycnondontiformes
    - Lepisosteidae
    - Amiiformes
- Class Amphibia
  - Inc. sedis
    - Albanerpetodontidae
      - 1 genus
  - Order Caudata
    - Batrachosauridae
      - cf. *Batrachosauroides* sp.
- Class Reptilia
  - Order Chelonia
    - cf. *Deinochelys* sp.
    - *Naomichelys* 3 sp.
    - *Glyptops* sp.
  - Order Squamata.
    - cf. *Saurillodon* sp.
    - 6 indet. gen. sp.
  - Order Crocodillia
    - Bernissartidae
      - *Goniopholis* sp.
      - *Telorhinus* sp.
      - indet. gen. sp.
  - Order Theropoda
    - Family Dromaeosauridae
      - 2 indet. gen. sp.
    - Family Troodontidae
      - cf. *Troodon* sp.
    - Family Tyrannosauridae
      - indet. gen. sp.
    - Family indet.
      - cf. *Paronychodon* sp.
      - cf. *Richardoestesia* sp.
  - Order Ornithopoda
    - Family Hypsilophodontidae
      - indet. gen. sp.
    - Family Hadrosauridae
      - indet. gen. n. sp.
  - Order Ankylosauria
    - Family Nodosauridae
      - indet. gen. sp.
    - Family Ankylosauridae
      - indet. gen. sp.
- Class Mammalia
  - Order Multituberculata
    - *Cimolodon* sp. cf. *C. similis*
    - *Paracimexomys* sp. cf. *P. robisoni*
    - *Dakotamys malcolmi*
  - Order Symmetrodonta
    - indet. gen. sp.
  - Order Tribotheria
    - *Dakotadens morrowi*
  - Order Marsupialia
    - *Alphadon clemensi*
    - *Alphadon lilligraveni*
    - *Protalphadon* sp.
    - *Pariadens kirklandi*

Dakota Sandstone on the Missouri River near Dakota, Nebraska (Meek and Hayden, 1862). Recognizing this problem, Young (1960) referred these strata to the Naturita Formation, with a type area near Naturita, western Colorado. Additionally, he joined the Cedar Mountain and Naturita into a Dakota Group providing continuity with the terminology being employed in the Colorado Front Range (Fig. 4). Young (1960) reported extensive intertonguing of the Cedar Mountain with his Naturita Formation from west to east. Craig et al., (1961) emphasized the unconformable nature of the contact between the Cedar Mountain and "Naturita" Formation. The term Naturita Formation has largely been ignored by subsequent authors.

The Dakota Formation on the Colorado Plateau has generally been divided into three informal members (ex. Katich, 1956; Eaton, 1987): (1) a lower 0–20 m thick basal sandstone or conglomerate; (2) a middle 0–24 m thick interval of sandy carbonaceous shales, channel sandstones with coal; and (3) an upper 0–25 m thick interval of transgressive marine shale and sandstone. The Dakota Formation is generally thin and highly variable throughout the central Colorado Plateau. Locally it may pinch out completely (ex. Eaton et al., 1990) or where sandstones are largely absent it forms a continuous slope between the upper Cedar Mountain Formation and Mancos Shale.

Most terrestrial vertebrate remains from the Dakota Formation are from the middle carbonaceous member. No radiometric dates exist as yet for this interval but assuming the coals were deposited proximal to the Mancos Sea, these units can be approximately dated from marine fossils capping the sequence (Cobban, 1976; Eaton et al., 1990) and lateral relationships with marine strata (Elder and Kirkland, 1993, 1994). These relationships provide dates of middle to early late Cenomanian for these strata, which is supported by macrofloral and palynological studies summarized by Tidwell (1996).

The dinosaur fauna from the Dakota Formation is based on the wet screenwashing of microvertebrate sites (Parrish, 1991; Eaton et al., 1997) and includes teeth of dromaeosaurids, troodontids, cf. *Richardoestesia* sp., cf. *Paronychodon* sp., tyrannosaurids, nodosaurids, ankylosaurids, hypsilophodontids, and hadrosaurids. Most noticeably absent, but represented in all the earlier faunas, are sauropods, recording the base of the North American mid-Cretaceous sauropod hiatus (Table 4). Rushforth (1971) speculated that the carbonaceous units were deposited in a lush swampy mudflat near the edge of the Mancos Sea. The floras are dominated by ferns and horsetails; various gymnosperms and angiosperms grew along streams and adjoining upland areas.

STOP 1. Christianburg locality, southeastern San Pitch Mountains. T. Lawton

Stop at milepost 213 on US Highway 89, 4.5 miles east of Gunnison, Utah. We will hike across a section of slope-forming mudstones (Cedar Mountain Formation) and overlying conglomerate beds. At Christianburg, the Lower Cretaceous section is well studied and generally representative of the section of the San Pitch Mountains. It is thinner here than in the western part of the San Pitch Mountains; the Cedar Mountain is 132 m thick (Witkind et al., 1986): the overlying conglomeratic section is 197 m thick (Sprinkel et al., written commun. 1996). The beds here dip steeply and overturned to the east. They are in fault contact with the Jurassic Arapien Formation to the east (Weiss, 1994), contain a number of east dipping thrust faults, and are onlapped by Paleocene (?) beds of the North Horn Formation on the southwest and west (Weiss, 1994; Sprinkel et al., written commun. 1996). This structure represents the faulted west flank of a box fold or popup cored by Jurassic shale and evaporite of the Sanpete Valley. The entire Cretaceous section is detached from Jurassic and older strata beneath this location at a decollement, termed the Gunnison thrust, in the evaporite beds (Standlee, 1982; Lawton, 1985).

Beds assigned to the Cedar Mountain here consist of mudstone with abundant calcareous nodules and subordinate sandstone and light gray limestone. The mudstone represents flood-plain deposits, the calcareous nodules represent paleosols, and the limestones were deposited in freshwater ponds (Schwans, 1988b). Soil horizons within the section appear to be composite or stacked, and thus indicate slow deposition punctuated by unconformities.

The base of the San Pitch Formation is at the lowermost conglomerate in the section. Beds of the conglomeratic section above the Cedar Mountain are on the order of 10 m thick and have a broadly lenticular or channel form. They are interbedded with red siltstone and mudstone. Clasts within the lower 57 m include green quartzite clasts of the Proterozoic Dutch Peak Formation, as well as sandstone clasts derived from Jurassic and Triassic formations. The Dutch Peak Formation is now exposed in the Sheeprock Mountains northwest of the San Pitch Mountains, and the Mesozoic clasts were presumably derived from the Pavant thrust plate to the west. These diverse lithologies were contributed in part by a large Early Cretaceous drainage network that departed the thrust belt at the Leamington cross-strike discontinuity (Lawton et al., 1994). Conglomerate beds of the overlying 96 m contain boulders and cobbles of both quartzite and carbonate, mostly dolostone. Interbedded mudstone is reddish orange and silty. The uppermost part of the section consists of 44 m of reddish-brown to gray silty mudstone (Sprinkel et al., written. commun. 1996). It is unconformably overlain by a striking quartzite-boulder conglomerate that marks the base of the Sanpete Formation, which is equivalent to the Dakota Sandstone.

STOP 2. The Mussentuchit Member of the Cedar Mountain Formation along Mussentuchit Wash. R. Cifelli & J. Kirkland

At this stop (Figs. 2, 5), we will have an opportunity to examine the type section of the Mussentuchit Member described above. Over the past several years discoveries in the upper Cedar Mountain along Mussentuchit Wash by field crews from the Oklahoma Museum of Natural History have revealed a diversity of vertebrate sites in the Mussentuchit Member. Extensive quarry operations and wet screen washing have revealed an extraordinary diversity of vertebrate taxa rivaling the most productive sites in North America. Of nearly 80 taxa recorded in this area, many record the first or last occurrences for their particular families. Among the freshwater elasmobranchs these include the first occurrence of freshwater orectolobids and sclerorhynchids. Among the Squamata, there are early occurrences of helodermatids and snakes. The dinosaurs include many first occurrences including those of the tyrannosaurids, the enigmatic tooth form "*Paronychodon*," hadrosaurids (Fig. 10), pachycephalosaurids, and the neoceratopsids. There are

Figure 10. Skull elements of juvenile specimen of early hadrosaur from one of the OMNH's Mussentuchit sites. Scale in cm.

also first North American occurrences of birds (ex. herperornithiformes) and mammals (ex. marsupials) (Cifelli, 1993; Cifelli et al., in press a, b).

The basal Buckhorn Conglomerate member of the Cedar Mountain Formation in this area forms a distinct ledge 1–3 meters thick (Fig. 12). The overlying Ruby Ranch Member forms a mauve slope 25 m thick covered by carbonate nodules. No fossils have been found in the Ruby Ranch Member in this area. The Ruby Ranch Member is overlain by 25 m of drab smectitic mudstone of the Mussentuchit Member. About midway up in the Mussentuchit Member, a thin lignitic layer preserves abundant plant debris and a volcanic ash (or ashes) associated with several of the OMNH localities (Fig. 11), for which Radiometric Dating is now in progress. The basal Dakota Formation consists of a thick buff sandstone that weathers into large blocks that cover much of the Cedar Mountain slope (Fig. 11).

STOP 3. The Mussentuchit Member of the Cedar Mountain Along the Moore Cutoff Road. R. Cifelli and J. Kirkland.

At this stop (Figs. 2, 5), we will examine a microvertebrate site with abundant dinosaur egg fragments in the Mussentuchit Member. The Cedar Mountain Formation along the Moore Cutoff Road is thinner than that observed either to the south or to the north. The Buckhorn Conglomerate is well developed here, but the Ruby Ranch is very thin. In fact, if it were not for carbonate nodules weathered out on the bench formed by the Buckhorn, it would be hard demonstrate its presence at all. The Mussentuchit Member is well developed and is on the order of 20 m thick.

In this area, we will examine a significant OMNH microvertebrate site that is characterized by abundant dinosaur egg shell fragments. Jensen (1970) first reported eggshell in the Cedar Mountain Formation from the Castledale area. The eggshell at this site (Fig. 12) appears to have been transported and mixed with microvertebrate remains, however the large volume of eggshell appears to indicate a nesting site was nearby.

Transported eggshell that may pertain to the Mussentuchit hadrosaur is abundant at this site together with isolated teeth. This egg shell has a reticulate surface pattern and is about 3 mm thick. In fact, some of the eggshell described from the Cedar Mountain Formation by Jensen (1970) may pertain to this animal (Karl Hirsch, pers. commun.) as they certainly came from the same stratigraphic level. Part of an embryonic maxilla has also been identified. The presence of embryonic, juvenile, and adult material indicates that the entire growth history of this common new dinosaur will eventually be documented.

STOP 4. The Cedar Mountain and Dakota Formations East of Ferron. J. Eaton and J. Kirkland.

At this stop (Figs. 2, 5) we will examine field evidence documenting local uplift unroofing of the Buckhorn Conglomerate in the basal Turonian.

The diverse fauna found in the Mussentuchit Member in the area of Mussentuchit Wash and the Moore Cutoff Road have been found in the area east of Ferron and Castledale, Utah including the Rough Road Quarry and Robison's Eggshell Quarry (Nelson and Crooks, 1987; Pomes, 1988; Eaton and Nelson, 1991). Important collections from these sites are housed at the Sternberg Museum, Hays, Kansas, University of Colorado Museum, University of California at Berkeley, Paleontological Museum, Brigham Young University Geological Museum, and the Oklahoma Museum of Natural History.

The specimens of *Tenontosaurus* from the Cedar Mountain Formation noted by Weishampel and Weishampel (1983) are from somewhere in this area. The nodular carbonate matrix on many of the bones suggests that these specimens are from the Ruby Ranch Member.

Perhaps most significantly, a terrestrial vertebrate fauna was recovered by Eaton (1987) from the Dakota Formation in this area, (University of Colorado, UCM Loc. 83275). In regard to dinosaurs, this site produced hadrosaurid, iguanodontid, and theropod teeth. It has also produced fishes, turtles, crocodilians, and a multituberculate mammal tooth. A much more diverse fauna of 50 taxa has been recovered in correlative units of the Dakota Formation in southern Utah (Eaton, 1987, 1993a, 1993b; Eaton et al., 1997; Kirkland, 1987) that can be dated as middle to very basal upper Cenomanian based on intertonguing relationships with overlying and laterally adjacent marine rocks (Eaton, 1987; Elder and Kirkland, 1993, 1994). Dinosaurs include veloceraptorine and dromaeosaurine dromaeosaurs, cf. *Troodon*

Figure 11. Arrow points to one of the most productive OMNH microvertebrate sites in Mussentuchit Member. Basal sandstone Dakota Formation caps exposure and litters slope with large blocks of sandstone.

sp., tyrannosaurids, cf. *Richardoestesia* sp., cf. "*Paronychodon*" sp., nodosaurids, ankylosaurids, hypsilophodontids, and hadrosaurids. Taxa from this fauna also includes four freshwater elasmobranchs, eight osteichthians, two amphibians, six turtles, seven lizards, three crocodilians and ten mammals (Table 4). The Dakota fauna is most significant in that it records the last occurrence of many freshwater taxa such as lungfish, semionotids, and the turtle, *Glyptops* (Kirkland, 1987; Eaton et al., 1997). However, while this records a major extinction of freshwater taxa, terrestrial faunas show no extinctions to speak of.

The Dakota Formation ranges from 0–60 meters thick in the area. Marine and mixed brackish water invertebrate fossils from the top of the Dakota Formation from south of the Moore Road date the strata to the latest Cenomanian *Neocardioceras juddii* Zone. In this area, the Dakota coarsens up section to the top of the formation, where there are abundant isolated chert pebbles. Eaton et al., (1990) recognized that the basal Tununk Shale of the Mancos Shale throughout this area is characterized by a pebble-to-cobble, mud/clay supported conglomerate (Fig. 13) that weathers back, leaving a broad surface at the top of the Dakota Formation covered in dark chert pebbles and cobbles (Fig. 14). Small pebbles are often found nestled in the shells of the abundant gryphaeoid oyster, *Pycnodonte newberryi umbontatus,* a subspecies characteristic of the basal Turonian (Kirkland, 1996c). Shales above this conglomerate can be best dated as late early Turonian (Eaton, 1987; Eaton et al., 1990). The Dakota Formation pinches out locally between Ferron and Castledale, whereas the conglomerate at the base of the Tununk extends throughout the area.

As the chert pebbles resemble those preserved in the Buckhorn Conglomerate, it was proposed that the presence of these along the Dakota/Tununk contact represents local tectonic activity (Eaton et al., 1990). Shortly following the marine transgression into the area during the latest Cenomanian, local uplift, perhaps of the San Rafael Swell, led to unroofing and erosion of the Buckhorn Conglomerate. With continued sealevel rise during the earliest Turonian, the locally derived chert pebbles and conglomerate were re-

Figure 12. Arrow points to OMNH's egg and microvertebrate site near Moore Road.

worked over a wide area. The area was fully submerged below wave base by the late early Turonian (Elder and Kirkland, 1993, 1994).

A local source for the chert pebbles, rather than one in the Sevier thrust belt, is supported by the fact that the correlative Indianola Group conglomerates are rich in Precambrian clasts and are poor in chert (Sprinkel et al., written commun. 1996). Secondly poorly dated Cretaceous faulting on the west side of the San Rafael Swell has been documented (Neuhauser, 1988). At present, recycling of Lower Cretaceous conglomerate seems to be the simplest explanation for the basal Tununk conglomerate.

STOP 5. The Long Walk Quarry, Ruby Ranch Member. F. DeCourten

At this stop (Figs. 2, 5), we will examine the Long Walk Quarry in western Emery County, Utah, that was opened by the Utah Museum of Natural History in 1987. Following the initial collection of surface material, excavations at the site were conducted during three consecutive field seasons and resulted in the removal of 16 large blocks of the bone-bearing matrix. Quarrying operations were suspended after the 1990 field season to avoid an excessive backlog of unprepared material. Preparation of the material collected from 1987–1990 is still under way, due in part to the hard limestone matrix present at the site. However, the material thus far available clearly documents no less than three individual dinosaurs representing at least two taxa.

In the vicinity of the Long Walk Quarry, the Cedar Mountain Formation is 130 m thick (Fig. 15). The lower contact of the Cedar Mountain Formation is marked by the abrupt, vertical transition from red pebbly mudstones of the Brushy Basin Member of the Morrison Formation to nodular, calcareous mudstone. No Buckhorn Conglomerate is present and the lowermost beds of the Cedar Mountain Formation are the Ruby Ranch Member at the Long Walk Quarry. The Morrison-Cedar Mountain contact is clearly unconformable as indicated by a scoured surface, with up to 1 meter of relief, which separates the two formations. In addition, well developed root traces in the uppermost Morrison mud-

Figure 13. Conglomerate filled scour surface between Tununk Member of Mancos Shale and underlying Dakota Formation.

Figure 14. Lag of black chert pebbles and cobbles on bench formed by Dakota Formation.

stones are locally truncated along this contact, confirming the interpretation of the boundary as an omission surface. The regional extent and temporal significance of this Cedar Mountain/Morrison disconformity remain uncertain, but it may represent a profound pre-Barremian-Aptian period of erosion. The upper contact of the Cedar Mountain Formation with the thin and discontinuous "Dakota" Formation is obscure, but can be defined by the first occurrence of well-sorted, yellow-gray, arenitic to subarenitic sandstone which exhibits small-scale tabular and trough cross-stratification. This sandstone, where present, is from 1 to 3.5 meters thick and grades vertically into the overlying gray marine shale of the Tununk Member of the Mancos Shale. While the sandstone representing the "Dakota" Formation at the Long Walk Quarry serves as a convenient horizon marking the top of the Cedar Mountain Formation, its correlation with the Dakota Formation, as that term is used by other workers in other areas, is uncertain.

The Ruby Ranch Member of the Cedar Mountain Formation is dominantly composed of calcareous mudstone which contains abundant carbonate nodules. The calcareous mudstones are associated with several thin, lenticular, and commonly conglomeratic sandstones. Approximately 135 ft (45 m) above the base of the Cedar Mountain Formation, a ribbon of channel sandstone, similar to those in the Ruby Ranch Member on the east of the San Rafael Swell (Young, 1960; Harris, 1980), is exposed and can be traced for several hundred meters along its generally west-east course.

The base of the Mussentuchit Member is picked where mudstone rich in carbonate nodules are replaced by smectitic mudstone. The Mussentuchit Member makes up the upper 30 meters of the Cedar Mountain Formation at the Long Walk Quarry. It is composed dominantly of carbonaceous, rather than calcareous, mudstone in association with numerous thin, lenticular sandstone bodies. One of these sandstone units, about 10 meters below the "Dakota" Formation, yields numerous isolated dinosaur tracks. These tracks are assigned to ornithopods (Fig. 16) and ankylosaurs (Lockley et al., in press). Toward the top of the Mussentuchit Member is an important paleobotanical site (Katich, 1951; Stokes, 1952; Tschudy et al., 1984) that has long been used to date the Cedar Mountain Formation (Fig. 15).

The bone bed forming the Long Walk Quarry occurs in a nodular limestone layer, approximately 0.6 meters thick, overlain and underlain by softer calcareous mudstone typical of the lower portion of the Cedar Mountain Formation. The quarry horizon is approximately 15 meters above the Cedar Mountain-Morrison contact. The nodular limestone may represent a mature calichified surface developed between fluvial channels, though other evidence of pedogenic origin is weak. The preserved bones are completely disarticulated, and each fossil has no direct anatomical association with adjacent material. The long axes of the elongate elements exhibit a preferred orientation in a northeast-southwest direction. This orientation, coupled with previous studies documents a northeastward pattern of sediment dispersal in central Utah during the Early Cretaceous (Heller and Paola, 1989; Harris, 1980). It suggests that the bones were transported to the point of accumulation by streams flowing from a source to the southwest. This inferred northwest paleodrainage is consistent with a source in the southern Sevier Orogenic Belt, as proposed by Fillmore (1993).

The articular surfaces of elongate elements from the Long Walk Quarry exhibit varying degrees of abrasion and most fossils bear small fractures on the outer surfaces that are filled by carbonate material identical to the enclosing matrix. These features suggest at least some pre-burial transportation of the fossils from the Long Walk Quarry. The primary preservational mode of bone is carbonate per-

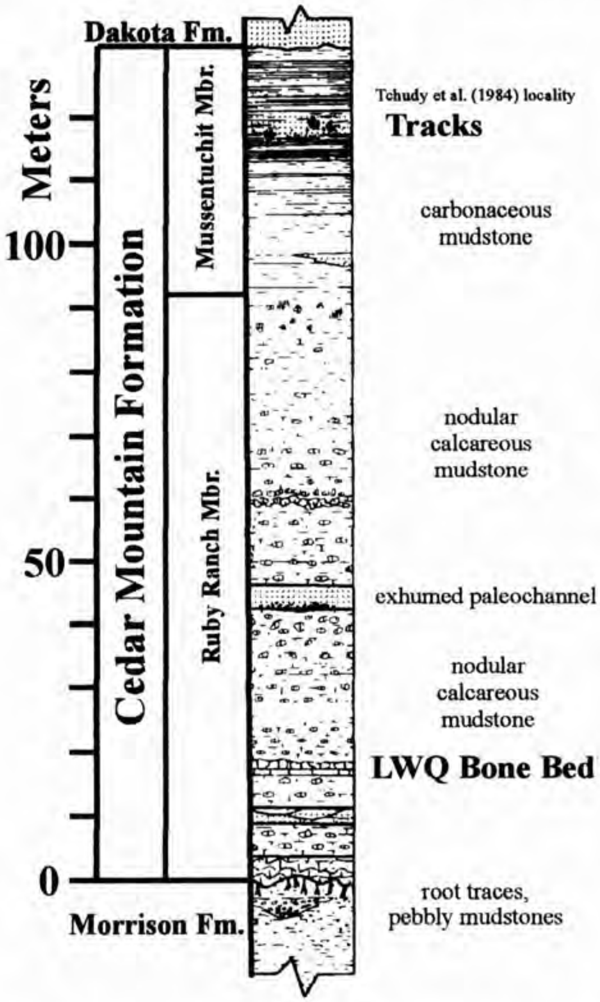

Figure 15. Measured section of the Cedar Mountain Formation at the UMNH's Long Walk Quarry (LWQ), Emery County, Utah (from DeCourten, 1991).

Figure 16. Ornithopod track from Long Walk track site near top of Cedar Mountain Formation in Mussentuchit Member.

Figure 17. Close up of teeth in early lambeosaurine hadrosaurid jaw from CEU's Carol Site.

mineralization, which may reflect both depositional and diagenetic events. For additional details concerning the nature of the fossil accumulation at the Long Walk Quarry, see the review of DeCourten (1991).

The Long Walk Quarry is significant because it represents the largest known concentration of dinosaur material in the Ruby Ranch Member of the Cedar Mountain Formation. In spite of the discovery of numerous vertebrate localities in the Cedar Mountain Formation in recent years, very few fossils had been found in the middle portions of the formation. The majority of the elements thus far recovered from the Long Walk Quarry can be tentatively identified as belonging to a *Pleurocoelus*-like sauropod. Sauropod material thus far recovered includes several isolated teeth, a dentary fragment, caudal and dorsal vertebrae, ribs, and fragmentary limb elements. Though current knowledge of the osteology of *Pleurocoelus* is incomplete, the Long Walk Quarry material is nearly identical to the type material for this genus from the Arundel Formation in Maryland and to the fossils referred to this genus from the Cloverly Formation of Wyoming and Montana. Several dorsal vertebrae have now been recovered that have the deep pleurocoels and rugose neural suture typical of *Pleurocoelus* (Marsh, 1888). The identification of a *Pleurocoelus*-like animal at the Long Walk Quarry represents the first published account of sauropod dinosaurs in the Lower Cretaceous of the Colorado Plateau region. Some of the sauropod elements evidently represent a juvenile specimen, indicating that the remains of at least two individual sauropods are preserved at the Long Walk Quarry.

In addition to the *Pleurocoelus*-like material, two nearly complete teeth, several partial teeth, and an ilium presently

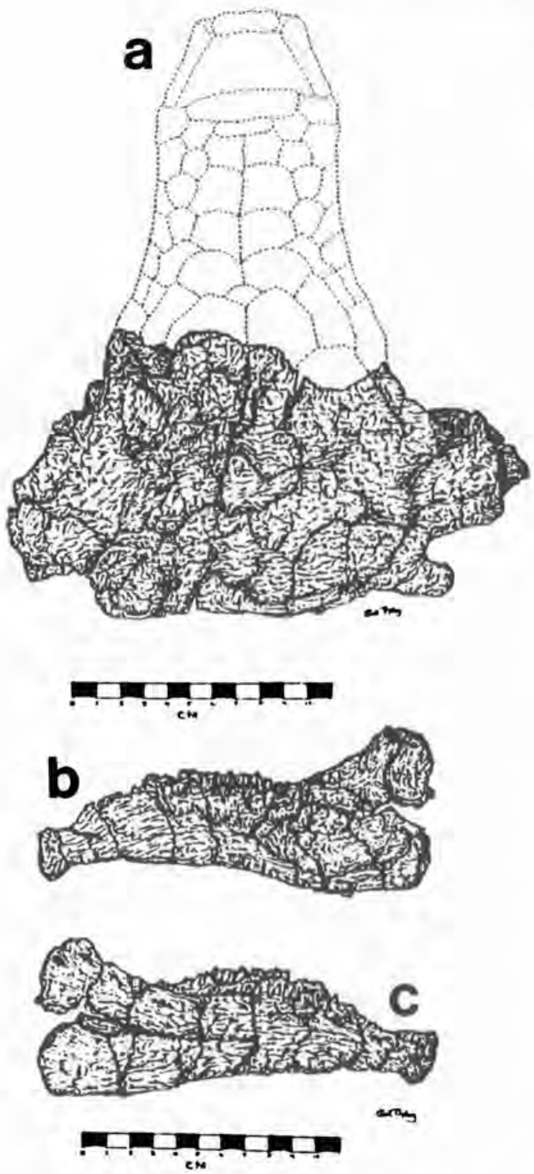

Figure 18. Skull and jaws of cf. Pawpawsaurus *n. gen. & n. sp., a. dorsal view of skull, b. medial view of jaw, c. lateral view of jaw (from Burge, 1996).*

undergoing preparation document the presence of at least one large theropod dinosaur at the Long Walk Quarry. The teeth are of typical theropod form, with coarse serrated edges and a curved anterior margin. The two complete teeth are 84 mm and 99 mm long, comparable in size to the teeth of *Allosaurus*, a well-known large theropod from the Upper Jurassic of east-central Utah. The ilium is at least 40 cm long and appears to belong to a bipedal predator of about average *Allosaurus* size as well. The only known Early Cretaceous theropod similar in size to the Long Walk Quarry

Figure 19. Assorted postcranial elements cf. Pawpawsaurus *n. gen. & n. sp. skeleton.*

specimen is *Acrocanthosaurus* (Stovall and Langston, 1950) from the Commanchean Series of Texas and Oklahoma. However, Kirkland and Parrish (1995) suggested that the teeth of the Long Walk Quarry theropod are distinct from *Acrocanthosaurus* in that they are much more coarsely serrated.

The Long Walk Quarry, and about 6 hectares (15 acres) of surrounding land, has been deeded to the Utah Museum of Natural History at the University of Utah. Plans for the future development of the quarry are being formulated at the present time. Only an estimated 3–5% of the bone bed has been excavated, and even less of it has been thoroughly processed in the preparation laboratory. It is anticipated that between 5000 and 10,000 elements may eventually be recovered at the Long Walk Quarry. This material will provide much needed data on dinosaur fauna from the main body of the Cedar Mountain Formation. The Long Walk Quarry clearly has the potential to develop into one of the most significant fossil localities of the Colorado Plateau region.

STOP 6. The Carol Site, The Ruby Ranch/Mussentuchit Contact. D. Burge and J. Kirkland

At this stop (Figs. 2, 5), we will examine the Carol Site, just above the contact between the Ruby Ranch and Mussentuchit members. This locality was discovered by Carol and Ramon Jones of Salt Lake City, Utah. Material collected so far is from near the surface in a highly rooted interval. As such, portions of some of the bones were completely destroyed by roots. However, careful preparation by John Bird of the CEU Prehistoric Museum in Price, Utah has resulted in a very significant specimen being made available for study. Initial excavations revealed an associated adult hadrosaur skeleton with a disarticulated skull (Fig. 17).

A radiological technician at the University of Utah, Ramon Jones developed a specially shielded device to care-

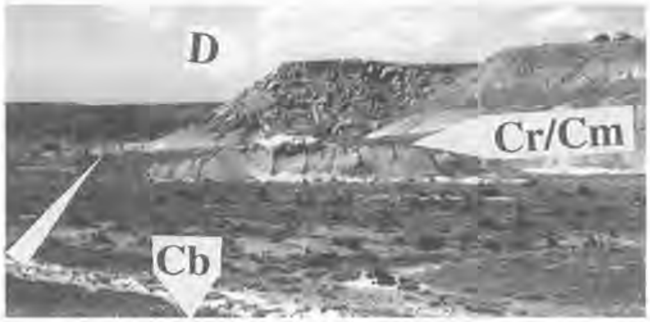

Figure 20. CEU Prehistoric Museum's Carol Site indicated by arrow northwest of Castledale, Utah. Arrow indicates Carol Site. Abbr. Cb = Buckhorn Conglomerate, Cr/Cm = contact between Ruby Ranch and Mussentuchit Members, D = Dakota Formation.

Figure 21. Bluff held up by massive calcrete at top of Morrison Formation.

fully record radiation levels in the shallow subsurface (Jones and Burge, 1995). This resulted in the discovery of a small nodosaurid ankylosaur (Figs. 18, 19) related to *Pawpawsaurus* (= *Texasetes*) from the Late Albian of Texas (Coombs, 1995; Lee, 1996). The greatest significance of this discovery, beyond it being a new species of nodosaurid, is that it is the first dinosaur skeleton ever discovered solely using a remote sensing instrument. Additionally, this specimen will be useful in resolving the *Pawpawsaurus/Texasetes* question, as *Pawpawsaurus* is based on a skull (Lee, 1996) and *Texasetes* is based mainly on a postcranial skeleton (Coombs, 1995) and the new Cedar Mountain specimen preserves both (Figs. 18, 19).

A 3–4 m thick section of Buckhorn Conglomerate marks the base of the Cedar Mountain section at this site. It forms a broad northwest sloping bench about a mile. It has abundant black and white chert and limestone clasts up to 10 cm in diameter. Crossbeds indicate a transport direction of N 75 E in this area. The Ruby Ranch Member is 18.3 meters thick, with a prominent ribbon sandstone 0.7 m thick and 100 m across about 10 m above its base. A pebble conglomerate 60 cm thick with a mudstone matrix is replaced by a greenish sandstone to the west just below the Carol site (Fig. 20). The Carol site lies at the base of the Mussentuchit Member, which is 12.3 m thick. It is remarkable that the Cedar Mountain section is only 27% as thick as it is a few kilometers south at the Long Walk Quarry and so close to the type area at Cedar Mountain.

STOP 7. Cedar Mountain Formation at Ruby Ranch. J. Kirkland and S. Hasiotis

At this stop (Figs. 2, 5), we will examine the type section of the Ruby Ranch Member of the Cedar Mountain Formation. The Cedar Mountain Formation has a total thickness of 46.2 m at Ruby Ranch (Fig. 8). The Yellow Cat Member is 11.1 meters thick, with a 0.5–1.5 meter thick algal limestone 6.8 m above the base locally. The overlying Poison Strip Member is 3–4 meters thick and consists of trough-crossbedded gravely sandstone with interbeds of pale greenish mudstone. The overlying type section of the Ruby Ranch Member described above is 31.1 m thick below its contact with the basal sandstone of the Dakota Formation.

The base of the Cedar Mountain at the Ruby Ranch section is remarkable. Locally, it is at the top of a 8–10 m thick calcrete bed (Fig. 21) (Aubrey, 1996, in press). Laterally, this calcrete grades into an 8 m thick interval rich in carbonate nodules at the base of the Yellow Cat Member. Coincidentally, where the calcrete is best developed, there is a silicified algal limestone bed developed within the overlying Yellow Cat Member of the Cedar Mountain Formation. This suggests post-burial diagenesis may have played a role forming this thick carbonate unit.

No vertebrate body fossils have been found at the Ruby Ranch site, but ornithopod tracks have been recognized (Lockley et al., in press) in a fluvial sandstone 2.1 meters above the base of the Ruby Ranch Member (Fig. 22). Additional invertebrate trace fossils of the *Scoyenia* assemblage are common in many sandstone units in the Cedar Mountain Formation. These include traces produced by ants, termites, and crayfish.

STOP 8. Cedar Mountain Formation Sites on the West side of Arches. J. Kirkland and K. Carpenter

At this stop (Figs. 2, 5), we will examine Denver Museum of Natural History (DMNH) localities in the Yellow Cat Member and Poison Strip Sandstone. There are several important dinosaur sites in the Cedar Mountain Formation on the west side of Arches National Park. The Bodily (1969) nodosaurid site (Fig. 23) was discovered in the early 1960s by Lin Ottinger of Moab, Utah, who reported it to Jim Jensen of Brigham Young University. Bodily (1969) described this large nodosaurid ankylosaur as *Hoplitosaurus* sp. In his review of the Ankylosauria, Coombs (1969) referred the

Figure 22. Ornithopod track from fluvial sandstone from near base of Ruby Ranch Member.

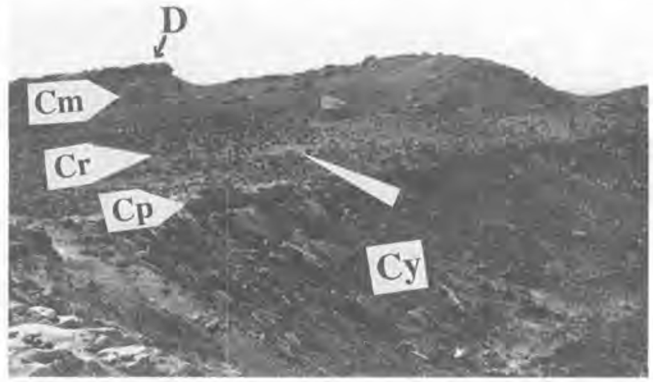

Figure 23. Brigham Young University's Bodily's Nodosaur Site indicated by arrow on west of Arches National Park. Arrow points to quarry. Abbr. Cm = Mussentuchit Member, Cp = Poison Strip Sandstone, Cr = Ruby Ranch Member, Cy = Yellow Cat Member, D = Dakota Formation.

Figure 24. Brigham Young University's Dalton Wells Quarry indicated by D and brackets. Abbr. Cp = Poison Strip Sandstone, Mor = Morrison Formation.

specimen to *Sauropelta* sp. In 1996, field crews with the Denver Museum of Natural History began to excavate a second specimen of *Sauropelta* a few kilometers north of the Bodily site. This specimen is clearly preserved within the Poison Strip Sandstone. Further examination of the Bodily site suggests that it too may lie within the Poison Strip Sandstone. Vertebrae and ribs of a sauropod were excavated from about six meters above the base of the Yellow Cat Member just north of the DMNH nodosaurid site.

Galton and Jensen (1981) reported on a highly eroded hadrosaur femur 112–117 cm long from a few kilometers south of these sites. Although, the exact horizon of this specimen is not known, smectitic mudstones at the top of the Cedar Mountain Formation in this area suggest it may have been recovered from strata equivalent to the Mussentuchit Member of the San Rafael Swell. This is the first report of a hadrosaur in the Cedar Mountain Formation.

STOP 9. Dalton Wells, Yellow Cat Member.
Brooks Britt

At this stop (Figs. 2, 5), we will examine the extraordinarily rich deposit of dinosaur remains at the Dalton Wells Quarry (Fig. 24). It is rich not only in the number of bones, but in the number of different types of dinosaurs preserved, several of which are new to science. This Cedar Mountain Formation locality is in the Yellow Cat Member and is particularly important because it is one of the best samples of Early Cretaceous dinosaurs in North America. The quarry is being developed in a joint project of Brigham Young University's Earth Science Museum and the Museum of Western Colorado.

The Dalton Wells quarry takes its name from a homestead established by Earl Dalton. In the early 1930's, the federal government erected a Civilian Conservation Corps (CCC) camp on the homestead. During World War II, following a 15 month closure, the site was converted to a Japanese interment camp, complete with high watch towers, for male Japanese-Americans vocal in their opposition to the imprisonment of American citizens. Today, a grove of cottonwood trees and concrete foundation slabs are all that remain of the camps, but crews working the quarry use the site as a campground.

Figure 25. Holotype maxilla fragment with two teeth of Iguanodon ottingeri *(Galton and Jensen (1979) from the Dalton Wells Quarry. Darker* Iguanodon *tooth resting on top from the Gaston Quarry (Stop 11).*

The quarry area has been known to casual collectors for decades but until Lin Ottinger showed James A. Jensen a small maxilla with teeth in 1968, the significance of the site was not recognized (Fig. 22). Ottinger's find revealed that the formation was Early Cretaceous in age, and the skull fragment was later designated as the holotype of *Iguanodon ottingeri* (Galton and Jensen, 1979). Jensen and Stadtman of BYU conducted a preliminary excavation in 1975, and a quarry was opened in 1978. The quarry remained dormant until 1994, when BYU and MWC joinedforces to systematically collect the site and prepare recovered elements for study. At the time of this writing nearly 1400 bones have been recovered and are being analyzed.

In the immediate area of the quarry, the boundary between the Yellow Cat Member of the Cedar Mountain Formation and the underlying Morrison Formation remains to be determined. Calcrete and conglomerate horizons used in other areas to differentiate the formations are discontinuous in the area. Doelling (1988) and Aubrey (1996) noted that, during the deposition of the Cedar Mountain Formation, salt diapirs in the underlying Permian Paradox Formation were actively flowing, resulting in the formation of small depositional centers. This hypothesis accounts for the discontinuity of marker beds in the Cedar Mountain Formation.

In the Dalton Wells, quarry bones occur in the basal meter of a 4 meter thick, conglomeratic, silty, mudstone lithosome (Fig. 26). This fossiliferous horizon extends for some 400 meters but is nearly devoid of internal sedimentary structures. The largest clasts are bones (up to 1.5 m long) and 10 cm in diameter, well rounded, chert pebbles. With the exception of the larger bones, the clasts are matrix supported. Mud drapes in the middle of the conglomeratic

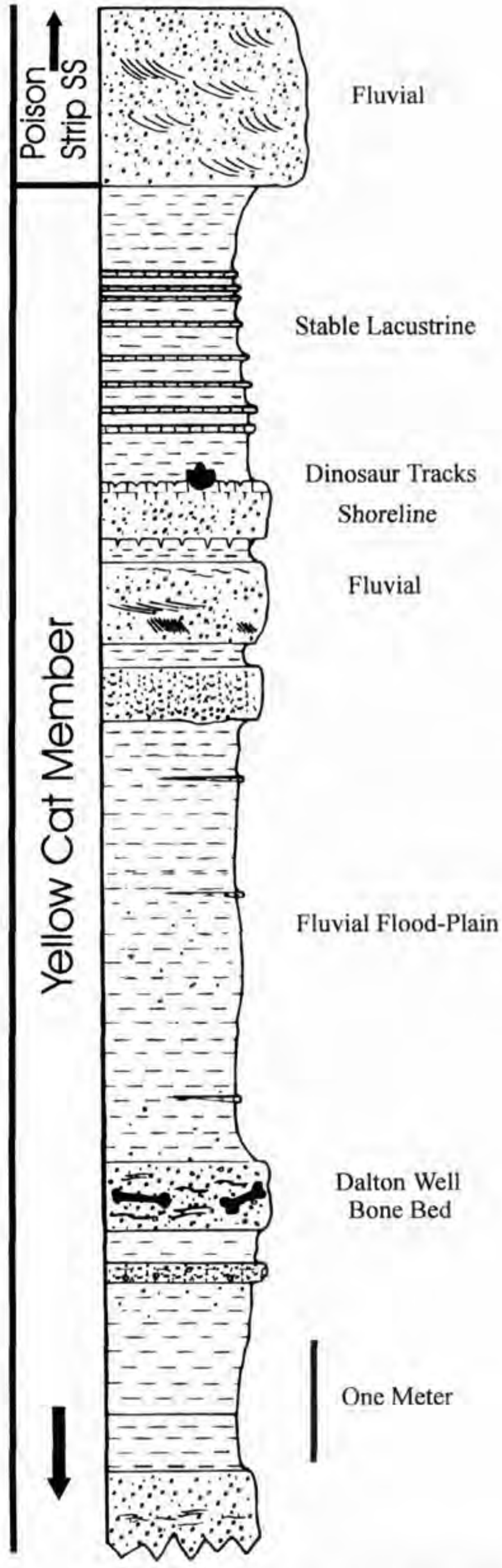

Figure 26. Detailed stratigraphic section of the upper Yellow Cat Member at Dalton Wells Quarry. Sandstone at top, base of Poison Strip Sandstone. Scale bar equals one meter.

Figure 27. Brooks Britt holding dorsal vertebra of high spined iguanodontid at Dalton Wells Quarry.

Figure 28. Oklahoma Museum of Natural History's Hotel Mesa Site indicated by arrow looking east across the Colorado River. Abbr. Cp = Poison Strip Sandstone, D = Dakota Formation.

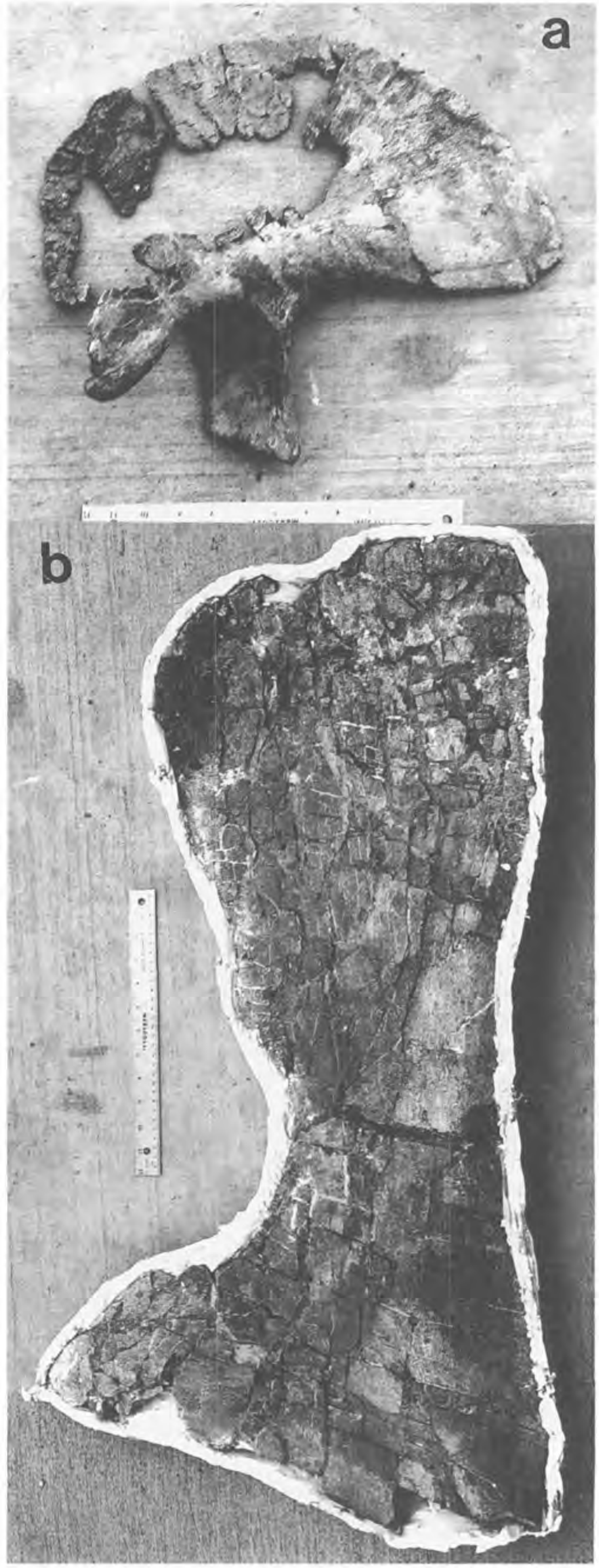

Figure 29. Pleurocoelus *bones from OMNH's Hotel Mesa Quarry. a. ilia of juvenile specimen, b. scapula of adult specimen. Scale is one foot (30 cm).*

Figure 30. Bone bed at CEU's Gaston Quarry. Bones include, polacanthid ankylosaur ribs, sacrum, caudal vertebrae, femur, and abundant armor and Utahraptor *tibia and premaxilla.*

Figure 31. Utahraptor *bones, top, premaxilla; middle, first manus ungual (claw); bottom second pedal ungual (sickle-claw). Swiss army knife for scale.*

mudstone indicate at least two flow events are preserved. The bone-bearing lithosome is interpreted to have originated as viscous crevass splay(s) deposited into a broad, topographic low. Thin sandstones overlying the conglomeratic mudstone represent more normal, continuous flow events. Desiccation-cracked marl with sauropod and ornithopod tracks overlie the sandstones and represent a fluctuating, lacustrine shoreline. Thin micritic limestone beds indicate the lake was relatively shallow but stable for some period of time before fluvial conditions again dominated the area.

Although articulated bones are rare, several spectacular specimens have been recovered, including three partial cervical sets. Two of the sets are of sauropods, with one cervical set still in articulation with the cranium. A partial cervical series of a nodosaurid was also found. Most bones are disarticulated, but clusters of associated bones make it possible to recognize individuals. Preserved bones range from pristine, delicate cervical vertebrae of sauropods to badly fractured, 1.5 meter long limb bones. Preliminary investigations suggest that most of the bones were broken by fluvial action. Taxonomic diversity and the range of growth stages represented in the quarry suggest a catastrophic event led to the demise of a large number of animals. Later, the bones were picked up and concentrated by a fluvial event. The rarity of articulated bones the presence of tooth marks on some bones indicate the skeletons were subaerially exposed prior to being entrained in a fluvial system. The rare articulated bones represent portions of skeletons entombed while flesh still bound them together.

The Dalton Wells fauna is diverse, with six dinosaur genera currently recognized. Sauropod elements dominate excavated areas and account for about three-quarters of the 1400 recovered bones. Rare turtle shell fragments are the only non-dinosaurian remains. Few theropod elements have been recovered, but they represent at least two taxa. *Utah-*

Figure 32. Skull of new genus of polacanthid ankylosaur.

Figure 33. Interbedded limestones and shales at CEU's Gaston Quarry. Arrow indicates level of bone pavement.

Figure 34. Sauropod tracks (round shadowed depressions in foreground) at base of bone bed CEU's Gaston Quarry. Rob Gaston standing in background.

raptor, a large dromaeosaurid, is the most common and largest theropod at the site. A relatively small, maniraptoran theropod is also present but remains to be described. A minimum of six juvenile and adult sauropods have been identified, representing two genera; a camarasaurid and a titanosaurid. The adults are of medium size, but several elements indicate the presence of a large individual 21+ meters long. The tentative identification of the camarasaurid is based on unusually large, spatulate teeth set in vertically deep mandibular and maxillary elements, and delicate, thin-walled, cervical vertebrae with bifurcated neural spines. A cranium was found in articulation with the atlas and axis, which in turn were closely associated with several succeeding vertebrae. The caudal vertebrae are amphicoelous. The robustness of the skull elements, cranial and tooth morphology, and the cleft spines in the mid-cervicals suggest a camarasaurid affinity. A titanosaurid is recognized based on the presence of strongly procoelous cau-

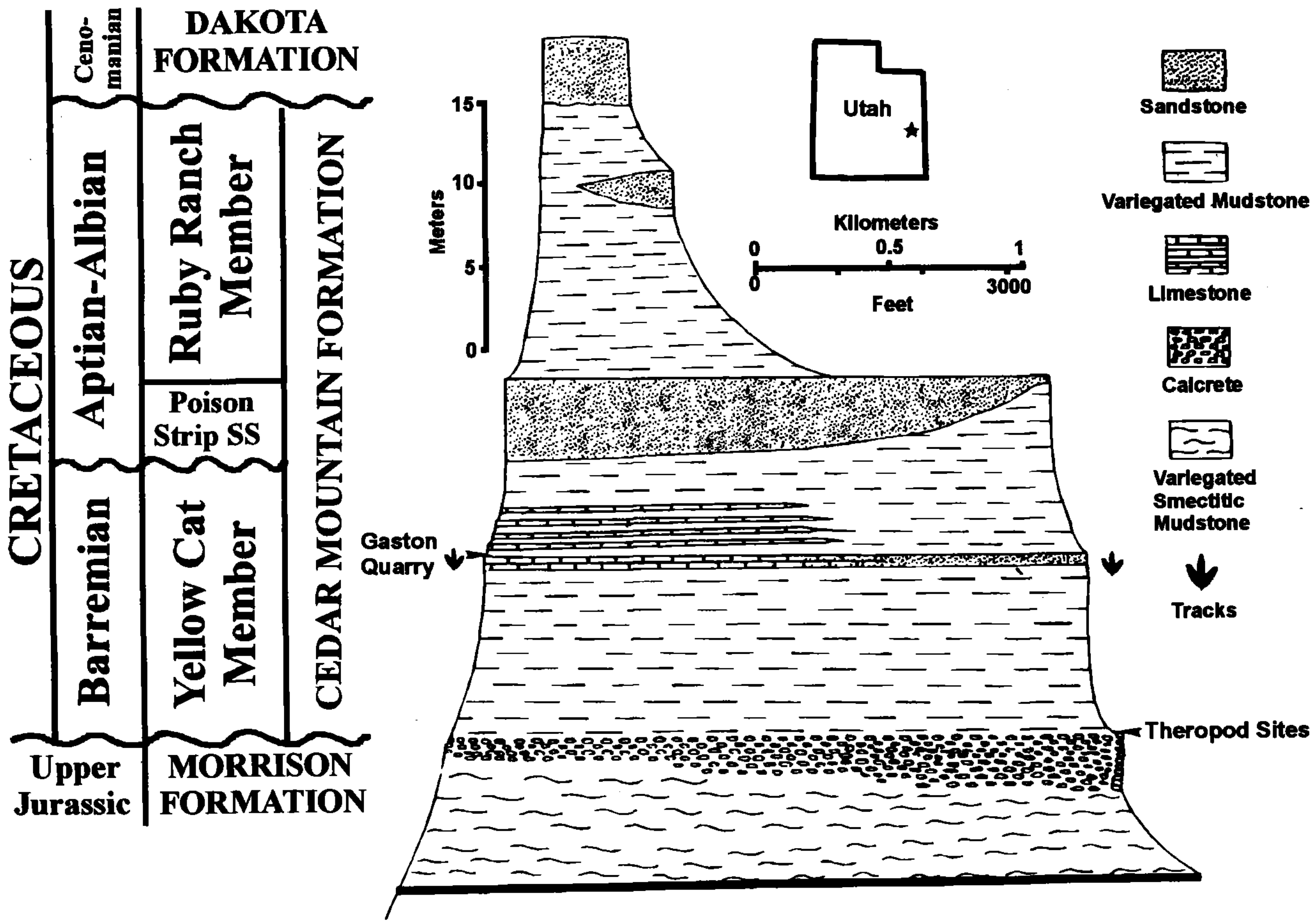

Figure 35. Cross-section of butte at Gaston Quarry showing relationships of sites on western and eastern sides.

dal vertebrae. Vertebrae from all vertebral regions have been recovered. All postaxial presacral vertebrae are pneumatic but are of the underived, camerate form with large camerae surrounded by thick bone. Neural spines of the cervical, dorsal, and caudal vertebrae are short and nonbifid, and the neural arches of the dorsal vertebrae are markedly tall. A partial skull is tentatively assigned to this taxon. The hypothesized Barremian age of this fauna make this the oldest titanosaurid in North America.

A large iguanodontid, with an estimated length of 8 meters, is represented by a minimum of three individuals. The type specimen of *Iguanodon ottingeri*, (Galton & Jensen, 1979), a partial maxilla of a juvenile, is currently designated *nomen dubium* by Weishampel and Bjork (1989). However, the taxon is now known from an array of cranial and postcranial elements. The North American *Iguanodon lakotaensis* from the Lakota Formation of South Dakota is correlated in relative geographic and stratigraphic context. The broad neural spine of the dorsal vertebrae from Dalton Wells is longer than any other iguanodont (Fig. 27) except the African form, *Ouranosaurus nigeriensis* (Taquet, 1976). Two small (2.5 m) polacanthid ankylosaur specimens are represented by femora, vertebrae, numerous scutes and spikes, and fragmentary pectoral and pelvic elements.

In summary, the Dalton Wells quarry is yielding a significant fauna that will contribute to an understanding of the Early Cretaceous dinosaurs of North America and to biogeography.

Stop 10. The Hotel Mesa, Ruby Ranch Member of the Burro Canyon Formation. Jim Kirkland

At this short stop (Figs. 2, 5) we will look at the Hotel Mesa site in the Ruby Ranch Member just to the east across the Colorado River (Fig. 28). It can be considered to be the first productive dinosaur quarry in the Burro Canyon Formation as the formation names traditionally change at the Colorado River (Stokes, 1952; Craig, 1981). Discovered by Ralph Pavonka of Grand Junction, Colorado, it was first reported to paleontologists by William Hawes of Grand

Figure 36. Loose ornithopod tracks formed at base of crevasse splay near Yellow Cat Road east of Gaston Quarry.

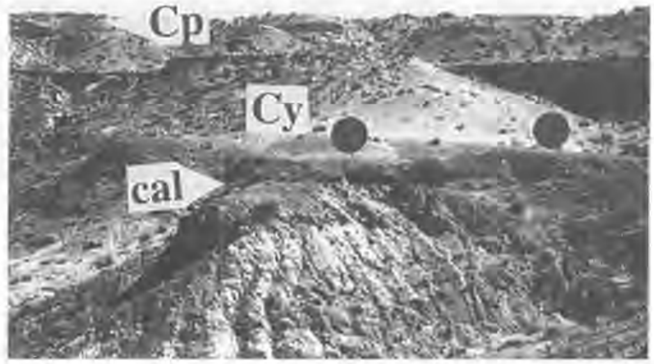

Figure 37. CEU Prehistoric Museum's small theropod sites indicated by dotes just to the east of the Gaston Quarry. Abbr. Cp = Poison Strip Sandstone, Cy = Yellow Cat Member. cal = calcrete.

Junction. In this area, the Cedar Mountain and correlative Burro Canyon formations are relatively thin. The Yellow Cat Member has not been recognized in this area, and only the Poison Strip Sandstone and Ruby Ranch Member are present and thus clearly can be recognized in the Burro Canyon Formation east of The Colorado River. The Hotel Mesa site is located just a few meters below the base of the Dakota Formation.

To date, the Hotel Mesa site has only undergone preliminary salvage excavations by the Oklahoma Museum of Natural History, but the materials so far discovered are interesting. Most of the fossils pertain to a sauropod comparable to *Pleurocoelus* (Fig. 29). These include elements of both a large and a young individual and include numerous ribs, a caudal vertebra, an ilium, and most of a broad scapula. Additionally, microvertebrate material is also present including teeth of a hybodont shark, large and small crocodilian teeth, turtle shell fragments, a small theropod claw, and teeth possibly referable to the dromaeosaurid *Deinonychus*.

This site is significant in being the easternmost Lower Cretaceous dinosaur quarry sampled to date on the Colorado Plateau. Fossil vertebrates are known further to the east in Colorado, but the material discovered so far has been very scrappy and indeterminate.

STOP 11. The lower Cedar Mountain Formation along the Poison Strip. J. Kirkland and R. Cifelli.

At this stop (Figs. 2, 5) and we will examine the Yellow Cat Member and Poison Strip Sandstone south of Cisco, Utah on the eastern end of the Poison Strip. A number of small vertebrate sites have been discovered in the Yellow Cat Member in this area. These sites have been investigated by field crews from the Oklahoma Museum of Natural History. Surface material collected includes a number of partial turtles similar to *Glyptops*, ganoid fish scales and teeth, a partial jaw of an eilenodontine sphenodontid, teeth of a small theropod and ankylosaur, and fragments from a polacanthid ankylosaur. The sphenodontid jaw is significant in that together with a specimen from the Kootenai Formation (Lower Cretaceous) it represents one of the youngest occurrences of this family outside of New Zealand (Throckmorton et al., 1981). Some small fragments of eggshell were also recovered that have been examined by Karl Hirsch and are currently under study by Emily Bray of the University of Colorado. The greater abundance of turtles and fishes suggest that these sites in the Yellow Cat Member may represent a wetter environment than sites farther west. An attempt was made to wet screenwash one productive layer, but it did not break down readily. However, this sample did produce numerous charophytes.

The presence of the charophyte, *Nodosoclavator bradleyi* (Harris) suggests an age of no younger than Barremian for the lower Cedar Mountain Formation in this area (Michael Schudack in a report to Fred Peterson). The only report suggesting a younger age (Aptian) for this taxon is by Peck (1957), who described this form as *Clavator nodosus* from the lower half of the Lakota Formation in South Dakota. In an examination of the Ostracoda, Sohn (1979) subsequently considered these strata to be pre-Aptian. Thus the limited data from charophytes supports the Barremian age suggested by the dinosaur fauna.

Along the southern side of the escarpment held up by the Poison Strip Sandstone (Fig. 7) various aspects of the Poison Strip Sandstone can be observed. These include thinning and thickening of the member, the lateral relationships of individual sandstone units in the member, and large scale epsilon crossbeds supporting the interpretation of the Poison Strip Sandstone as representing a complex meandering river system. Pale brown to white petrified wood is present at a number of localities along this escarpment and in addition to conifers includes the cycads, *Cyca-*

Figure 38. Foot of juvenile specimen of small maniraptoran theropod, top proximal view of metatarsals, bottom overview of foot.

deoidea and *Monanthesia* (Tidwell; personal commun. 1997). The Poison Strip Sandstone is of economic significance in this area, as it is the primary target in the Cisco Oil and Gas Field to the northeast (Moyer, pers. commun.). Detailed sedimentology has never been done for the Poison Strip Sandstone, but the quality of exposures in this area make an interesting study of this sequence boundary very feasible.

STOP 12. Gaston Quarry. J. Kirkland and D. Burge

At this stop (Figs. 2, 5) we will examine the Gaston Quarry and type section of the Yellow Cat Member of the Cedar Mountain Formation. The Gaston Quarry was discovered by Robert Gaston in the winter of 1990 near the top of a 100 meter butte held up by the Poison Strip Sandstone Member. To date, over 1100 completely disarticulated bones have been recovered from approximately 30 square meters (Burge, 1996), forming a literal pavement of bones (Fig. 30). Most of the bones represent a new, undescribed polacanthid ankylosaur represented by a minimum of four individuals (Kirkland et al., 1991; Kirkland, 1993, 1996; Carpenter et al., 1996). Additionally the type material of *Utahraptor ostrommaysorum* (Fig. 31) (Kirkland et al., 1993) and an iguanodont tentatively assigned to *Iguanodon ottingeri* Galton and Jensen (1979) have been recovered from the site. It is thought that rather than representing the "sail-backed" iguanodont as proposed by Britt et al., (1996; this paper), that *Iguanodon ottingeri* (Fig. 25) may prove to be a conservative iguanodont perhaps synonymous with *Iguanodon lakotaensis* (Weishampel and Bjork, 1989).

The polacanthid ankylosaur compares closely to *Polacanthus foxi* from the Wealden of England and *Polacanthus marshi* from the Lakota Formation of South Dakota on the basis of possessing a sacral shield of fused armor; asymmetric, hollow-based lateral plates; hollow-based, laterally directed, shoulder spines with a long posterior groove; and in having an additional set of large erect, solid-based, shoulder spines (Blows, 1987; Pereda-Suberbiola, 1993, 1994; Kirkland, 1993, 1996a). It differs from *Polacanthus* in not having a free lessor trochanter on the femur, not having diverging lateral margins of ilia, and a more massively constructed ulna (Kirkland, 1993; 1996). It has the only well preserved skull known for any polacanthid ankylosaur (Fig. 32), which suggests a close relationship with the Ankylosauridae and not the Nodosauridae (Kirkland, 1993; in manuscript; Carpenter et al., 1996). It also appears to be closely related to ankylosaurs recently discovered in the Morrison Formation (Kirkland and Carpenter, 1994; Carpenter, et al., 1996).

The bones are preserved in an interval of alternating limestone and silty shale (Fig. 33) 6.5 m below the top of the Yellow Cat Member of the Cedar Mountain Formation. Bones preserved in the limestone are beautifully three dimensional, while those preserved in the underlying silty shale are badly crushed. Isolated barite roses are present in association with these beds, suggesting the site may represent an ephemeral alkaline pond and that the limestone is largely diagenetic. The limestone at the base of the bone-bearing interval was found to be a sauropod tracksite (Fig. 34), with the next limestone layer up preserving ornithopod tracks. This interval of alternating limestone and shale was thought to mark the base of the Cedar Mountain Formation in this area (Young, 1960, Fig. 6, sec. 37). In redefining the base of the Cedar Mountain, Aubrey (1996; in press) lowered the boundary to the calcrete 7 m down section.

On the other side of the butte toward the Yellow Cat Road, the quarry horizon correlates with a dark brown crevasse splay (Fig. 35). Ornithopod tracks have been found at the base of this splay (Fig. 36). Immediately above the calcrete (Fig. 37) at the base of the Yellow Cat Member, three partial skeletons of a small maniraptoran theropod (Fig. 38) have been excavated (Kirkland et al., 1995). Other fossils from this area include a lungfish tooth plate and a small crocodilian tooth fragment. Also, there have been spiral concretions filled with ganoid fish scales found at approximately this level. These are thought to represent enterospires of a hybodont shark, for which a fragment of a dorsal fin spine has been found. Additionally, fragments of the polacanthid ankylosaur have been found just below the Poison Strip Sandstone on this side of the butte also.

The Yellow Cat Member measures 24 meters thick in its type area as described above (Fig. 3). The overlying Poison Strip Sandstone measures as much as five meters thick near the Gaston Quarry but pinches out at the Yellow Cat Road 1.5 miles to the east (Fig. 34). It reappears again just to the east of the road and the type section is visible a short distance to the south. The Ruby Ranch Member is 17 meters thick in this area and has a prominent east trending ribbon sandstone 2–3 meters thick, 10 meters above its base. The overlying Dakota Formation has a chert pebble-to-cobble conglomerate at its base locally. A section of *Tempskya* log was found within this conglomerate.

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