FLUVIAL FACIES AND ARCHITECTURE OF THE POISON STRIP SANDSTONE, LOWER CRETACEOUS CEDAR MOUNTAIN FORMATION, GRAND COUNTY, UTAH

by
Mathew W. Stikes

MISCELLANEOUS PUBLICATION 06-2
UTAH GEOLOGICAL SURVEY
a division of
Utah Department of Natural Resources
2007

FLUVIAL FACIES AND ARCHITECTURE OF THE POISON STRIP SANDSTONE, LOWER CRETACEOUS CEDAR MOUNTAIN FORMATION, GRAND COUNTY, UTAH

by

Mathew W. Stikes

Cover Photo:
Part of Morrison and Cedar Mountain Formations along the Poison Strip mining region, north-central section of field area.

ISBN 1-55791-751-5

MISCELLANEOUS PUBLICATION 06-2
UTAH GEOLOGICAL SURVEY
a division of
Utah Department of Natural Resources
2007

STATE OF UTAH

Jon Huntsman, Jr., Governor

DEPARTMENT OF NATURAL RESOURCES

Michael Styler, Executive Director

UTAH GEOLOGICAL SURVEY

Richard G. Allis, Director

PUBLICATIONS

contact
Natural Resources Map/Bookstore
1594 W. North Temple
Salt Lake City, Utah 84116
telephone: 801-537-3320
toll-free: 1-888-UTAH MAP
Web site: http://mapstore.utah.gov
email: geostore@utah.gov

THE UTAH GEOLOGICAL SURVEY

contact
1594 W. North Temple, Suite 3110
Salt Lake City, Utah 84116
telephone: 801-537-3300
fax: 801-537-3400
Web site: http://geology.utah.gov

The Miscellaneous Publication series provides non-UGS authors with a high-quality format for documents concerning Utah geology. Although review comments have been incorporated, this publication does not necessarily conform to UGS technical, policy, or editorial standards.

The Utah Department of Natural Resources, Utah Geological Survey, makes no warranty, expressed or implied, regarding the suitability of this product for a particular use. The Utah Department of Natural Resources, Utah Geological Survey, shall not be liable under any circumstances for any direct, indirect, special, incidental, or consequential damages with respect to claims by users of this product.

The Utah Department of Natural Resources receives federal aid and prohibits discrimination on the basis of race, color, sex, age, national origin, or disability. For information or complaints regarding discrimination, contact Executive Director, Utah Department of Natural Resources, 1594 West North Temple #3710, Box 145610, Salt Lake City, UT 84116-5610 or Equal Employment Opportunity Commission, 1801 L. Street, NW, Washington, DC 20507.

CONTENTS

ABSTRACT . . . 1
INTRODUCTION . . . 1
Purpose and scope . . . 2
Field area description . . . 2
Previous work . . . 2
Stratigraphy . . . 5
Regional stratigraphy . . . 5
Local stratigraphy . . . 6
Paleo-tectonic and climatic setting . . . 8
Methods . . . 9
SEDIMENTARY FACIES . . . 12
Conglomerate facies . . . 13
Description . . . 13
Interpretation . . . 14
Sandstone facies . . . 14
Description . . . 14
Interpretation . . . 20
Fine-grained facies . . . 21
Description . . . 21
Interpretation . . . 22
Carbonate facies . . . 23
Description . . . 23
Interpretation . . . 23
STRATIGRAPHIC SECTIONS AND FLUVIAL ARCHITECTURE . . . 23
Paleoflow evidence . . . 24
Architectural analysis . . . 24
Bounding surfaces . . . 24
Architectural elements of the Cedar Mountain Formation . . . 25
Architectural profiles . . . 25
Dalton Well . . . 32
Description . . . 32
Interpretation . . . 34
Communication Tower . . . 34
Description . . . 34
Interpretation . . . 34
Long Valley East . . . 34
Description . . . 34
Interpretation . . . 39
Window Wash . . . 39
Description . . . 39
Interpretation . . . 39
Kokopelli Trail . . . 41
Description . . . 41
Interpretation . . . 41
STRATIGRAPHIC ANALYSIS . . . 41
Vertical profile analysis . . . 41
Paleocurrent analysis . . . 46
Fluvial style and facies model . . . 46
Evolution of the Poison Strip fluvial system . . . 48
Sedimentary controls . . . 48
Intra-basinal controls . . . 48
Extra-basinal controls . . . 49
Sequence stratigraphic considerations . . . 49
Regional relations . . . 50
CONCLUSIONS . . . 50
ACKNOWLEDGMENTS . . . 52
REFERENCES . . . 53
APPENDIX 1: SANDSTONE PETROGRAPHY . . . 58
APPENDIX 2: STRATIGRAPHIC SECTIONS . . . 60

FIGURES

1. Location map of study area 2
2. Overview photo along the Poison Strip 3
3. Stratigraphic nomenclature progression 4
4. Lower Cretaceous chronostratigraphic chart 5
5. Lower Cretaceous/Dakota outcrop on Colorado Plateau 6
6. Cedar Mountain Formation cross-section for east-central Utah 7
7. Early Cretaceous paleogeography of western United States 9
8. Paradox Basin features 10
9. Salt Valley anticline cross-section 11
10. Photo of facies Gm with vertebrate limb 13
11. Photo of fining-upward sequence with facies Gs 14
12. Photomicrographs 16
13. Banded and spherical shaped cement forms 17
14. Ternary diagram for sandstone petrography 18
15. Photo of facies St 18
16. Photo of facies Sr 19
17. Photo of facies Sh/Sl with cement bands 19
18. Close-up photo of facies Sh/Sl and facies Gm 19
19. Photo of current parting lineation, facies Sh/Sl 20
20. 3-D illustration of facies St 21
21. Photo of overturned cross-strata 22
22. Photo of calcrete 23
23. Locations of measured section and lines of correlation 25
24. North-South section correlation 26
25. West-East section correlation 27
26. Arches National Park section correlation 28
27. Rose diagrams for section locations 29
28. Rose diagrams according to facies type 30
29. Scale of alluvial deposits and bounding surfaces 31
30. Dalton Well, section 6 architectural profile 33
31. Low-sinuosity channel with alternate bars facies model 35
32. Distal, sandy, sheetflood braided facies model 35
33. Communication Tower, section 9 architectural profile 36
34. Photo of facies Sla, alternate bar 37
35. Flashy, ephemeral, sheetflood, sand-bed river facies model 37
36. Long Valley East, section 21 architectural profile 38
37. Photo of bar foresets and silicified log 40
38. Plan view sketch of barform 40
39. Deep, perennial, braided facies model 40
40. Window Wash, section 14 architectural profile 42
41. Kokopelli Trail, section 18 architectural profile 43
42. Photo of laminated sand sheet 44
43. Photo of overturned cross-strata at Kokopelli Trail 44
44. Three vertical profiles through Poison Strip Sandstone 45
45. Poison Strip Sandstone facies model with trunk stream 47
46. Poison Strip Sandstone facies model, braided streams 47
47. Sequence indications for the Cedar Mountain Formation 51
48. Regional relations between Lower Cretaceous deposits 52

TABLES

1. Lithofacies summary displaying codes, physical characteristics, and depositional interpretations 12
2. Architectural elements common to the Cedar Mountain Formation in the field area 32

FLUVIAL FACIES AND ARCHITECTURE OF THE POISON STRIP SANDSTONE, LOWER CRETACEOUS CEDAR MOUNTAIN FORMATION, GRAND COUNTY, UTAH

by

Mathew W. Stikes[1]

ABSTRACT

The Lower Cretaceous Cedar Mountain Formation has recently been subdivided into five members including in ascending order, the Buckhorn Conglomerate, the Yellow Cat Member, the Poison Strip Sandstone, the Ruby Ranch Member, and the Mussentuchit Member. The Yellow Cat Member, the Poison Strip Sandstone, and the Ruby Ranch Member outcrop in the study area near Arches National Park. The Poison Strip Sandstone is a fluvial sheet sandstone whereas the Yellow Cat and the Ruby Ranch members are predominantly calcareous mudstone; all contain a diverse vertebrate fauna, and are dated as Barremian to lower Albian. This study characterizes and interprets the fluvial systems responsible for deposition of the Poison Strip Sandstone through analysis of extensive field data and comparison to modern and ancient fluvial systems. Conclusions on fluvial style are related to depositional controls and to regional Lower Cretaceous rocks.

The Cedar Mountain Formation is investigated through facies, paleocurrent, vertical profile, and architectural profile analysis. Gravel facies consist of granule-pebble quartzose conglomerate, and granule-cobble intra-clast conglomerate of mudstone and carbonate nodules. Sand facies are numerous and include various types of cross-stratified sandstone, ripple-cross laminated sandstone, and plane-bedded sandstone. Gently inclined bar accretion surfaces occur locally. Fine-grained facies consist of massive mudstone and mudstone with carbonate nodules. Limestone facies include pedogenic calcrete and lacustrine limestone. Paleocurrent indicators show a strong northeast direction, although with moderate dispersion. The stratigraphic architecture displayed by the Cedar Mountain shows a consistent pattern through the field area: 1) a lower calcareous mudstone, the Yellow Cat Member, 2) a medial sandstone 2 to 15 meters thick, the Poison Strip Sandstone, and 3) an upper mudstone with carbonate nodules, the Ruby Ranch Member. Vertical lithofacies sequences in the Poison Strip Sandstone typically fine-upward, although sequences also commonly occur without order or trend. Investigation of two-dimensional architectural profiles of the Poison Strip Sandstone suggests deposition in channels of varying character with the most common types as low-moderate sinuosity channels with lateral bars, and distal, braided channels.

Sedimentation in the Poison Strip Sandstone was controlled by multiple extra-basinal and intra-basinal factors, of which the Sevier thrust belt is regarded as the most significant. Avulsion, both intra-channel and entire channel belt, is interpreted to be a more influential intra-basinal control than lateral accretion processes in construction of the Poison Strip Sandstone. Slow subsidence rates, likely related to a medially positioned forebulge, limited accommodation development during the Aptian-Albian which caused fluvial systems to migrate extensively across one stratigraphic level. The braided sheet Poison Strip Sandstone reflects deposition of a degradational systems tract, related to reduced accommodation development as a result of the migration of the forebulge into eastern Utah.

INTRODUCTION

The Cedar Mountain Formation of east-central Utah has been the topic of recent study through the contribution of numerous paleontologists (e.g. Gillette, 1999) – a rather surprising development given that early workers described the Cedar Mountain Formation as unfossiliferous. In spite of this, sedimentologic and stratigraphic studies have lagged behind this paleontologic research. The Cedar Mountain Formation consists of a westward-thickening wedge of terrestrial conglomerate, sandstone, and mudstone deposited between the underlying Morrison Formation and overlying Dakota Formation. The Cedar Mountain Formation occurs in south-central and northeastern Utah and northwestern Colorado; the coeval Burro Canyon Formation occurs in southeastern Utah and southwestern Colorado. Previous workers only recognized the basal Buckhorn Conglomerate as a separate member of the Cedar Mountain Formation. However in 1997, Kirkland and eight other authors subdivided the upper Cedar Mountain Formation into four units based on lithostratigraphic and vertebrate fossil evidence (Kirkland et al., 1997). These new members, in addition to the Buckhorn Conglomerate, are the Yellow Cat Member, the Poison Strip Sandstone, the Ruby Ranch Member, and the Mussentuchit Member.

[1] *Nadel and Gussman Permian, LLC, 601 N. Marienfeld, Suite 508, Midland, Texas 79701*

Pupose and Scope

The primary objective of this project is to examine in detail the Poison Strip Sandstone of the Cedar Mountain Formation and to characterize the fluvial systems responsible for its deposition. A facies model for the Poison Strip Sandstone is developed through the investigation of both measured sections and lateral outcrop profiles. The relative importance of depositional controls, both extra-basinal and intra-basinal, is assessed and compared to regional studies in order to clarify Early Cretaceous foreland basin development.

Field Area Description

The Cretaceous outcrop belt along the northern and western perimeter of Arches National Park as well as a small locality within the Park provide the area of study to address these issues (figure 1). These outcrops form homoclines on the northwest-trending Salt Valley anticline and as local exposures within Salt Valley and Cache Valley. The Cedar Mountain Formation crops out as distinct hogbacks (figure 2) between the Green River Desert to the north, and slick rock exposures within Arches National Park to the south. Continuous outcrop of the Poison Strip Sandstone in the field area allowed for detailed investigation of both alluvial facies and alluvial architecture. The field area also contains important dinosaur localities such as the Dalton Wells and Gaston quarries.

Previous Work

Lower Cretaceous deposits are problematic strata across the Western Interior of the United States. This is in part due to their similar appearance to the underlying Morrison Formation and overlying Dakota Formation. The lack of marker beds as well as lack of fossil control (Coffin, 1921) and/or radiometric ages has made correlation enigmatic. In 1952, Stokes named the Cedar Mountain Formation for thick con-

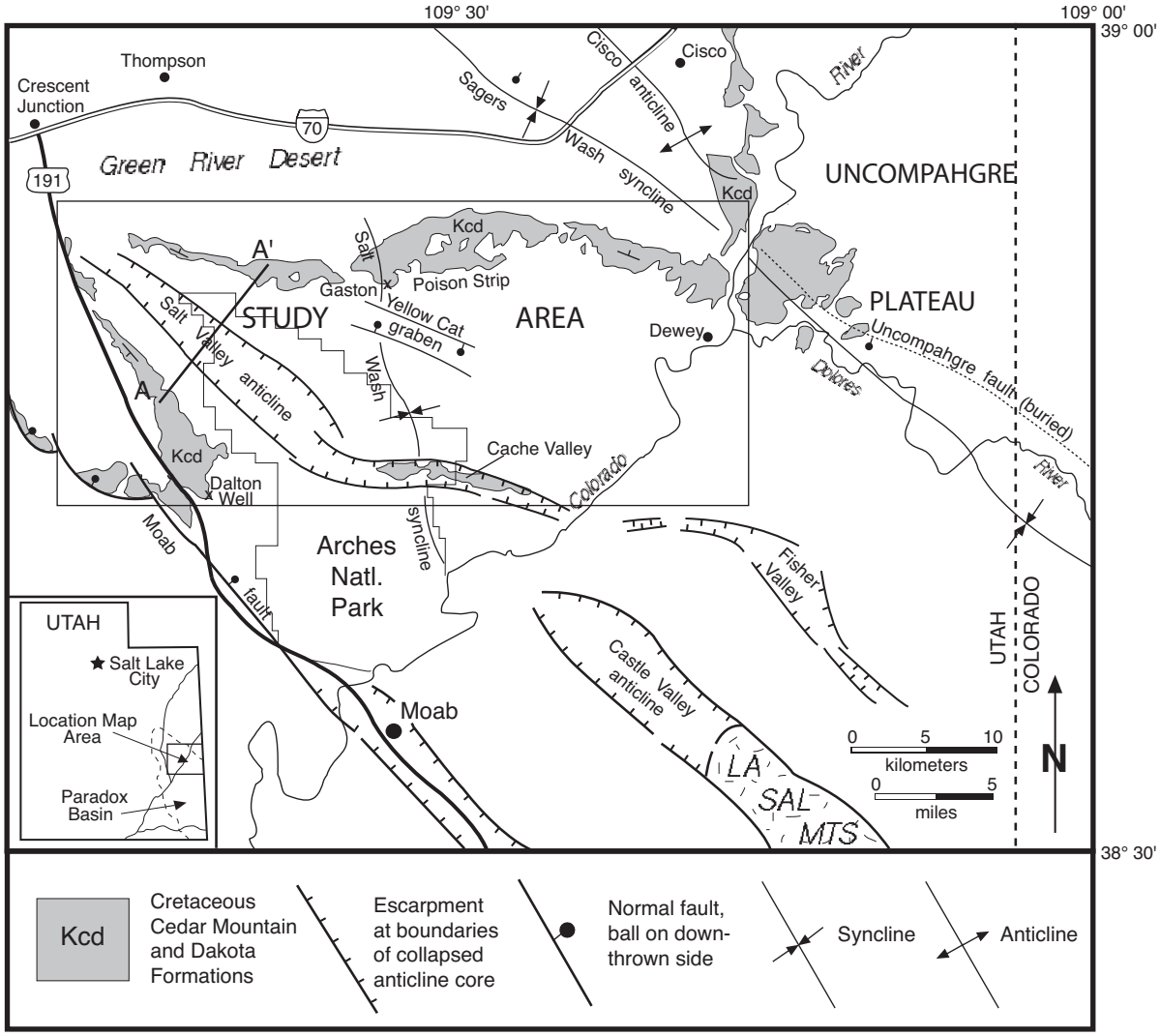


Figure 1. Location map of study area, modified from Doelling, 1996. Outcrop of Cedar Mountain and Dakota Formations from Hintze, 1980. A-A′ line of section in figure 9.

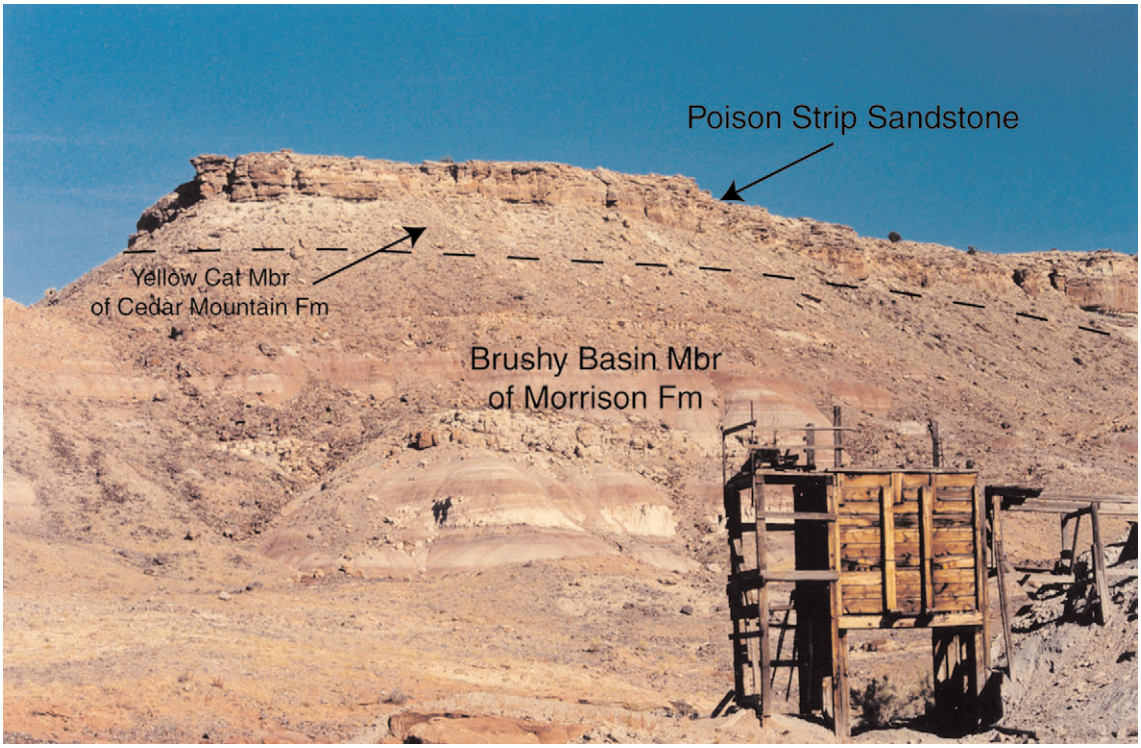


Figure 2. *Part of Morrison and Cedar Mountain Formations along the Poison Strip mining region, north-central section of field area.*

glomerate and shale exposures at Cedar Mountain on the northwest side of the San Rafael Swell (figure 3). Stokes (1944,1952), Young (1960), and Craig (1955, 1959) compiled early descriptive work on Lower Cretaceous deposits (both Cedar Mountain and Burro Canyon Formations) on the Colorado Plateau. They noted thickness distributions, the presence of chert-pebble conglomerate, gastroliths, mudstone with abundant carbonate nodules, and the largely unfossiliferous nature of the strata. Terminology consistent with that of the Colorado front range proposed by Young (1960), which placed the Cedar Mountain and Naturita Formations in the Dakota Group, was not widely accepted (figure 3).

Age control on these rocks improved through a combination of palynology (Tschudy et al., 1984), isotopic dating (Cifelli et al., 1997), and significant vertebrate fossil discoveries (Kirkland et al., 1997). These data indicate a Barremian-Albian age. Kirkland et al. (1997) subdivided the Cedar Mountain Formation into five members based on faunal and lithostratigraphic evidence. In ascending order the members are the Buckhorn Conglomerate, the Yellow Cat Member, the Poison Strip Sandstone, the Ruby Ranch Member, and the Mussentuchit Member. Vertebrate faunal assemblages contained in the three mudstone members – the Yellow Cat Member, the Ruby Ranch Member, and the Mussentuchit Member – displayed zonation separated by approximately ten million years each over the Barremian-Albian interval (figure 4). This informal subdivision has been applied to the Lower Cretaceous outcrop belt of east-central Utah only. Although not accepted by all subsequent workers, this subdivision has proven useful for the purposes of this project as the members represent roughly continuous facies belts throughout the field area. The author is aware that these new members may not qualify as formal members based upon the North American Stratigraphic Code (1983).

Currie (1997a, 1997b, 1998) made a significant contribution to the understanding of foreland basin development with his data compilation of the Lower Cretaceous rocks of Utah and Colorado. He divided the Cedar Mountain Formation into two parts: the lower Buckhorn Conglomerate consisting of sandy-gravelly braided channel deposits, and an upper shale portion of low-sinuosity channel sand bodies and overbank fine-grained deposits. These two facies assemblages were tied to flexural foreland basin development as a result of the developing Sevier thrust belt. Specifically, the Buckhorn Conglomerate represented deposition within the foredeep whereas the upper shale portion represented deposition over the foredeep and forebulge. Furthermore, Currie (1997a) placed the Morrison, Cedar Mountain, and Dakota Formations into a nonmarine sequence stratigraphic framework consisting of degradational, transitional, and aggradational systems tracts based on sandstone/mudstone ratios and sand body interconnectedness. In the Cedar Mountain Formation, the Buckhorn Conglomerate represented degradational and transitional system tracts while the upper Cedar Mountain represented transitional and aggradational systems tracts.

In the study area near Moab, Aubrey (1996, 1998) and Eberth et al. (1997) documented the effects of Paradox Basin salt tectonism on Lower Cretaceous sedimentation. They suggested that local lacustrine basins likely captured the oldest sediments (Barremian of Yellow Cat Member) in the Cedar Mountain Formation prior to the initiation of Cretaceous thrusting in the Sevier Orogenic belt. Eberth et al. (1997) interpreted an unusual facies, structureless pebbly siltstones, as debris flow deposits at lake margins; Kirkland et al. (1997) interpreted this facies as the result of dinosaur bioturbation.

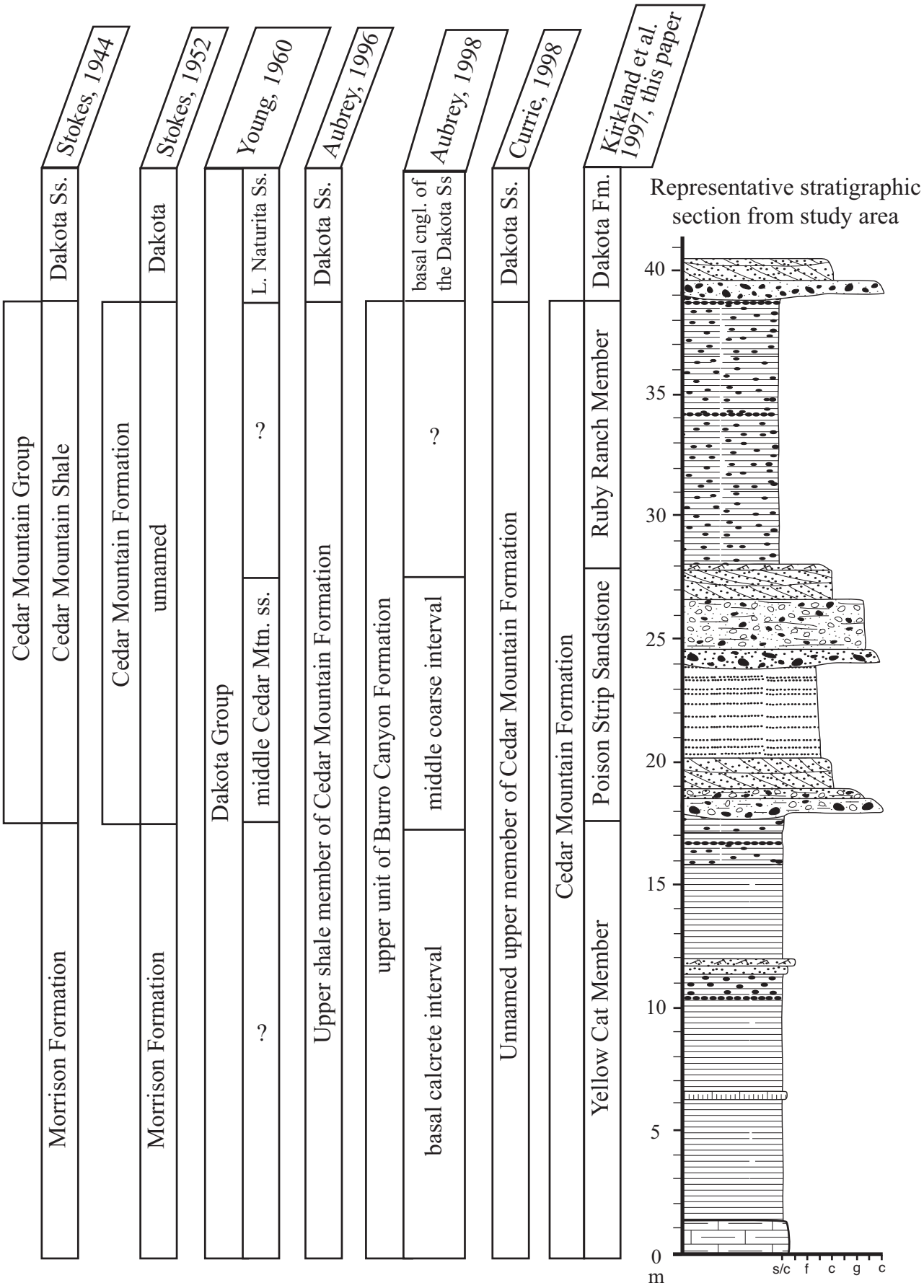


Figure 3. *Late Jurassic through middle Cretaceous stratigraphic nomenclature progression as applied to field area.*

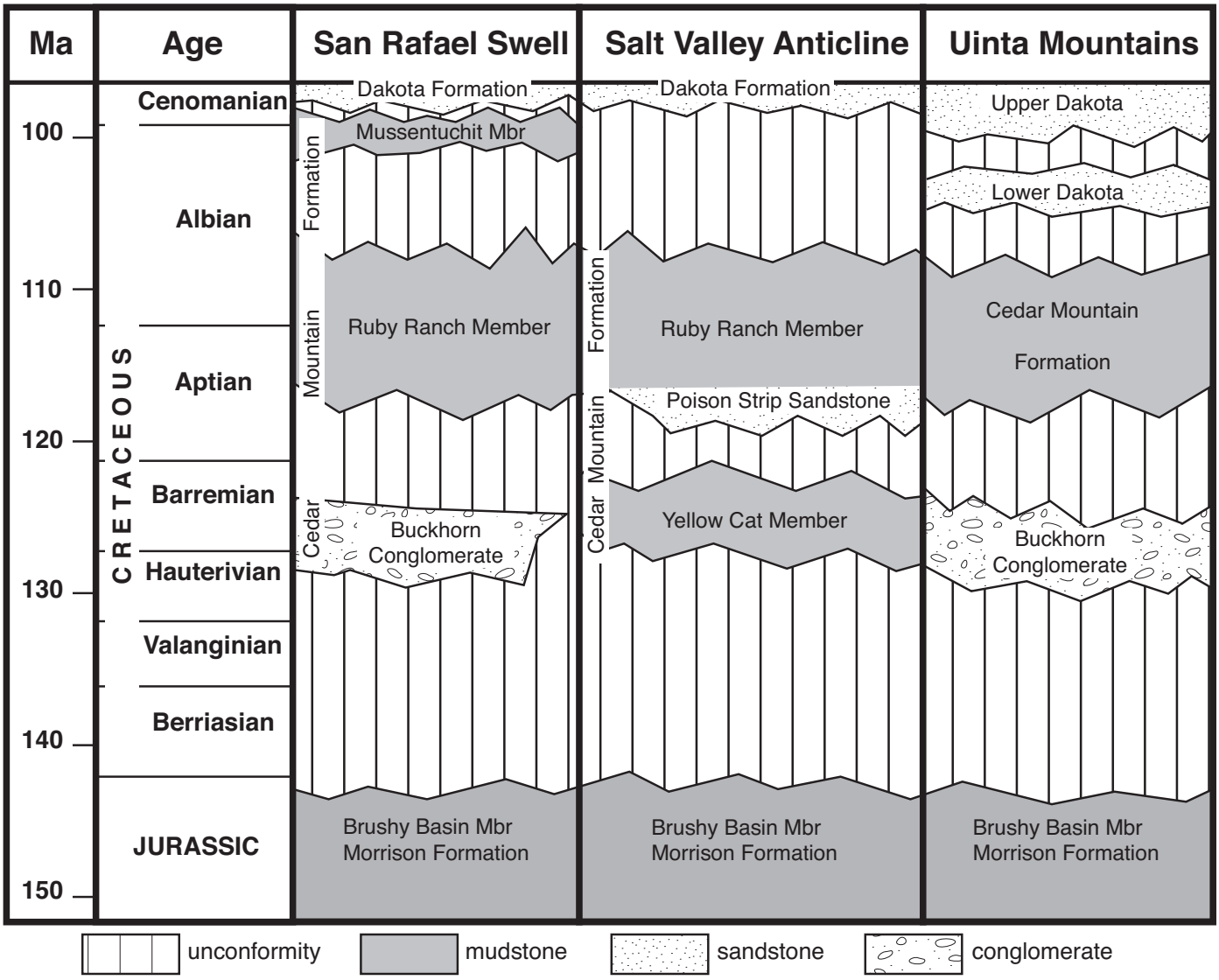


Figure 4. *Chronostratigraphic chart of Lower Cretaceous rocks on the central Colorado Plateau. Modified from Kirkland et al., 1997, and Currie, 1998, time scale of Gradstien et al., 1995.*

Stratigraphy

Regional Stratigraphy

The Cedar Mountain Formation is exposed in narrow belts across the western and northern Colorado Plateau (figure 5). Exposures flank the San Rafael Swell, the Henry Basin, the Uinta Basin, and continue along the desert east of Green River. The Cedar Mountain Formation everywhere lies unconformably upon the Late Jurassic Morrison Formation. The nature of this unconformity is unclear and has been the point of considerable debate. Estimates of the duration of the hiatus are based upon radiometric dates and terrestrial vertebrate fauna. The Brushy Basin Member, which is the uppermost member of the Morrison Formation, is considered latest Jurassic (Tithonian) in age (Turner and Peterson, 1999) and has yielded Ar/Ar dates ranging from 147.6 ± 0.8 to 150.2 ± 0.5 Ma (Kowalis, 1991, 1998). The lowest vertebrate discovery from the Cedar Mountain Formation has faunal affinities to the Barremian of Europe and to the Lakota Formation of South Dakota (~132 Ma) (Kirkland et al., 1997). Based on this data, the unconformity represents 15 to 25 million years (Obradovich, 1993). This gap is recognized throughout North America in strata correlative to the Cedar Mountain Formation such as the Cloverly Formation of the northern Rocky Mountains, the Antlers Formation of Oklahoma, Arkansas, and Texas, the Paluxy and Twin Mountain formations of Texas, and the Arundel Formation of Maryland (Kirkland et al., 1997). These formations have been broadly considered Aptian–Albian in age and thus they overlie a significant, widespread latest Jurassic–earliest Cretaceous unconformity.

The basal deposit of the Cedar Mountain Formation is the Buckhorn Conglomerate, which consists of chert-pebble conglomerate. The unit crops out in the Henry Basin, around the San Rafael Swell, in the Uinta Basin, but not in the study area. The unit shows fluvial paleoflow to the northeast and has been interpreted as occupying a broad northeast trending

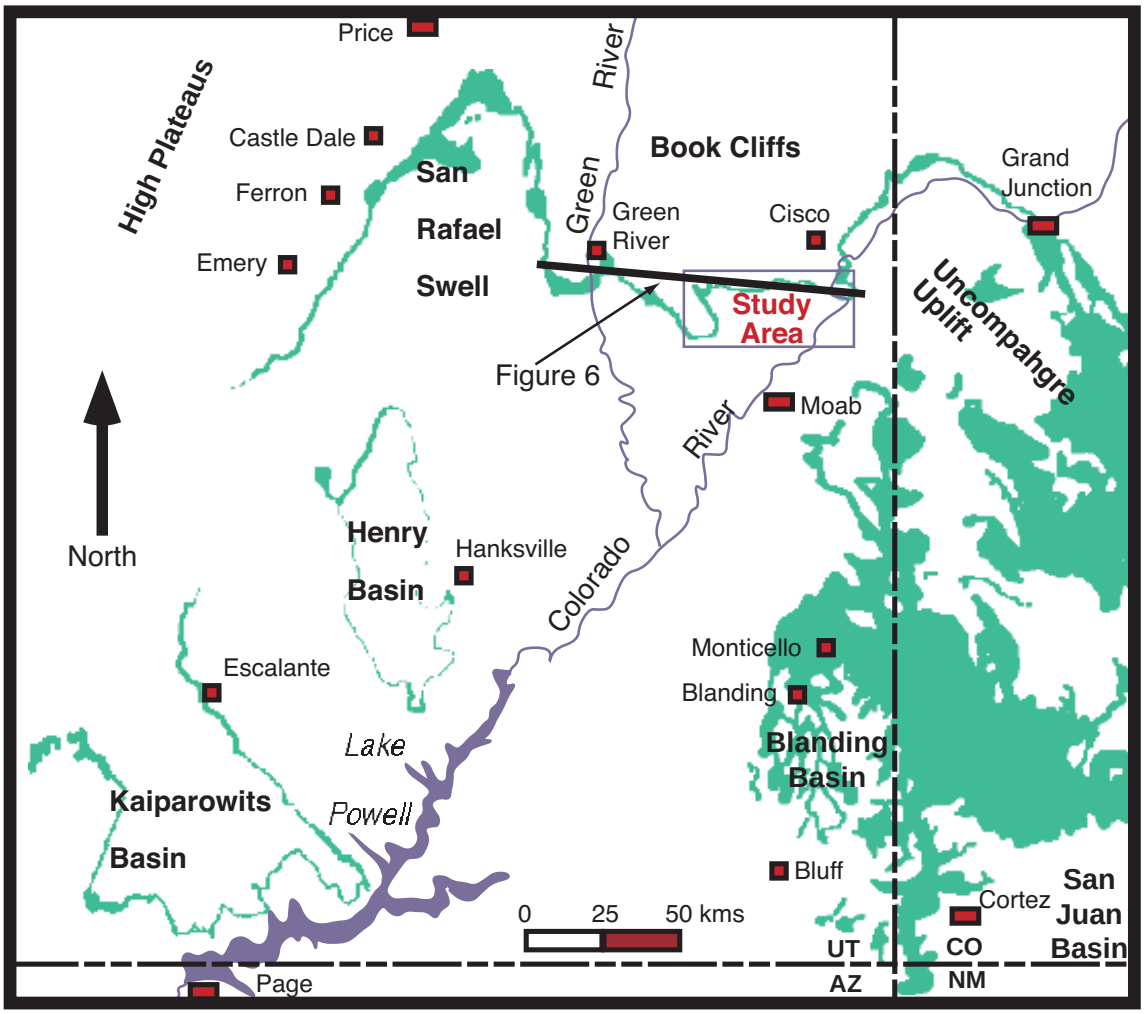


Figure 5. Map of the central Colorado Plateau showing distribution of Cedar Mountain, Burro Canyon, and Dakota Formations in relation to study area. Modified after Kirkland et al., 1997.

valley (Currie, 1998). Similar basal Cretaceous chert conglomerates are present throughout the Western Interior including the Kootenai Formation of Montana and the Cloverly Formation of Wyoming (DeCelles, 1986; Heller et al., 1986). These conglomerates are thin and widely distributed, which suggested to Heller and Paola (1989) that their deposition predated formation of the Cretaceous foreland basin. The Buckhorn Conglomerate has yet to be dated by means other than stratigraphic position and is considered to be variously Late Jurassic (Aubrey, 1996), mid-Neocomian (Currie, 1998), or Early Cretaceous (Kirkland et al., l997).

The upper shale portion of the Cedar Mountain Formation has remained formally unnamed (figure 3). It is composed of mudstone with carbonate nodules and minor ribbon sandstone. The upper unnamed member was considered by early workers to be primarily unfossiliferous except for a few mollusc and plant fossils (Stokes, 1952; Katich, 1951; Simmons, 1957; Thayn, 1973). The upper part of the Cedar Mountain thickens markedly to the west, recording the onset of Cretaceous thrusting and the development of an asymmetric foreland basin (Heller and Paola, 1989). Kirkland et al. (1997) subdivided the upper shale member into four informal members based on rough lithofacies distributions and vertebrate fauna that were observed throughout the San Rafael Swell, the Henry Basin, and the outcrop belt east of Green River (figure 6). Three of the four new members, the Yellow Cat Member, the Poison Strip Sandstone, and the Ruby Ranch Member are exposed in the study area and will be discussed in the following section. The youngest member, the Mussentuchit Member, is named for Mussentuchit Wash on the southwest side of the San Rafael Swell. It is a gray smectitic mudstone with carbonaceous material but lacks typical Cedar Mountain Formation carbonate nodules. This member averages 25 meters in thickness and occurs only in the western San Rafael Swell and the Henry Basin (figures 4 and 6). Based on radiometric dates (Cifelli et al., 1997) and palynology (Nichols and Sweet, 1993) the Mussentuchit Member crosses the Albian-Cenomanian boundary and may be part of the Cenomanian Dakota Formation (figure 4) (Kirkland et al., 1997).

Local Stratigraphy

Upper Jurassic Morrison Formation, Brushy Basin Member

The Cedar Mountain Formation in the study area overlies the Brushy Basin Member of the Upper Jurassic Morrison For-

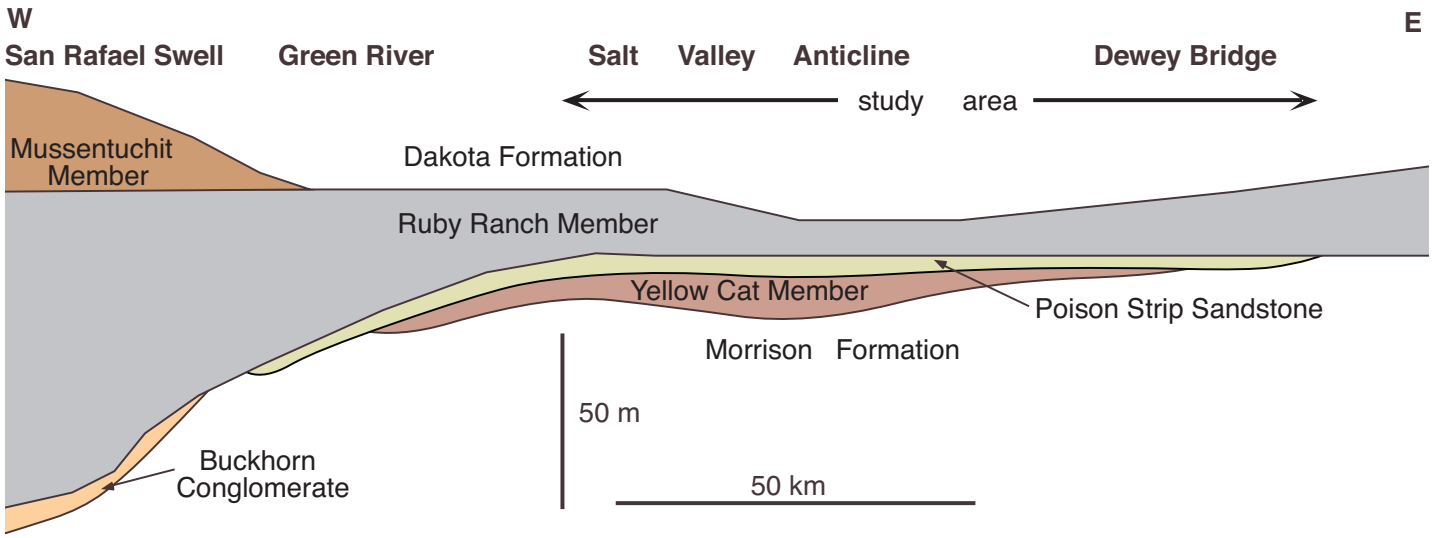


Figure 6. *Cross-section for east-central Utah displaying the distribution of the new informal Cedar Mountain Formation members. Line of section shown in figure 5. Modified after Kirkland et al., 1997.*

mation. The Brushy Basin consists of highly smectitic mudstone with minor sandstone ribbons and conglomeratic sandstone ribbons (Keller, 1962). It forms slopes and badlands covered with "popcorn" textured or variegated surfaces. The Brushy Basin Member is widespread throughout the Colorado Plateau and is 90-140 meters thick in the study area (Doelling, 1985), exhibiting vibrant banded colors of blue and green or deep red/maroon (figure 2). Fossils discovered in the field area consist only of a few sauropod remains, but the Brushy Basin Member is very fossiliferous in other parts of the Colorado Plateau (e.g., Dinosaur National Monument, Turner and Peterson, 1999). Radiometric ages (Kowallis et al., 1991) from the middle of the Brushy Basin Member indicate a late Jurassic age; however the upper part of the member is poorly constrained and may be Late Jurassic or Early Cretaceous. The unconformity at the top of the Brushy Basin Member has one or more of the following characteristics in the field area:

- well-developed paleo-calcrete horizon,
- change in mudstone color,
- presence or absence of mudstone color banding,
- yellow/orange mottling (early soil development),
- gastroliths (vertebrate stomach stones?), and
- thin chert gravel lag deposits, (deflation surface).

The presence of highly smectitic mudstone in the Brushy Basin Member has been interpreted as lacustrine and overbank deposits supplemented by large quantities of volcanic ash (Turner and Peterson, 1999).

Lower Cretaceous Cedar Mountain Formation

Yellow Cat Member: The basal Cretaceous deposits in the study area consist of mudstones of the Yellow Cat Member (figure 6). The member is 10-15 meters thick, consists of predominately non-smectitic mudstone, and contains numerous carbonate nodule horizons. Massive to nodular carbonate development, quite different from the common nodules, exists at some well-exposed locales. This type of carbonate has been interpreted as a groundwater calcrete rather than pedogenic calcrete (Eberth et al., 1997). Colors range from blue/green to maroon/purple, which are similar to those of the Brushy Basin Member; however colors are more subdued, drab, mottled and lack distinct banding. Structureless, silty sandstone beds are distributed throughout the member and are commonly 0.5-1.0 m thick but may reach lenticular thicknesses of 10 meters. Silty sandstone units are laterally persistent but may grade into micritic limestone or claystone beds. The Yellow Cat Member produces common ankylosaur fauna from the Dalton Wells and Gaston quarries, both located within the study area. These quarries are significant because they contain the oldest Cretaceous vertebrate fauna (Barremian) yet discovered on the Colorado Plateau (Kirkland et al., 1997). Recent discoveries including the Crystal Geyser Quarry (Kirkland et al., 2005) have revealed a distinct, earlier Cretaceous fauna from horizons below the assumed calcrete Jurassic/Cretaceous boundary (Kirkland pers. comm., 2005) suggesting subdivision of the Yellow Cat into lower and upper members. This has significant implications including placement of the calcrete within the Cedar Mountain Formation rather than developed atop the Morrison Formation, a concept proposed by Aubrey in 1998. Based upon this new evidence, the Morrison contact is placed at the first occurrence of chert pebbles above the highly smectitic clays of the Brushy Basin Member (Kirkland, 2005).

The type section of the Yellow Cat Member is near Yellow Cat Flat, southwest of the Gaston Quarry (figure 1). This member has been interpreted to be the product of overbank and lacustrine deposition and subsequently altered by soil formation and fluctuating groundwater levels. The structureless, silty sandstone beds have been interpreted as debris flow deposits at the margins of shallow lakes (Eberth et al., 1997), whereas others prefer a dinosaur bioturbated interpre-

tation (Kirkland et al., 1997). Eberth et al. (1997) and Aubrey (1996) supported the influence of salt tectonics in the deposition of this basal mudstone. Eberth et al. (1997) contend that long-standing salt withdrawal of the Salt Valley anticline was instrumental in creation of a localized, shallow basin. Aubrey (1996) suggested that axial graben formation along the Salt Valley anticline, rather than salt withdrawal, was the cause of local basin development.

Poison Strip Sandstone: The Yellow Cat Member is overlain by the 2 to 15 meter-thick Poison Strip Sandstone, a sheet-like fluvial succession of sand bodies. This laterally continuous sandstone unit occurs from Green River eastward to Dewey Bridge, but is best developed within the study area (figure 6). The basal contact is an erosional scour with up to 5 meters of relief. The magnitude of the unconformity between the Yellow Cat Member and the Poison Strip Sandstone is approximately ten million years based on vertebrate fauna (Kirkland et al., 1997). The Poison Strip Sandstone is composed of very fine to very coarse-grained sandstone, pebbly sandstone, and conglomerate. Sedimentary structures include trough-cross stratification and planar cross-stratification with minor ripple cross-lamination and horizontal stratification. A typical vertical sequence in the Poison Strip Sandstone (figure 3) commences with a basal conglomerate overlain by trough cross-stratified sandstone, changing upsection to horizontally stratified sandstone and capped by ripple-bedded sandstone or heterolithic sandstone - mudstone, low-angle cross-stratification. Clast lithologies are an assemblage of durable white, gray, and black chert with subordinate quartzite and limestone. Mineralogic composition of sand within the Poison Strip Sandstone is predominantly quartz with minor feldspar and lithic fragments. This mineralogic maturity is inherited from the source area, which was a thick succession of Proterozoic through Mesozoic sedimentary rocks contained in the thrust sheets of the Sevier thrust belt west of the study area (Currie, 1998). The Poison Strip Sandstone has generally been interpreted as the deposit of a meandering stream system (Kirkland et al., 1997). Sediment dispersal patterns are to the northeast, similar to those of the Buckhorn Conglomerate; however, these systems were most likely geomorphically separated from each other (Currie, 1998; DeCelles, 1986). It is currently not possible to directly correlate these two units, as the Buckhorn Conglomerate has yet to be accurately dated (Kirkland et al., 1997). Dinosaur fossils are rare in the Poison Strip Sandstone, but the few discoveries are similar to those in the overlying Ruby Ranch Member, which is dated as Aptian-Lower Albian (Kirkland et al., 1997). The type section for the Poison Strip Sandstone is near the center of the study area; an area with a high concentration of uranium mines (figures 1, 2) termed the "Poison Strip." These mines in the Morrison Formation were operational in the 1950s and 1960s while the federal government subsidized the price of uranium.

Ruby Ranch Member: The Ruby Ranch Member conformably overlies the Poison Strip Sandstone. This fine-grained unit is widely distributed throughout east-central Utah and is 10-30 meters thick in the study area (figure 6). The unit consists of drab purple or green non-smectitic mudstone and contains abundant carbonate nodules. Septarized carbonate nodules, ribbon sandstone bodies, and thin carbonate nodule or chert horizons are common. This unit has been interpreted as pedogenically altered overbank deposits and low-sinuosity fluvial deposits (Currie, 1998). Vertebrate fauna within this member are similar to those contained in the Poison Strip Sandstone which indicates an Aptian-early Albian age (Kirkland et al., 1997). The member was named for the Ruby Ranch homestead to the northwest of the study area (Kirkland et al., 1997).

Upper Cretaceous Dakota Formation

The Cedar Mountain Formation is unconformably overlain by the Dakota Formation (Doelling, 1996). In the study area, the unconformity displays relief of up to five meters and has a magnitude of approximately 10 million years (Kirkland et al., 1997). The Dakota Formation is thin (2-10 m) and discontinuous throughout the study area. Dakota sandstone is yellow/brown and contrasts with the tan sandstone of the Cedar Mountain Formation. The Dakota Formation consists of conglomeratic fluvial units, which contain larger clasts than those of the Poison Strip Sandstone. Rarely, the Dakota Formation exhibits thick, coarsening-upward sand bodies of marginal-marine origin that were deposited during the initial westward transgression of the Cretaceous Interior Seaway. Coals and carbonaceous mudstone common elsewhere to the Dakota Formation are absent within the study area. Fossils contained in the Dakota Formation compare with typical Late Cretaceous faunas and have been dated as middle to early late Cenomanian (Kirkland et al., 1997).

Paleo-tectonic and Climatic Setting

During the Early Cretaceous, subduction of the Farallon plate along the western margin of North America resulted in development of the Sevier thrust belt across the Western Interior (figure 7) (Lawton, 1994; Jordan, 1981). This thin-skinned thrust belt flexurally deformed the crust causing formation of a foreland basin immediately to the east. Eastern Utah and western Colorado were located within the foreland basin and occupied a portion of an expansive alluvial plain that extended eastward from the thrust belt. The foreland basin was asymmetric and increased in depth toward the thrust belt as evidenced by a Lower Cretaceous sedimentary wedge that thickens and coarsens westward (Lawton, 1994). The foreland basin contained foredeep, forebulge, and backbulge depozones that migrated eastward in response to Sevier thrusting (Currie, 1998).

Timing of foreland basin development in the Western Interior is controversial. Based on present outcrop patterns, the Morrison Formation and lower portion of the Cedar Mountain Formation (Buckhorn Conglomerate) do not thicken westward and this evidence has been used to exclude a foreland basin setting during their deposition (Heller and Paola, 1989). However, other workers have suggested that a foreland basin was continuous from the Late Jurassic through the Cretaceous (Bjerrum and Dorsey, 1995; Currie, 1998). The lack of thrust related basin development during latest Jurassic through Neocomian time may have been caused by a decrease in convergence rates, or oblique convergence of the Farallon plate (Currie, 1997b). Isopachs of the upper portion of the Cedar Mountain Formation (Aptian-Lower Albian) show marked westward thickening and have been recognized by some as the earliest deposits in the foreland basin (Lawton, 1994; Yingling, 1987).

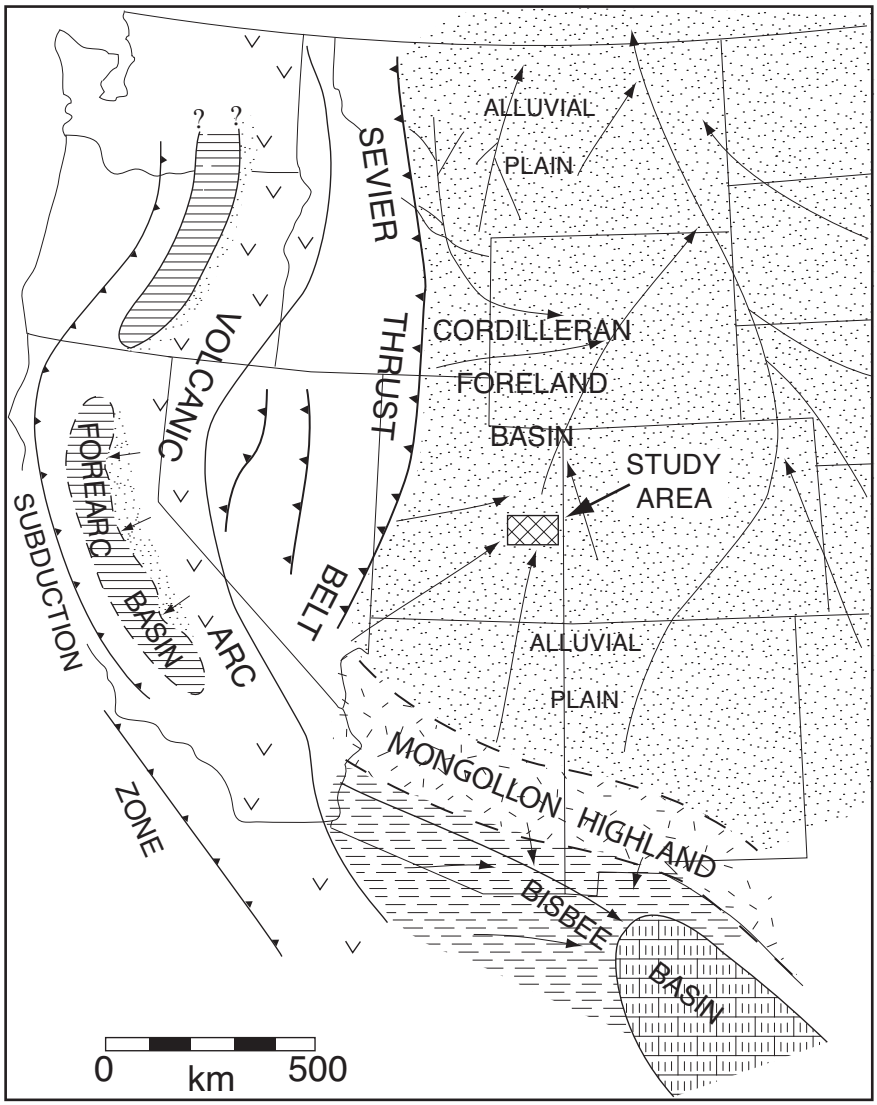


Figure 7. *Paleogeographic map of the western United States during the late Early Cretaceous (Albian) depicting major tectonic elements (from Lawton, 1994) in relation to the field area. Arrows show sediment dispersal patterns.*

Within the study area, the influence of salt tectonism on the foreland basin has been proposed by Eberth (1997) and Aubrey (1996). The study area is located over the northern portion of the Paradox Basin, a Pennsylvanian-Permian basin that accumulated thick evaporite deposits (Baars and Stevenson, 1981). These salt deposits deformed after burial and formed into northwest-southeast trending anticlines (figure 8), including the Salt Valley anticline in the study area (figure 9). Paradox salt tectonics effected sedimentation prominently through the Permian and Triassic (Hazel, 1994), less significantly through the Jurassic (Doelling, 1985), and may have effected Cretaceous sedimentation as well. It is likely that the Salt Valley anticline experienced dissolution during the Early Cretaceous, which created a local, low-relief basin that captured the basal mudstone and limestone of the Yellow Cat Member (Kirkland et al., 1997).

Previous studies indicate that the late Early Cretaceous climate of the Colorado Plateau was semi-arid to monsoonal, similar to that of the Morrison Formation (Kirkland et al., 1997). The abundant calcareous paleosols imply that carbonate material accumulated in the soil profile rather than being leached from it, similar to modern soil processes in arid settings (Birkeland, 1999). The commonly preserved conifer logs and ankylosaur fauna, however, suggest that the environment was not extremely dry. Stable isotope research by Skipp (1997) indicated that the climate became progressively more humid through Cedar Mountain deposition and into Dakota deposition; a transition to Late Cretaceous wet climates.

Methods

Methods employed in this project include stratigraphic section measurement, fluvial architectural analysis, and paleocurrent analysis. Twenty-two stratigraphic sections were measured at locations evenly distributed throughout the field area. The Poison Strip Sandstone was documented in detail, whereas the mudstone-rich Ruby Ranch and Yellow Cat Members were given cursory examination. The sedimentol-

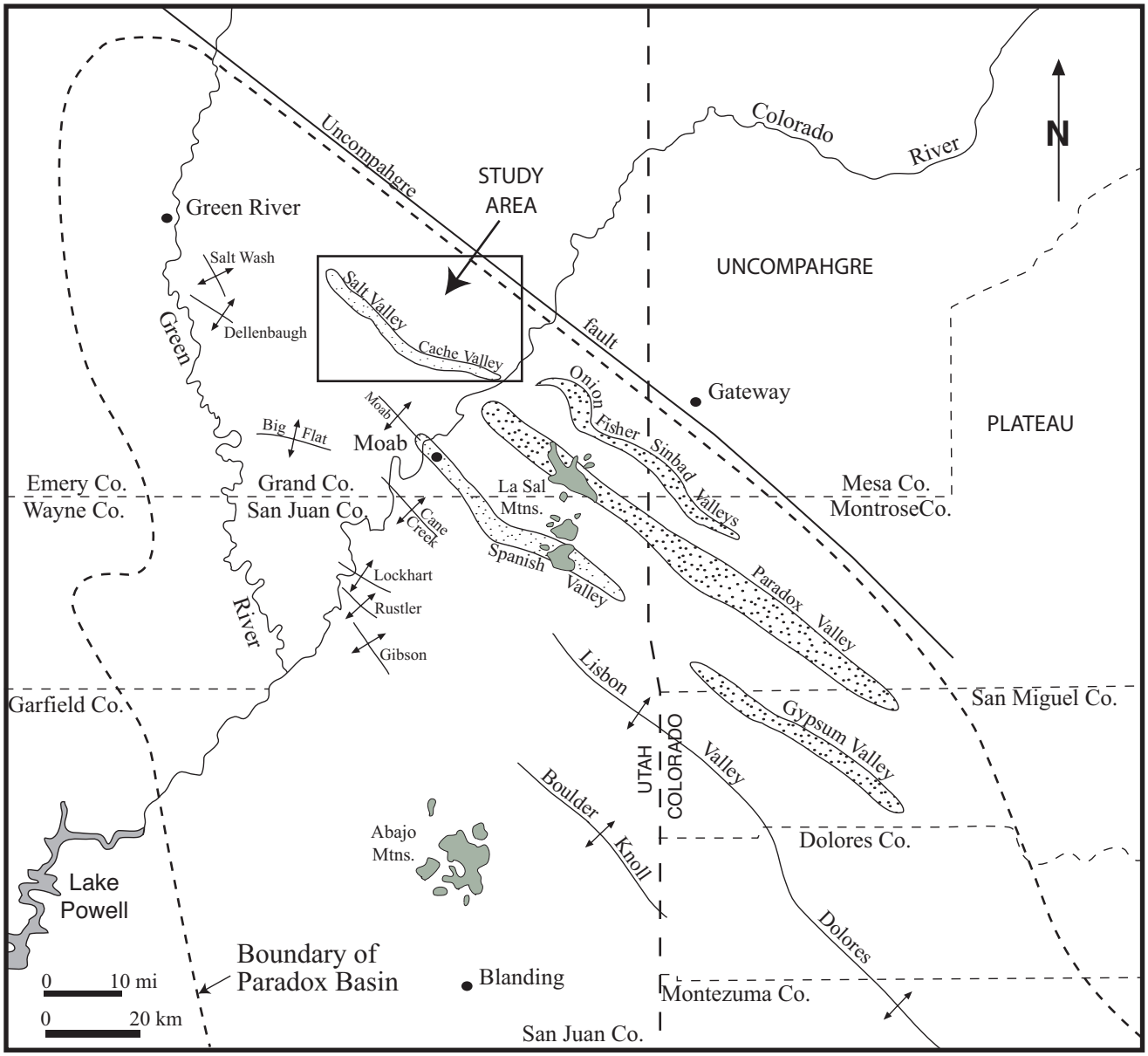


Figure 8. *Study area location in relation to Paradox Basin fold and fault belt. Stippled valleys are collapsed anticlinal crests; many other fold axes remain intact (from Doelling, 1985).*

Figure 9. *A-A′ cross-section in the northwest part of the field area straddling the northern end of the Salt Valley (see figure 1 for line of section). The topography and near surface geology from Doelling (1985), and diagrammatic subsurface geology from Lohman (1975). Width of cross-section is approximately 12 km.*

ogy and stratigraphy were documented by unit thickness, nature of contacts, sedimentary structures, textural variation, mineralogic variation, and diagenetic alteration. Using photo-mosaics, five lateral profiles of the Poison Strip Sandstone were analyzed in conjunction with the measured sections. The resulting architectural analysis documented the two-dimensional distribution of sedimentary facies, sedimentary structures, paleocurrents, and architectural elements. Paleocurrent measurements were determined (and corrected for structural tilt where necessary) by recording the dip direction of cross-strata and the trend of current parting lineation.

Subsequent laboratory work consisted of point-counting ten medium-grained sandstone samples from the Poison Strip Sandstone. Twenty additional slides from the Poison Strip Sandstone and other strata were examined for identification and qualitative description.

SEDIMENTARY FACIES

The Cedar Mountain Formation is characterized by a heterolithic assemblage of sedimentary rocks including conglomerate, sandstone, mudstone, and minor carbonate rocks. Across eastern Utah and western Colorado the formation is primarily mudstone, however within the study area the Poison Strip Sandstone accounts for one-quarter of the preserved thickness. The lithofacies defined in this study are recognized in an effort to accurately define the fluvial systems responsible for deposition of the Poison Strip Sandstone. The facies codes used in this project are a modification of the Miall fluvial lithofacies scheme (1977, 1996). Significant modifications include additional sandstone facies Sla and Ss. Facies Sla denotes lithosomes of gently inclined, heterolithic sandstone-mudstone strata and facies Ss represents massive, silty sandstones that occur as tabular, laterally continuous bodies. Facies Ss is completely unrelated to the "scour fill" definition given by Miall (1996). Other additions to the Miall system include facies Fc signifying mudstone with carbonate nodules, and facies L for micritic limestone units. Important elements used to describe these sedimentary facies are presented in table 1.

The designation and definition of lithofacies are based upon the correlation of a rock of certain characteristics and a specific environment of deposition (Reading, 1978, 1996). In a practical sense, sedimentary facies are defined in this study by "lithological, structural, and organic aspects detectable in the field" (De Raaf et al., 1965). Using this premise enables accurate environmental interpretations based upon our current understanding of modern depositional processes and environments.

Table 1. *Lithofacies summary displaying codes, physical characteristics, and depositional interpretations. Codes adapted from Miall, 1977, 1996.*

FACIES	LITHOFACIES	TEXTURES	STRUCTURES	GEOMETRY	INTERPRETATIONS
Gm	massive gravel	primarily pebble/cobble conglomerate, typically in sand matrix	structureless or crude horizontal bedding	lensoid, basal scour surfaces	channel lag deposits, diffuse gravel sheets, overbank incorporation
Gs	stratified gravel	primarily pebble conglomerate, typically in sand matrix	cross-stratified or horizontally stratified	lenses above scour surfaces, thickness to 5 m	Dunes, linguoid bar fronts or bar tops, lower flow regime
St	trough cross-stratified sand	med. to very coarse sand, commonly pebbly	trough cross-strata	cosets to 10 m thick, widths 10s-100s m	3-D dunes, upper portion of lower flow regime
Sp	planar cross-stratified sand	med. to very coarse sand, commonly pebbly	planar cross-strata, tangential base common	narrow, tabular sheets	2-D dunes, transverse bars, lower flow regime
Sr	ripple cross-laminated sand	very fine to medium sand	climbing and solitary sets	thin lenses or tabular sheets	falling stage, lower flow regime, crevasse splays
Sh/Sl	plane bed or slightly inclined plane bed sand	very fine to med. sand	plane-bed or low angle lamination, parting lineation	narrow sheets	upper flow regime or lower flow regime, bar tops, crevasse splays, shallow flow
Sla	heterolithic sandstone/mudstone	sand – very fine to med.; silt and clay	low-angle cross-strata	laterally restricted units, thickness to 3 m	lateral accretion surfaces
Ss	silty sandstone	very fine-med sand with silt and floating pebbles, disarticulated vert. remains	massive, stuctureless	continuous tabular sheets or lenticular; thickness 0.5-10 m, width 10s-1000s m	lake margin debris flows? dinosaur bioturbated horizons?
Fm	mudstone	silt and clay	massive – fissile	tabular units	floodplain and lacustrine deposits
Fc	mudstone with carbonate nodules	silt and clay, carbonate nodules - typically cobble size	massive – nodular; pedogenic alteration	tabular units	pedogenically altered overbank deposits
Fl	heterolithic sandstone/mudstone	very fine to med sand; silt and clay	horizontal lamination	tabular units	proximal overbank, waning flood flow, crevasse splay
P	calcrete	nodular limestone with mud and floating chert granules/pebbles	coalescing nodules, blocky	discontinuous sheets, often lenticular; thickness to 3 m, width 10s-100s m	pedogenic calcrete
L	limestone	micritic, marly limestone	irregular lamination	thin, laterally continuous units	lacustrine limestone

Conglomerate Facies

Description

Conglomerate forms a significant component of the Poison Strip Sandstone, especially at the base of scours and channels. Both extraformational and intraformational clasts are present. Extra-clasts include granules and pebbles (average diameter 2-15 mm), which are generally subrounded to well-rounded. Quartzose clasts predominate and include varieties of chert, quartzite, and quartz. Clasts primarily display drab colors including gray, white, tan, and brown with trace red and green varieties. Most extra-clasts are non-imbricated as many grains are subrounded to well-rounded. Intra-clasts range from granule to boulder size but are commonly granule to cobble size. Intra-clast colors vary with clast lithology and include green, white, or tan mudstone and dark gray carbonate nodules. Intra-clasts show little evidence of flow fabric despite a common angular to subrounded grain shape. A count of 100 clasts from a granule-pebble conglomerate sample collected at the northeast end of the Salt Valley yielded the following percentages.

Quartzose clasts*	
Dark Gray:	9
Light Gray:	28
White:	12
Tan:	8
Brown:	6
Green:	5
Red:	0
Carbonate Clasts:	0
Tan Mudstone Clasts:	12

* Quartzose clasts grouped since unequivocal field identification of granule-sized clasts was not possible

Conglomerate sorting is generally poor and ranges from grain supported to matrix supported, although matrix support is more common. The majority of conglomerate is massive, but stratification does occur and includes both horizontal stratification and trough and planar cross-stratification, characteristics used in facies classification. Conglomerate percentage and distribution varies greatly as discussed below but ranges from beds of nearly pure conglomerate, to pebbly zones within sandstone beds to pebble stringers along sandstone foreset surfaces. The amount of sandstone and mudstone matrix also varies between stratified and non-stratified deposits with non-stratified deposits containing a higher matrix percentage. The mudstone matrix, where present, usually is green or is less commonly white. The varying amount of matrix material can make differentiation between pebbly sandstone and sandy conglomerate (at least 30% greater than 2 mm) a subjective decision. Based on textural and compositional characteristics, much conglomerate contained within the study area classifies as quartzose, granule/pebble conglomerate (cf. Boggs, 1995).

Facies Gm – Massive Gravel

Deposits of massive or structureless conglomerate commonly line concave-up basal scour surfaces (figure 10). Thickness of these lithosomes is rarely greater than a few meters and is commonly less than one meter. Color ranges from white on fresh surfaces to brown on weathered, varnished surfaces. Green is the dominant color when the matrix has a significant mudstone component. Usually the gravel is matrix-supported by sandstone or by mudstone and sandstone mixtures. Intra-clasts of mudstone and carbonate nodules are common and range from granule to cobble size. Large blocks of mudstone and small boulder-sized carbonate nodules may be included within these gravels. Extraforma-

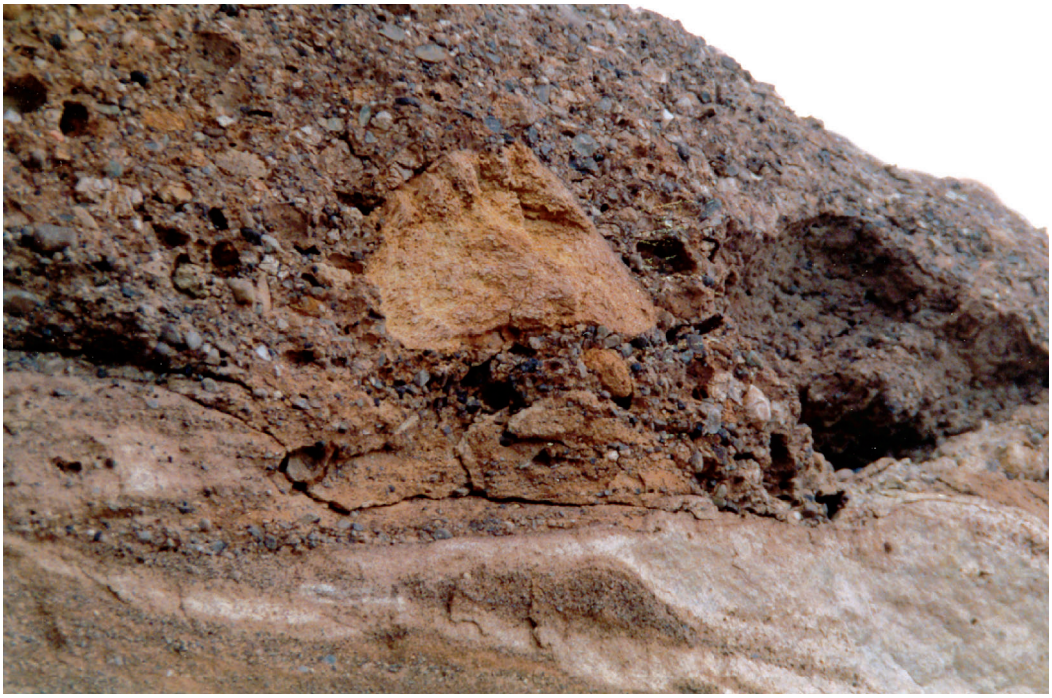


Figure 10. *Exposure of a vertebrate limb encased in massive, matrix-supported chert-pebble conglomerate, facies Gm, section 20. Diameter of bone approximately 15 cm. Chert clasts are primarily gray or white whereas intra-basinal carbonate clasts are tan.*

tional clasts are typically pebble-sized and consist of chert, quartzite, and other durable clasts. Crude horizontal bedding may be present as well as poorly developed normal grading.

Facies Gs – Stratified Gravel

Stratified gravel deposits are common in the lower half of sand bodies, especially in the western half of the study area (figure 11). This facies combines cross-stratified gravels and gravels with well-developed horizontal stratification. Color ranges from white on fresh surfaces to tan or brown on weathered, varnished surfaces. Geometrically, facies Gs may line concave-up scours or be present as rough tabular bodies. Typically, the gravel is matrix-supported by sandstone and is less commonly clast-supported. Granule-size to pebble-size intra-clasts of green and tan mudstone as well as gray carbonate nodules are common. Pock-marked surfaces of facies Gs attest to the presence of easily eroded intra-clasts. Extra-clasts of chert, quartzite, and other durable clasts are present in the granule to pebble size range. Trough cross-stratification is common and set thickness ranges between 0.1-1 m but is commonly between 0.1-0.5 m. Horizontally bedded gravel occurs less commonly and consists of gravel-lined stratification surfaces.

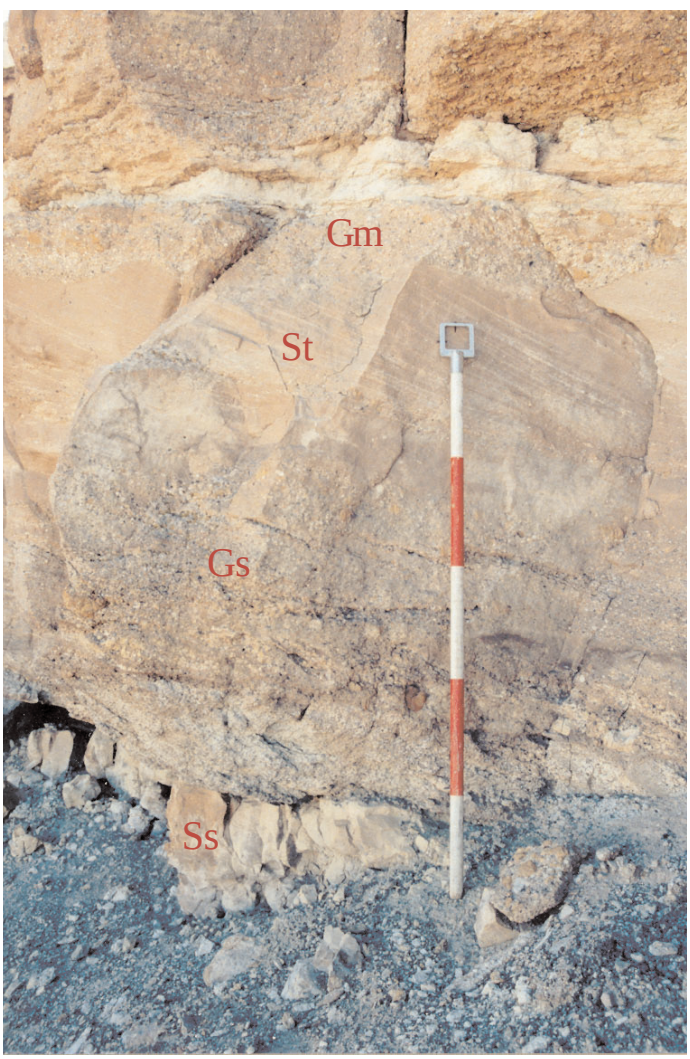


Figure 11. *Base of the Poison Strip Sandstone at section 19 exhibiting multiple fining-upward sequences. Staff measures 5.0 feet.*

Interpretation

The conglomerate contained within the study area was probably deposited by the migration of large bars or bedforms within a low-sinuosity braided river system. The massive, poorly graded, matrix-supported conglomerate was most likely deposited as a channel lag (Allen, 1965) or as diffuse gravel sheets (Hein and Walker, 1977). Deposition of massive conglomerate composed of intra-clasts was likely related to widespread scour during flood stage. Massive, crudely bedded conglomerate can also be deposited from the lateral and downstream growth of longitudinal bars as described from many modern braided streams (Doeglas, 1962; Ore, 1964; Williams and Rust, 1969; Bluck, 1979). The common matrix-supported texture is indicative of low flow strength that deposits sand and gravel simultaneously (Harms et al., 1975). Also, well-rounded gravels and sand can be hydraulically equivalent as explained by rolling and suspension relationships, another factor which may account for the common matrix support (Harms et al., 1982). Framework-supported gravels were probably in-filled with sand as flow strength decreased.

Stratified conglomerate was most likely deposited as the result of traction transport as three-dimensional dunes analogous to subaqueous dune formation in sands (Blatt et al., 1980). Alternatively, gravelly cross-stratification can form on the downstream faces of linguoid or transverse bars (Harms et al., 1982). This downstream bar-front accretion is caused by vertical bar aggradation, which occurs during lower flow regime conditions (Hein and Walker, 1977). Lithosomes of horizontally bedded conglomerate were likely deposited on gravel-capped bars (Bluck, 1979).

The abundance of intra-clasts including carbonate nodules and mudstone clasts indicate floodplain reworking and cut-bank incorporation (Allen, 1965), whereas the durable chert, quartzite, and quartz pebble clasts indicate reworking and recycling of sedimentary units in the source area (Dickinson and Suczek, 1979). The source area has been identified as the thrust sheets of the Sevier thrust belt, which include uplifted Precambrian through Jurassic siliciclastic and carbonate sedimentary rocks (Yingling, 1987; Currie, 1998). The coarse, angular, and poorly sorted intra-clasts suggest short transport distance between the site of erosion and the site of deposition. Bio-clasts such as tree fragments and vertebrate remains were likely washed from the floodplain into the channel by lateral accretion processes or during flood events (figure 10).

Sandstone Facies

Description

The Poison Strip Sandstone accounts for the middle portion of the Cedar Mountain Formation throughout the study area. In addition, there are common ribbon sand bodies in the upper section and rare thin sand bodies in the lower section. Weathered sandstone exhibits tan and varnished brown colors, whereas fresh surfaces are white or light tan. Sandstone ranges from very fine-grained to very coarse-grained but is predominantly medium to very coarse-grained. Sand grains are primarily subrounded to well-rounded and sorting ranges from very poor to very well sorted. Sorting is depend-

ent on grain size: coarse-grained sandstone is typically well-sorted and fine-grained sandstone is often poorly sorted. Extraformational pebbles are common and a continuum exists between sandy conglomerate and pebbly sandstone. Common stratification types include trough cross-bedding, tabular-planar cross-bedding, ripple lamination, and plane/inclined lamination. Overturned, recumbently folded cross-bedding occurs locally. Bedding thickness ranges from centimeter-scale upward to 10 meters, although most bedding is between 0.2 to 1.0 meters. Geometrically, sand bodies encompass a spectrum of sheets to lenses with varying thicknesses and shapes.

Sandstone Petrology

Although petrographic examination was not one of the objectives outlined in this project, a small sampling of sandstone and other lithologies were investigated for identification, classification, and comparison to previous studies (Yingling, 1987; Currie, 1998). Sandstone slides were stained for K-feldspar and at least 300 points were counted on each slide. Based upon thin section analysis of ten slides, framework sand grains consist of a mineralogically mature assemblage of monocrystalline quartz, polycrystalline quartz, chert (including chalcedony), and minor intra-basinal mudstone and carbonate clasts. The point-count results and recalculated percentages are listed in appendix 1. Monocrystalline quartz is rounded to well-rounded, commonly contains abraded overgrowths and varying degrees of undulosity. Although feldspar content is minimal, potassium feldspar content greatly exceeds that of plagioclase. Lithic grains are rare except when classifying chert and polycrystalline quartz in the total lithic population (Lt). Heavy minerals are nearly absent, except for a few zircon and tourmaline grains. Common cement types include micritic and spar carbonate cement, fibrous chalcedony, and normal quartz overgrowths. Sand bodies commonly display interbedded friable and indurated sandstone which is likely attributable to alternating fibrous chalcedony and carbonate cement (figures 12, 13, 17). These alternating cemented bands often take on bulbous or spherical shapes (figure 13). Harris (1980) recognized similar cementation forms which crossed stratification surfaces near Green River in fluvial channels correlative to the Poison Strip Sandstone. However, the odd geometric shapes Harris described were composed of chert cement rather than chalcedony cement. The intergranular volumes indicate burial depths of 1 to 2 km prior to cementation (Paxton et al., 2002). The point-counted samples from the Poison Strip Sandstone classify as quartzarenite (McBride, 1963) or as sublitharenite (Folk, 1968). A QmFLt ternary diagram with the tectonic setting provenance fields of Dickinson et al. (1983) is presented in figure 14 (Average Qm, F, Lt = 89.2, 1.6, 9.2). The local sandstone is consistent with the regional provenance of the sedimentary rocks of the Sevier thrust belt, an interpretation which is well constrained (Currie, 1998). However, the local sandstone contains fewer lithics than those reported by Yingling (1987) and Currie (1998) and this may be due to the study area's increased distance from the source area and resulting attrition of all but the most stable grain types. Alternatively, this may be a reflection of the small sample size. Accordingly, the local sandstone plots in both the "craton interior" and "quartzose recycled" fields corresponding to the continental block and recycled orogen provenance categories respectively (Dickinson et al., 1983).

Facies St – Trough Cross-Stratified Sandstone

Trough cross-stratified sandstone is the most abundant facies within the Poison Strip Sandstone (figures 11, 15). Texturally, facies St consists of medium to very coarse-grained sandstone and commonly contains chert granules and pebbles. Foresets are often inclined at the angle of repose but occur equally as gently inclined surfaces (10-20?). Basal scour geometry ranges between scoop shaped (festoon) to broad scours. Sets have erosive lower and upper contacts and range in thickness between 0.1-1.5 meters but are commonly between 0.1-0.5 meters. Cosets of facies St amalgamate laterally and vertically to form ribbon and sheet sand bodies.

Facies Sp – Planar Cross-Stratified Sandstone

Planar cross-stratified sandstone is subordinate to trough-cross-stratified sandstone. Texturally facies Sp is similar to facies St consisting of medium-grained to very coarse-grained sandstone with an abundant granule to pebble fraction. Many trough cross-stratified sets resemble wedge-shaped planar sets, but when traced laterally they fill broad, shallow scours and thus are classified with facies St. Planar foresets are inclined at the angle of repose and commonly have a tangential contact with the lower set boundary. Planar set geometries include both tabular and wedge-shaped sets (McKee and Weir, 1953) and set thickness is typically between 0.1-0.3 meters, but range as large as 1.5 meters. Planar cross-stratified sets comprise thin, tabular sand sheets within the Poison Strip Sandstone.

Facies Sr – Ripple-Cross-Laminated Sandstone

Ripple-cross-laminated sandstone (laminae thickness less than 1 cm thick; McKee and Weir, 1953) of many types is moderately common within the Poison Strip Sandstone (figure 16). Rippled strata consist of very fine-grained to medium-grained sand and are moderately sorted containing a small silt or clay fraction. Ripple laminae have distinctive asymmetric morphology with steep lee faces and gently inclined stoss faces. Ripple marks exposed on bedding planes include both straight and sinuous crested varieties. Ripple-cross laminae are arranged as in-phase solitary trains, or as out-of-phase climbing sets. Bioturbation is very common within facies Sr. Facies Sr forms thin lenses or more continuous, tabular sand bodies.

Facies Sh/Sl – Plane Laminated to Slightly Inclined Laminated Sandstone

Plane bed lamination or slightly inclined plane bed lamination is widespread within the Poison Strip Sandstone and other sand bodies (figures 17, 18, 19). The facies consists of very fine-grained to medium-grained sandstone and may contain a minor fine-grained component. Individual bed thickness is on the order of a few centimeters. Current parting lineation is commonly displayed on fresh surfaces but weathers away rather quickly due to poor cementation (figure 19). In some instances, facies Sh/Sl is associated with

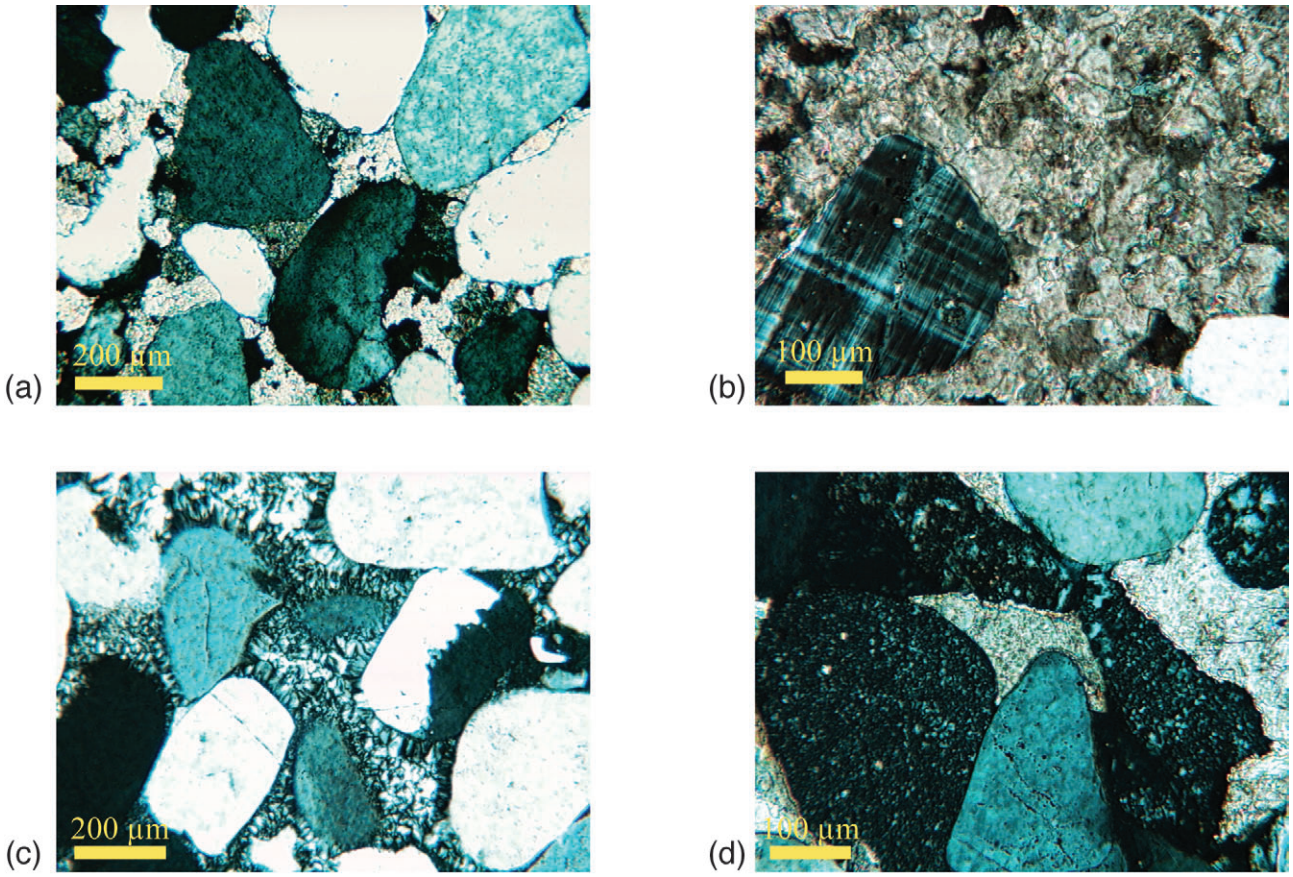


Figure 12. *Photomicrographs showing variations in texture, mineralogy, and cement type. (a) carbonate spar cement and rounded monocrystalline quartz grains, (b) K-feldspar grain floating in carbonate cement, uppermost sand body section 12, (c) fibrous chalcedony cement, (d) chert grains.*

a

b

Figure 13. *Unusual cement induced sandstone morphology. (a) layered cement bands of alternating chalcedony and carbonate cement at section 2. (b) spherical shaped forms at top of Poison Strip Sandstone, section 3.*

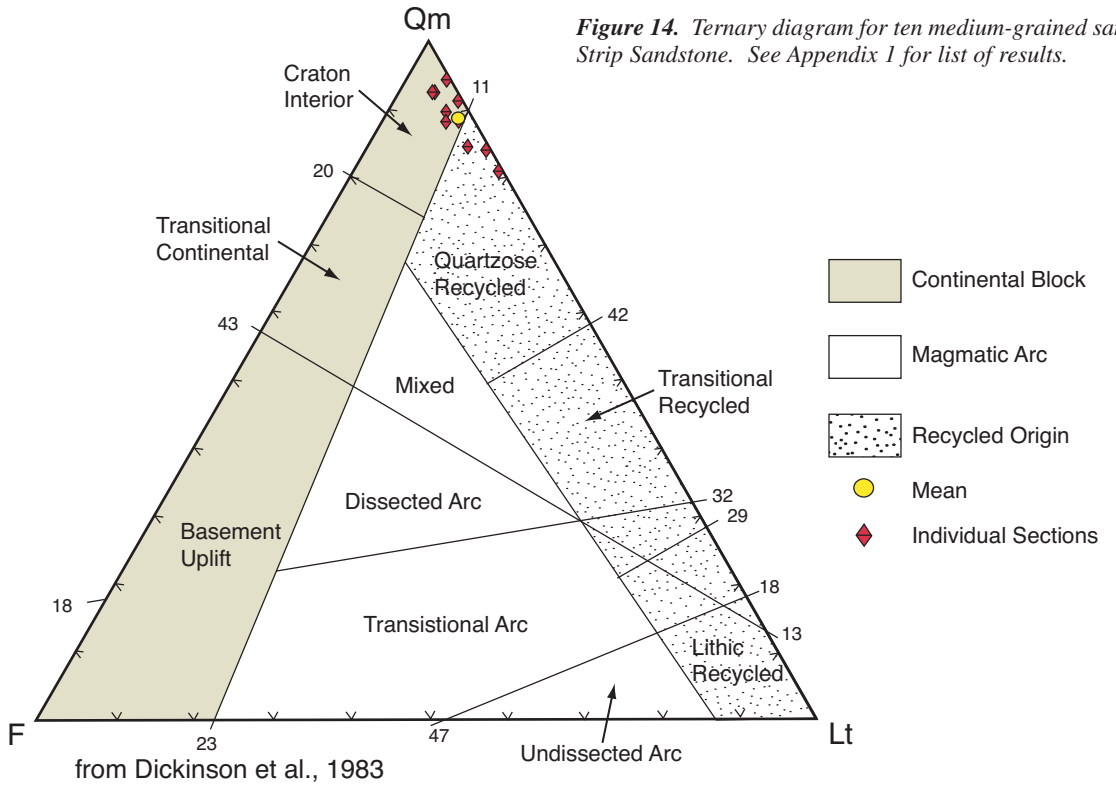


Figure 14. *Ternary diagram for ten medium-grained sandstone samples from the Poison Strip Sandstone. See Appendix 1 for list of results.*

Figure 15. *Well-exposed sets of facies St at section 9. Many foresets are gently inclined rather than at the angle of repose; indicative of low amplitude, long-wave-length dunes. Staff scale in decimeters.*

Figure 16. *Climbing ripple-cross-lamination at section 9. Staff scale in decimeters. This type of lamination classifies as type B of Jopling and Walker (1968) and is indicative of mixed bedload and suspension transport.*

Figure 17. *Thick succession of facies Sh/Sl over facies Gs at section 3. Note alternating dark and light thin beds which correspond to carbonate and fibrous chalcedony cementation bands. Staff measures 5.0 feet.*

Figure 18. *Sharp contact between facies Gm and facies Sh/Sl likely due to marked fluctuation of flow regime in shallow channels. Intra-basinal clasts consist of drab green mudstone and tan carbonate nodules. Extra-basinal chert is primarily black, gray, or white.*

Figure 19. *Current parting-lineation is commonly displayed on bedding-plane exposures of facies Sh/Sl.*

facies Sr, where plane lamination surfaces are lined with ripples. In these Sh/Sl/Sr occurrences, bioturbation is very common. Facies Sh/Sl forms tabular sheets of narrow extent and occurs as lithosomes near the top of sand bodies, commonly grading upward from facies St.

Facies Sla – Heterolithic Sandstone and Mudstone

Gently inclined heterolithic strata of alternating sandstone and mudstone comprise facies Sla. Facies Sla is rather uncommon within the Cedar Mountain Formation and does not form the classic, sigmoidal geometry with tangential upper and lower contacts (epsilon cross-stratification of Allen, 1963). The facies consists of very fine to medium-grained sandstone with interlaminations of green mudstone (IHS of Thomas et al., 1987), but can also occur without mudstone interlamination. In some instances, the gently inclined strata are traceable laterally for 5-10 meters and may attain heights of several meters. Lithosomes of facies Sla typically occupy horizons in the upper portion of sand bodies.

Facies Ss – Silty Sandstone

Anomalous sandy lithosomes, designated as facies Ss, are common within the Yellow Cat Member. Facies Ss consists of silty, very-fine-grained to medium-grained sandstone with clay and rounded pebbles. The pebbles are typically floating within the sandstone and consist primarily of reddish chert. Other floating, highly polished pebbles or cobbles (gastroliths) may be present within facies Ss. Randomly oriented dinosaur remains have been discovered in these lithosomes at localities including the Brigham Young University Dalton Well quarry. Stratification is lacking within these lithosomes and large-scale bioturbation occurs rarely. Infrequently, faint horizontal bedding or poorly defined ripple lamination occurs. Facies Ss usually forms tabular, laterally continuous sand bodies which are 0.5-2 meters in thickness and 100s of meters to kilometers in width. These tabular bodies have a very regular, vertical fracture pattern that yields rhomboid sandstone blocks. Less commonly, facies Ss consists of thick lenses (up to 10 meters) that transition laterally to the more common 0.5-2.0 meter height. Facies Ss may transition laterally into micritic limestone (facies L) or into laterally continuous, claystone beds.

Interpretation

Sandstone lithofacies commonly overlie gravel lithofacies in fining-upward cycles probably created by a combination of channel and bar evolution in bedload braided rivers. Modern braided rivers as described by numerous authors contain lateral and midstream bars that migrate and are dissected in response to fluctuating flow conditions (Doeglas, 1962; Coleman, 1969; Collinson, 1970; Smith, 1970; Cant and Walker, 1978; Bluck, 1979). Additionally, lateral-accreting point bars may have played an important role in sand body construction as explained by numerous studies of modern and ancient meandering river deposits (Allen, 1965, 1970; McGowen and Garner, 1970; Jackson, 1976).

The sandstone lithofacies were created by the migration of bedforms within a fluvial system. Bedform geometry is controlled by three primary variables: grain size, flow depth, and flow velocity (Ashley, 1990). Furthermore, the sand lithofacies are interpreted in terms of lower and upper flow regime as outlined by hydraulic-engineering flume studies (Simons and Richardson, 1961) and as subsequently applied to sedimentology (Harms and Fahenstock, 1965).

Trough cross-stratification (facies St) forms in the upper part of the lower flow regime by the migration of three-dimensional dunes (figure 20). Three-dimensional dunes typically form on the floor of channels or atop bars (Harms et al., 1963, 1975, 1982). Dune geometry shows a strong correlation with water depth (Allen, 1968). The common gentle scour surfaces and gently inclined foresets indicate bedforms of low amplitude and relatively long wavelength that may be created by washed out dunes, which occur as flow stage or flow depth decrease (Cotter and Graham, 1991; Miall, 1996). An alternative theory for the formation of low amplitude, long wavelength dunes is the transition from lower to upper regime flow occupying a stage of the continuum between angle of repose dunes and plane-bed lamination (Simons and Richardson, 1961; Williams, 1971).

Planar cross-stratified sandstone deposits (facies Sp) are created at lower flow velocities than three-dimensional dunes by the migration of straight-crested or two-dimensional dunes (Harms et al., 1982). Of equal importance in the creation of planar cross-bedding is the downstream accretion of transverse bars (Smith, 1970, 1971). Other fluvial sub-environments where planar cross-bedding may develop include the tops of mid-channel bars and within side bars.

Ripple cross-laminated sandstone (facies Sr) occurs at the top of fining-upward cycles and probably represents low-velocity flow in shallow channels or high upon channel bars. Ripples may also form during falling-stage or shallowing conditions during a flood recession. Single ripple-trains or climbing ripple-sets form depending on flow velocity and the rate of sediment supply (Jopling and Walker, 1968). Thin, ripple-form strata incased by fine-grained deposits are most likely the result of crevasse splays upon the floodplain.

Plane bed lamination and slightly inclined plane bed lamination (facies Sh/Sl) with current parting lineation are the results of super-critical, upper regime flow. These conditions would have existed during peak flood flow as occurs during flash floods on ephemeral streams (McKee et al., 1967; Picard and High, 1973; Miall, 1977). Where plane and low-angle cross-lamination occur together, formation may have taken place in the transition between lower and upper stage flow. Research by Saunderson and Lockett (1983) indicated that scour hollows in the lee side of dunes decrease in scale as flow velocity increases leading to low-angle lamination. Plane bed and slightly inclined plane bed lamination, when associated with ripple cross-lamination, is interpreted to have formed in shallow channels under sub-critical, rather than super-critical flow conditions.

Heterolithic deposits of gently inclined strata (facies Sla) were most likely formed by lateral channel migration such as occurring by fluctuating flow conditions high on point-bars (Allen, 1963). When the strata occur in a non-heterolithic manner the interpretation of lateral migration is still preferred.

Massive, pebbly, silty sandstones (facies Ss) possibly represent shallow, poorly channelized debris flow deposits between fluvial and lacustrine settings as interpreted by Eberth et al. (1997). An alternative hypothesis for massive bedding could be widespread bioturbation, an explanation preferred by some paleontologists (Kirkland et al., 1997). Although vertebrate remains are found in strata near and within these lithosomes, little to no evidence of bioturbation is present. The presence of common reddish quartzose clasts within facies Ss were likely scoured from agate in the underlying Brushy Basin Member (see measured section 22), as described by Yingling (1987). A thorough investigation of these lithosomes was not performed in this study and thus no further interpretation is provided here.

Overturned recumbently folded cross-bedding (facies St, Sp) is interpreted to have formed by a passive folding caused by penetrative shearing of saturated sediments (figure 21) (Rust, 1968; Allen and Banks, 1972; Turner, 1981; Wells et al., 1993). The beds were likely sheared by flashy, flood related forces. A substitute explanation is earthquake triggered liquefaction resulting in deformation of saturated sediments. Ore (1964) identified overturned cross-beds in the correlative Cloverly Formation of Wyoming and these may have formed contemporaneously with those in the Poison Strip Sandstone.

Fine-Grained Facies

Description

Fine-grained rocks dominate the lower and upper portion of the Cedar Mountain Formation within the study area, the Yellow Cat and Ruby Ranch members respectively. These units are drab blue-green or drab purple-maroon and are composed of siltstone and moderately smectitic claystone with varying proportions of fine-grained to very fine-grained

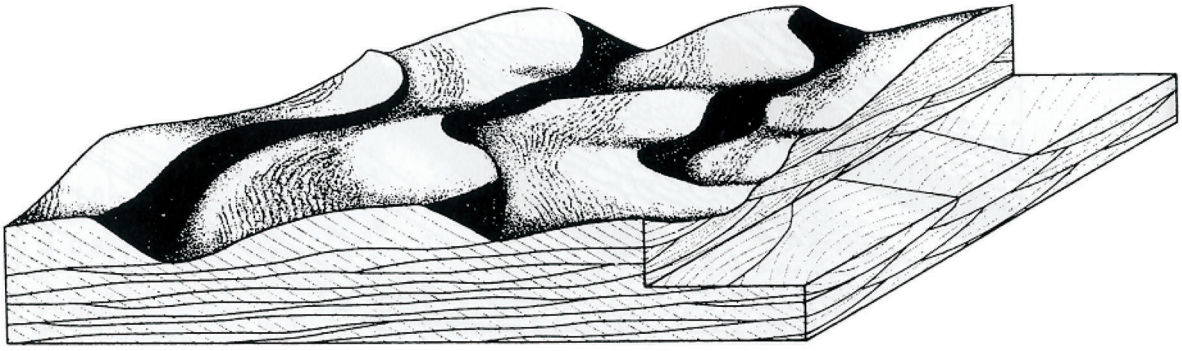


Figure 20. *Aggrading trough cross-strata as illustrated by Harms et al., 1982. The majority of the Poison Strip Sandstone is composed of lithofacies St which is envisioned to have been deposited in a similar fashion.*

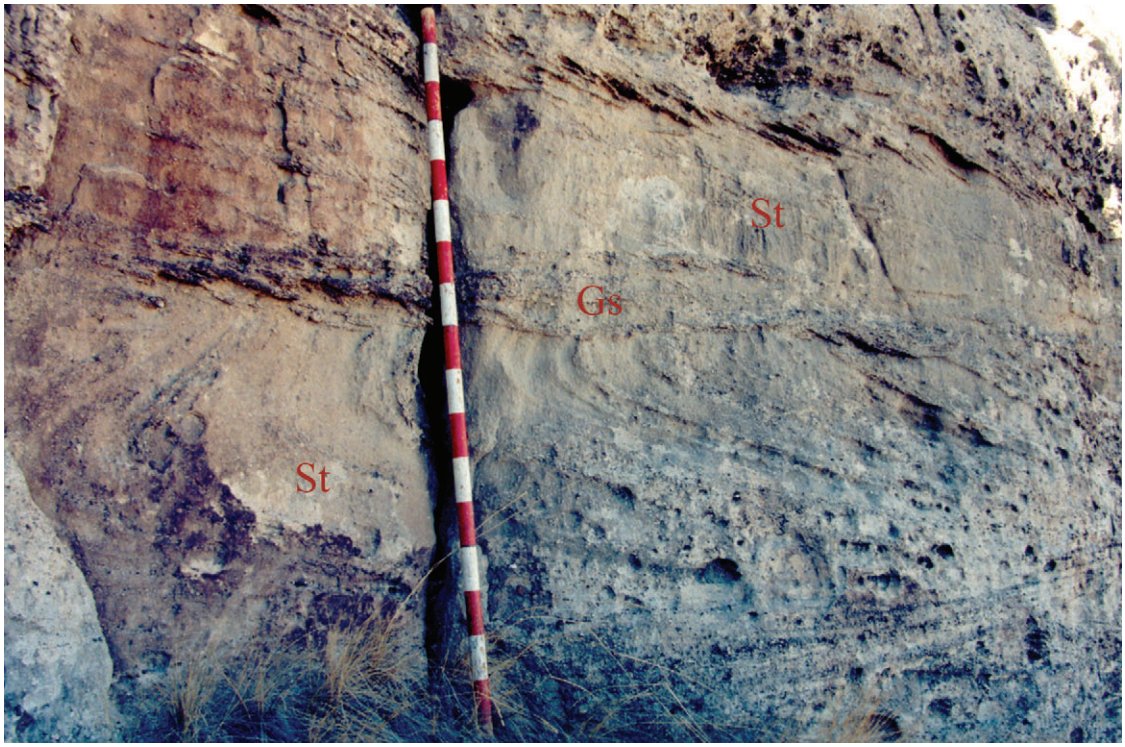


Figure 21. *Overturned, recumbently folded cross-strata at measured section 9. Overturned strata are truncated by several small-scale sets of facies Gs and St. Sediment transport direction to the right, staff scale in decimeters.*

sandstone. The dominant clay minerals are illite and mixed layer illite/smectite (Skipp, 1997). Swelling clays create moderately variegated slope exposures, which have a tough, stiff surface. Due to this outcrop expression, stratification in the mudstones is rarely observed.

The mudstones are usually calcareous as evidenced by abundant carbonate nodules. Within the lower portion or the Yellow Cat Member, the carbonate nodules are white, have an ovoid shape, and range from 2-25 cm in size. The carbonate nodules commonly occur as sparsely distributed horizons in the Yellow Cat Member. Massive calcareous development is also common to the Yellow Cat Member and is well-exposed below cliff exposures of the Poison Strip Sandstone. Within the upper portion or the Ruby Ranch Member, the nodules are gray, have an irregular spheroid shape, are often septarized, range from 2-15 cm in size, and are more abundant than nodules in the Yellow Cat Member. Carbonate nodule horizons within the Ruby Ranch Member commonly create continuous, thin hardgrounds encased in mudstone.

Facies Fm – Massive Mudstone

Massive, fine-grained rocks make up a significant fraction of the sedimentary rocks within the field area. They typically comprise thick, laterally continuous units of drab green or drab purple mudstone. Lenticular mudstone bodies indicative of channel abandonment have not been observed within the field area. Where exposed facies Fm displays a laminated, fissile character. Lithofacies Fm contrasts with the more abundant mudstone with carbonate nodules, facies Fc.

Facies Fc –Mudstone with Carbonate Nodules

Mudstone with carbonate nodules is common to the Cedar Mountain Formation (Stokes, 1952). Texturally, lithofacies Fc is composed of siltstone, claystone, and very-fine-grained to fine-grained sandstone with pebble to cobble-size carbonate nodules. The carbonate nodules are commonly aligned in horizons or create thin hardgrounds. Many of the nodules have been partially septarized or agatized. The mudstone is drab green or drab purple or locally contains bands of white or gray.

Facies Fl – Laminated Fine-Grained Rocks

Facies Fl, laminated fine-grained rocks consist of thin beds of alternating fine-grained sandstone, siltstone, claystone, or mudstone. The tan, very fine-grained to medium-grained sandstone beds are generally structureless or ripple-laminated, contain a significant mudstone fraction, and have sharp upper and lower contacts. Mudstone beds are either drab green or drab purple and do not contain carbonate nodules. This lithofacies is commonly observed in exposures below the Poison Strip Sandstone, but may exist at other levels that are covered by slope debris.

Interpretation

The fine-grained lithofacies represent deposition of suspension load in overbank and lacustrine settings (Allen, 1965). This deposition occurs during separate increments from flood events, or as continuous settling from lakes or ponds. The moderately variegated, hard mudstone surface expression is attributed to a significant fraction of swelling clays (Skipp, 1997). Carbonate nodules are most likely pedogenic in origin and may reflect semiarid climatic conditions (Bown and Kraus, 1981). This widespread pedogenic modification indicates relatively low rates of sedimentation on the floodplain (Bown and Kraus, 1987). Alternatively, massive-concretionary carbonate development, common to the Yellow Cat Member, may be a groundwater feature, not directly related to soil formation (Eberth et al., 1997). The

Yellow Cat Member is typically drab green possibly reflecting high-water table conditions and gleying that were related to lacustrine settings. The common green mudstone is interpreted as the result of anaerobic, iron-reducing conditions, whereas iron-oxidizing, or aerobic, conditions are interpreted as the cause of the common purple mudstone. The thin sandstone bodies contained within facies Fl are attributed to waning flood deposits and crevasse-channel or crevasse-splay deposits. Thick successions of facies Fl are interpreted to be deposited in close proximity to the active channel belt (Miall, 1996).

Carbonate Facies

Description

Calcareous rocks within the Cedar Mountain Formation consist of primarily, pedogenically, and diagenetically deposited carbonate. Facies P and facies L are here designated because they record important environmental conditions that existed following deposition of the Morrison Formation and during deposition of the Yellow Cat Member. Lithosomes consisting of facies P and L occur mainly in the vicinity of the Salt Valley anticline and eastward to the Poison Strip.

Facies P – Calcrete

Facies P represents the nodular calcrete horizon at the base of the Cedar Mountain Formation (figure 22). The calcrete horizon may attain thickness of 3 meters but is commonly 0.5-2 meters thick. Internally the calcrete is composed of moderately indurated, gray to white coalesced carbonate nodules, concretions, and vadose pisolites ranging from 2-10 cm in diameter. The carbonate nodules occur in a matrix of either green or purple mudstone. Floating, red chert pebbles are commonly present within the carbonate nodules. The calcrete horizon is laterally continuous throughout the northwest portion of the field area but is discontinuous or absent in the balance of the field area. In some locations, there are multiple calcrete beds in the contact zone between the Morrison and Cedar Mountain formations.

Facies L - Limestone

Thin, clayey, micritic limestone beds are present within the lower portion of the Cedar Mountain Formation, especially in the western half of the field area. The limestone is gray, has irregular laminations, and may be replaced by red agate. These units are typically thin ranging from 0.1-0.5 meters. They are laterally continuous over hundreds of meters to kilometers in the western half of the study area.

Interpretation

Facies P is interpreted as a well-developed petrocalcic horizon or pedogenic calcrete formed on the upper surface of the Morrison Formation. New paleontologic evidence however, indicates that the calcrete may be entirely Cretaceous age in the Arches area (Kirkland et al., 2005). While the calcrete still represents a significant period of non-deposition, its magnitude is not likely the entire 25 million year gap between the latest Jurassic and the late early Cretaceous (Kirkland, 2005). Similar calcrete horizons have been described from many modern and fossil soils (Allen, 1974; Leeder, 1975; Bown and Kraus, 1987; Retallack, 1997). The connectivty of the carbonate nodules within the calcrete indicate classification in the stage III to stage V of Hawley and Gile (1966) or Machette (1985). The presence of calcrete suggests an arid to semiarid, oxidizing climate during deposition of the Upper Morrison and Lower Cedar Mountain Formations (Hubert, 1977). Volumetrically insignificant limestone (facies L) is interpreted as the deposits of shallow lakes (cf. Picard and High, 1972, 1981).

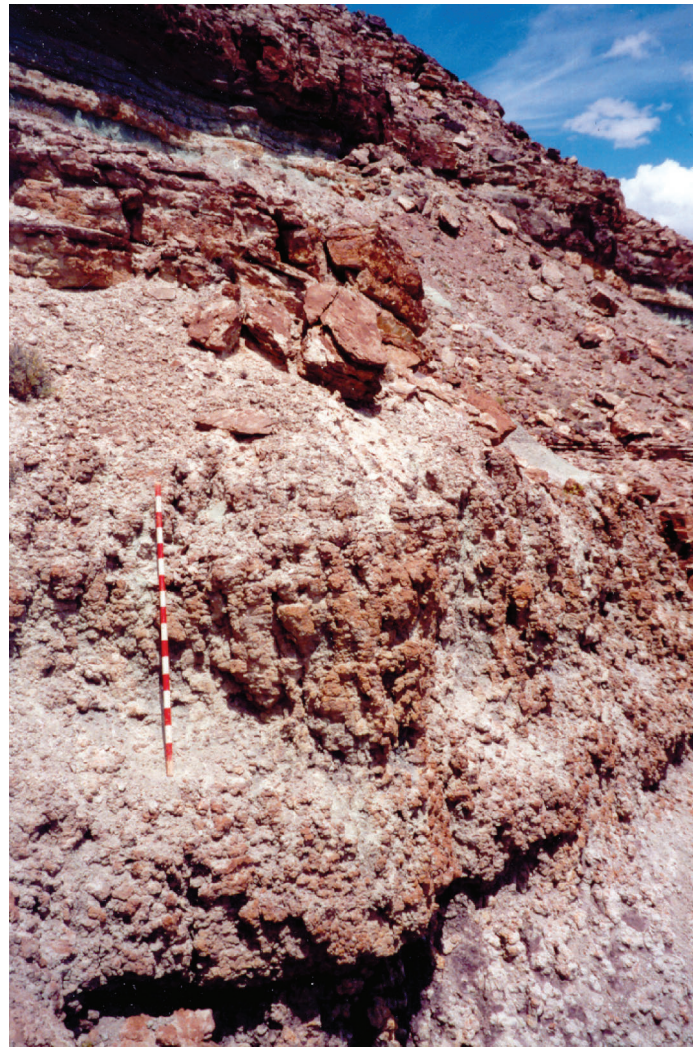


Figure 22. *Nodular calcrete at the top of the Morrison Formation, section 20. Staff measures 1.8 meters.*

STRATIGRAPHIC SECTIONS AND FLUVIAL ARCHITECTURE

This segment presents outcrop data gathered from measured sections and architectural panels to illustrate the range of fluvial styles exhibited by the Cedar Mountain Formation and to provide a synthesis and a fluvial facies model for the Poison Strip Sandstone. Eight weeks were spent in the field documenting twenty-two stratigraphic sections and five

architectural panels. No geologic mapping was performed as excellent geologic maps, including two 7.5 minute quadrangles, already exist (Williams, 1964; Doelling, 1985, 1993, 1996; Doelling and Morgan, 2000). The sections and panels were distributed throughout the field area at well-exposed locales of the Poison Strip Sandstone (figure 23). Section measurement consisted of documentation and photography of the lithofacies presented in chapter 2, including parameters such as lithology, grain size, bedding, nature of contacts, sedimentary structures, fauna/flora, and paleocurrent indicators. The individual measured sections are displayed in appendix 2 and are correlated along separate outcrop belts in figures 24, 25, and 26. Architectural panels were located at well exposed sand bodies oriented both parallel and perpendicular to the direction of paleoflow. Using the methodology outlined by Miall (1988), vertical facies maps of the Poison Strip Sandstone were created.

Paleoflow Evidence

Paleocurrent indicators were measured and recorded during both section measurement and architectural analysis. At locations where the structural dip was greater than 10 degrees (sections 10, 11, 13, 19, and 22), the paleocurrent measurements were restored using stereographic techniques. The dip direction of trough cross-strata was the predominant paleocurrent indicator although the dip direction of planar cross-strata and facies Sla was also logged. Lithofacies Sh/Sl commonly displayed current parting-lineation of which the trend was recorded. The strike of ripple crests was not measured as ripples tend to be ephemeral bedforms of high directional variance. Rose diagrams were plotted using Stereographic Projections, version 3.00; a program written by Martin Walters. Individual rose diagrams are presented for each measured section on a map of the field area in figure 27. Rose diagrams according to facies type and a combined rose diagram are presented in figure 28.

Architectural Analysis

Research on fluvial sedimentology in the last twenty years has pointed out the limitations of facies models based on conventional vertical profiles, and emphasized the lateral variability related to the internal geometry and organization of fluvial deposits (Collinson, 1978; Friend et al., 1979; Bridge and Diemer, 1983; Friend, 1983; Ramos and Sopena, 1983; Blakey and Gubitosa, 1984; Soegaard, 1990; Bridge, 1993). The concept of architectural analysis was introduced through quantitative modeling of fluvial systems by Allen (1978), Leeder (1978), and Bridge and Leeder (1979). Theories regarding bedform hierarchy were first developed for eolian sequences by Brookfield (1977) and Kocurek (1981). Formalization of architectural concepts for fluvial deposits, including architectural elements and bounding surfaces, was performed by Allen (1983) and later expanded upon and clarified by Miall (1985, 1988, 1991).

Bounding Surface Hierarchy

Bounding surfaces, as defined by Miall (1988), are surfaces of nondeposition or erosion that represent a lull or hiatus in the depositional system from periods of a few minutes to hundreds of thousands of years. Accordingly, a hierarchy of bounding surfaces then records the nature and rate of depositional processes operative within a fluvial system. Allen (1983) devised a three-fold classification of bounding surfaces, which led to the recognition of architectural elements using lateral profiles of the Old Red Sandstone from the Welsh Borders. An expanded scheme consisting of six bounding surface orders was presented by Miall (1985, 1988) to provide details to the analysis. Subsequently, Miall (1991) expanded the bounding surface types to include eight orders encompassing more regional surfaces and sequence-stratigraphic concepts. The annotated architectural panels displayed in this chapter were recorded and described using these methods of Miall (1985, 1988).

The first five of the eight bounding surface orders (Miall, 1991) are recognized in this study and each order is described in the following discussion. The bounding surfaces are essentially bedding contacts ranked according to size and significance as evidenced by cross-cutting relationships (figure 29). First-order bounding surfaces represent little or no erosion and simply bound cross-bedded sets of similar type. Cross-bed sets include bedforms or microform and mesoform deposits such as created by ripple and dune migration. These surfaces represent the continuous sedimentation by a train of bedforms of similar type at a given point in time (Miall, 1985). Second-order bounding surfaces outline microform and mesoform facies of similar type akin to the cosets of McKee and Weir (1953). These surfaces indicate changes in flow conditions or flow direction but with no significant break with respect to time. Second-order surfaces do not show significant erosion or bedding truncation (Miall, 1996).

Third-order and fourth-order surfaces ("minor surfaces" of Bridge and Diemer, 1983) bound genetically related facies into macroforms or bars and channels. These depositional products constitute facies associations and are used to demarcate the geometry of architectural elements; elements which are included in the construction of the facies model, the final interpretative step. Third-order surfaces are present within point bars (lateral-accretion macroform of Miall) as epsilon-crossbeds (Allen, 1963) and in transverse or linguoid bars (downstream-accreting macroform of Miall) as reactivation surfaces or bar fronts (Collinson, 1970). Surfaces within point bars typically dip at a low angle and represent deposition by lateral stream movement on point bars or side bars. Gently-dipping surfaces within transverse or linguoid bars are likely the result of erosion by larger scale events, such as seasonal floods or flow stage adjustments.

Fourth-order surfaces are typically flat to convex-upward and mark the upper surface of channels or macroforms. These surfaces represent erosion or accretion occurring on average from hundreds to thousands of years. Additionally, fourth-order surfaces bound floodplain elements such immature paleosols and crevasse splays.

Fifth-order surfaces are laterally extensive and bound major sand sheets or groupings of channels. They are generally planar to slightly concave-upward and may be marked by a basal conglomerate. These are the third-order surfaces of Allen (1983) and the major surfaces of Bridge and Diemer (1983). Mature paleosols are included as a fifth-order surface, such as the basal calcrete of the Cedar Mountain Formation.

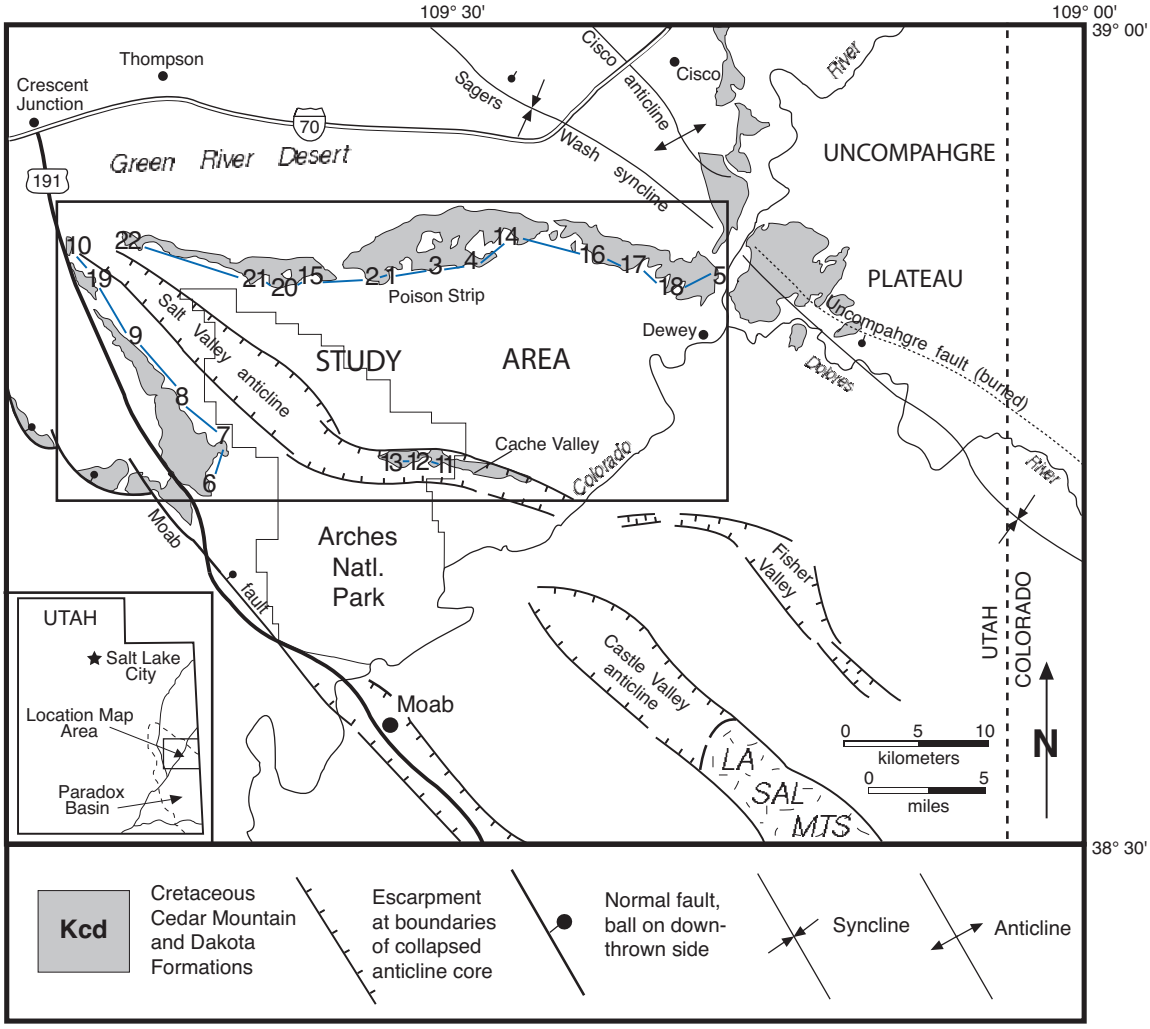


Figure 23. *Map of study area with location of measured sections and lines of correlation. Modified from Doelling, 1996.*

Sixth-order surfaces envelop large-scale depositional features such as groups of channels or paleovalley fill complexes. Sixth-order bounding surfaces separate depositional sequences such as a formation, member, or submember. Discrete bounding surfaces of sixth-order are probably not present within the Cedar Mountain Formation.

Architectural Elements of the Cedar Mountain Formation

The Cedar Mountain Formation displays the majority of the nine fluvial architectural elements as defined by Miall (1996). The scour hollow architectural element recognized in the Westwater Canyon Member of the Morrison Formation by Cowan (1991) is the only one not recognized in this study. The Poison Strip Sandstone in particular contains bar forms or macroforms of both vertical aggradation and lateral- accretion origin. The type, nature, and characteristics of architectural elements identified are outlined in table 2.

Architectural Profiles

Architectural profiles or photo-mosaics are used to illustrate the geometry, facies associations, and architectural elements of sand bodies in the Cedar Mountain Formation, specifically the Poison Strip Sandstone. The profiles are annotated in the following ways: (1) the lithofacies are labeled according to those established in table 1, (2) bounding surfaces are labeled with circled numbers according to rank, and (3) architectural elements are labeled as defined in table 2. Some of the architectural elements identified are not strict macroforms as defined by Jackson (1975), but are likely the mesoforms of Miall (1985). While mesoforms do not have the size and temporal significance of macroforms, they are nonetheless classified to add important environmental information to the investigation. Paleocurrents are denoted by small arrows oriented relative to the outcrop. Horizontal arrows represent paleocurrents which parallel the outcrop, whereas vertical arrows represent paleocurrents which are perpendicular to the outcrop. Paleocurrent rose diagrams are presented to illustrate the distribution of flow directional indicators not only from the profile, but also from paleocurrents taken at the associated measured section and other nearby outcrops. A thorough description of each of the profiles is given including general geological character, facies associations, architectural elements, nature and distribution of bounding surfaces, flow orientation evidence, and key sedimentological characteristics. Following the description is a

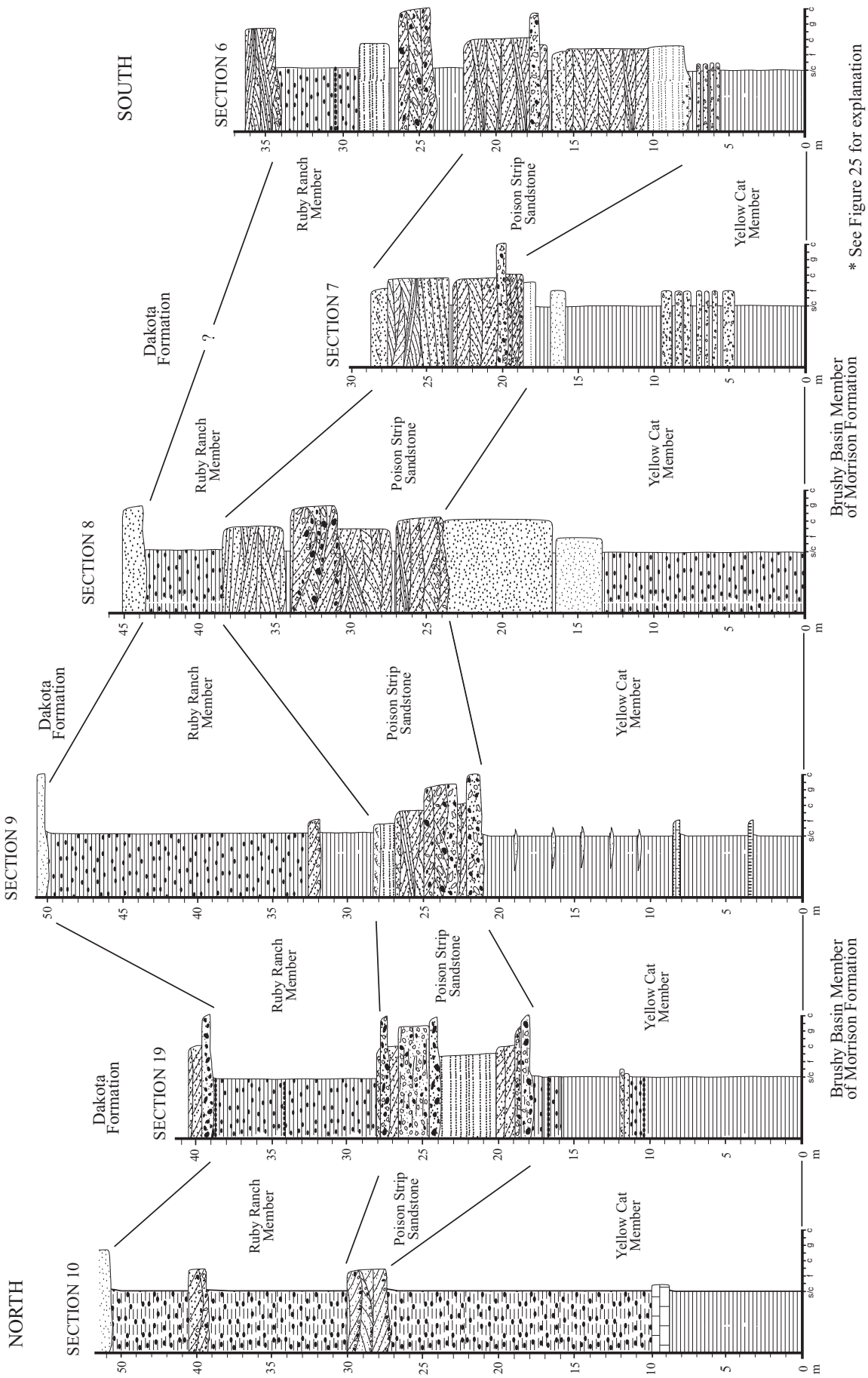


Figure 24. *Cedar Mountain Formation stratigraphic correlation, north-south (see figure 23 for section locations).*

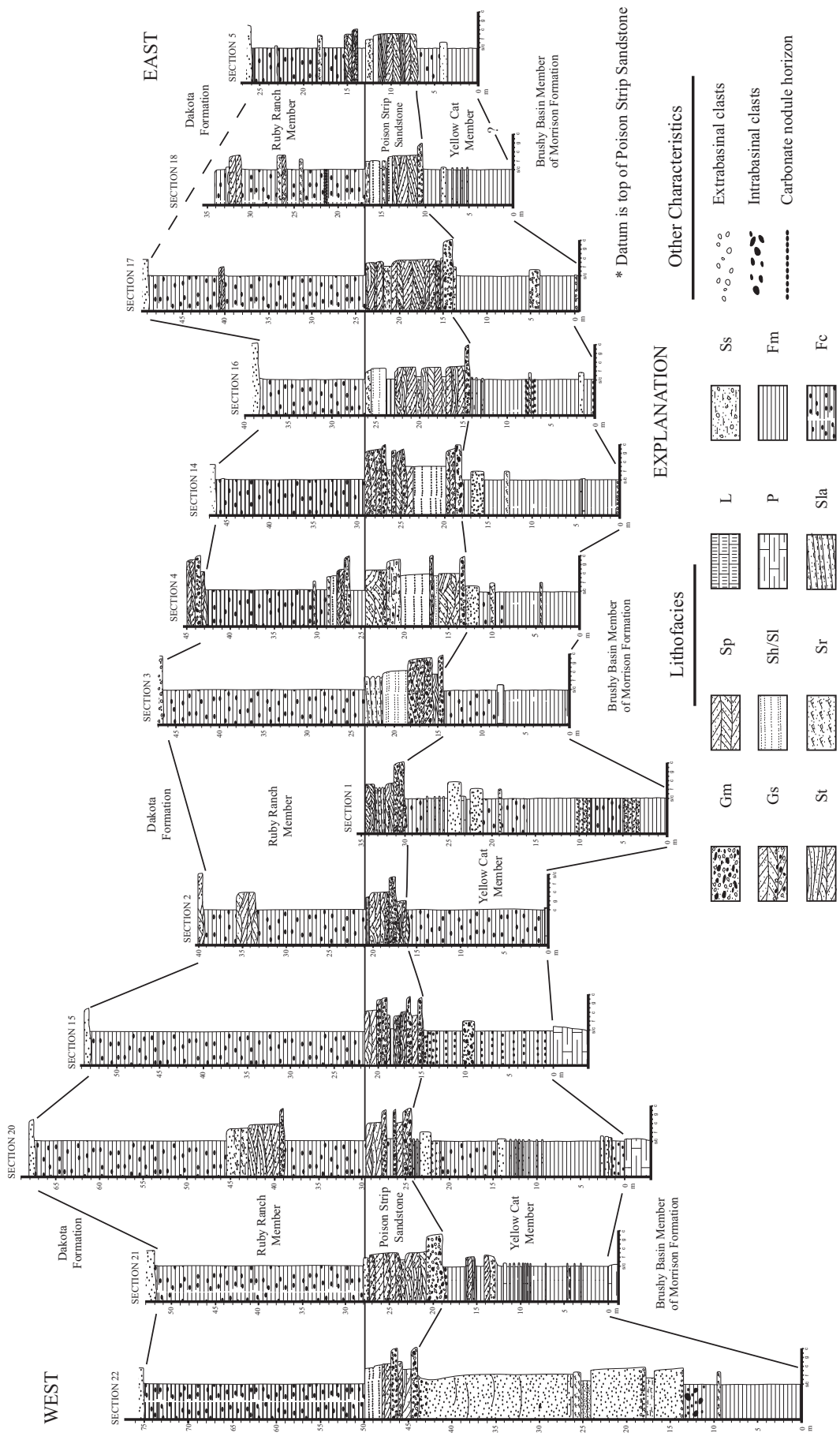


Figure 25. *Cedar Mountain Formation stratigraphic correlation, west-east (see figure 23 for section locations).*

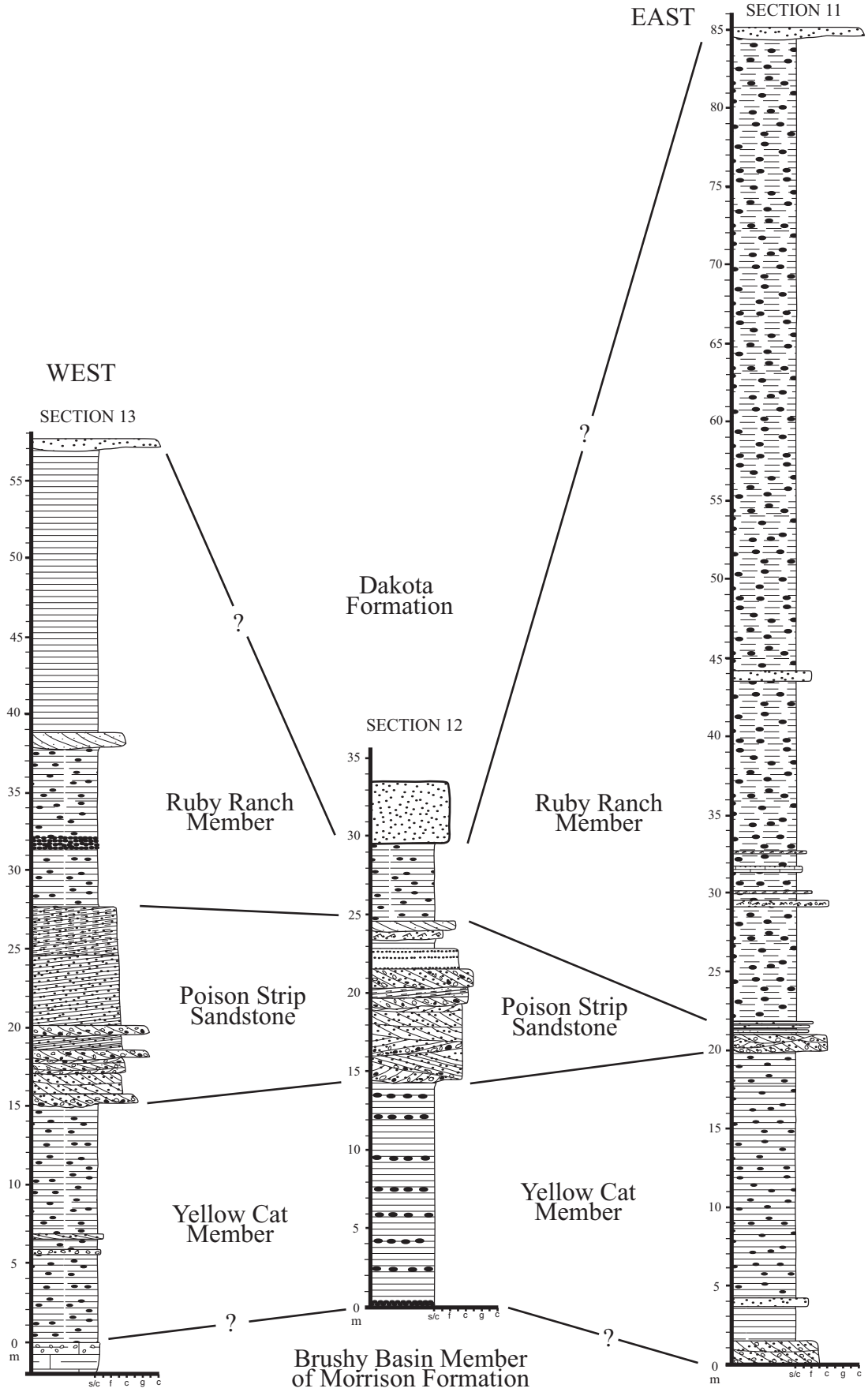


Figure 26. Cedar Mountain Formation stratigraphic correlation, Arches National Park (see figure 25 for explanation and figure 23 for section locations).

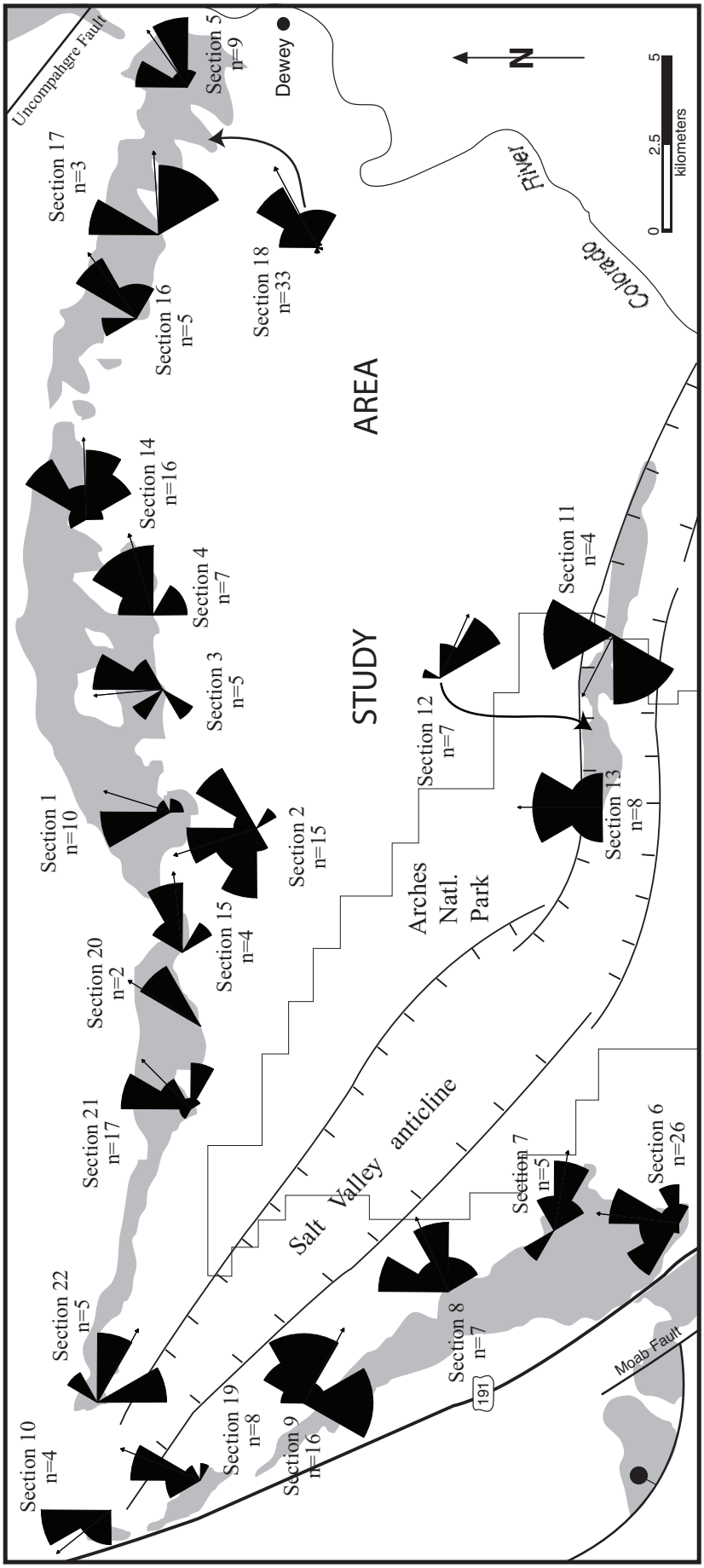


Figure 27. *Distribution of paleocurrent indicators across study area and location of stratigraphic sections shown in figures 24, 25, and 26. Data unweighted, vector means shown with arrows, petal width is 30 degrees, n equals the number of readings. Many diagrams have few readings but are provided for comparison purposes.*

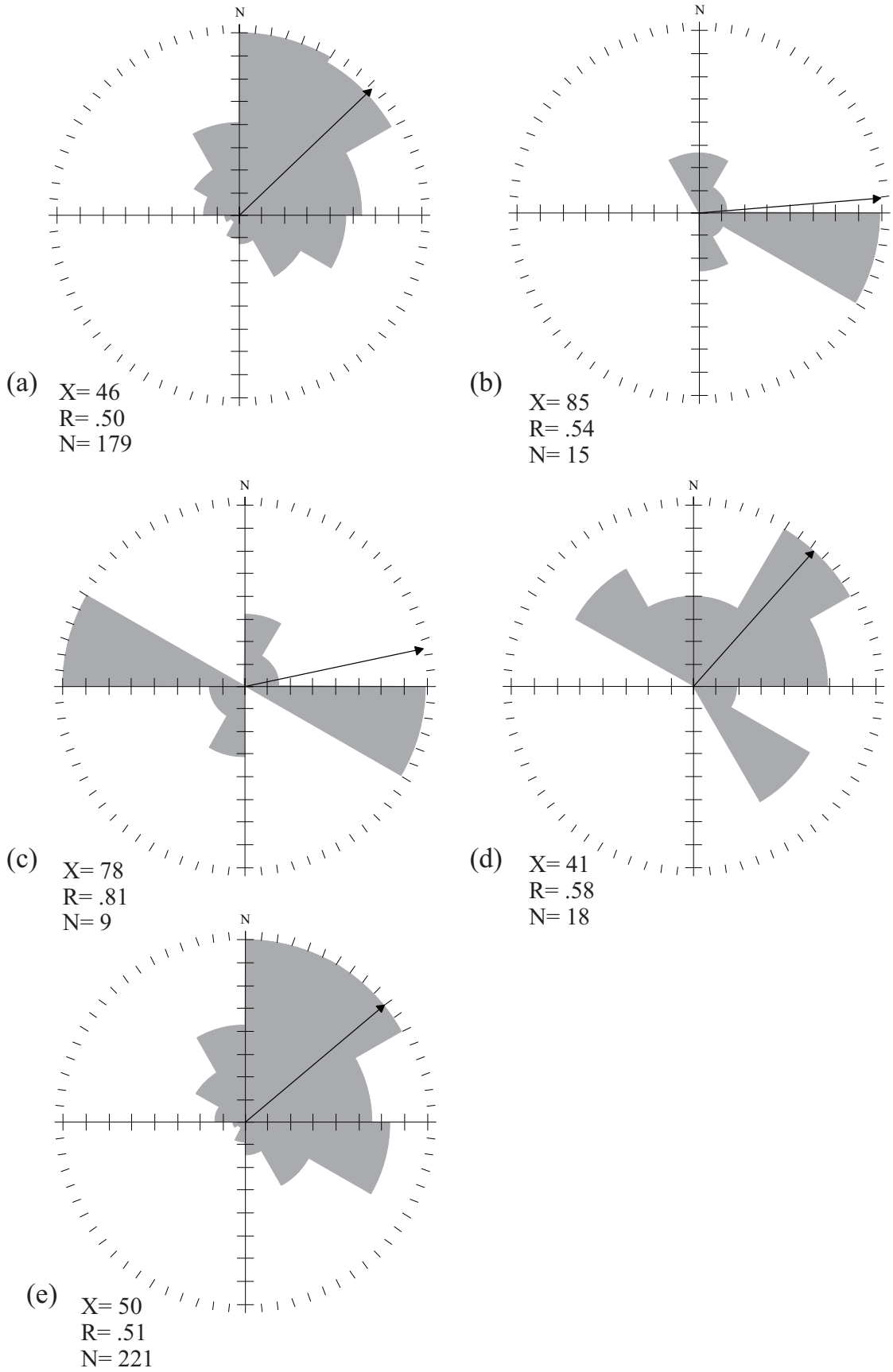


Figure 28. *Rose diagrams according to lithofacies type. a - facies St, b - facies Sp, c - facies Sh/Sl, d - facies Sla, e - grand total of all paleocurrent indicators. Vector means (X) shown with arrows, R refers to vector magnitude with 1.0 as 0% dispersal, N is number of readings.*

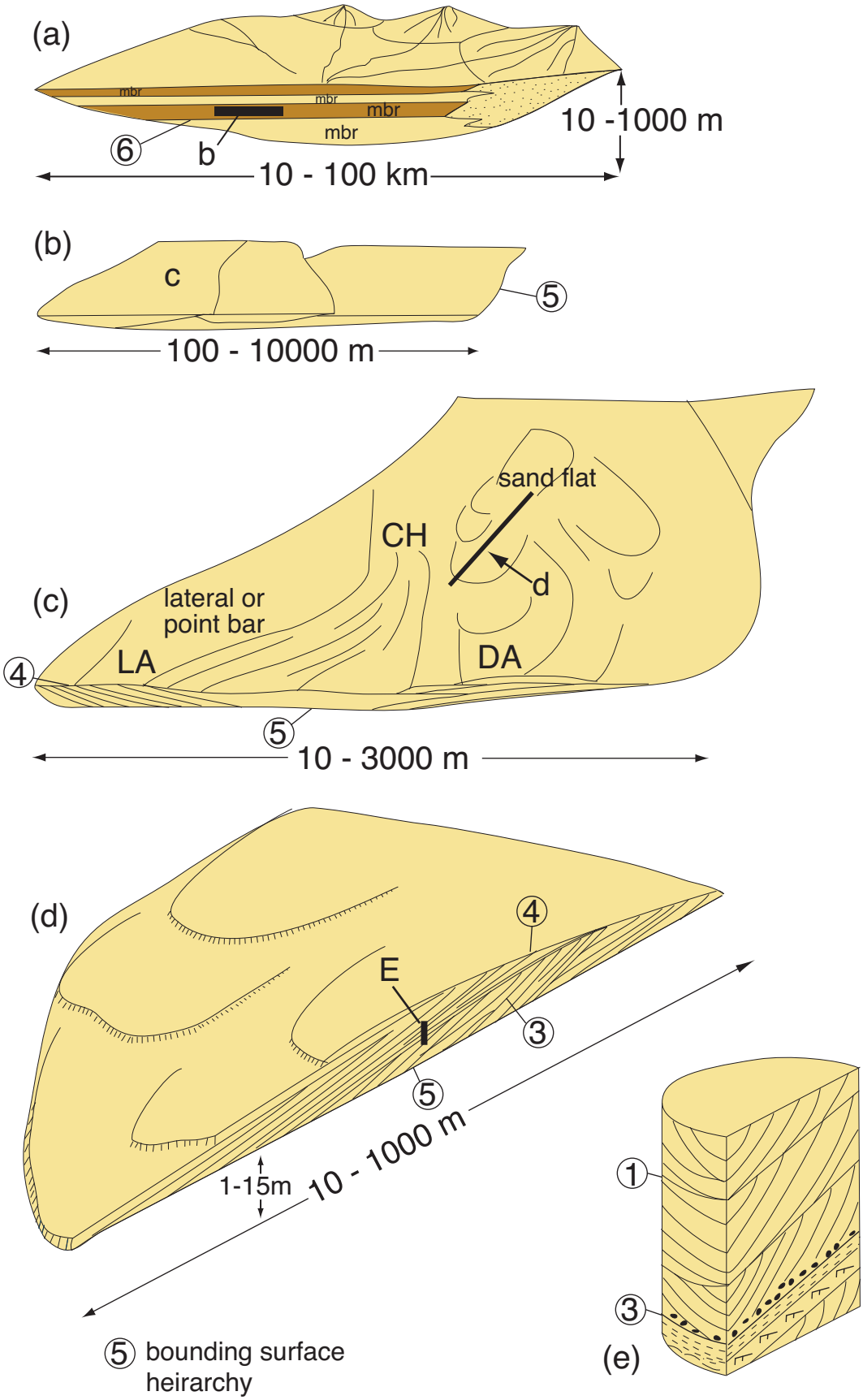
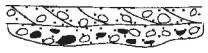
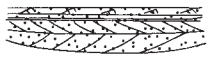
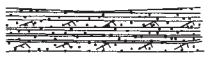
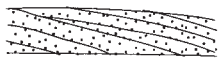
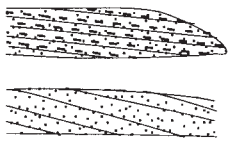
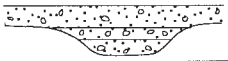


Figure 29. *The bounding-surface hierarchy as defined by Miall (1996) depicting the various scale of alluvial deposits. Two-lettered codes denote architectural elements, and circled numbers indicate the rank of bounding surface.*

Table 2. Architectural elements common to the Cedar Mountain Formation in the field area (adapted from Miall, 1985, 1988, 1996).

Architectural Element	Facies Assemblage	Geometry	Depiction	Interpretations
Channels CH	Gm, Gs, St, Sp, Sr, Sh/Sl, Sla	w/d: 20-100, concave-up with gentle margins		Full channel preservation, may include any other architectural element
Gravelly Bedforms GB	Gm, Gs	Lenticular to tabular lithosomes at channel base		Channel lag or gravelly bedforms
Sandy Bedforms SB	St, Sp, Sr, Sh/Sl	Various - from tabular to channel shaped		Dune fields at channel base or atop bars
Laminated Sand Sheets LS	Sh/Sl, Sr	Thin, tabular bodies but may reach 5 m in thickness		Unchannelized flow, upper-regime plane bed followed by low velocity, shallow flow
Downstream Accreting Macroform DA	Gm, Gs, St, Sp, Sh/Sl	Planar base with gently dipping internal-surfaces, height 3-8 m and width 10-100 m		Transverse or linguoid bars where foresets or reactivation surfaces dip in downstream direction
Laterally Accreting Macroform LA	Sla, Gm, Gs, St, Sp, Sh/Sl	Gently dipping internal surfaces with horiz. base, thickness up to 5 m, width to 100 m		Lateral channel migration with deposits of various textures and bedforms dependent on flow velocity and flow depth
Overbank Fines OF	Fm, Fc, Fl, Sr, L, P	Thick, tabular fine-grained units divided by thin sandy or calcareous beds		Overbank deposits both floodplain and lacustrine, crevasse splays and pedogenic units
Sediment Gravity-Flows SG	Ss	Thin (0.3-1.0 m), tabular units or thick and lenticular		Lake-margin debris flows, possibly bioturbated sand bodies

detailed interpretation covering sedimentary structures, paleocurrents, depositional processes, evolution of channels, and possible analogs.

Dalton Well

Description

This architectural profile is at the western end of the study area and is also the location of measured section 6 (appendix 2, figure 30). The Dalton Well profile is located north of the Brigham Young University Dalton Well dinosaur quarry. The sand bodies contained in the profile are situated in the middle of the Cedar Mountain Formation, above massive to nodular mudstone and stacked lithosomes of facies Ss. The sand bodies are assigned to the Poison Strip Sandstone and the carbonate nodule bearing mudstones above the sand bodies are likely the Ruby Ranch Member. Explicit identification of the Dakota Formation is difficult in this area as many thin ribbon sand bodies are present near the top of this and other nearby mesas. The outcrop is oriented N 18°W and is approximately 110 meters in width. The profile shown is the tallest portion (likely thalweg position) of an expansive outcrop extending across the eastern side of the bluff approximately 1800 feet (550 meters). The outcrop is oriented perpendicular to paleoflow accentuating channel outlines but not clearly showing bedform and barform foreset surfaces.

The multi-storey sand body is composed of a basal ribbon and an upper sheet, each floored by a fifth order bounding surface. A dark-tan gravelly ribbon is located at the top of the photograph (possibly upper Cedar Mountain sandstone of Young, 1960) and is separated from the lower multi-storey sand body by a few meters of mudstone. The basal ribbon is denoted as CH-1, has a width to depth ratio of 15, and is made up of amalgamated elements of SB and GB. The overlying sheet sand body consists of architectural element SB with gravelly lags. Gently-dipping third order surfaces indicative of lateral accretion are not found within this or adjacent outcrops. Facies associations primarily consist of Gs, St, Sl with internal fining-upward sequences and an overall fining-upward trend. The lithofacies are heterolithic both laterally and vertically. The upper sheet sand body is characterized by gently-dipping cross-bed foresets suggesting bedforms of low amplitude and long wavelength. Palocurrents indicate that flow conditions for the lower ribbon were generally out-of-the-photo, towards the east whereas the upper sheet shows paleoflow to the north and east.

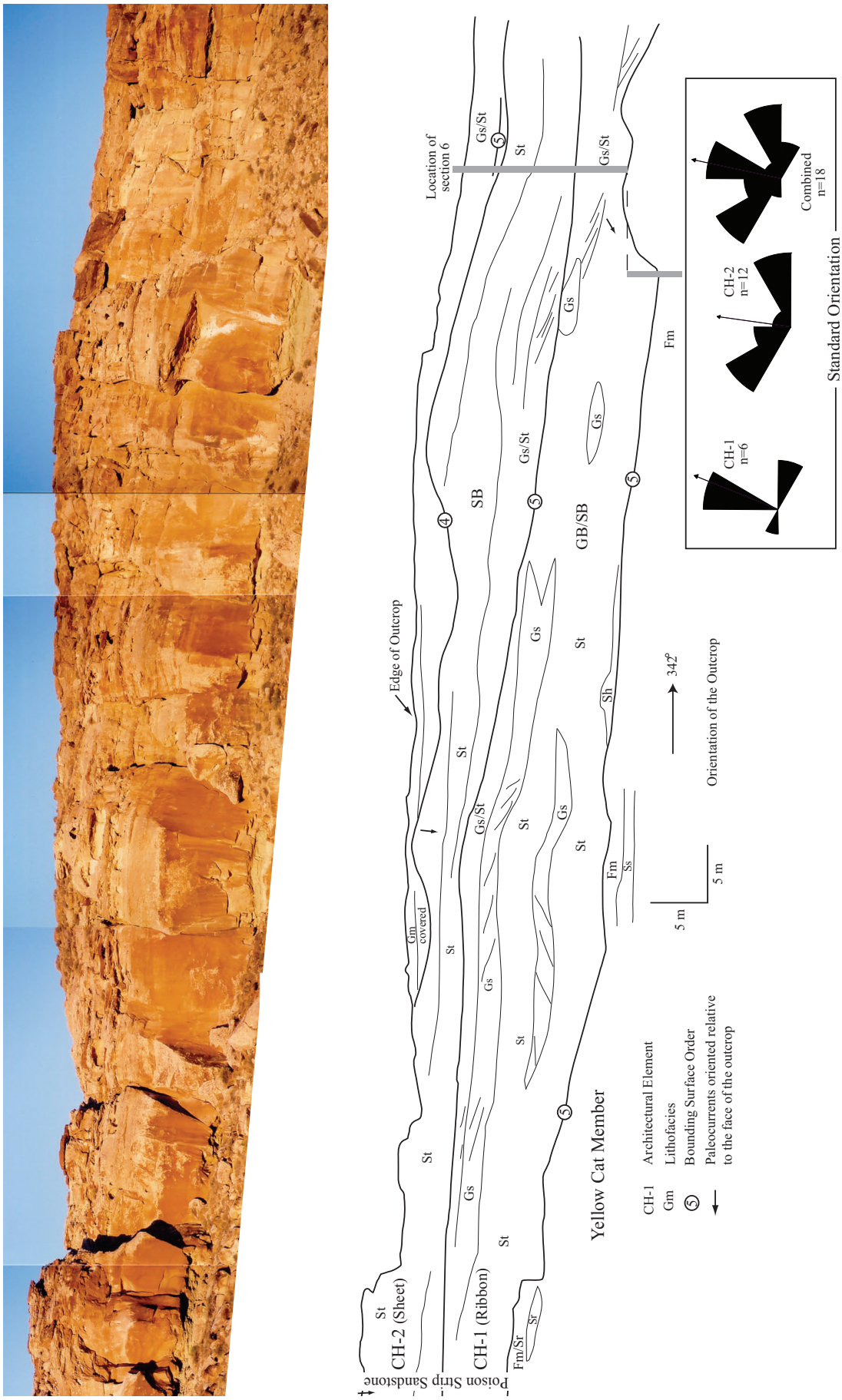


Figure 30. *Panel diagram for area of Dalton Well, section 6 (see figure 23 for section location).*

Interpretation

The sand bodies contained in the Dalton Well mosaic were deposited by a combination of low-sinuosity and braided channels. The lowermost ribbon sand body was likely a straight channel with alternate bars, although no lateral-accretion surfaces are visible in this outcrop exposure (figure 31). Similar channel forms were investigated by Harris (1980) in the Cedar Mountain Formation southwest of Green River and were found to be low-sinuosity channels containing side or alternate bars. The moderately dipping channel cut-banks of the lower channel are indicative of the relative stability of the underlying Yellow Cat mudstone. The sandy and gravelly lithofacies of the lower channel suggest deposition by vertical aggradation, which likely occurred as flow competence was reduced. The overlying sheet sand body was likely deposited by shallow braided channels during a period of high sediment supply (figure 32). The outcrop is oblique to paleoflow and thus the sand body margins are not visible on this mesa. Bedforms are characterized by dunes of low amplitude and were likely reworked trough-crossbeds (Cotter and Graham, 1991) or were deposited by high-energy, shallow discharge events as described by Cowan (1991). Cowan interpreted sedimentation in the Westwater Canyon Member of the Morrison Formation as commonly occurring in the upper and transitional flow regimes resulting in plane lamination (facies Sh) and gently inclined cross-bedding (facies Sl).

Communication Tower

Description

The section 9 architectural panel is located in the western part of the field area, west of Arches National Park (figure 33). This exposure is oriented roughly northwest-southeast and is set on the east side of a hogback that dips gently to the west. Channel geometry is exhibited as the outcrop is approximately perpendicular to paleoflow. The annotated portion of the photomosaic is approximately 150 meters wide and the central sandy interval, the Poison Strip Sandstone, measures 7-8 meters thick. Stratigraphic section 9 was measured slightly south of the architectural profile. The outcrop belt between section 8 to the south and section 19 to the north contains thin and discontinuous sand bodies, typically thinner than those shown in figure 33.

The outcrop consists of stacked, thin tabular sand bodies or architectural elements separated by poorly exposed mudstone units. The lowest part of the exposure is the Yellow Cat Member and contains spaced resistant beds of lithofacies Ss and L. The upper mudstone unit, the Ruby Ranch Member, contains a channel-form sand body and is covered with grass and sandstone blocks of the Dakota Formation. Architectural elements SB, LS, and LA comprise the sheet sand bodies, which are amalgamated vertically or separated by thin deposits of mudstone. The two lower sand bodies are composed of facies St with gravelly portions at the channel base (figure 15). The facies are arranged vertically in a generally fining-upward fashion, although significant variation exists. Notable lateral facies changes include St to Gs or St to Sh/Sl. The upper sheet sand body is composed of facies Sh/Sl and Sr and forms a laminated sand sheet, LS-1 (figure 16). Large inclined foresets are located near the north end of the basal sand body and form a lateral-accretion element (figure 34). This set of inclined foresets is situated at the perimeter of the sand body and is thus an attached bar or side bar. Another lateral-accretion element or possibly a simple cut bank is located at the left-center of the outcrop. Paleocurrents indicate flow was primarily to the east, out-of-the-photo, except for an anomalous southwest direction in the Ruby Ranch Member ribbon channel.

Interpretation

The sand bodies contained in the Communication Tower photomosaic were likely deposited by a sandy bedload braided fluvial system (figure 32). The vertical scale of the individual bodies and the bedforms suggest shallow flow conditions and an ephemeral discharge pattern. The three individual channels separated by mudstone drapes indicate multiple episodes of erosion and sedimentation (Stear, 1983). The two lowermost sand bodies primarily contain channel lag and three-dimensional dune deposits. The lithofacies transition laterally reflecting different flow conditions at different channel locations. The channel dimensions and sedimentary fill are indicative of lower flow regime conditions. The attached or side bar located at the north end of the middle sand body is a small macroform or mesoform as defined by Miall (1996) (figure 31). This bar accreted south, transverse to regional paleoflow, into a channel whose southern margin is marked by a gently dipping cutbank approximately 100 meters away. This bar form has affinities to the lateral bar of intermediate grain size in braided streams as described by Bluck (1979). No secondary sedimentary structures exist on the lateral accretion surfaces of the attached bar (figure 34). The majority of the two lower sand bodies have affinities to the sandy distal braidplain similar to model 11 of Miall (1985) (figure 32).

The tabular upper sand body (LS-1) is comprised of lithofacies Sh/Sl and Sr and thus is classified as a laminated sand sheet. It is here interpreted as a product of shallow, fluctuating flow conditions that likely quickly transitioned between plane-bed lamination and ripple-lamination for fine-grained sand. It is also possible that the entire laminated sand sheet was the result of a single discharge event with a falling limb recession when the majority of vertical aggradation occurred. A reasonable analog for this sand body is the Bijou Creek ephemeral flood deposits of McKee et al. (1967). Miall's interpretation of this setting is shown in figure 35. Similar unchannelized sheet flow conditions in the medial portion of an arid braidplain were described by Williams (1971) from a flood event in the Australian interior.

Long Valley East

Description

The Long Valley East architectural profile is associated with measured section 21, both of which are located north of Arches National Park (appendix 2, figure 36). The photomosaic was taken on the east face of a north dipping hogback, whereas the stratigraphic section was measured on the south face. The northwest part of the field area is typified by restricted sheet sands comprising the Poison Strip Sandstone.

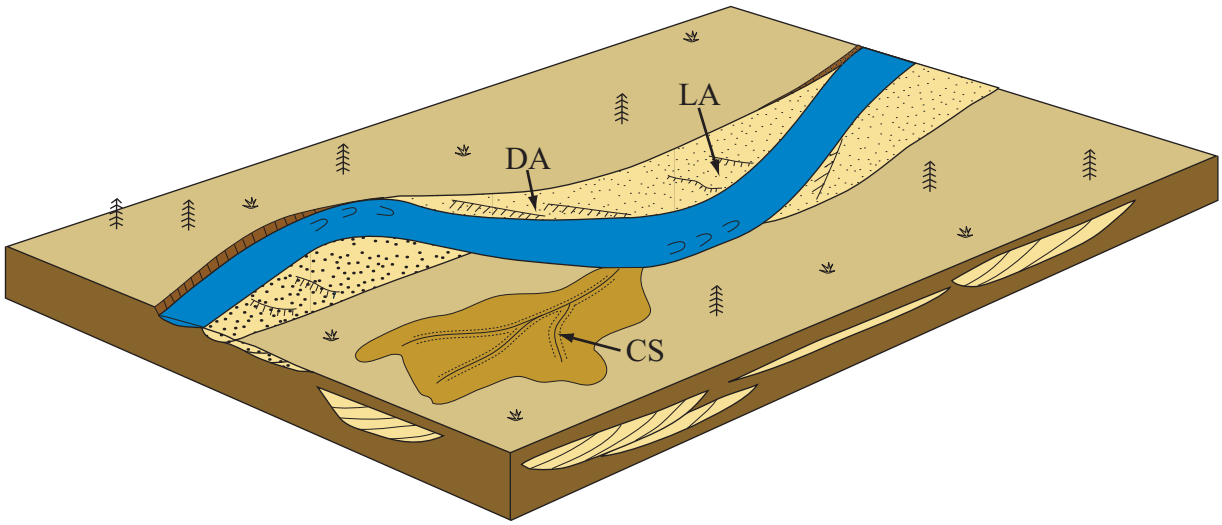


Figure 31. *Low-sinuosity channel with alternate bars depicting the fluvial style of the lowest sand body of the Dalton Well photomosaic. (From Miall, 1996).*

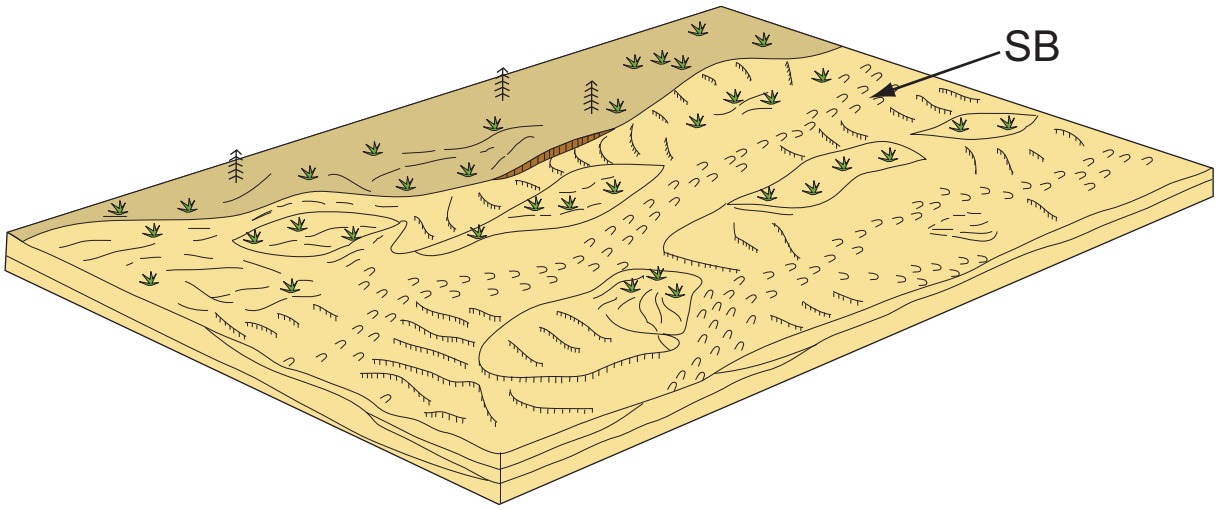


Figure 32. *Facies model 11 of Miall (1985), distal, sheetflood, sand-bed river, depicting the fluvial style represented by the upper sheet sand body of the Dalton Well photomosaic.*

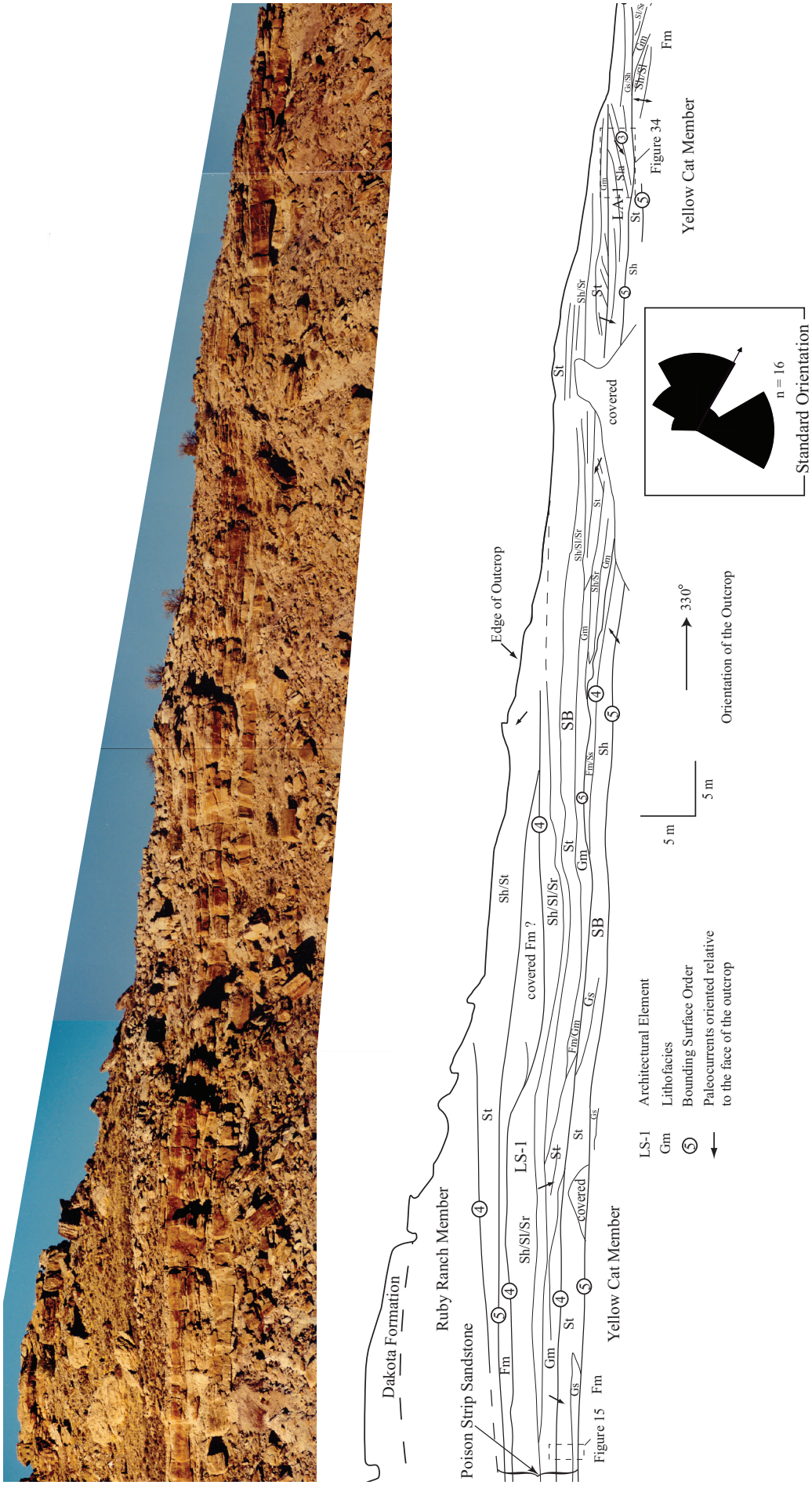


Figure 33. *Panel diagram for area of Communication Tower, section 9 (see figure 23 for section location).*

Figure 34. *Close-up of attached bar composed of lithofacies Sla at the north end of the Communication Tower photomosaic.*

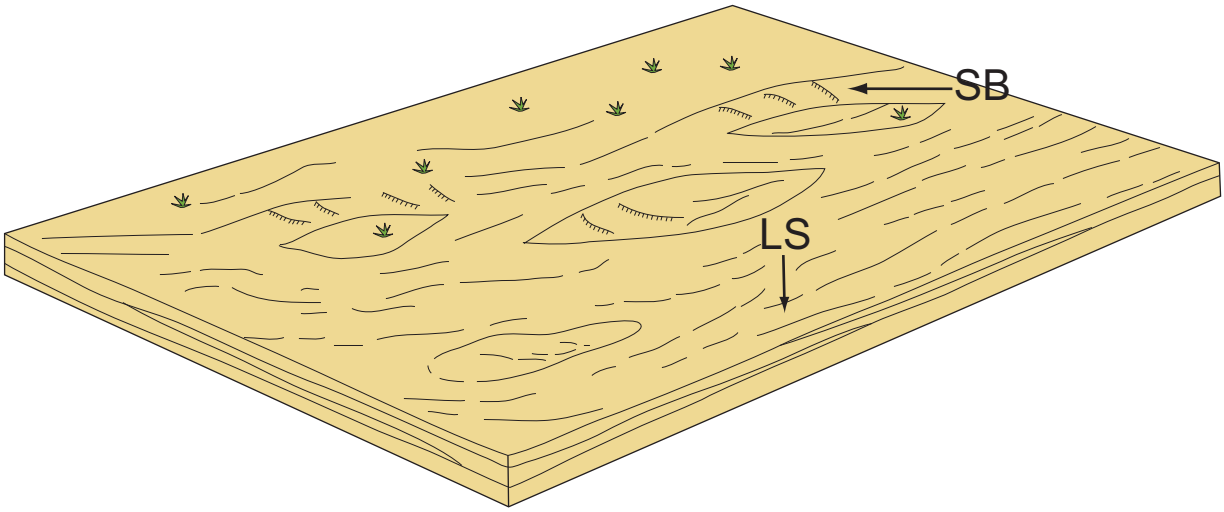


Figure 35. *Facies model 12 of Miall (1985); flashy, ephemeral, sheetflood, sand-bed river, depicting the fluvial style represented by the upper sheet sand body of the Communication Tower/section 9 photomosaic.*

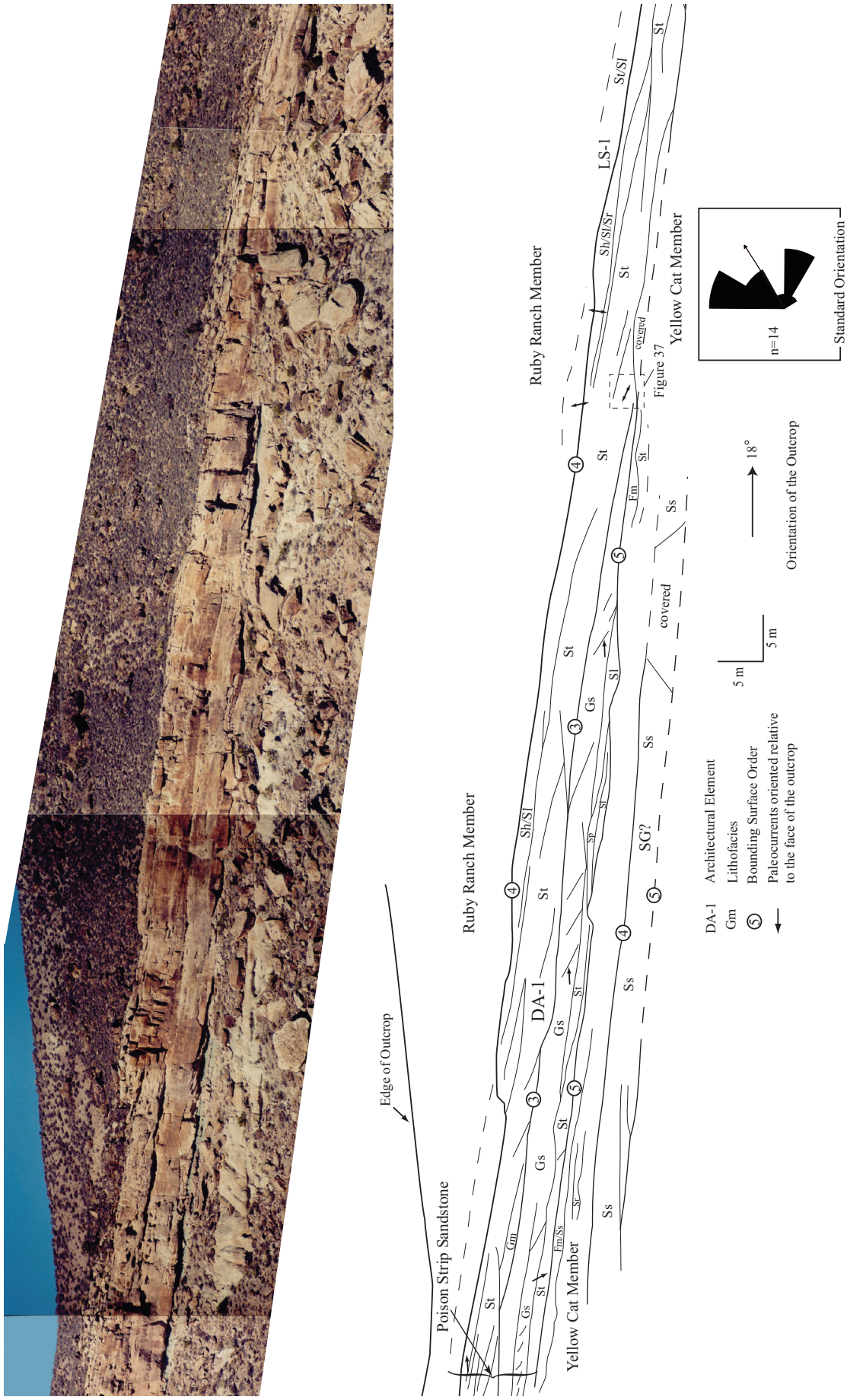


Figure 36. *Panel diagram for area of Long Valley East, section 21 (see figure 23 for section location).*

The outcrop is oriented roughly north/northeast – south/southwest which is parallel to paleoflow.

The Poison Strip Sandstone occupies the central portion of the photomosaic and is underlain and overlain by mudstone of the Yellow Cat and Ruby Ranch members, respectively. The lower mudstone is primarily covered except for a thick lithosome of facies Ss and a minor show of green mudstone beneath overhang exposures of the Poison Strip Sandstone. The light-tan lithosome of facies Ss is related to exposures directly to the south of the photomosaic, which consist of 5-6 stacked one meter thick sand sheets related unconfined flood flow (similar to other Yellow Cat Member unchannelized conditions). The Poison Strip Sandstone is comprised of two stacked bar forms with many scales of surfaces inclined in the downstream direction. The vertical nature of the outcrop made the central portion of the sand body inaccessible. The Ruby Ranch Member surface is vegetated and covered with dark brown sandstone blocks of the Dakota Formation. Bounding surfaces consist of a basal fifth order scour surface, a central third order reactivation surface, an upper convex-up fourth order surface, and numerous first and second order surfaces throughout. Facies sequences are ordered in fining and coarsening upward sequences and consist primarily of facies Gs and St capped by facies Sh/Sl. A silicified log is preserved perpendicular to the strike of bedforms and bar fronts (figure 37). There is lateral continuity of lithofacies within the larger DA macroforms. Paleocurrents are primarily parallel to the outcrop and face north except for a few parting lineations that trend east to west.

Interpretation

The bar and bedforms displayed in the Long Valley East profile were likely constructed in a sandy braided fluvial system characterized by perennial flow. The sand body is composed of the architectural element DA; a downstream accreting macroform. The paleocurrent evidence is roughly parallel to the dip of the numerous first, second, and third order bounding surfaces indicating surfaces of accretion were oriented downstream and not lateral to localized flow conditions. The hierarchy of bounding surfaces suggests deposition was active and flow conditions were non-periodic. The central reactivation surface, which parallels the strike of bar foresets, was likely a result of erosion during low-stage flow (McCabe and Jones, 1977). A probable outcrop orientation for this exposure is a downstream trending cut through a midchannel bar with an irregular front (figure 38). If this is the case, it is likely that the downstream form would grade laterally (in an east-west direction) into a laterally accreting macroform with oblique or perpendicular bar surfaces. The South Saskatchewan deep, perennial braided facies model for sandy rivers first proposed by Cant and Walker (1978) has similar characteristics to the bar forms observed in this profile (figure 39).

Window Wash

Description

An architectural profile and stratigraphic section 14 are located at an exposure informally named Window Wash (appendix 2, figure 40). This locale is at the eastern end of the Poison Strip mining region and the Poison Strip Sandstone is thicker and more continuous here in comparison to the balance of the field area. Individual sandstone sheets are between 5-15 meters in thickness and have widths in excess of one kilometer. The sand bodies are either shingled or stacked at slightly different stratigraphic levels. The panel measures 125 meters wide by 12 meters tall and is set on the east face of northward dipping mesa. The sheer nature of the exposure did not allow access to the middle section of the outcrop. The outcrop is oriented north eleven degrees east which is slightly oblique to average paleoflow direction.

The photomosaic displays a massive face of the Poison Strip Sandstone and a small mudstone exposure of the Yellow Cat Member. The Ruby Ranch Member and Dakota Formation have been eroded from this mesa but are preserved on a nearby mesa to the southeast. The sand body is comprised of architectural elements including GB, SB, and LA/DA. Massive gravels of granule to boulder size line the base of the sand body and are succeeded by gravelly and sandy cross-bedded units. The middle-left portion of the profile shows a lateral/downstream accretion element overlying the GB and SB elements, and is internally composed of faint epsilon cross-beds or lateral accretion surfaces. This element is outlined by distinct channel outlines and successive channel outlines. The internal bedding within these channel outlines is not visible from the photo and could not be accessed at the outcrop. A gravelly lithosome of planar cross-beds occupies the top of the sand body and is assigned to element GB. The lithofacies are ordered in fining-upward sequences within individual channels, but the sand body does not fine-upward overall. Facies associations of Gm, Gs, St, Sh/Sl are the typical upsection trend. The lithofacies display moderate continuity laterally within individual sandstone beds. The lower mudstone contains a few sandy beds of facies Ss and Sr which are assigned with the mudstone to architectural element OF.

Interpretation

The sand body contained in the Window Wash profile was deposited by various sub-environments within a sandy braided fluvial typified by perennial discharge. The basal architectural element, GB-1, can be classified as intra-clast breccia. The coarse grain-size, poor sorting, and angular shape of abundant intra-clasts of mudstone and carbonate nodules present a picture of an initial, violent flash flood. Following upper flow regime conditions, the channel was filled vertically by the migration of sandy and gravelly three-dimensional dunes. Stacked atop these vertical aggradation deposits are barforms created by lateral-accretion processes. The majority of the bar front surfaces dip to the north, similar to the regional paleoflow direction. Some of the internal bar geometry is not visible on the photomosaic and was not accessible due to the sheer nature of the outcrop. With limited paleocurrent evidence, these bar features are assigned to architectural element LA/DA. These bars are likely similar to the Long Valley East mid-channel bars, with a slightly different outcrop orientation; however this is a tentative interpretation. The top of the sand body contains a gravelly dune complex assigned to architectural element GB-2. Discharge was primarily lower flow regime and was contained within a wide, shallow channel. The lithofacies distribution and bar-

Figure 37. *Silicified log preserved below bar foresets and oriented in the direction of paleoflow at the Long Valley East profile.*

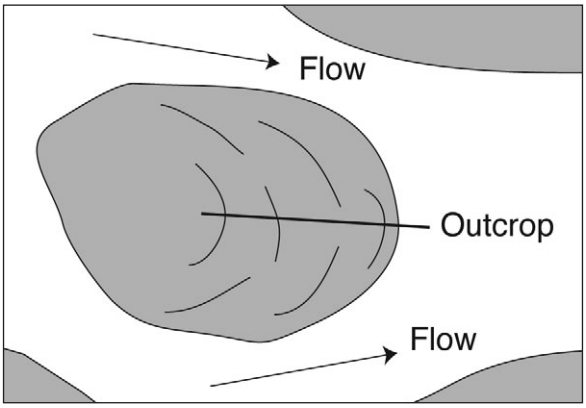
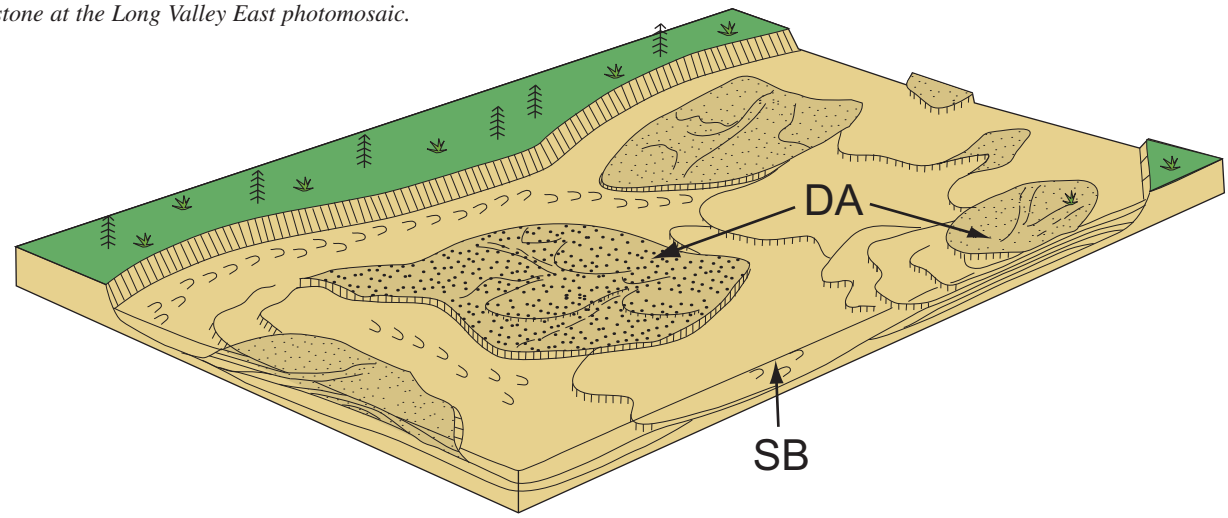


Figure 38. *Plan view sketch of the interpreted barform observed in the two-dimensional cut at the Long Valley East profile.*

Figure 39. *Facies model 10 of Miall (1985); deep, perennial, braided, depicting a fluvial style similar to the Poison Strip Sandstone at the Long Valley East photomosaic.*



forms are suggestive of the South Saskatchewan braided river described by Cant and Walker (1978) (figure 39).

Kokopelli Trail

Description

The Kokopelli Trail architectural profile was recorded in conjunction with measured section 18 (appendix 2, figure 41). They are located near the eastern edge of the field area on a NE–SW trending mesa. The eastern third of the field area is more vegetated and thus less well-exposed than the remainder of the study area. Sand bodies in this region are more varied in shape (e.g. ribbon, restricted sheet, and sheet) and exist at more stratigraphic levels than the other panel locales. The photomosaic was taken on the east face of the mesa, whereas the section was measured on the mesa's south face. The orientation of the east face is approximately parallel to paleoflow.

The photomosaic consists of four separate thin sand bodies, each separated by 2-10 meters of mudstone. The informal Cedar Mountain Formation members are difficult to define at this location. The lowest sand body is designated to architectural element LS and contains lithofacies Sh/Sl, Sr, and minor St (figure 42). The next sand body upsection is structureless and is composed of lithofacies Ss. The third sand body consists of architectural elements SB and DA, some of which are stacked in the thick exposures. Numerous first, second, and third order surfaces are inclined in the downstream direction. Overturned, recumbently folded cross-strata are common to this channel sequence (figure 43). Fining-upward facies sequences are common starting with basal Gm and grading to St and Sh. The uppermost sand body is thin with first and second order surfaces dipping in the downstream direction. This sand body is capped by an anomalous silicified bed of green or white chert. Paleoflow in the basal sandstone trends to the southeast with significant dispersion whereas the upper two sandstones have consistent northeasterly directions.

Interpretation

The sand bodies contained within the Kokopelli Trail profile were deposited by flashy unchannelized, sheetfloods and by low-sinuosity channels with alternate bars. The basal channel is classified as a laminated sand sheet (LS) and is here interpreted as a product of shallow, fluctuating flow conditions that likely quickly transitioned between plane-bed lamination and ripple-lamination for fine-grained sand (figure 35). The dispersion of paleocurrents in the laminated sand sheet suggests that shallow, lower flow regime conditions might have been more common than upper flow regime conditions.

The second channel, CH-2, is a tabular, structurless fine-grained silty sandstone that is a product of poorly channelized flow. Possible interpretations include sediment gravity flow, crevasse splay, or bioturbation. CH-3 is the thickest sand body and is categorized in both the sandy bedform and downstream accreting macroform architectural elements. They are internally composed of sandy dunes and bar fronts with foresets dipping in the downstream direction. Fining-upward sequences from facies Gm/Gs to St or Sh/Sl are evident in the lower portion where the channels are stacked. The overturned cross-strata face downstream and were likely formed by extreme variation in flow conditions causing the overriding current to shear the underlying saturated beds. The upper sections of CH-3, above the central fifth order surface, are likely the repetition of downstream accreting barforms of the same low-sinuosity channel (figure 31). On this basis, the meander wavelength of this low-sinuosity channel is approximately 80 to 100 meters. Similar alternate barforms with both downstream and lateral migration were documented by Wizevich (1992) in the Carboniferous Lee Formation. The uppermost channel, CH-4, is a simple channel fill with a regular pattern of paleocurrent indicators (figure 41). CH-4 is capped by an authigenic silica or chert bed likely formed by diagenetic alteration of silica-rich mudstone.

STRATIGRAPHIC ANALYSIS

This discussion provides an appraisal of the sedimentary data presented in the previous sections and presents a fluvial facies model for the Poison Strip Sandstone. Additionally, it provides an evaluation of sedimentary controls and ties together correlative fluvial deposits on the Colorado Plateau. Included herein is a review of vertical profiles from appendix 2 and correlations from figures 24, 25, and 26. Common sand body lithofacies sequences are presented and indications from paleoflow data shown in figures 28 and 29 are analyzed in terms of channel sinuosity and basin-tilt direction. The vertical profile and architectural data in combination provide the basis for construction of a facies model for the Poison Strip Sandstone. Sedimentary controls, both extra-basinal and intra-basinal, are reviewed in light of the local section. A regional paleogeographic assessment follows, relating correlative fluvial environments on the Colorado Plateau.

Vertical Profile Analysis

The measured sections presented in the previous sections and appendix 2 display a sequence of terrestrial sedimentation including a central sandy interval, the Poison Strip Sandstone. The Poison Strip Sandstone is here evaluated by review of criteria such as the nature of contacts and trends in grain size, bedding, and sedimentary structures. Vertical lithofacies sequences are presented as well as indications of cyclicty. Lateral trends within the field area are investigated in light of the progressive downstream changes that occur within a fluvial system.

The contacts between coarse-grained and fine-grained rocks are typically erosive, scoured surfaces. This is common where current-traction deposits including lithofacies Gs, St, and Sp are preserved above overbank fines. The evolution and migration of sinuous dunes involves a hydrodynamic continuous scour and fill process that creates basal concave-up scours (figure 20). The erosive contacts are not only observed where coarse-grained deposits overlie fine-grained deposits, but also occur within individual sand bodies. Planar, non-erosive contacts are also preserved and occur between crevasse splay deposits of lithofacies Sh/Sl, Sr, Ss overlying floodplain deposits of Fm, Fc, and Fl. Where

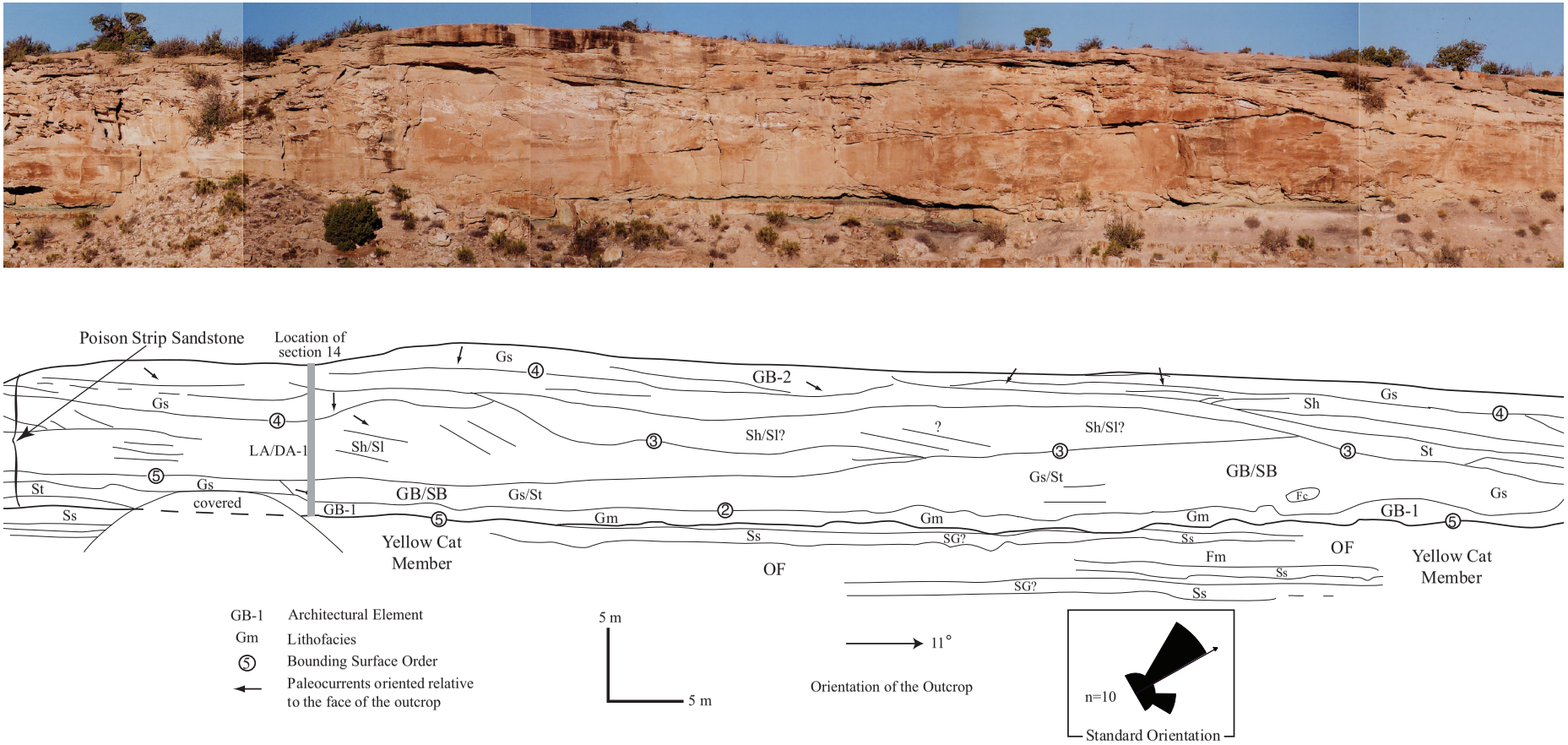


Figure 40. *Panel diagram for area of Window Wash, section 14 (see figure 23 for section location).*

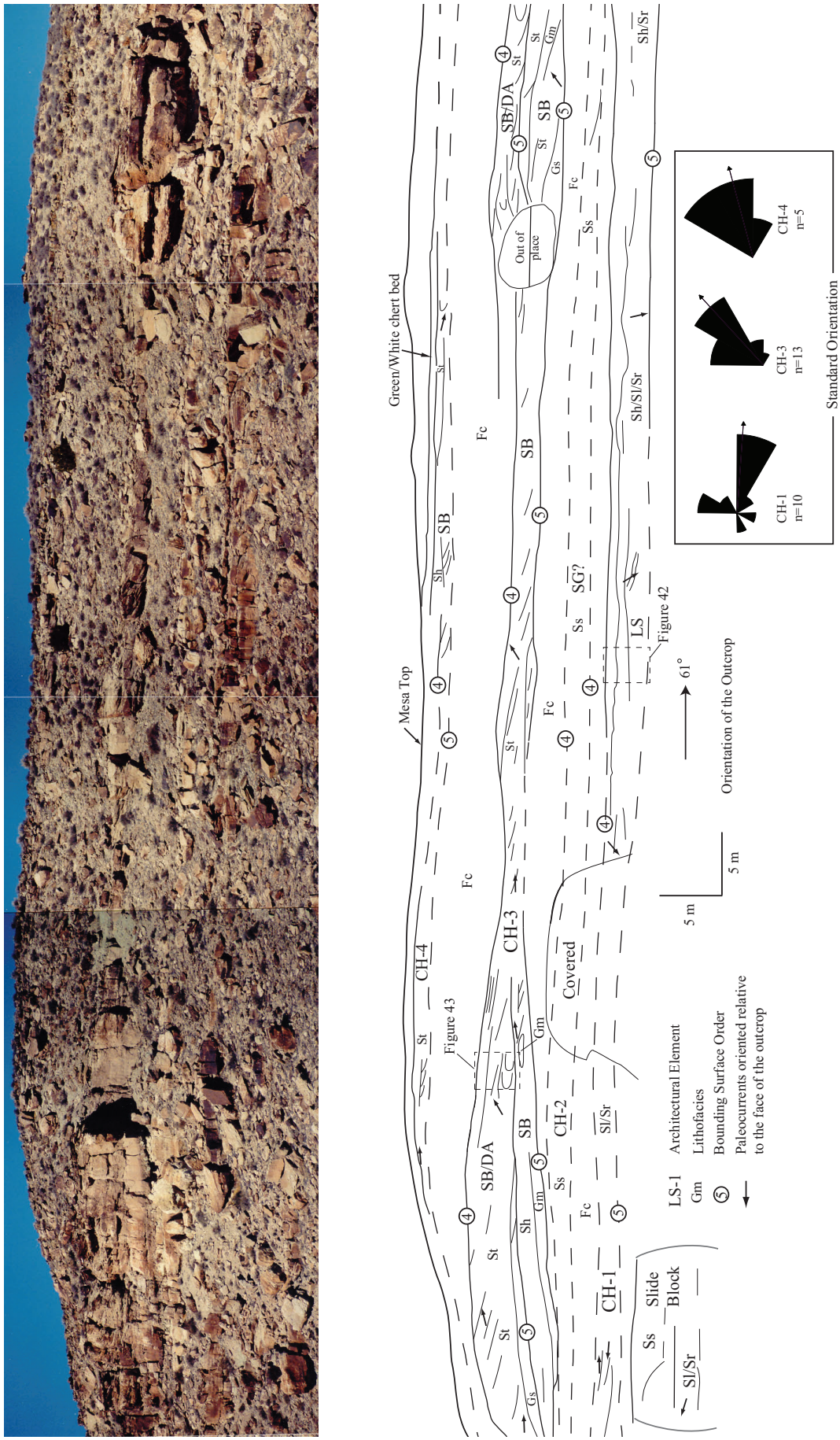


Figure 41. *Panel diagram for area of Kokopelli Trail, section 18 (see figure 23 for section location).*

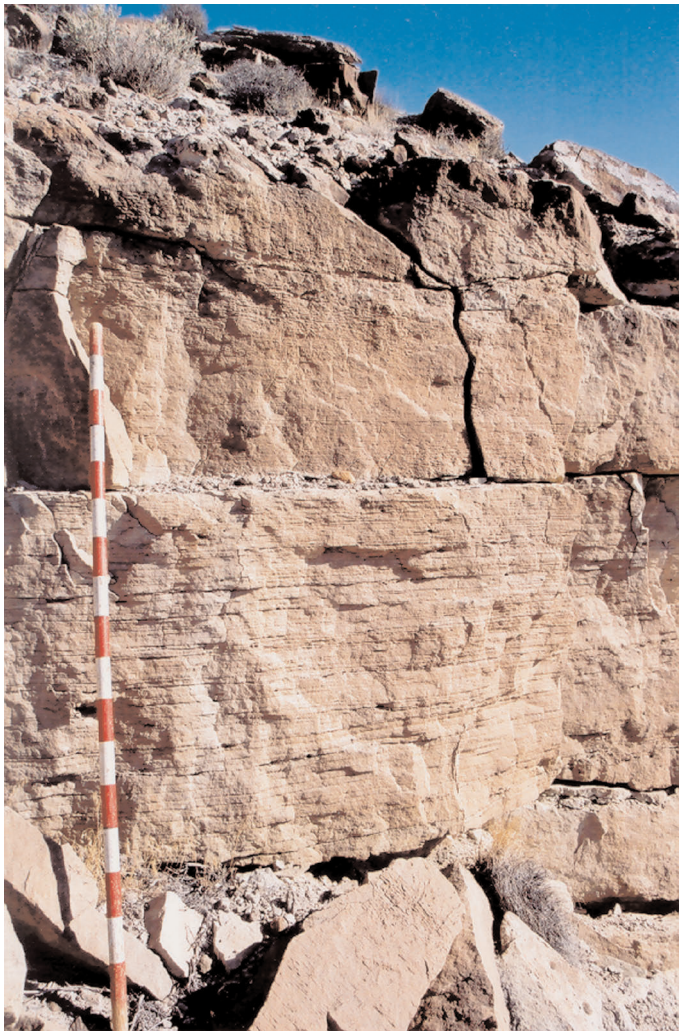


Figure 42. *Lithofacies Sh/Sl overlain by Sr, which together comprise a laminated sand sheet (LS) architectural element.*

Figure 43. *Overturned, recumbently folded cross-strata between dune or bar foreset cross-bedded sandstone. Direction of folding is oriented downstream to the northeast.*

lithofacies Sh/Sl and Sr overlie dune deposits of Gs, St, and Sp, the contact is also typically flat and non-erosive.

The most prevalent characteristic of the Poison Strip Sandstone is a fining-upward trend in grain size. Although not without exception, this vertical trend is very common to sand bodies in the Cedar Mountain Formation. Basal channel lags of lithofacies Gm and gravelly dunes (lithofacies Gs) provide evidence of coarse-grained bedload that lined the channel base. Upsection, sand or pebbly sand cross-stratified deposits were deposited at various locations on the channel base or along bar surfaces. Presumably as flow depth and flow velocity decreased, very fine to medium-grained plane-bedded sand (lithofacies Sh/Sl) and ripple-laminated sand (lithofacies Sr) were preserved in the upper portion of sand bodies. Alternatively, the presence of lithofacies Sh/Sl overlying lower flow regime dunes may signify a flow velocity increase as a consequence of a decrease in the depth of flow. Several fining-upward cycles are often preserved reflecting multiple scour-fill cycles. Although fining-upward is common, the entire stratification sequence rarely occurs and usually only a portion of the sequence is preserved, or there is no discernable fining-upward trend. The sharp and frequent changes in grain-size are likely indicative of variations in discharge and channel switching processes.

The amplitude or height of bedforms varies systematically with position in an individual fining-upward sequence. The size of dune deposits, although rarely exceeding 0.5 m, decreases as position increases within a sequence. The trend is usually not gradual however and occurs as sharp, distinct changes. The relative bedform size is recorded on the measured sections to portray this important information. An upward decrease in the size of bedforms is related to discharge and flow velocity reductions that occur as an individual flood recedes, or as a channel aggrades, or as a channel migrates laterally and slowly abandons its course.

Vertical facies sequences show commonality between measured sections across the field area. Close-up views of the Poison Strip Sandstone from west to east across the field are shown in figure 44. Common lithofacies fining-upward sequences observed in the Poison Strip Sandstone include three types: (1) Gm/Gs → St → Sh/Sl → Sr; (2) Gm/Gs → St → Sla; and (3) Sh/Sl → Sr. All cycles are not preserved in total and there are numerous instances where, for example, lithofacies Sr overlies lithofacies Gm. This is in part due to the nature of fluvial processes which scour off the upper portion of a previously deposited sequence, or may be related to marked discharge fluctuation. The rarity of lithofacies Sp observed in the measured sections may reflect a lack of sustained intermediate flow strength related to ephemeral discharge (Luttrell, 1993). With the understanding of flow regime concepts and channel-fill processes, interpretations of depositional conditions based on the vertical profiles can be made. In general, three fining-upward sequences in figure 44 express sedimentologically, an up-ward reduction in discharge and a resulting decrease in capacity and competency of flow. They are considered here the product of single flood events rather than a result of lateral channel migration.

Cyclicity is expressed within the Poison Strip Sandstone as multiple fining-upward sequences, some of which are multi-storey. The size of the cycles is small enough to exclude extra-basinal control and is likely the result of multiple channel fill events related to superimposed flood cycles, channel division and reattachment, avulsion, and lateral migration.

Lateral trends within the field area are not clearly evident. Expected downstream transitions such as decrease in grain size, decrease in slope and consequent changes in sinuosity and bedform type frequency are not well expressed. This may be due to the limited vertical extent of the Poison

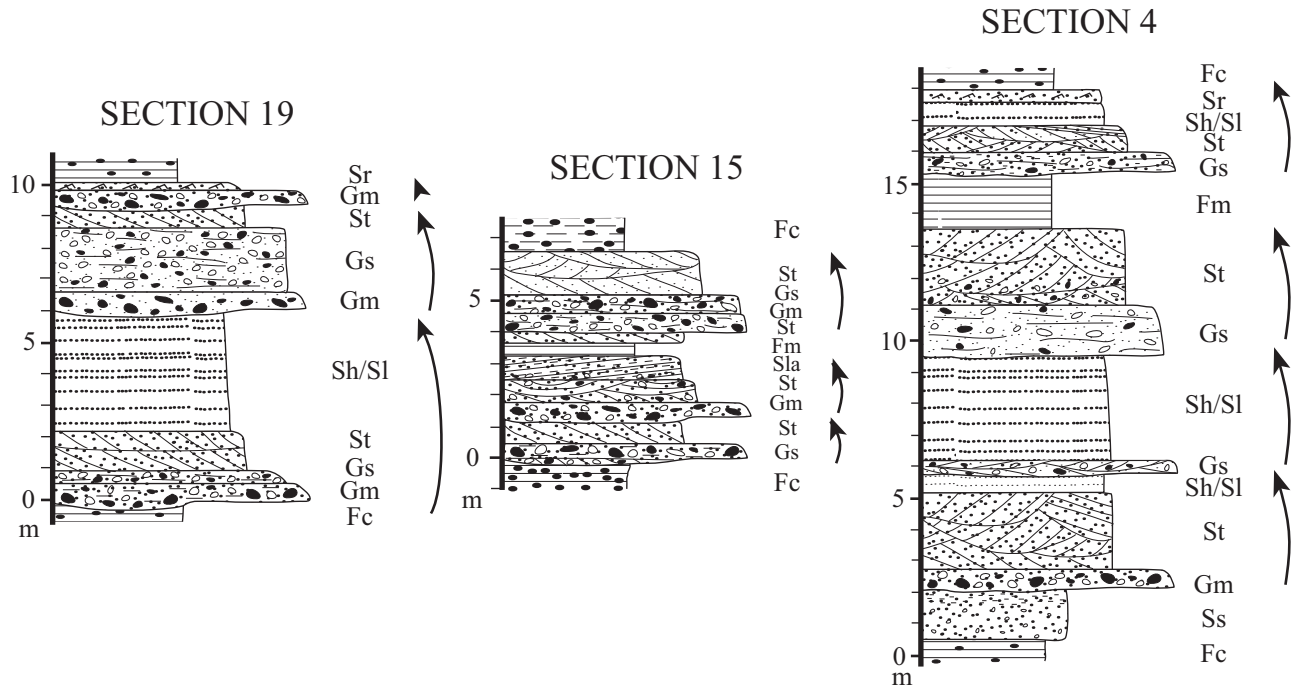


Figure 44. *Vertical profiles through three multi-storey sand bodies of the Poison Strip Sandstone. See figures 23 and 27 for section locations and figure 25 for facies explanation.*

Strip Sandstone or the small size of the field area. One lateral fining trend does exist and consists of a decrease in gravel content in the eastern one-third of the field area including sections 5, 16, 17, and 18.

Initial conclusions regarding a specific type of fluvial system from the measured sections are speculative and could include both braided and meandering types. Fining-upward sequences are ubiquitous to fluvial deposits and point bar growth, channel fill and abandonment, and tectonic processes can all create fining-upward cycles. Nevertheless, the caliber of sediment, the sharp changes between bedform type, and the variety of vertical sequences sway interpretation towards a braided rather than a meandering system.

Paleocurrent Analysis

The paleocurrent indicators recorded during section measurement and architectural analysis suggest a fluvial system of low to intermediate sinuosity. An average transport direction towards 50° with variance between 0° to 120° is displayed on the cumulative rose diagram (figure 28 e). The paleocurrent distributions shown on the facies rose diagrams show general commonality (figure 28 a-d). The most recorded direction was that of facies St, with a strong northeastern unimodal direction, however with moderate dispersion. Facies Sp has few readings and shows an east/southeast direction, possibly related to oblique accretion of dunes or bars. Facies Sh/Sl also has few readings and shows an orientation similar to the east/southeast direction of facies Sp. A polymodal distribution is shown by facies Sla indicating a combination of downstream and lateral progradation. Rose diagrams at section locations show paleoflow generally to the north, northeast, and east but there is scatter in the other quadrants as well (figure 27). The individual rose diagrams of most importance include sections 6, 9, 14, 18, and 21, which were architectural profile sites. These rose diagrams have the largest number of readings; whereas the remaining section rose diagrams often have few readings and are of low statistical validity. When assessing the architectural profile rose diagrams alone, less directional variance is evident. As established by numerous studies including Yingling (1987) and Currie (1998), the source area for the Cedar Mountain Formation was the sedimentary rocks of the Sevier thrust belt to the west of the study area. The paleocurrent information from the field area are in agreement with this interpretation but also show a southerly source component, possibly related to more northerly flowing channel system of the Burro Canyon Formation which had a partial source in the Mogollon Highlands (figure 7) (Craig, 1981). The paleocurrent pattern indicates an overall basin-tilt direction to the northeast. The presence of the Salt Valley anticline appears not to have had a geomorphic influence on paleoflow indicators recorded from the Poison Strip Sandstone. The paleocurrent indicators measured within Salt Valley and Cache Valley show high directional variance (sections 11, 12, and 13) but there is no incompatible trend with the regional pattern. Rose diagrams directly across the valley from each other are in general alignment (e.g. sections 8 and 21). Other geomorphic influences can not be deduced from the paleocurrent data and the overall variance in paleoflow direction is attributed to changing channel direction, and variation of in-channel sediment transport direction. One notable lateral paleocurrent trend is evident and consists of a more regular, northeasterly pattern in the eastern one-third of the field area (sections 5, 16, 17, and 18).

Fluvial Style and Facies Model

The combination of vertical profile and architectural profile analysis gives strong evidence of fluvial style and provides the basis for construction of a fluvial facies model. Studies on modern rivers by geomorphologists have established a range of channel patterns and the relationship between important variables such as discharge, sediment load, slope, channel width, channel depth, and sinuosity (Leopold and Wolman, 1957; Schumm, 1968b, 1981, 1985). The four major channel patterns are straight, braided, meandering, and anastomosed, although a continuum exists between these types. Sedimentologists have long been devising methods to apply the knowledge of modern fluvial systems to the interpretation of ancient fluvial sequences (e.g. Allen 1974, 1983; Cant and Walker, 1978; Ramos and Sopena, 1983). In this manner, the sedimentary data revealed in the previous chapters and interpreted by our understanding of modern environments, allows for the creation of an environmental reconstruction of the past, or a facies model (Reading and Levell, 1996). Only essential criteria are included in the model such as facies, architecture, and channel pattern. The model's purpose is primarily comparative and is provided as a guide for future study. Fluvial facies models for the Poison Strip Sandstone are shown in figures 45 and 46.

The vertical profiles, architectural profiles, and overall character of the Poison Strip Sandstone give mixed signals as to the type of river pattern, degree of sinuosity, and discharge nature. The vertical profiles generally indicate a braided fluvial system but alone are inconclusive. As described and interpreted in the previous section, the architectural profiles display a range of fluvial channels with various types of internal sedimentary fill deposited by channels of noticeably different character. Some of the affinities to a sinuous, meandering system include moderate paleocurrent dispersion, low-angle accretion surfaces in the form of side bars and point bars, some thick ribbon sand bodies, the occurrence of lithofacies Sla, and many examples of fining-upward sequences. Characteristics such as these are envisioned to have formed in a manner similar to the South Platte River of Crowley (1983) and the bedload, low-sinuosity channels with alternate bars of Gueydan fluvial axis on the Texas Gulf Coastal Plain described by Galloway (1981). It is possible that these sand bodies represent an eastward extension of the fluvial system described by Harris (1980) near Green River. A fluvial facies model with these characteristics is displayed in figure 45.

Alternatively, there is evidence in line with a braided system such as abundant coarse bedload, multi-storey/multilateral sheet and restricted sheet sand bodies, paucity of overbank deposits or channel plugs at the Poison Strip Sandstone level, flat to low-angle channel margins, mid-channel bars, low within-channel paleocurrent dispersion, common concave-up erosional scours, and multiple, stacked fining-upward cycles. In many respects, these deposits resemble the lower flow regime, primarily trough cross-stratified deposits described by Williams (1971) for sandy ephemeral

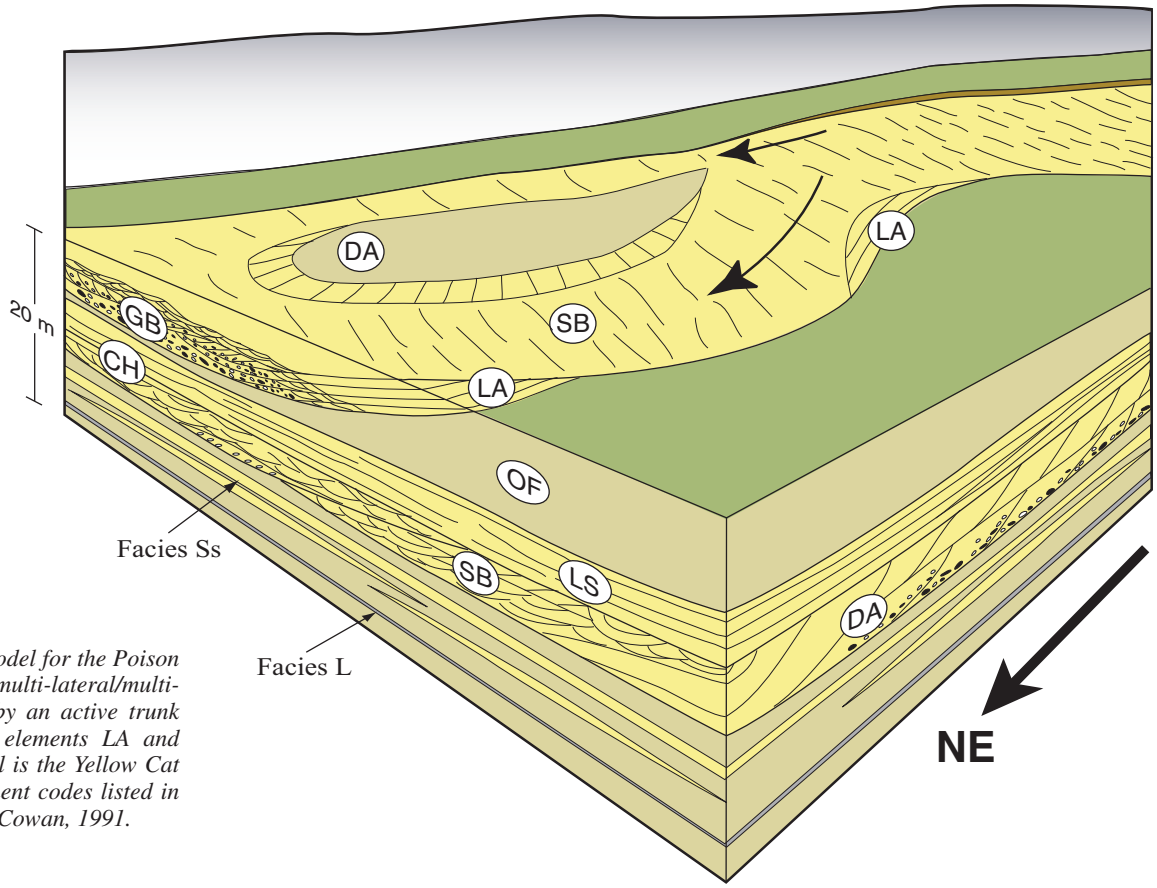


Figure 45. *Fluvial facies model for the Poison Strip Sandstone depicting a multi-lateral/multi-storey sand body overlain by an active trunk channel with architectural elements LA and DA. Lower section of model is the Yellow Cat Member. Architectural element codes listed in table 2. Model format from Cowan, 1991.*

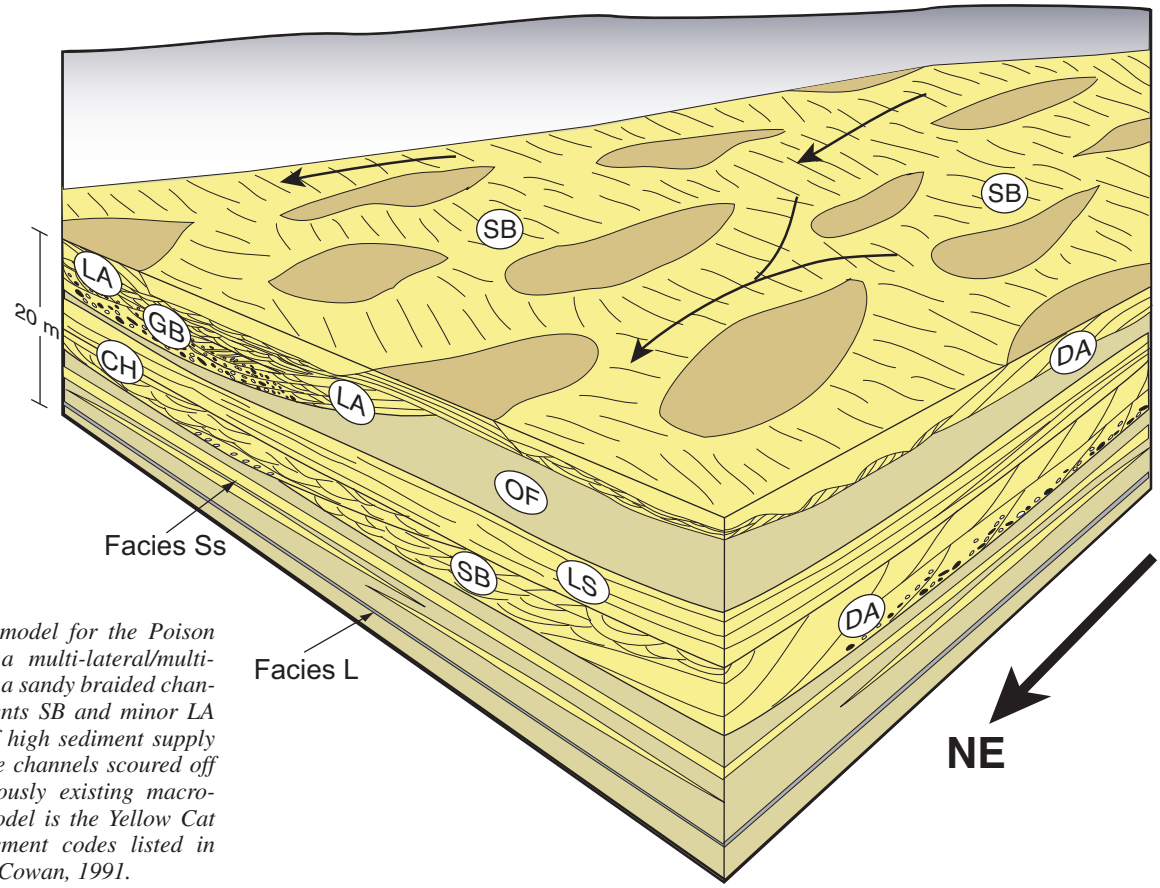


Figure 46. *Fluvial facies model for the Poison Strip Sandstone depicting a multi-lateral/multi-storey sand body overlain by a sandy braided channel with architectural elements SB and minor LA and DA. During periods of high sediment supply braiding occurred, and these channels scoured off the upper portion of previously existing macro-forms. Lower section of model is the Yellow Cat Member. Architectural element codes listed in table 2. Model format from Cowan, 1991.*

streams in the arid interior of Australia. A braided fluvial facies model with these characteristics is shown in figure 46. When considering the relative volume or occurrence rate of the two fluvial styles, the general interpretation falls with the braided system. The fluvial system seems to consist of low-moderate sinuosity channels with alternate bars occurring at locales such as sections 3, 4, 6, 13, 14, 17, 18, 19, and, more commonly, of shallow, braided channels and sandy braidplains occurring between (e.g. sections 1, 2, 5, 9, 10, 11, 15, 16, and 20).

The sedimentary characteristics also give differing indications with respect to discharge regime. Characteristics consistent with a perennial discharge regime are the presence of macroforms up to 5 meters in height, thick channel exposures, and the predominance of lower flow regime bedforms primarily as different forms of facies St. Observed ephemeral discharge regime characteristics include poor sediment sorting, angular and matrix supported intraformational conglomerate, low amplitude bedforms, rarity of lithofacies Sp, lithofacies Sh/Sl abundance and laminated sand sheets, overturned bedding, and the small scale of most fining-upward sequences.

Evolution of Poison Strip Fluvial System

The Poison Strip Sandstone represents part of an Aptian-Albian fluvial system which transferred sediment from the Sevier thrust belt north and east across a broad alluvial plain. The fluvial architecture and facies indicate that a braided fluvial system with major trunk streams and shallow between-trunk braidplains migrated across the field area at one stratigraphic interval amalgamating into multi-lateral and in some instances multi-storey channel sand bodies. The lower flow regime lithofacies contained in the between-trunk braidplains suggest they were not crevasse splays, but were constructed during periods of high sediment supply when flow overtopped channel banks and transported bedload across a broad portion of the floodplain. Macroforms and bedforms were deposited in trunk channels of low to moderate sinuosity with depths up to five meters (figures 30, 36, 40). Between-trunk channels were shallow and broad and contained simple channel fills primarily formed by single flood events (figures 30, 33, 41). The nature of discharge is interpreted as ephemeral to perennial and is likely a result of seasonality rather than of aridity. Average discharge was likely small to moderate as indicated by the small depth of most channels. The type of sediment transferred by the Poison Strip fluvial system was primarily bedload but had a significant fine-grained component. As thrusting progressed in the Sevier thrust belt and foreland basin subsidence increased, the fluvial system transformed from a bedload braided system to a dominantly fine-grained system, the Ruby Ranch Member, with abundant calcareous paleosols and straight ribbon channels.

Sedimentary Controls

Intra-basinal Controls

Intra-basinal sedimentary controls, or autocyclic controls, pertain to the redistribution of sediment within the basin by processes intrinsic to that basin. The most significant of these controls for fluvial systems include lateral channel migration and channel avulsion (Miall, 1996). Factors of less importance include vegetation and bank stability. An additional intra-basinal control in this study involves the possibility of intra-basinal tectonism by the Salt Valley anticline, a central feature of the field area.

Alluvial stratigraphic models have been developed to investigate the stacking pattern of fluvial channel and overbank deposits as controlled by intra-basinal processes (Allen, 1974, 1978; Leeder, 1978; Bridge and Leeder, 1979). The rate and style of avulsion is the major control of the experimental stratigraphy. Important factors that must be assumed or estimated in the creation of a quantitative model include avulsion position, avulsion frequency, channel and floodplain aggradation rate, and sediment compaction. Derivation of this type of data from the Cedar Mountain Formation is impossible with the resolution of age control in the local section. The Cedar Mountain Formation roughly spans the Cretaceous Barremian to the Cenomanian stages (120-100 Ma) based on vertebrate fauna (Kirkland et al., 1997). However, rather than working from process to product, but proceeding from product to process the relative importance of these intra-basinal controls can be assessed.

The sand body architecture of the Poison Strip Sandstone was likely controlled by a combination of channel avulsion and lateral channel migration. Within braided channels, the arrangement of architectural elements and bounding surfaces is primarily the product of autogenic avulsion of minor and major channels triggered by channel and bar aggradation (Miall, 1996). Under conditions of high sediment supply and rapid channel aggradation, smaller intra-channels would be forced to switch position within the larger channel belt, as their elevation reached a threshold value. This type of avulsion was an important factor in the creation of braided or laterally amalgamated channel deposits such as displayed in the Communication Tower profile. Also, switching of the entire channel belt, which occurred less frequently, was instrumental in formation of a multi-lateral sandstone. Thick sand bodies containing lateral and downstream accretion surfaces such as the Long Valley East and Window Wash profiles were likely locations of long-term channel stability and were formed during extended periods of low sediment supply and lower flow regime discharge. Fining-upward successions observed in the vertical profiles are likely the result of all of these processes. In some cases, a fining-upward trend is the result of lateral migration rather than vertical aggradation, as is the circumstance in sections 7 and 13 (appendix 2). The interconnected sheet and restricted sheet sand bodies within the field area attest to the importance of intra-channel avulsion as a mechanism of lateral sand body growth. Although macroform elements are present locally including lateral bars, and downstream-accreting bars, the majority of the sandstone is interpreted to be of vertical aggradation origin. Based on the multi-lateral, multi-storey sand bodies and the common channel fills indicative of vertical aggradation, avulsion is regarded as a more significant intra-basinal control than lateral migration. The depositional time frame of the Poison Strip Sandstone (Aptian-Albian) and the low rate of accommodation space generation in this part of the foreland basin likely allowed braided fluvial systems to cross this portion of the alluvial plain creat-

ing a large channel belt or alluvial ridge (Allen, 1965).

Vegetation and bank stability are also important factors in the behavior of fluvial channel systems. Cohesive banks composed of swelling clays and highly vegetated banks commonly found in humid climates promote channel stability (Schumm, 1968a; Smith, 1976). The moderately smectitic mudstone deposits in the Yellow Cat Member of the Cedar Mountain Formation were likely resistant to erosion by channel processes. Also the common conifer logs preserved in the channel fill and local cycads indicate a partially vegetated floodplain. The tree limbs may however be a product of the source area and not indicative of the local overbank flora.

The action of salt tectonism by the Salt Valley anticline does not appear to have had an influence on the deposition of the Poison Strip Sandstone. Local basin development related to salt withdrawal at the Salt Valley anticline are invoked as the likely cause for the capture of the lacustrine-floodplain sequence of the Yellow Cat Member (Aubrey, 1996; Eberth et al., 1997), despite the Salt Valley's previous history in the rock record as a structural high. It is too convenient of an explanation to simply reverse the salt tectonic movement to create a structural high, responsible for the low accommodation space during Poison Strip Sandstone deposition. The Cedar Mountain and Burro Canyon Formations show a broad thinning across the area from Green River to the Utah-Colorado state line, suggesting larger scale tectonic control such as the forebulge of Currie (1998). Also the magnitude of intra-basinal tectonic related topography in older Triassic and Jurassic sequences indicate much larger uplift related to salt tectonics than is evident in the Cedar Mountain Formation.

Extra-basinal Controls

Extra-basinal or allogenic controls are the major factors in a particular basin's geometry and the resulting sedimentary architecture. The two primary extra-basinal controls on continental depositional systems are tectonism and climate. Eustatic sea-level is also a primary control, but is not regarded as a critical factor in this study since the Cretaceous Interior Seaway was to the distant northeast during deposition of the Cedar Mountain Formation (Lawton, 1994). Additionally, the low resolution of biostratigraphy in the Cedar Mountain Formation precludes direct comparison to eustatic control. Secondary extra-basinal controls related to tectonism and climate are sediment supply and discharge regime.

The Cretaceous foreland basin was created by subduction along the west coast of North America (Lawton, 1994). Tectonic stress across the hinterland developed the Sevier thrust belt, which loaded the crust forming an asymmetric basin with a proximal foredeep and medially positioned forebulge (Currie, 1997b). The exact nature of the foreland during Early Cretaceous is greatly debated (Jordan, 1981; Heller and Paola, 1989; Currie, 1998); however there is general agreement that the basin had formed by Albian time (Yingling and Heller, 1992). The Poison Strip Sandstone was deposited in a portion of the expansive alluvial plain that extended east from the thrust belt. The field area is situated in the medial position of the foreland basin, too far removed to be directly effected by fault movements. Yet, as uplift in the Sevier thrust belt progressed, fluvial systems developed which transported sediment in a transverse to oblique direction, east to northeast across the alluvial plain.

The low amount of accommodation space created in the medial portion of the foreland does likely coincide with a flexural forebulge as proposed by Currie (1998). Isopachs of the Cedar Mountain Formation (Craig, 1981; Currie, 1998) show a thinning across a region from Green River to the Utah-Colorado state line probably related to asymmetric subsidence of the basin. At the western San Rafael swell, the Cedar Mountain measures approximately 100 meters, whereas to the east between Green River and the state line the formation averages 40 meters in thickness. The lack of subsidence and accommodation generation in this region allowed for coarse-grained fluvial deposits to be concentrated across one stratigraphic interval, as mentioned in the intra-basinal control section.

The climatic setting during late Early Cretaceous time in the study area has been described as semi-arid to monsoonal by Kirkland et al. (1997), similar to that for the underlying Morrison Formation. This is based primarily on the occurrence of calcite in the mudstone members as calcrete and carbonate nodules. Skipp (1997) also presented a picture of a climate that gradually became more humid during deposition of the Cedar Mountain Formation related to advance of the Cretaceous Interior Seaway.

The fluvial lithofacies and architecture described in this study provides additional clues as to the climate and discharge of the Poison Strip fluvial system. Channel characteristics related to climatic control include the arrangement of lithofacies, the varying types of gravel deposits, and the composition of gravel. The vertical stacking of deposits of extremely different flow conditions gives indication of flashy flow (McKee et al., 1967). These patterns are evident in many of the vertical profiles including sections 3, 9, and 19. This may be related to an ephemeral or seasonal discharge pattern in an arid to seasonal climate. The gravel encountered in this study is primarily a lag deposit, but also occurs as traction-current deposits; both which are indicative of humid, perennial conditions. Gravelly debris flow deposits, which are characteristic of arid, ephemeral systems (Blair and McPherson, 1994), are absent in the study area. The quartzose gravels contained in the channels may be related to high levels of chemical weathering by a humid climate, or may be inherited from the recycling of sedimentary rocks in the Sevier thrust belt. The recycling explanation is favored here as the overbank characteristics including calcrete suggest that chemical weathering was not intense during deposition of the Cedar Mountain Formation. The lack of exposure features such as desiccation cracks, evaporite deposits, and eolian deposits suggest a climate with seasonal variation rather than a climate of extreme aridity.

Sequence Stratigraphic Considerations

The nonmarine sequence stratigraphic framework established by Currie (1997) has direct implication regarding the new informal Cedar Mountain Formation members and the Poison Strip Sandstone. Currie's sequence model contained three system tracts: degradational, transitional, and aggradational which are analogous to marine system tracts lowstand, transgressive, and highstand. Although other terminology for nonmarine system tracts has been developed in the last ten years, (e.g. Wright and Marriott, 1993; Legarreta and Uliana, 1998; Martinsen et al., 1999) this discussion will

apply Currie's framework and terminology. Nonmarine sequences are controlled by accommodation space development and river profile adjustments to changes in relative base level. Particular controls are not specified as tectonics, climate, eustasy, and sediment supply can all control development or destruction of accommodation space. The Buckhorn Conglomerate was the initial Cretaceous sequence, classified as a degradational to transitional sequence and an incised valley-fill. The upper Cedar Mountain Formation, of which the Poison Strip is a member, was interpreted to represent transitional and aggradational system tracts related to increased accommodation space as a result of increased tectonic loading in the Sevier thrust belt. The sequence boundary between the Buckhorn and upper Cedar Mountain was a regionally developed calcrete, correlative to the calcrete at the base of the Yellow Cat Member in the field area.

This model fits the proximal Cedar Mountain Formation exposures well, however in the study area, which was located in the medial portion of the basin, further complexity exists. The calcrete within Currie's transitional system tract was developed upon an emergent forebulge which moved into eastern Utah during the Early Cretaceous. The Yellow Cat Member, consisting of overbank mudstone, above this calcrete, does not fit the model's sedimentary architecture for aggradational system tracts and likely reflects the fill of a local salt-related basin. The Yellow Cat Member, if interpreted in the model's context, would be deposited after the beginning of thrusting in the Sevier, rather than prior to thrusting as interpreted by Kirkland et al. (1997). The Poison Strip Sandstone likely represents a degradational system tract, related to lowering of relative base level. The Poison Strip Sandstone may represent the fill of an incised valley, although paleosols developed on the valley margins were not identified within the field area. The Ruby Ranch Member, above the Poison Strip Sandstone, fits the model's format for transitional and aggradational tracts consisting of ribbon channel deposits and abundant fine-grained deposits. The braided sheet sandstone of the Poison Strip gradually changes upsection to channel-form sand bodies and mudstone and transitions further upsection to dominantly mudstone. The Poison Strip Sandstone and Ruby Ranch Member within the field are thus very similar, at a reduced scale, to the proximal section of the Cedar Mountain Formation. The increase in accommodation space during Ruby Ranch deposition may be related to a sea-level rise and westward transgression, which deposited marine shale above the Cloverly basal conglomerate in central Wyoming (Currie, 1997a). An illustration of these nonmarine sequences for east-central Utah is shown in figure 47.

Regional Relations

The fluvial systems during Aptian-Albian time across the Colorado Plateau consisted of both multi-channel systems transporting primarily bedload and single-channel systems transporting a mixed load. The Poison Strip Sandstone as defined in this study consists of a combination of bedload, shallow braided channels and single-channels with macroforms. Through a review of previous studies, the broad nature of the interaction between the Poison Strip fluvial system and correlative fluvial environments can be assessed (Harris, 1980; Craig, 1981; Yingling, 1987; Aubrey 1996, 1998; Currie, 1998). Although detailed studies of fluvial architecture such as in this project have not been performed on adjacent areas with the exception of Harris (1980), the general sand to mud ratio and overall channel geometry have been adequately described. The previous studies considered here are located in the following areas: Henry Basin and San Rafael swell (Yingling, 1987); Dinosaur National Monument region (Currie, 1998); Green River (Harris, 1980); southeastern Utah and southwestern Colorado (Craig, 1981; Aubrey, 1996, 1998). A paleogeographic map covering the outcrop area of Lower Cretaceous rocks on the Colorado Plateau is shown in figure 48. This map corresponds broadly to the Aptian-Albian time interval of the late Early Cretaceous during which the upper Cedar Mountain Formation was deposited (figure 4). The fluvial systems responsible for deposition of the upper Cedar Mountain Formation show an unusual transformation from a proximal meandering system to a medial braided system. Furthermore, east of the field area the fluvial system becomes a single channel of straight to meandering type. A likely explanation for this fluvial style change through the foreland basin is tectonic control. In the proximal part of the basin, foredeep subsidence outpaced sedimentation resulting in preservation of ribbon channel sand bodies. In the medial portion of the basin, which includes the study area, a lack of accommodation possibly due to a flexural forebulge resulted in sedimentation outpacing subsidence and resulting formation of sheet sand bodies. The lack of subsidence allowed one stratigraphic level to be concentrated with channel deposits by allowing the fluvial system to migrate by lateral migration and channel avulsion. It is likely given the discharge nature, that only trunk channels observed in the field area passed through to the east in the Utah-Colorado state line vicinity, depositing widely spaced sand bodies.

CONCLUSIONS

The Lower Cretaceous Cedar Mountain Formation of east-central Utah contains a centrally positioned, laterally continuous sandstone, termed the Poison Strip Sandstone. The Yellow Cat Member below the Poison Strip, and the Ruby Ranch Member above the Poison Strip are characterized by abundant calcareous mudstone. Fluvial channel lithofacies of sandstone, pebbly sandstone, and conglomerate comprise the Poison Strip Sandstone. Facies vary systematically with channel position and consist of lag deposits, ripple and dune deposits, and bar or sand flat deposits. Sandstone and clast petrology are mineralogically mature and reflect the recycling of sedimentary rocks contained in the Sevier thrust belt.

Vertical profiles through the Cedar Mountain Formation display a variety of channel lithofacies which show fining-upward cycles and sequences containing sharp and rapid facies changes. Paleocurrent indicators, including the dip-direction of cross-strata and the orientation of current-parting lineation, show paleoflow to the northeast with significant dispersion to the north and east.

The Poison Strip Sandstone contains macroforms of both vertical aggradation and lateral accretion origin. Sandy bedforms and gravelly bedforms are most common with local occurrences of laterally and downstream accreting macro-

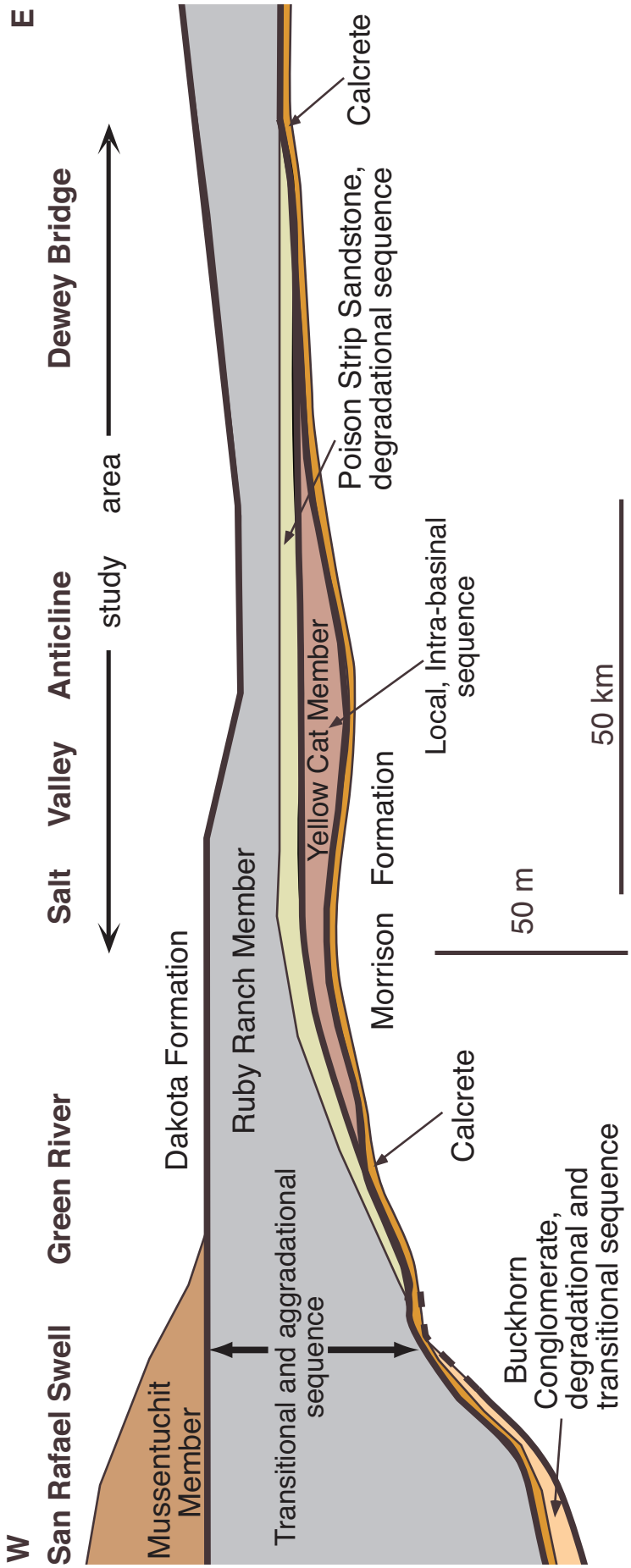


Figure 47. *Cross section for east-central Utah with sequence stratigraphic indications of new informal Cedar Mountain Formation members. Sequence boundaries shown with heavy lines. Line of section shown on figure 5 (modified from Currie, 1997a, and Kirkland et al., 1997).*

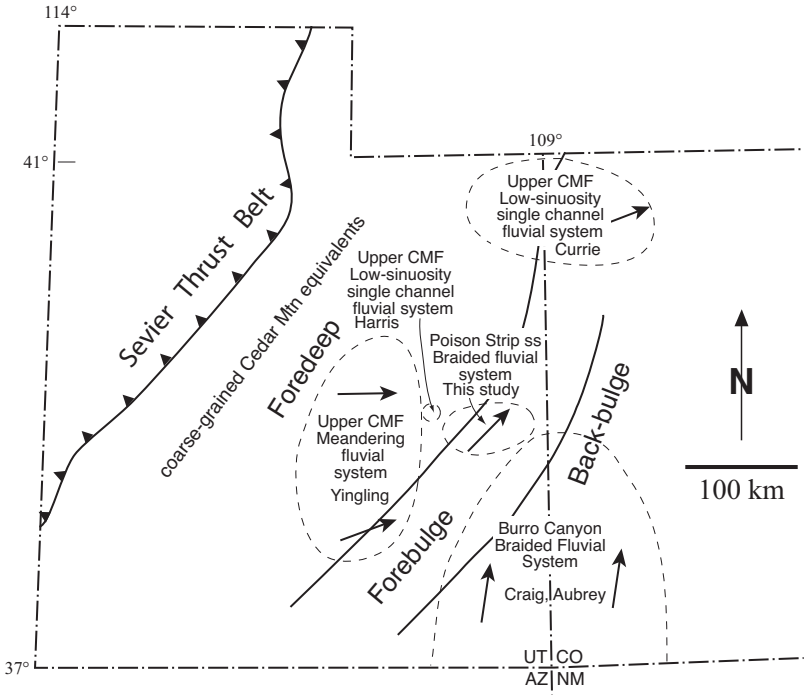


Figure 48. *Map depicting various fluvial subenvironments and foreland basin depozones on the Colorado Plateau during deposition of the upper Cedar Mountain Formation. Large arrows show sediment dispersal patterns. Position of the Sevier thrust belt from McGookey et al., 1972, and position of depozones from Currie, 1997a.*

forms. Laminated sand sheets occur less commonly. These macroforms were constructed in channels of varying character and include deep, perennial braided channels, low-moderate sinuosity channels with side bars, distal braidplains, and flashy, ephemeral channels. During periods of low water and sediment discharge, channel systems consisted of low-moderate sinuosity channels with macroforms. When discharge and sediment supply was high, flow overtopped banks and transported bedload across the floodplain in shallow, interlacing channels.

Tectonic foreland basin development is regarded as the primary formative control on the Poison Strip Sandstone. Intra-basinal controls such as avulsion and lateral accretion were instrumental, although to a lesser extent than extra-basinal tectonicsm. The climate was semi-arid to seasonal and is reflected in the lithofacies suggesting ephemeral to perennial flow conditions. Paradox Basin salt tectonism does not appear to have influenced sedimentation in the Poison Strip Sandstone. Foreland basin depozones, including a medial forebulge, limited accommodation development near the field area and kept subsidence and sedimentation rates low. The lack of accommodation space development during the Aptian-Albian allowed for fluvial systems to migrate extensively across one stratigraphic level and construct a multi-lateral, multi-storey sand body. This limited accommodation generation indicates the Poison Strip Sandstone likely represents a degradational systems tract.

The stratigraphic architecture of the Poison Strip Sandstone compares to regional Lower Cretaceous rocks in various ways. Proximal upper Cedar Mountain deposits to the west consist of ribbon channel deposits encased in mudstone and reflect increased subsidence associated with the foredeep depozone. Upper Burro Canyon deposits to the southeast are coarser, likely braided fluvial deposits, which sourced the Mogollon Highlands and were deposited in the back-bulge depozone. Collectively, the upper Cedar Mountain and upper Burro Canyon Formations strongly reflect Sevier thrust belt and foreland basin tectonics during the late Early Cretaceous.

ACKNOWLEDGMENTS

This master's thesis project was performed under the supervision of the department of geology at Northern Arizona University (Stikes, 2003). Completion of this report would have not been possible without the help of numerous individuals. This study was suggested by R. Cole, and J. Kirkland sold me on the project with his infamous enthusiasm. Thanks go to my advisor R. Blakey who demonstrated extreme patience in the protracted completion of this study. His thought-provoking questions, comments, and leadership are greatly appreciated. Also, thanks go out to other committee members L. Middleton, P. Umhoefer, and R. Cole for guidance and suggestions. Field assistance from Bill Parker and Angela Manacourt was invaluable. Thanks to Vince Santucci of NPS Fossil Resources and the staff at Arches National Park for access during the park's paleontological assessment. Thanks to D. Eberth and B. Currie for comments, suggestions, and direction during this study. Kitty Milliken and Earle McBride at the University of Texas are thanked for assistance with sandstone petrography. Financial support was provided by AAPG Grants-in-Aid and Friday Lunch Clubbe. Thanks to Western Technologies and Trinity Engineering/Kleinfelder for gainful employment during the completion of this project.

Thanks to my family who remained patient during my prolonged university study. I am grateful for my parents, Greg and Madelyn who have always supported and encouraged my academic endeavors. Without question, I am most indebted to my wife, Erin for her unending patience, support, and love over the years and during my graduate work.

REFERENCES

Allen, J.R.L., 1963, The classification of cross-stratified units, with notes on their origin: Sedimentology, v. 2, p. 93-114.

—1965, A review of the origin and characteristics of recent alluvial sediments: Sedimentology, v. 5, p. 89-191.

—1968, Current ripples: North Holland, Amsterdam, 433 p.

—1970, Studies in fluviatile sedimentation: a comparison of fining-upward cyclothems, with special reference to coarse-member composition and interpretation: Journal of Sedimentary Petrology, v. 40, p. 298-323.

—1974, Studies in fluviatile sedimentation: implications of pedogenic carbonate units, Lower Old Red Sandstone, Anglo-Welsh outcrop: Geological Journal, v. 9, p. 181-208.

—1978, Studies in fluviatile sedimentation: an exploratory quantitative model for the architecture of avulsion-controlled suites: Sedimentary Geology, v. 26, p. 129-147.

—1983, Studies in fluviatile sedimentation: bars, bar complexes and sandstone sheets (low-sinuosity braided streams) in the Brownstones (L. Devonian), Welsh Borders: Sedimentary Geology, v. 33, 237-293.

Allen, J.R.L., and Banks, N.L., 1972, An interpretation and analysis of recumbent-folded deformed cross-bedding: Sedimentology, v. 19, p. 257-283.

Ashley, G.M., 1990, Classification of large-scale subaqueous bedforms: a new look at an old problem: Journal of Sedimentary Petrology, v. 60, p. 160-172.

Aubrey, W.M., 1996, Stratigraphic architecture and deformational history of Early Cretaceous Foreland Basin, eastern Utah and southwestern Colorado, *in* Huffman, A.C., Jr., Lund, W.R., and Godwin, L.H., (eds.), Geology and Resources of the Paradox Basin: Utah Geological Association Guidebook 25, p. 211-220.

—1998, A newly discovered, widespread fluvial facies and unconformity marking the Upper Jurassic/Lower Cretaceous boundary, Colorado Plateau: Modern Geology, v. 22, p. 209-233.

Baars, D.L., and Stevenson, G.M., 1981, Tectonic evolution of the Paradox Basin, Utah & Colorado *in* Wiegand, D.L., (ed.), Geology of the Paradox Basin: Rocky Mountain Association of Geologists, 1981 Field Conference, p. 23-32.

Birkeland, P.W., 1999, Soils and Geomorphology: Oxford University Press, New York, 3rd edition, 430 p.

Blair, T.C., and McPherson, J.G., 1994, Alluvial fans and their natural distinction from rivers based on morphology, hydraulic processes, sedimentary processes, and facies assemblages: Journal of Sedimentary Research, v. A64, p. 450-489.

Blakey, R.C., and Gubitosa, R., 1984, Controls on sandstone body geometry and architecture in the Chinle Formation (Upper Triassic), Colorado Plateau: Sedimentary Geology, v. 38, p. 51-86.

Blatt, H., Middleton, G.V., and Murray, R., 1980, Origin of Sedimentary Rocks: Prentice-Hall, Englewood Cliffs, N.J., 2nd edition, 782 p.

Bluck, B.J., 1979, Structure of coarse grained braided alluvium: Transactions of the Royal Society of Edinburgh, v. 70, p. 181-221.

Boggs, S., Jr., 1995, Principles of Sedimentology and Stratigraphy: Prentice-Hall, New Jersey, 2nd edition, 774 p.

Bown, T.M., and Kraus, M.J., 1981, Lower Eocene alluvial paleosols (Willwood Formation, northwest Wyoming, USA) and their significance for paleoecology, paleoclimatology, and basin analysis: Palaeogeography, Palaeoclimatology, Palaeoecology, v. 34, p. 1-30.

—1987, Integration of channel and floodplain suites, I. Development of sequence and lateral relations of alluvial paleosols: Journal of Sedimentary Petrology, v. 57, p. 587-601.

Bjerrum, C.J., and Dorsey, R.J., 1995, Tectonic controls on deposition of Middle Jurassic strata in a retroarc foreland basin, Utah-Idaho trough, western interior, United States: Tectonics, v. 14, p. 962-978.

Bridge, J.S., 1993, The interaction between channel geometry, water flow, sediment transport and deposition in braided rivers, *in* Best, J.L., Bristow, C.S., (eds.), Braided rivers: Geological Society, London, Special Publication 75, p. 13-71.

Bridge, J.S., and Diemer, J.A., 1983, Quantitative interpretation of an evolving ancient river system: Sedimentology, v. 30, p. 599-623.

Bridge, J.S., and Leeder, M.R., 1979, A simulation model of alluvial stratigraphy: Sedimentology, v. 26, p. 617-644.

Brookfield, M.E., 1977, The origin of bounding surfaces in ancient aeolian sandstones: Sedimentology, v. 24, p. 303-332.

Cant, D.J., and Walker, R.G., 1976, Development of a braided-fluvial facies model for the Devonian Battery Point Sandstone, Québec: Canadian Journal of Earth Science, v. 13, p. 102-119.

—1978, Fluvial processes and facies sequences in the sandy braided South Saskatchewan River, Canada: Sedimentology, v. 25, p. 625-648.

Cifelli, R.L., Kirkland, J. I., Weil, A., Deino, A.L., and Kowallis, B.J., 1997, High precision $^{40}Ar/^{39}Ar$ geochronology and the advent of North America's Late Cretaceous terrestrial fauna: National Academy of Science, Proceedings, v. 94, p.11,163-11,167.

Coffin, R.C., 1921, Radium, uranium, and vanadium deposits of southwestern Colorado: Colorado Geological Survey Bulletin 16, 227 p.

Coleman, J.M., 1969, Brahmaputra River: channel processes and sedimentation: Sedimentary Geology, v. 3, p. 129-239.

Collinson, J.D., 1970, Bedforms of the Tana River, Norway: Geografiska Annaler, v. 52a, p. 31-55.

—1978, Vertical sequence and sand body shape in alluvial sequences, *in* Miall, A.D., (ed.), Fluvial sedimentology: Canadian Society of Petroleum Geologists, Memoir 5, p. 577-586.

Cotter, E., and Graham, J.R., 1991, Coastal plain sedimentation in the late Devonian of southern Ireland: hummocky cross-stratification in fluvial deposits: Sedimentary Geology, v. 72, p. 201-224.

Cowan, E.J., 1991, The large-scale architecture of the fluvial Westwater Canyon Member, Morrison Formation (Jurassic), San Juan Basin, New Mexico, *in* Miall, A.D., and Tyler, N., (eds.), The three-dimensional facies architecture of terrigenous clastic sediments, and its implications for hydrocarbon discovery and recovery: Society of Economic Paleontologists and Mineralogists, Concepts in Sedimentology and Paleontology, v. 3, p. 80-93.

Craig, L.C., Holmes, C.N., Cadigan, R.A., Freeman, V.L., Mullens, T.E., and Weir, G.W., 1955, Stratigraphy of the Morrison and related formations, Colorado Plateau region, a preliminary report: U.S. Geological Survey Bulletin 1009-E, p. 125-128.

Craig, L.C., 1981, Lower Cretaceous rocks, southwestern Colorado and southeastern Utah *in* Wiegand, D.L., (ed.), Geology of the Paradox Basin: Rocky Mountain Association of Geologists, 1981 Field Conference, p.195-200.

Currie, B.S., 1997a, Sequence stratigraphy of nonmarine Jurassic-Cretaceous rocks, central Cordilleran foreland-basin system: Geological Society of America Bulletin, v. 109, p. 1206-1222.

—1977b, Jurassic-Cretaceous evolution of the central cordilleran foreland-basin system: University of Arizona, unpublished Ph.D. dissertation, 239 p.

—1998, Upper Jurassic-Lower Cretaceous Morrison and Cedar Mountain Formations, NE Utah-NW Colorado: relationships between nonmarine deposition and early cordilleran foreland-basin development: Journal of Sedimentary Research, v. 68, p. 632-652.

DeCelles, P.G., 1986, Sedimentation in a tectonically partitioned, non-marine foreland basin: The Lower Cretaceous Kootenai Formation, southwestern Montana: Geological Society of America Bulletin, v. 97, p. 911-931.

DeCelles, P.G. and Giles, K.A., 1996, Foreland basin systems: Basin Research, v. 8, p.105-123.

De Raaf, J.F.M., Reading, H.G., and Walker, R.G., 1965, Cyclic sedimentation in the Lower Westphalian of north Devon, England: Sedimentology, v. 4, p. 1-52.

Dickinson, W.R., and Suczek, C.A., 1979, Plate tectonics and sandstone compositions: American Association of Petroleum Geologists Bulletin, v. 63, p. 2164-2182.

Dickinson, W.R., Beard, L.S., Brakenridge, G.R., Erjavec, J.L., Ferguson, R.C., Inman, K.F., Knepp, R.A., Lindberg, F.A., and Ryberg, P.T., 1983, Provenance of North American Phanerozoic sandstones in relationship to tectonic setting: Geological Society of America Bulletin, v. 94, p. 222-235.

Doeglas, D.J., 1962, The structure of sedimentary deposits of braided rivers: Sedimentology, v. 1, p. 167-190.

Doelling, H.H., 1985, Geology of Arches National Park: Utah Geological and Mineral Survey, Map 74, 15 p., scale 1:50,000.

—1993, Interim geological map of the Moab 30 x 60 minute quadrangle, Grand County, Utah: Utah Geological and Mineral Survey, Open-File Report 287, 16 p., scale 1:100,000.

—1996, Geologic map of the Dewey quadrangle, Grand County, Utah: Utah Geological Survey, Map 169, 20 p., scale 1:24,000.

Doelling, H.H., and Morgan, C.D., 2000, Geologic map of the Merrimac Butte quadrangle, Grand County, Utah: Utah Geological Survey, Map 178, 22 p, scale 1:24,000.

Eberth, D.A., Britt, B.B., and Brinkman, D.B., 1997, Sedimentology, facies architecture, and stratigraphy of the Cedar Mountain Formation (Lower Cretaceous) at Dalton Wells Quarry, eastern Utah, U.S.A.: Abstracts with Programs, Geological Society of America, v. 29, p. 113.

Eberth, D.A., and Miall, A.D., 1991, Stratigraphy, sedimentology and evolution of a vertebrate-bearing, braided to anastamosed fluvial system, Cutler Formation (Permian-Pennsylvanian), north-central New Mexico: Sedimentary Geology, v. 72, p. 225-252.

Folk, R.L., 1968, Petrology of sedimentary rocks: Austin, Texas, Hemphill's Book Store, 170 p.

Friend, P.F., 1983, Towards the field classification of alluvial architecture or sequence, *in* Collinson, J.D., and Lewin, J., (eds.), Modern and ancient fluvial systems: International Association of Sedimentologists, Special Publication 6, p. 345-354.

Friend, P.F., Slater, M.J., and Williams, R.C., 1979, Vertical and lateral building of river sandstone bodies, Ebro Basin, Spain: Journal of the Geological Society of London, v. 136, p. 39-46.

Gillette, D.D., (ed.), 1999, Vertebrate paleontology in Utah: Utah Geological Survey, Miscellaneous Publication 99-1, 553 p.

Gradstein, F.M., Agterberg, F.P., Ogg, J.G., Hardenbol, J., Van Veen, P., Thierry, J., and Huang, Z., 1995, A Triassic, Jurassic, and Cretaceous time scale, *in* Berggren, W.A., Kent, D.V., Aubry, M.P., and Hardenbol, J., (eds.), Geochronology, time scales and global stratigraphic correlation: Society of Economic Paleontologists and Mineralogists, Special Publication 54, p. 95-125.

Harms, J.C., and Fahnestock, R.K., 1965, Stratification, bed forms, and flow phenomena (with an example from the Rio Grande) *in* Middleton, G.V., (ed.), Primary sedimentary structures and their hydrodynamic interpretation: Society of Economic Paleontologists and Mineralogists, Special Publication 12, p. 84-115.

Harms, J.C., Mackenzie, D.B., McCubbin, D.G., 1963, Stratification in modern sands of the Red River, Louisiana: Journal of Geology, v. 71, p. 566-580.

Harms, J.C., Southard, J.B., Spearing, D.R., and Walker, R.G., 1975, Depositional environments as interpreted from primary sedimentary structures and stratification sequences: Society of Economic Paleontologists and Mineralogists, Short Course 2, Dallas, 161 p.

Harms, J.C., Southard, J.B., and Walker, R.G., 1982, Structures and sequences in clastic rocks: Society of Economic Paleontologists and Mineralogists, Short Course 9, Calgary, 249 p.

Harris, D.R., 1980, Exhumed paleochannels in the Lower Cretaceous Cedar Mountain Formation near Green River, Utah: Brigham Young University Geology Studies, v. 27, p. 51-66.

Hawley, J.W., and Gile, L.H., 1966, Landscape evolution and soil genesis in the Rio Grande region, southern New Mexico, *in* 11th Annual Field Conference Guidebook, Rocky Mountain Section, Friends of the Pleistocene, 74 p.

Hazel, J.E., Jr., 1994, Sedimentary response to intrabasinal salt tectonism in the Upper Triassic Chinle Formation, Paradox Basin, Utah: U.S. Geological Survey Bulletin 2000, v. F, 34 p.

Hein, F.J., and Walker, R.G., 1977, Bar evolution and development of stratification in the gravelly, braided, Kicking Horse River, British Columbia: Canadian Journal of Earth Sciences, v. 14, p. 562-570.

Heller, P.L., Bowdler, S.S., Chambers, H.P., Coogan, J.C., Hagen, E.S., Shuster, M.W., Winslow, N.S., and Lawton, T.F., 1986, Time of initial thrusting in the Sevier orogenic belt, Idaho-Wyoming and Utah: Geology, v. 14, p. 388-391.

Heller, P.L. and Paola, C., 1989, The paradox of Lower Cretaceous gravels and the initiation of thrusting in the Sevier orogenic belt, United States Western Interior: Geological Society of America Bulletin, v. 101, p. 864-875.

Hintze, L.F., 1980, Geologic map of Utah: Utah Geological and Mineral Survey, scale 1:500,000.

Hubert, J.F., 1977, Paleosol caliche in the New Haven arkose, Connecticut: a record of semiaridity in Late Triassic/Early Jurassic time: Geology, v. 5, p. 302-304.

Ingersoll, R.V., Bullard, T.F., Ford, R.L., Grimm, J.P., Pickel, J.D., and Sares, S.W., 1984, The effect of grain size on detrital modes: a test of the Gazzi-Dickinson point-counting method: Journal of Sedimentary Petrology, v. 54, p. 103-116.

Jackson, R.G., 1976, Depositional model of point bars in the lower Wabash River: Journal of Sedimentary Petrology, v. 46, p. 579-594.

Jopling, A.V., and Walker, R.G., 1968, Morphology and origin of ripple-drift cross-lamination, with examples from the Pleistocene of Massachusetts: Journal of Sedimentary Petrology, v. 38, p. 971-984.

Jordan, T.E., 1981, Thrust loads and foreland basin evolution, Cretaceous, Western United States: American Association of Petroleum Geologists Bulletin, v. 65, p. 2506-2520.

Katich, P.J., 1951, Occurrence of *Tempskya* in the Lower Cretaceous of the Western Interior: Journal of Paleontology, v. 26, no. 4, p. 677.

Kirkland, J.I., 2005, Dinosaurs from the Lower Cretaceous Cedar Mountain Formation: Canyon Legacy, Dan O'Laurie Museum, Moab, Utah, vol. 55, p. 28-36.

Kirkland, J.I., Britt, B., Burge, D.L., Carpenter, K., Cifelli, R., DeCourten, F., Eaton, J., Hasiotis, and S., Lawton, T., 1997, Lower to Middle Cretaceous dinosaur faunas of the central Colorado Plateau: a key to understanding 35 million years of tectonics, sedimentology, evolution and biogeography: Brigham Young University, Geology Studies, v. 42, Part 2, p. 69-103.

Kirkland, J.I., Cifelli, R.L., Britt, B.B., Burge, D.L., DeCourten, F., Eaton, J.G., Lawton, Parrish, J.M., 1999, Distribution of vertebrate faunas in the Cedar Mountain Formation, east-central Utah, *in* Gillette, D.D., (ed.), Vertebrate paleontology in Utah: Utah Geological Survey Miscellaneous Publication 99-1, p. 201-217.

Kirkland, J.I., Zanno, L.E., Sampson, S.D., Clark, J.M., and DeBlieux, D.D., 2005, A primitive therizinosauroid dinosaur from the Early Cretaceous of Utah: Nature, v. 435, no. 7038, p. 84-87.

Keller, W.D., 1962, Clay minerals in the Morrison Formation of the Colorado Plateau: U.S. Geological Survey Bulletin 1150, 90 p.

Kocurek, G., 1981, Significance of interdune deposits and bounding surfaces in aeolian dune sands: Sedimentology, v. 28, p. 753-780.

Kowallis, B.J., Christiansen, E.H., and Deino, A.L., 1991, Age of the Brushy Basin Member of the Morrison Formation, Colorado Plateau, western USA: Cretaceous Research, v. 12, p. 483-493.

Lawton, T.F., 1994, Tectonic setting of Mesozoic sedimentary basins, Rocky Mountain region, United States, *in* Caputo, M.V., Peterson, J.A., and Franczyk, K.J., (eds.), Mesozoic Systems of the Rocky Mountain region, USA: Society of Economic Paleontologists and Mineralogists, Rocky Mountain Section, Denver, p. 1-25.

Leeder, M.R., 1975, Pedogenic carbonates and flood sediment accumulation rates: a quantitative model for aridzone lithofacies: Geological Magazine, v. 112, p. 257-270.

—1978, A quantitative stratigraphic model for alluvium, with special reference to channel deposit density and interconnectedness, *in* Miall, A.D., (ed.), Fluvial sedimentology: Canadian Society of Petroleum Geologists Memoir 5, p. 587-596.

Legarreta, L., and Uliana, M.A., 1998, Anatomy of hinterland depositional sequences: Upper Cretaceous fluvial strata, Neuquen Basin, West-Central Argentina, *in* Shanley, K.W., and McCabe, P.J., (eds.), Relative role of eustasy, climate, and tectonism in continental rocks: Society for Sedimentary Petrology, Special Publication 59, p. 83-92.

Leopold, L.B., and Wolman, M.G., 1957, River channel patterns; braided, meandering, and straight: U.S. Geological Survey Professional Paper 282-B.

Luttrell, P.R., 1993, Basinwide sedimentation and the continuum of paleoflow in an ancient river system: Kayenta Formation (Lower Jurassic), central portion Colorado Plateau: Sedimentary Geology, v. 85, p. 411-434.

Machette, M.N., 1985, Calcic soils of the southwestern United States, *in* Weide, D.L., (ed.), Soils and Quaternary geology of the southwestern United States: Geological Society of America Special Paper 203, p. 10-201.

Martinsen, O.J., Ryseth, A., Helland-Hansen, W., Flesche, H., Torkildsen, G., and Idil, S., 1999, Stratigraphic base level and fluvial architecture: Ericson sandstone (Campanian), Rock Springs Uplift, SW Wyoming, USA: Sedimentology, v. 46, p. 235-259.

McBride, E.F., 1963, A classification of common sandstones: Journal of Sedimentary Petrology, v. 33, p. 664-669.

McCabe, P.J., and Jones, C.M., 1977, Formation of reactivation surfaces within surperimposed deltas and bedforms: Journal of Sedimentary Petrology, v. 4, p. 707-715.

McGookey, D.P., Haun, J.D., Hale, L.A., Goodell, H.G., McCubbin, D.G., Weimer, R.J., and Wulf, G.R., 1972, Cretaceous system *in* Mallory, W.M., (ed.), Geologic Atlas of the Rocky Mountain Region: Rocky Mountain Association of Geologists, p. 190-228.

McGowen, J.H., and Garner, L.E., 1970, Physiographic features and stratification types of coarse-grained point bars; modern and ancient examples: Sedimentology, v. 14, p. 77-112.

McKee, E.D., and Weir, G.W., 1953, Terminology for stratification and cross-stratification in sedimentary rocks: Geological Society of America Bulletin, v. 64, p. 381-389.

McKee, E.D., Crosby, E.J., and Berryhill, H.L., Jr., 1967, Flood deposits, Bijou Creek, Colorado, June, 1965: Journal of Sedimentary Petrology, v. 37, p. 829-851.

Miall, A.D., 1977, A review of the braided-river depositional environment: Earth-Science Review, v. 13, p. 1-62.

—1985, Architectural-element analysis: a new method of facies analysis applied to fluvial deposits: Earth-Science Review, v. 22, p. 261-308.

—1988, Reservoir heterogeneities in fluvial sandstones: lessons from outcrop studies: American Association of Petroleum Geologists Bulletin, v. 72, p. 682-697.

—1991, Hierarchies of architectural units in clastic rocks, and their relationship to sedimentation rate, *in* Miall, A.D., and Tyler, N., (eds.), The three-dimensional facies architecture of terrigenous clastic sediments, and its implications for hydrocarbon discovery and recovery: Society of Economic Paleontologists and Mineralogists, Concepts in Sedimentology and Paleontology, v. 3, p. 6-12.

—1996, The geology of fluvial deposits: sedimentary facies, basin analysis, and petroleum geology: Springer-Verlag, Berlin, 582 p.

Molenaar, C.M., and Cobban, W.A., 1991, Middle Cretaceous stratigraphy on the south and east sides of the Uinta basin, northeastern Utah and northwestern Colorado: U.S. Geological Survey Bulletin 1787-P, 34 p.

Nichols, D.J., and Sweet, A.R., 1993, Biostratigraphy of Upper Cretaceous non-marine palynofloras in a north-south transect of the Western Interior Basin, *in* Caldwell, W.G.E., and Kauffman, E.G., (eds.), Evolution of the Western Interior Basin: Geological Association of Canada Special Paper, v. 39, p. 539-584.

North American Stratigraphic Code, 1983, North American Commission on Stratigraphic Nomenclature: American Association of Petroleum Geologists Bulletin, v. 67, p. 841-875.

Obradovich, J., 1993, A Cretaceous time scale, *in* Caldwell, W.G.E., and Kauffman, E.G., (eds.), Evolution of the Western Interior Basin: Geological Association of Canada, Special Paper 39, p. 379-396.

Ore, H.T., 1964, Some criteria for recognition of braided stream deposits: Contributions to Geology of the University of Wyoming, v. 3, p. 1-14.

Paxton, S.T., Szabo, J.O., Ajdukiewicz, J.M., and Klimentidis, R.E., 2002, Construction of an intergranular volume compaction curve for evaluating and predicting compaction and porosity loss in rigid-grain sandstone reservoirs: American Association of Petroleum Geologists Bulletin, v. 86, p. 2047-2067.

Picard, M.D., and High, L.R., Jr., 1972, Criteria for recognizing lacustrine rocks, *in* Rigby, J.K., and Hamblin, W.K., (eds.), Recognition of Ancient Sedimentary Environments: Society of Economic Paleontologists and Mineralogists, Special Publication 16, p. 108-145.

—1973, Sedimentary structures of ephemeral streams: Elsevier, New York, 223 p.

—1981, Physical stratigraphy of ancient lacustrine deposits, *in* Ethridge, F.G., and Flores, R.M., (eds.), Recent and nonmarine depositional environments: Models for exploration: Society of Economic Paleontologists and Mineralogists, Special Publication 31, p. 233-259.

Ramos, A., and Sopeña, A., 1983, Gravel bars in low-sinuosity streams (Permian and Triassic, central Spain), *in* Collinson, J.D., Lewin, J., (eds.), Modern and ancient fluvial systems: International Association of Sedimentologists, Special Publication 6, p. 301-312.

Reading, H.G., (ed.), 1978, Sedimentary Environments and Facies: Blackwell Scientific Publications, Oxford, 1st edition, 557 p.

Reading, H.G., and Levell, B.K., 1996, Controls on the sedimentary rock record *in* Reading, H.G., (ed.), Sedimentary Environments: processes, facies, and stratigraphy: Blackwell Science Ltd., Oxford, 3rd edition, p. 5-36.

Retallack, G.J., 1997, A colour guide to paleosols: John Wiley & Sons, West Sussex, England, 175 p.

Rust, B.R., 1968, Deformed cross-bedding in Tertiary-Cretaceous sandstone, Arctic Canada: Journal of Sedimentary Petrology, v. 38, p. 87-91.

Saunderson, H.C., and Lockett, F.P.J., 1983, Flume experiments on bedforms and structures at the dune-plane bed transition *in* Collinson, J.D., and Lewin, J., (eds.), Modern and ancient fluvial systems: International Association of Sedimentologists, Special Publication 6, p. 49-58.

Schumm, S.A., 1968a, Speculations concerning paleohydrologic controls of terrestrial sedimentation: Geological Society of America Bulletin, v. 79, p. 1573-1588.

—1968b, River adjustment to altered hydrologic regimen – Murrumbidgee River and paleochannels, Australia: U.S. Geological Survey Professional Paper 598.

—1981, Evolution and response of the fluvial system, sedimentological implications *in* Ethridge, F.G., and Flores, R.M., (eds.), Recent and ancient nonmarine depositional environments: models for exploration: Society of Economic Paleontologists and Mineralogists Special Publication 31, p. 19-29.

—1985, Patterns of alluvial rivers: Annual Review of Earth and Planetary Sciences, v. 13, p. 5-27.

Simmons, G.C., 1957, Contact of the Burro Canyon Formation with the Dakota Sandstone, Slick Rock district: American Association of Petroleum Geologists Bulletin, v. 41, p. 2519-2529.

Simons, D.B., and Richardson, E.V., 1961, Forms of bed roughness in alluvial channels: Proceedings of the American Society of Civil Engineers, v. 87, n. HY3, p. 87-105.

Skipp, G.L., 1997, Characterization and paleoenvironmental interpretation of pedogenic carbonate at the J-K boundary, east-central Utah and west-central Colorado: Colorado School of Mines, unpublished master's thesis, 104 p.

Smith, D.G., 1976, Effect of vegetation on lateral migration of anastomosed channels of a glacial meltwater river: Geological Society of America Bulletin, v. 87, p. 857-860.

Smith, N.D., 1970, The braided stream depositional environment: comparison of the Platte River with some Silurian clastic rocks, north central Appalachians: Geological Society of America Bulletin, v. 81, p. 2993-3014.

—1971, Transverse bars and braiding in the lower Platte River, Nebraska: Geological Society of America Bulletin, v. 82, p. 3407-3420.

Soegaard, K., 1990, Fan-delta and braid-delta systems in Pennsylvanian Sandia Formation, Taos Trough, northern New Mexico: depositional and tectonic implications: Geological Society of America Bulletin, v. 102, p. 1325-1343.

Stear, W.M., 1983, Morphological characteristics of ephemeral stream channel and overbank splay sandstone bodies in the Permian Lower Beaufort Group, Karoo Basin, South Africa *in* Collinson, J.D., Lewin, J., (eds.), Modern and ancient fluvial systems: International Association of Sedimentologists Special Publication 6, p. 405-420.

Stikes, M.W., 2003, Fluvial facies and architecture of the Poison Strip Sandstone, Lower Cretaceous Cedar Mountain Formation, Grand County, Utah: Northern Arizona University, unpublished master's thesis, 147 p.

Stokes, W.L., 1944, Morrison and related deposits in the Colorado Plateau: Geological Society of America Bulletin, v. 55, p. 951-992.

—1952, Lower Cretaceous in Colorado Plateau: American Association of Petroleum Geologists Bulletin, v. 36, p. 1766-1776.

Thayn, G.F., 1973, Three species of petrified dicotyledonous wood from the Lower Cretaceous Cedar Mountain Formation of Utah: Brigham Young University, unpublished master's thesis, 43 p.

Thomas, R.G., Smith, D.G., Wood, J.M., Visser, J., Calverley-Range, E.A., and Koster, E.H., 1987, Inclined heterolithic stratification – terminology, description, interpretation and significance: Sedimentary Geology, v. 53, p. 123-179.

Tschudy, R.H., Tschudy, B.D., and Craig, L.C., 1984, Palynological evaluation of Cedar Mountain and Burro Canyon Formations, Colorado Plateau, U.S. Geological Survey Professional Paper 1281, p. 1-21.

Turner, B.R., 1981, Deformed cross-bedding patterns in the Upper Triassic Molteno Formation in the Main Karoo Basin, South Africa: a model for their genesis: Geologische Rundschau., v. 70, p. 910-924.

Turner, C.E., and Peterson, F., 1999, Biostratigraphy of dinosaurs in the Upper Jurassic Morrison Formation of the Western Interior, U.S.A., *in* Gillette, D.D., (ed.), Vertebrate paleontology in Utah: Utah Geological Survey Miscellaneous Publication 99-1, p. 77-114.

Wells, N.A., Richards, S.S., Peng, S., Keattch, S.E., Hudson, J.A., and Copsey, C.J., 1993, Fluvial processes and recumbently folded crossbeds in the Pennsylvanian Sharon Conglomerate in Summit County, Ohio, U.S.A.: Sedimentary Geology, v. 85, p. 63-83.

Williams, G.E., 1971, Flood deposits of the sand-bed ephemeral streams of central Australia: Sedimentology, v. 17, p. 1-40.

Williams, P.L., 1964, Geology, structure, and uranium deposits of the Moab quadrangle, Colorado and Utah: U.S. Geological Survey, Miscellaneous Investigations Series, Map I-360, scale 1:250,000.

Williams, P.F., and Rust, B.R., 1969, The sedimentology of a braided river: Journal of Sedimentary Petrology, v. 39, p. 649-679.

Wizevich, M.C., 1992, Sedimentology of Pennsylvanian quartzose sandstones of the Lee Formation, central Appalachian Basin: fluvial interpretation based on lateral profile analysis: Sedimentary Geology, v. 78, p. 1-47.

Wright, V.P., and Marriott, S.B., 1993, The sequence stratigraphy of fluvial depositional systems: the role of floodplain sediment storage: Sedimentary Geology, v. 86, p. 203-210.

Yingling, V.L., 1987, Timing of initiation of the Sevier orogeny; Morrison and Cedar Mountain Formations and Dakota Sandstone east-central Utah: University of Wyoming, unpublished master's thesis, 169 p.

Yingling, V.L., and Heller, P.L., 1992, Timing and record of foreland sedimentation during the initiation of Sevier orogenic belt in central Utah: Basin Research, v. 4, p. 279-290.

Young, R.G., 1960, Dakota Group of the Colorado Plateau: American Association of Petroleum Geologists Bulletin, v. 44, p. 156-194.

APPENDIX 1

SANDSTONE PETROGRAPHY

Ten thin-sections of medium-grained sandstone were point-counted for identification and comparison to previous studies. Sections were impregnated with blue epoxy and stained for K-feldspar. At least 300 grains were counted per thin-section. Sections are listed by section number and height in meters, and sample locations are marked with an asterisk (*) on the stratigraphic sections displayed in Appendix 2.

Framework Grains	**2(20.3)**	**5(10.6)**	**7(18.0)**	**11(20.8)**	**12(22.4)**	**13(20.3)**	**14(22.1)**	**15(18.6)**	**19(24.0)**	**21(24.1)**
Qm	90.0	94.6	83.4	88.1	88.3	90.7	87.8	83.0	91.1	81.3
Qp	6.8	3.6	7.1	6.0	3.1	1.1	10.6	6.0	3.9	4.9
Chert	0.5	0.9	4.7	2.5	0.5	2.2	0.0	8.8	4.4	13.2
K-Feldspar	2.7	0.0	2.8	3.0	2.6	3.3	1.1	0.0	0.0	0.0
Plagioclase	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0
Mudclasts	0.0	0.4	1.9	0.0	5.6	2.7	0.5	0.0	0.0	0.0
Intracarbonate Clasts	0.0	0.4	0.0	0.0	0.0	0.0	0.0	2.2	0.6	0.5
Intergranular										
Carbonate Cement	0.0	5.7	28.0	0.3	0.0	4.7	0.3	18.0	1.7	24.7
Silica Cement	26.0	8.7	0.7	28.0	16.0	23.0	35.3	20.3	36.0	9.0
Porosity	0.3	8.7	0.3	4.7	11.0	6.0	0.7	0.3	2.3	4.3
Matrix	0.0	2.7	0.3	0.0	7.7	3.0	0.7	0.7	0.0	1.3
Other	0.0	0.0	0.3	0.0	0.0	2.7	0.3	0.0	0.0	0.0
Recalculated Values										
Qm	90.0	95.5	85.0	88.1	93.5	93.2	88.2	84.8	91.6	81.8
F = K-spar + Plagioclase	2.7	0.0	2.9	3.4	2.7	3.4	1.1	0.0	0.0	0.0
Lt = chert + Qp	7.3	4.5	12.1	8.5	3.8	3.4	10.7	15.2	8.4	18.2
IGV % = Matrix + Porosity + Carb cement + Silica Cement	26.3	25.7	29.3	33.0	34.7	36.7	37.0	39.3	40.0	39.3

APPENDIX 2

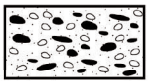
STRATIGRAPHIC SECTIONS

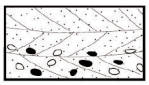
Stratigraphic Section Locations, USPLS, Salt Lake Base Line

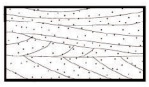
Stratigraphic Section	Township (South)	Range (East)	Section	Primary Quadrant	Secondary Quadrant
1	22	21	36	NE	NW
2	22	21	36	SE	NW
3	22	22	32	NW	NE
4	22	22	28	SW	SE
5	23	24	5	NW	NE
6	24	20	15	SE	NE
7	24	20	2	SE	NW
8	23	20	28	SW	SE
9	23	20	18	Center	
10	22	19	27	Center	
11	24	22	8	NE	SE
12	24	22	7	NW	NW
13	24	21	12	NW	NW
14	22	22	27	NE	NE
15	22	21	32	NE	SW
16	22	23	19	SE	NW
17	22	23	28	SW	SE
18	23	23	1	NE	NW
19	22	19	35	SE	NE
20	22	21	31	SE	Center
21	22	20	36	SE	SW
22	22	20	30	SE	NE

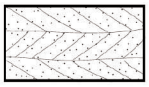
STRATIGRAPHIC SECTION EXPLANATION

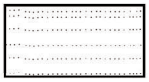
Lithofacies


Gm

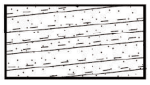

Gs

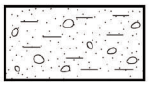

St

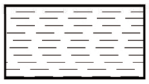

Sp

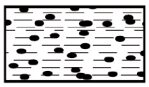

Sh/Sl

Sr

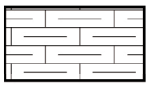

Sla


Ss


Fm


Fc

L


P

Other Characteristics

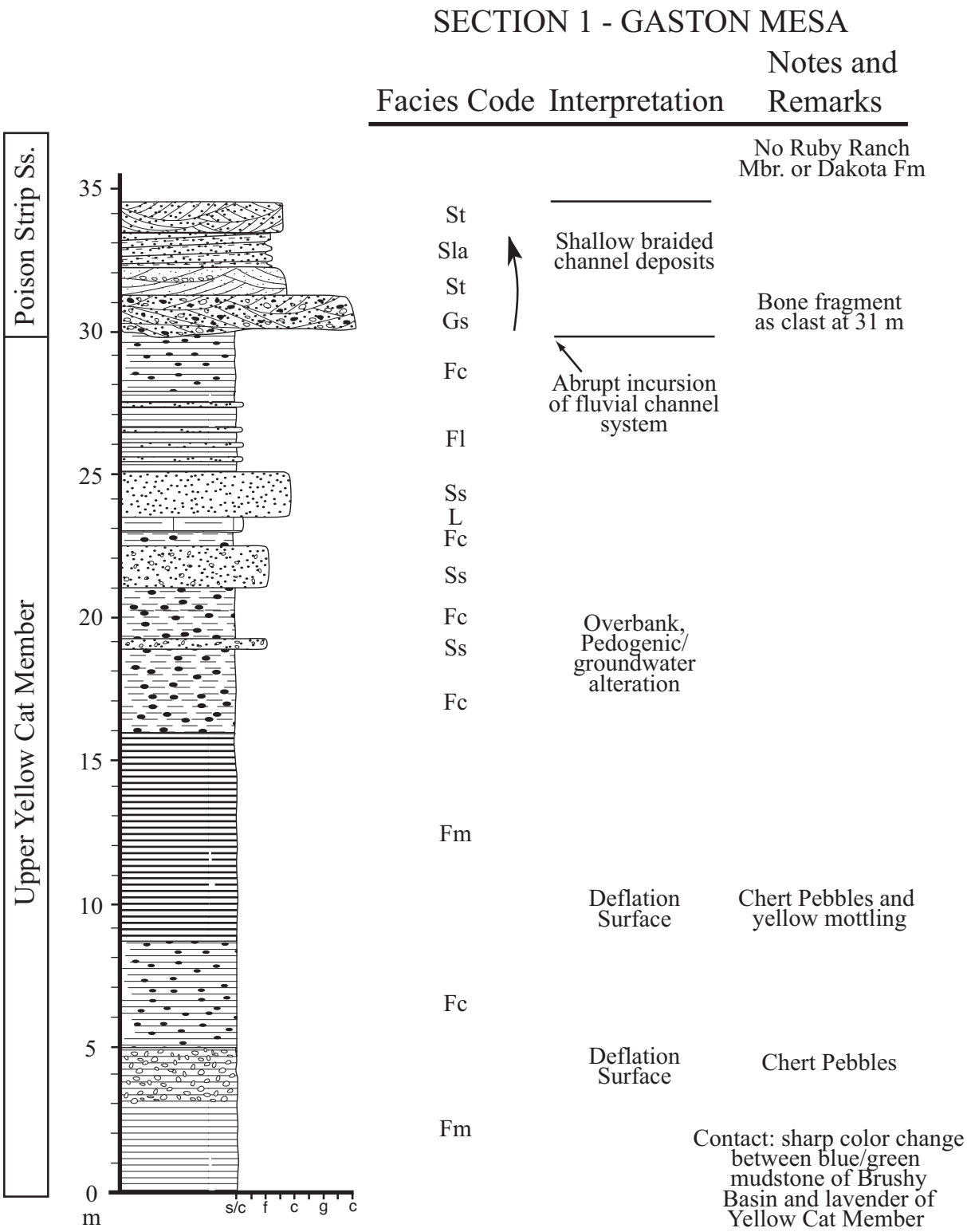
Extra-basinal clasts

Intra-basinal clasts

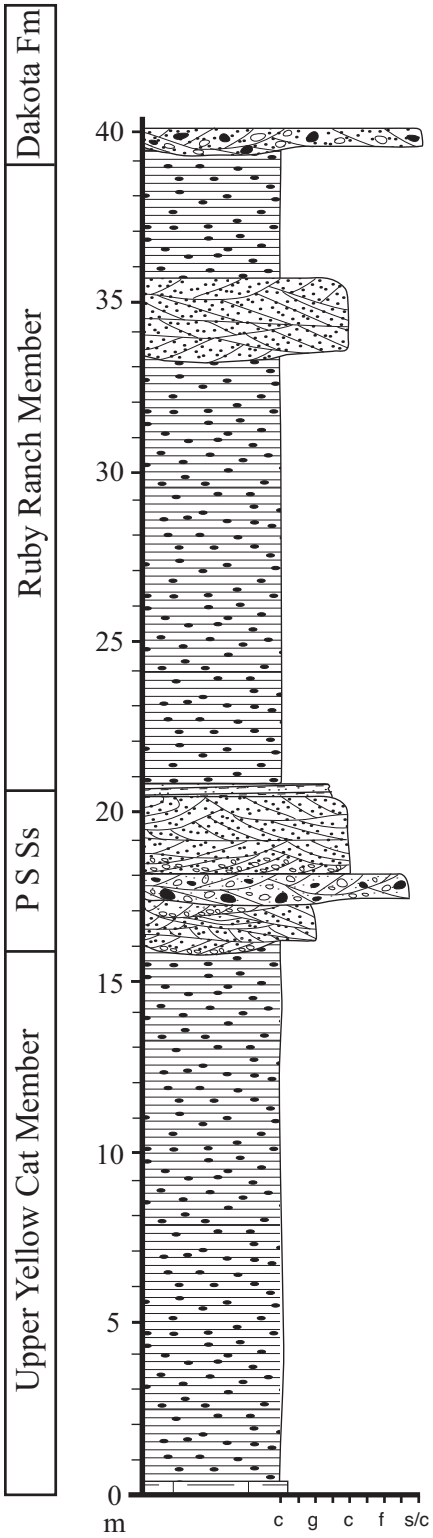
Carbonate nodule horizon

Fining-upward sequence

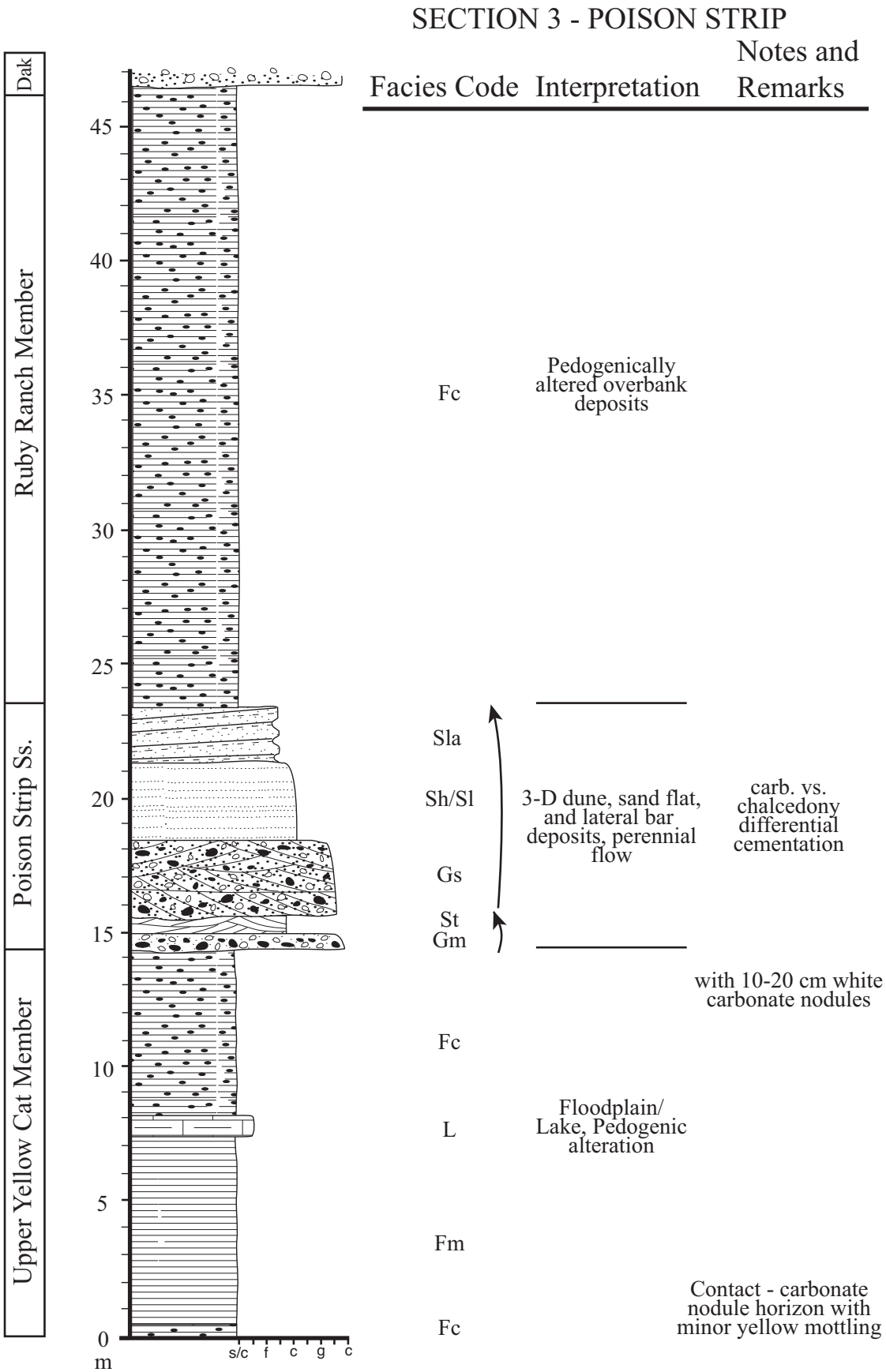
* Point-counted thin-section

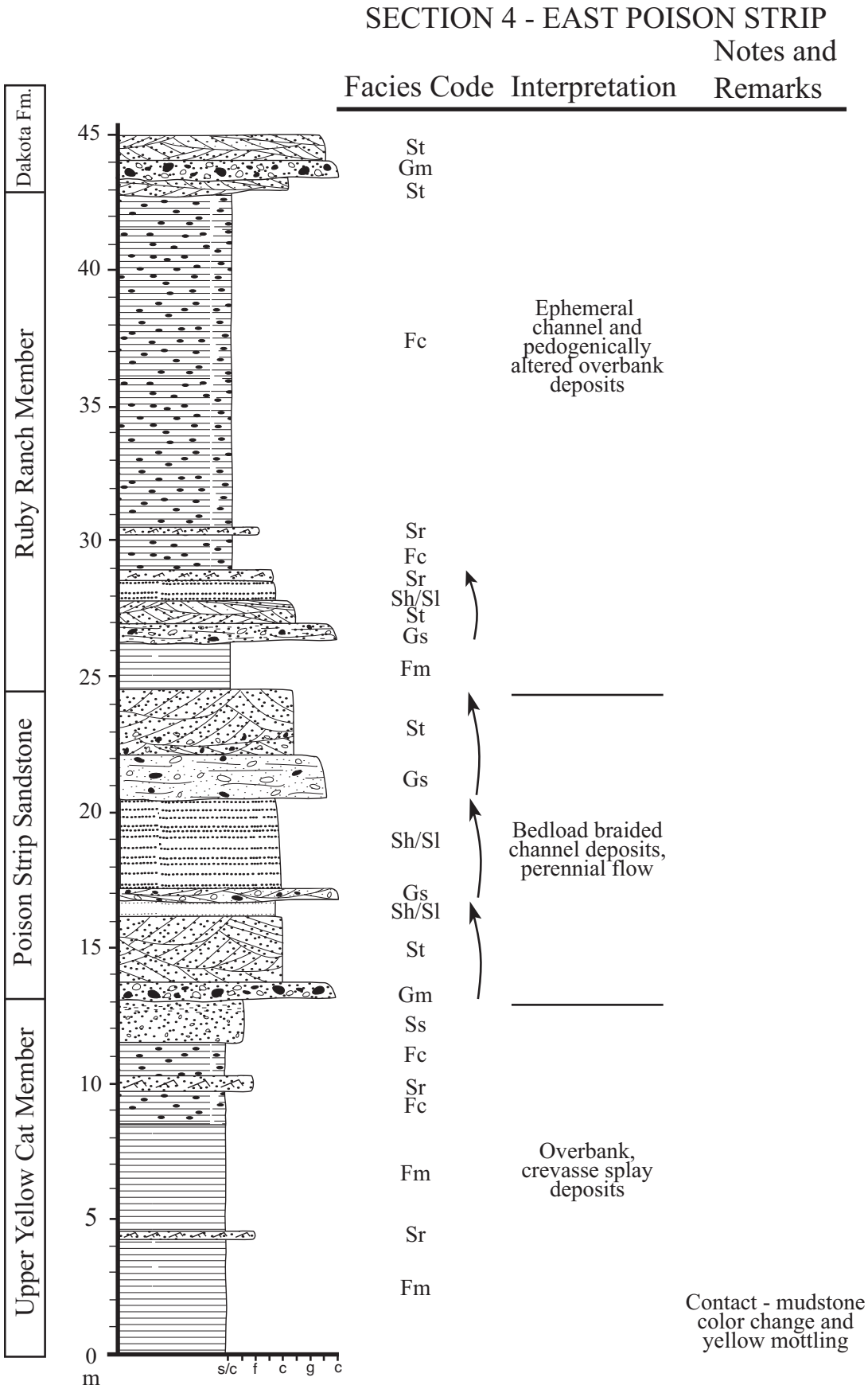

SECTION 1 - GASTON MESA
Facies Code
Interpretation
Notes and Remarks
Poison Strip Ss.
Upper Yellow Cat Member
35
30
25
20
15
10
5
0
m
s/c f c g c
No Ruby Ranch Mbr. or Dakota Fm
St
Sla
St
Gs
Shallow braided channel deposits
Bone fragment as clast at 31 m
Fc
Abrupt incursion of fluvial channel system
Fl
Ss
L
Fc
Ss
Fc
Ss
Fc
Overbank, Pedogenic/ groundwater alteration
Fm
Deflation Surface
Chert Pebbles and yellow mottling
Fc
Deflation Surface
Chert Pebbles
Fm
Contact: sharp color change between blue/green mudstone of Brushy Basin and lavender of Yellow Cat Member

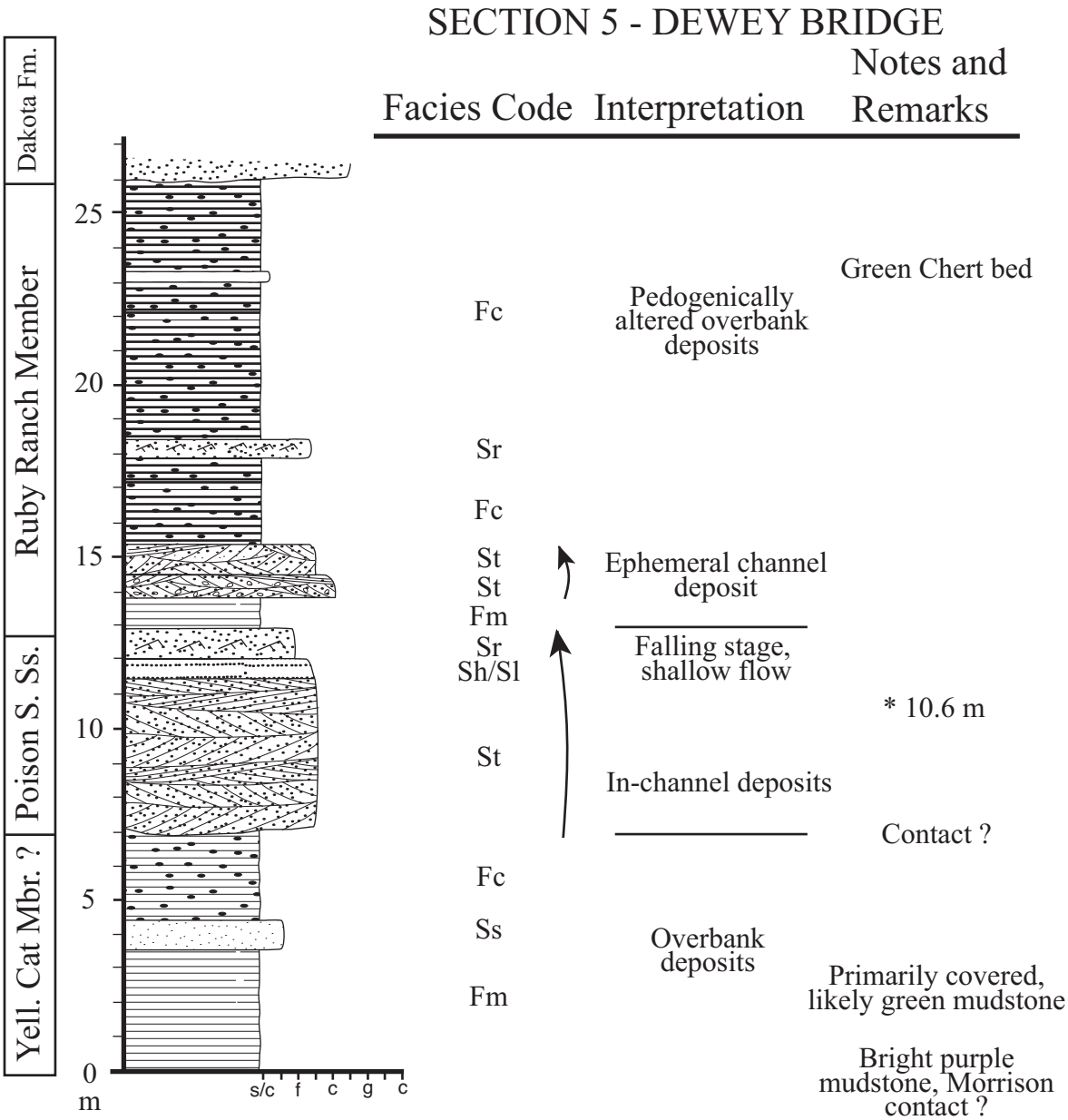
SECTION 2 - GASTON QUARRY



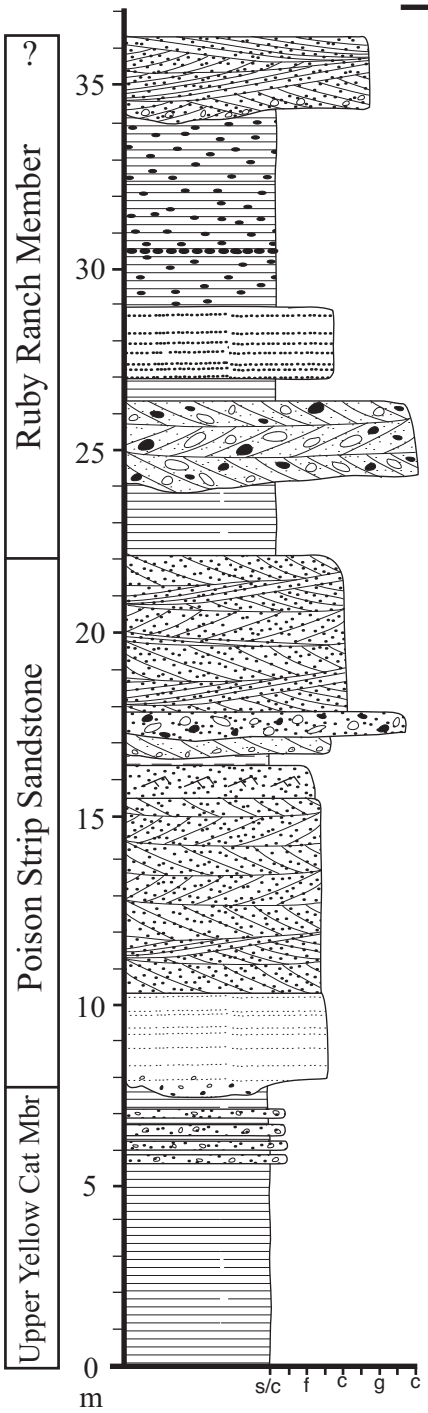
Facies Code	Interpretation	Notes and Remarks
Gs		
Fc		
St	Straight, ephemeral channel	3 m deep x10m wide ribbon; few floating chert/ mudstone pebbles
Fc	Pedogenically altered overbank deposits	
Sla	Mixed-load braided channel	* 20.3 m Some overturned bedding, differential cementation
St		
Gs		
St		Worm bioturbation
Fc	Floodplain and Lacustrine Complex	
P		Thin Calcrete


SECTION 3 - POISON STRIP
Facies Code
Interpretation
Notes and Remarks
Dak
Ruby Ranch Member
Poison Strip Ss.
Upper Yellow Cat Member
45
40
35
30
25
20
15
10
5
0
m
s/c f c g c
Fc
Pedogenically altered overbank deposits
Sla
Sh/Sl
Gs
St
Gm
3-D dune, sand flat, and lateral bar deposits, perennial flow
carb. vs. chalcedony differential cementation
with 10-20 cm white carbonate nodules
Fc
L
Floodplain/ Lake, Pedogenic alteration
Fm
Fc
Contact - carbonate nodule horizon with minor yellow mottling


SECTION 4 - EAST POISON STRIP
Facies Code
Interpretation
Notes and Remarks
Dakota Fm.
Ruby Ranch Member
Poison Strip Sandstone
Upper Yellow Cat Member
45
40
35
30
25
20
15
10
5
0
m
s/c f c g c
St
Gm
St
Fc
Sr
Fc
Sr
Sh/Sl
St
Gs
Fm
St
Gs
Sh/Sl
Gs
Sh/Sl
St
Gm
Ss
Fc
Sr
Fc
Fm
Sr
Fm
Ephemeral channel and pedogenically altered overbank deposits
Bedload braided channel deposits, perennial flow
Overbank, crevasse splay deposits
Contact - mudstone color change and yellow mottling

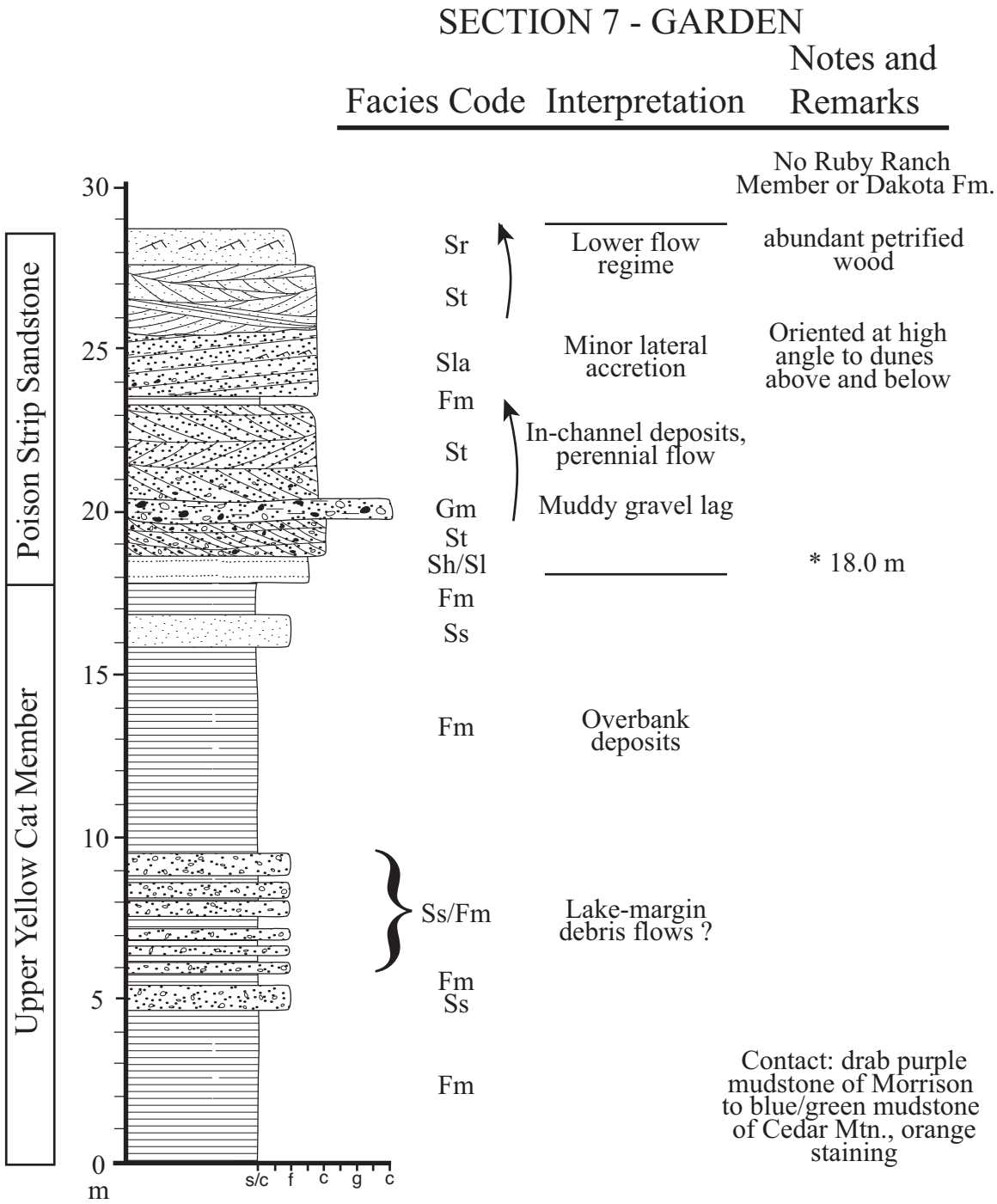

SECTION 5 - DEWEY BRIDGE
Facies Code
Interpretation
Notes and Remarks
Dakota Fm.
Ruby Ranch Member
Poison S. Ss.
Yell. Cat Mbr. ?
25
20
15
10
5
0
m
s/c f c g c
Fc
Sr
Fc
St
St
Fm
Sr
Sh/Sl
St
Fc
Ss
Fm
Pedogenically altered overbank deposits
Ephemeral channel deposit
Falling stage, shallow flow
In-channel deposits
Overbank deposits
Green Chert bed
* 10.6 m
Contact ?
Primarily covered, likely green mudstone
Bright purple mudstone, Morrison contact ?

SECTION 6 - DALTON WELL

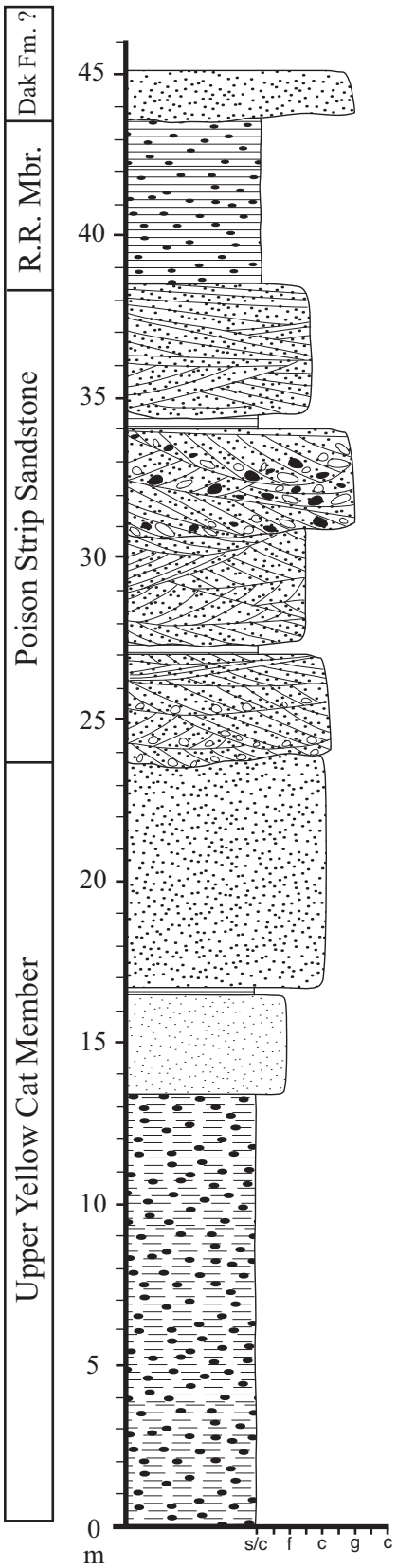


Facies Code	Interpretation	Notes and Remarks
St		Dakota or Ruby Ranch ribbon?
Fc	Pedogenically altered overbank deposits	Carb. nodule horizon
Sh/Sl	Ephemeral channel, lower flow regime	
Fm		
Gs	Preserved bar fronts	Anomalously coarse-grained
Fm		
St	In-channel deposits	
Gm	Channel lag	
St		
Fm	Falling stage, shallow flow	
Sr		
St	In-channel deposits, perennial flow	
Sh/Sl		
Fm/Ss		
	Overbank deposits	
Fm		

Contact: bright purple mudstone of Morrison to gray/green mudstone of Cedar Mtn., orange staining

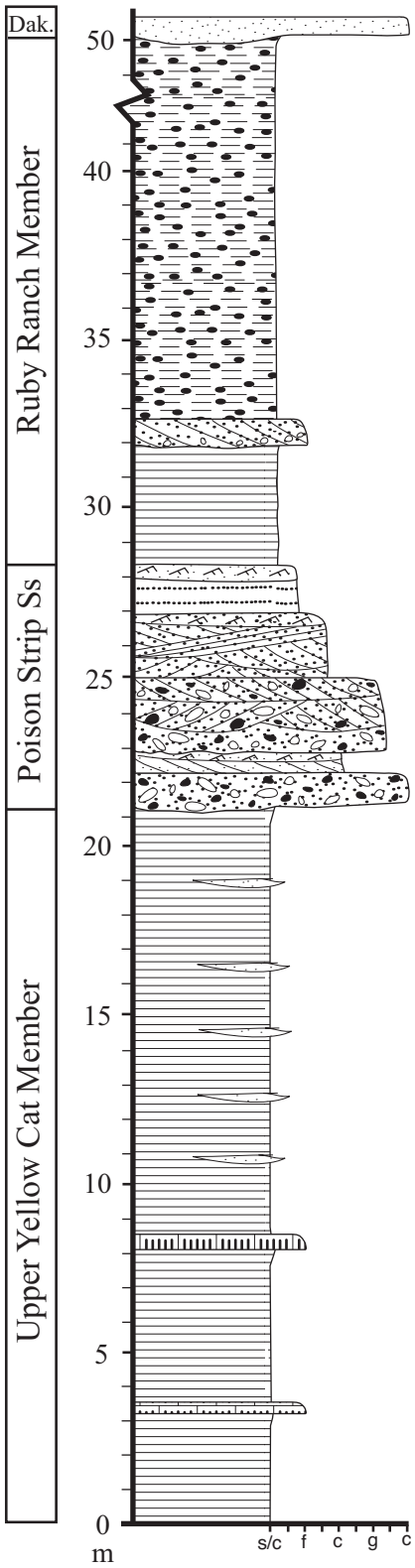

SECTION 7 - GARDEN
Facies Code
Interpretation
Notes and Remarks
No Ruby Ranch Member or Dakota Fm.
Poison Strip Sandstone
Upper Yellow Cat Member
30
25
20
15
10
5
0
m
s/c f c g c
Sr
St
Sla
Fm
St
Gm
St
Sh/Sl
Fm
Ss
Fm
Ss/Fm
Fm
Ss
Fm
Lower flow regime
Minor lateral accretion
In-channel deposits, perennial flow
Muddy gravel lag
Overbank deposits
Lake-margin debris flows ?
abundant petrified wood
Oriented at high angle to dunes above and below
* 18.0 m
Contact: drab purple mudstone of Morrison to blue/green mudstone of Cedar Mtn., orange staining

SECTION 8 - KLONDIKE BLUFFS

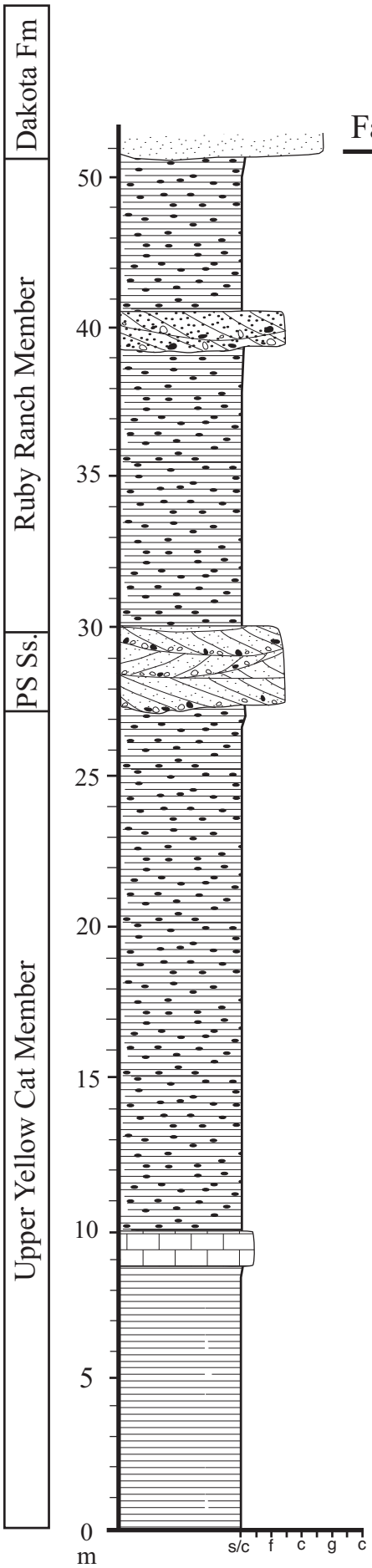


Facies Code	Interpretation	Notes and Remarks
Fc	Pedogenically altered overbank deposits	
St	Low-amplitude dunes of shallow or low-stage flow	Slighty inclined foresets
Fm		31.0-38.5 m variable silica and cabonate cementation
Gs		
St	In-channel deposits, ephemeral flow	
Fm		
St	In-channel deposits	
Ss	Lake-margin debris flows ?	Green mud fraction, possible horizontal bedding
Fm		
Ss	Lake-margin debris flows ?	
Fc	Pedogenically or diagenetically altered overbank, deposits	
		Contact - orange/ yellow mottling

SECTION 9 - COMMUNICATION TOWER



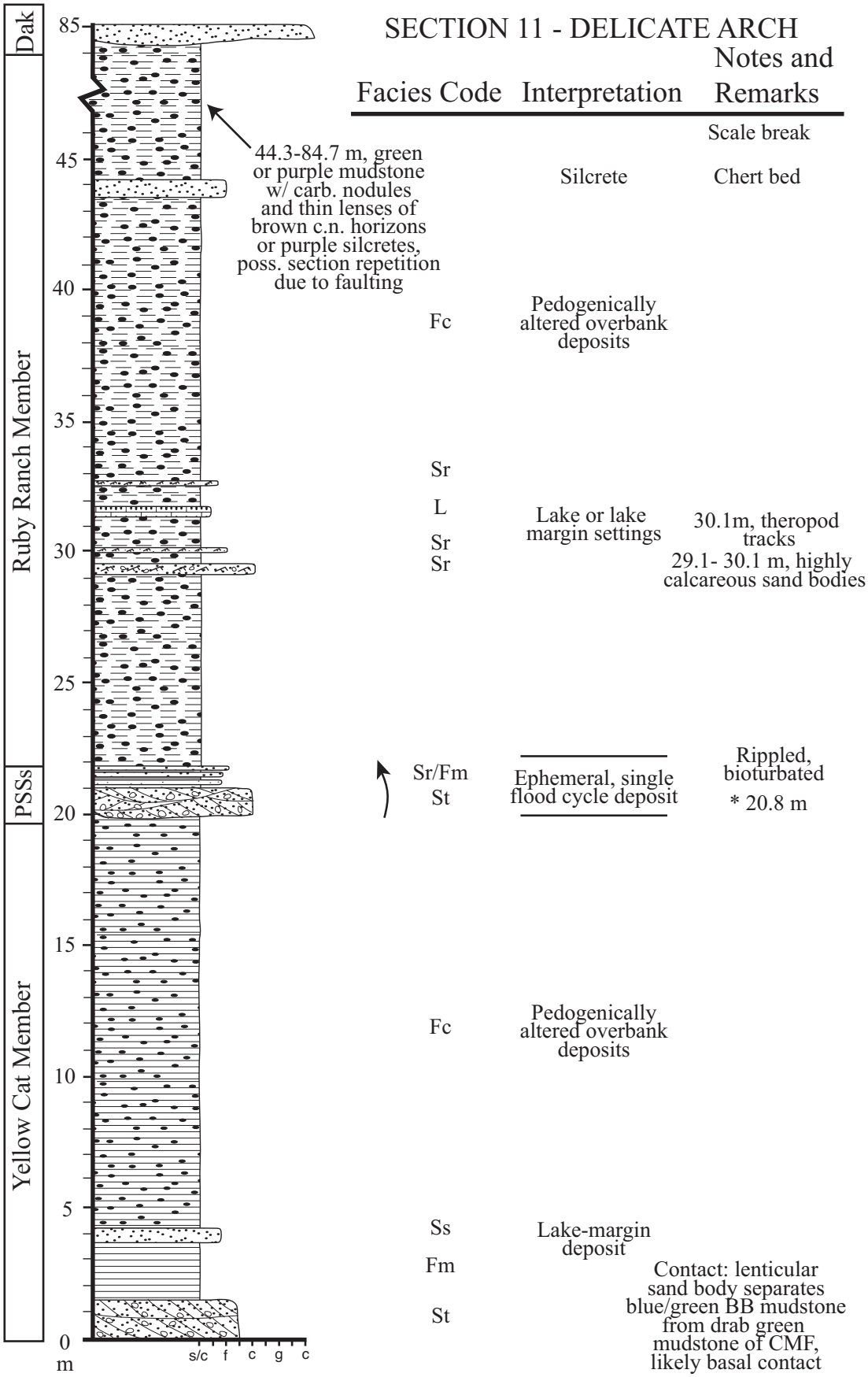
Facies Code	Interpretation	Notes and Remarks
		scale break
Fc	Pedogenically altered overbank deposits	Green mudstone 40.1-50.1 m, purple mudstone 32.6-40.1 m
St	Ephemeral channel	
Fm		
Sr Sh/Sl Sr St Gs Sr St Gm	Multi-storey, fining-upward bedload, ephemeral channels	
Fm	Overbank deposits	8.4-21.2 m spaced < 5 cm thick beds of facies Ss
L	Lacustrine deposits	
Fm		
L	Lacustrine deposits	Contact: banded reddish-purple mudstone of Morrison to lavendar/green mudstone of Cedar Mtn.
Fm		



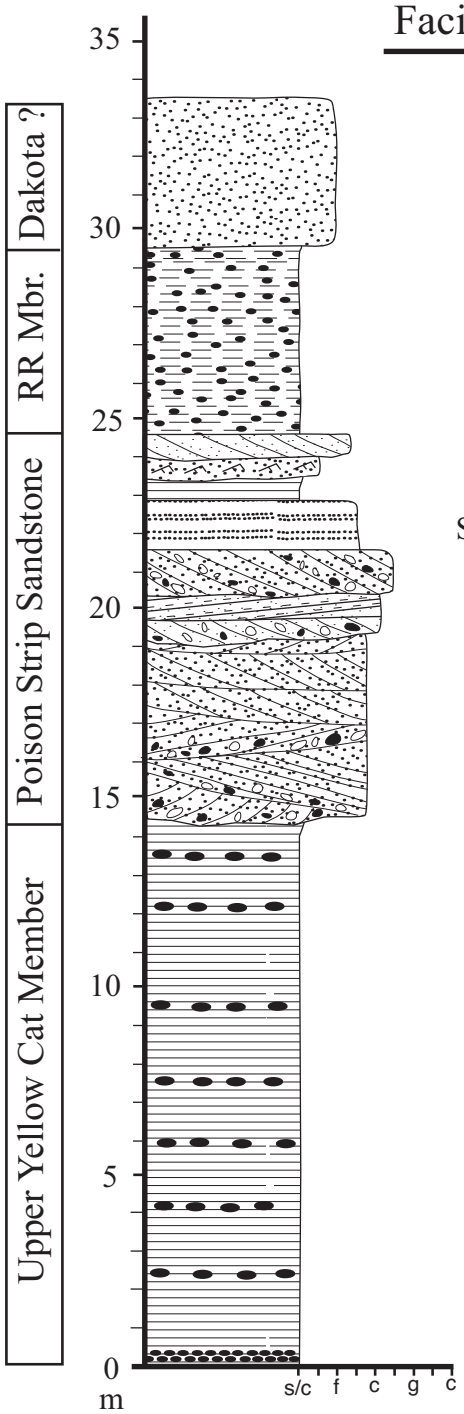
SECTION 10 - VALLEY CITY

Facies Code	Interpretation	Notes and Remarks
Fc		
St	Ephemeral channel	Small ribbon
Fc	Pedogenically altered overbank deposits	
St	In-channel sinuous dunes, ephemeral flow	
Fc	Pedogenically altered overbank deposits	scale break
L	Lacustrine deposit	
Fm	Overbank deposits	

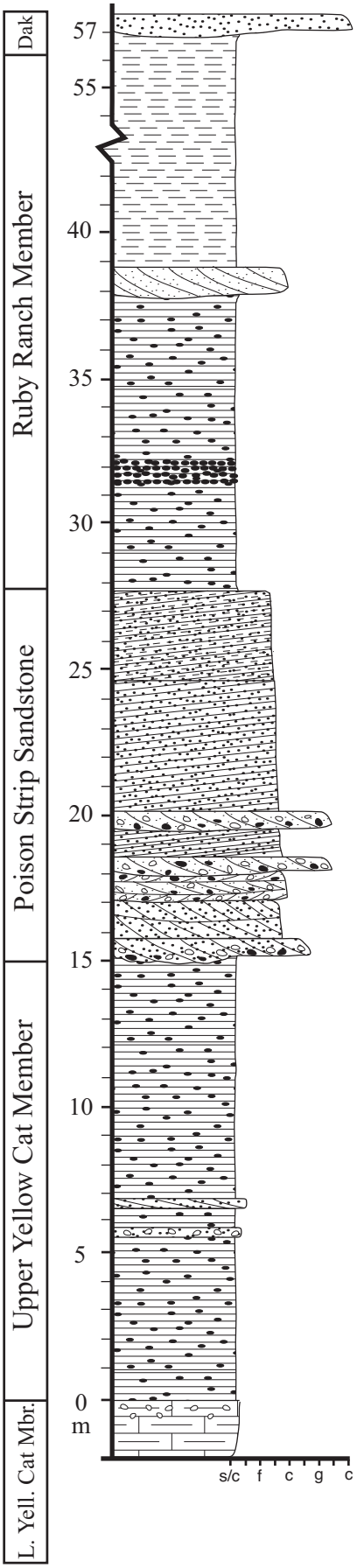
Contact: dark red mudstone of Morrison to green mudstone of Cedar Mtn.; orange staining, slickensides


SECTION 11 - DELICATE ARCH
Facies Code
Interpretation
Notes and Remarks
Dak
Ruby Ranch Member
PSSs
Yellow Cat Member
85
45
40
35
30
25
20
15
10
5
0
m
s/c f c g c
44.3-84.7 m, green or purple mudstone w/ carb. nodules and thin lenses of brown c.n. horizons or purple silcretes, poss. section repetition due to faulting
Scale break
Silcrete
Chert bed
Fc
Pedogenically altered overbank deposits
Sr
L
Sr
Sr
Lake or lake margin settings
30.1m, theropod tracks
29.1- 30.1 m, highly calcareous sand bodies
Sr/Fm
St
Ephemeral, single flood cycle deposit
Rippled, bioturbated
* 20.8 m
Fc
Pedogenically altered overbank deposits
Ss
Fm
St
Lake-margin deposit
Contact: lenticular sand body separates blue/green BB mudstone from drab green mudstone of CMF, likely basal contact

SECTION 12 - SALT/CACHE JUNCTION

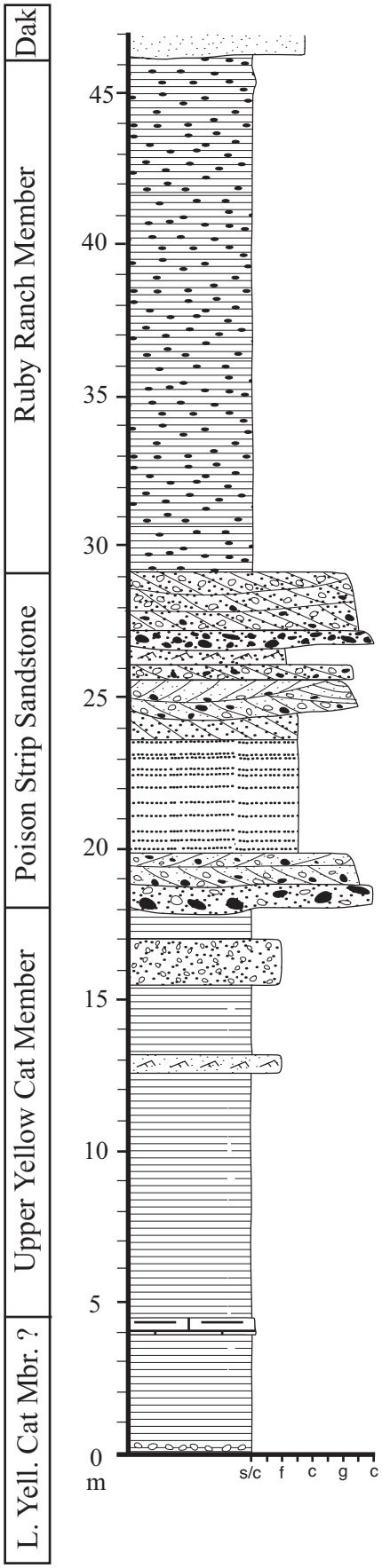


Facies Code	Interpretation	Notes and Remarks
L	Lacustrine deposit ?	massive unit with spiny limestone surface, see Figure 12b
Fc	Pedogenically altered overbank deposits	
St Sr Fm	Ephemeral channel crevasse splay	
Sh/Sl	bar top	* 22.4 m
St Sla St	bar front small lateral bar	
St	dunes, channel base	
Fc	Overbank deposits	Green mudstone with occasional carbonate nodule horizons
		Contact: gray/ purple carb. nodule horizon ? poorly exposed slope



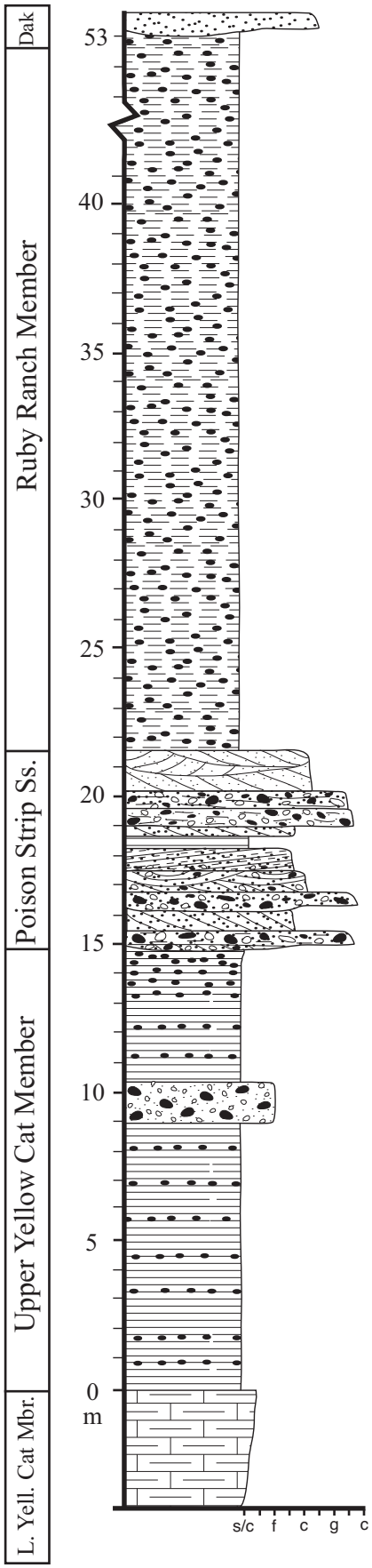
SECTION 13 - SALT VALLEY

Facies Code	Interpretation	Notes and Remarks
Fm		Scale break
St	Ephemeral channel	5 x 1 m ribbon
Fc	Pedogenically altered overbank deposits	Carb. nodule horizon
Sla	Upper point bar	Heterolithic
	Alternate bar with perennial flow	
Sla	Lower point bar	Non-hetrolithic
		* 20.3 m
Gs Sla Gs	Lower point bar	
St	Channel lag and dune deposits	
Fc	Groundwater or pedogenic alteration of overbank deposits	
St	Crevasse splay	
Ss	Lake-margin debris flow?	
Fc		
P		Contact: 2.0 m brown/gray calcrete, some floating chert granules



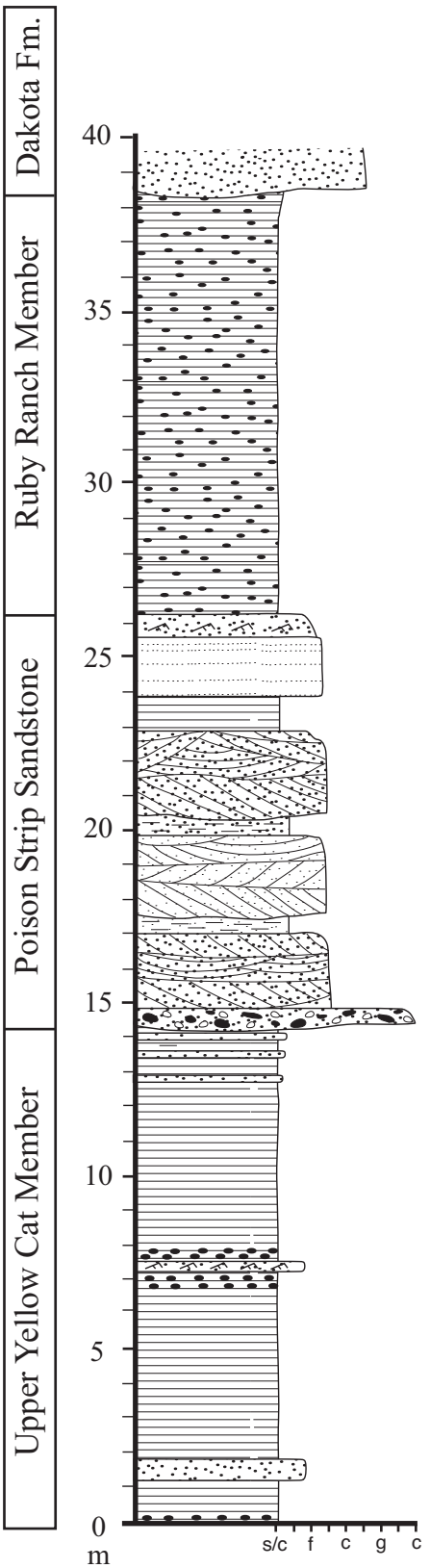
SECTION 14 - WINDOW WASH

Facies Code	Interpretation	Notes and Remarks
Fc	Pedogenically altered overbank deposits	
Gs, Gm, Sr	Gravelly dune complex	Abundant logs, sauropod fragment
Gs, Gs, Sp	Channel shift	
Sl	Bar accretion surfaces	* 22.1 m
Gs, Gm	Channel lag and gravelly dunes	Rip-up clasts of gray ls and white siltstone to 0.8 m
Fm, Ss	Lake-margin debris flows?	
Fm, Sr	Crevasse splay	
Fm	Overbank deposits	
P	Pedogenic calcrete	Contact ?
Fm		Contact: red/purple banded mudstone of BB to drab purple non-banded of CMF, less smectitic, pebble lag, orange stain at 0.5 meters



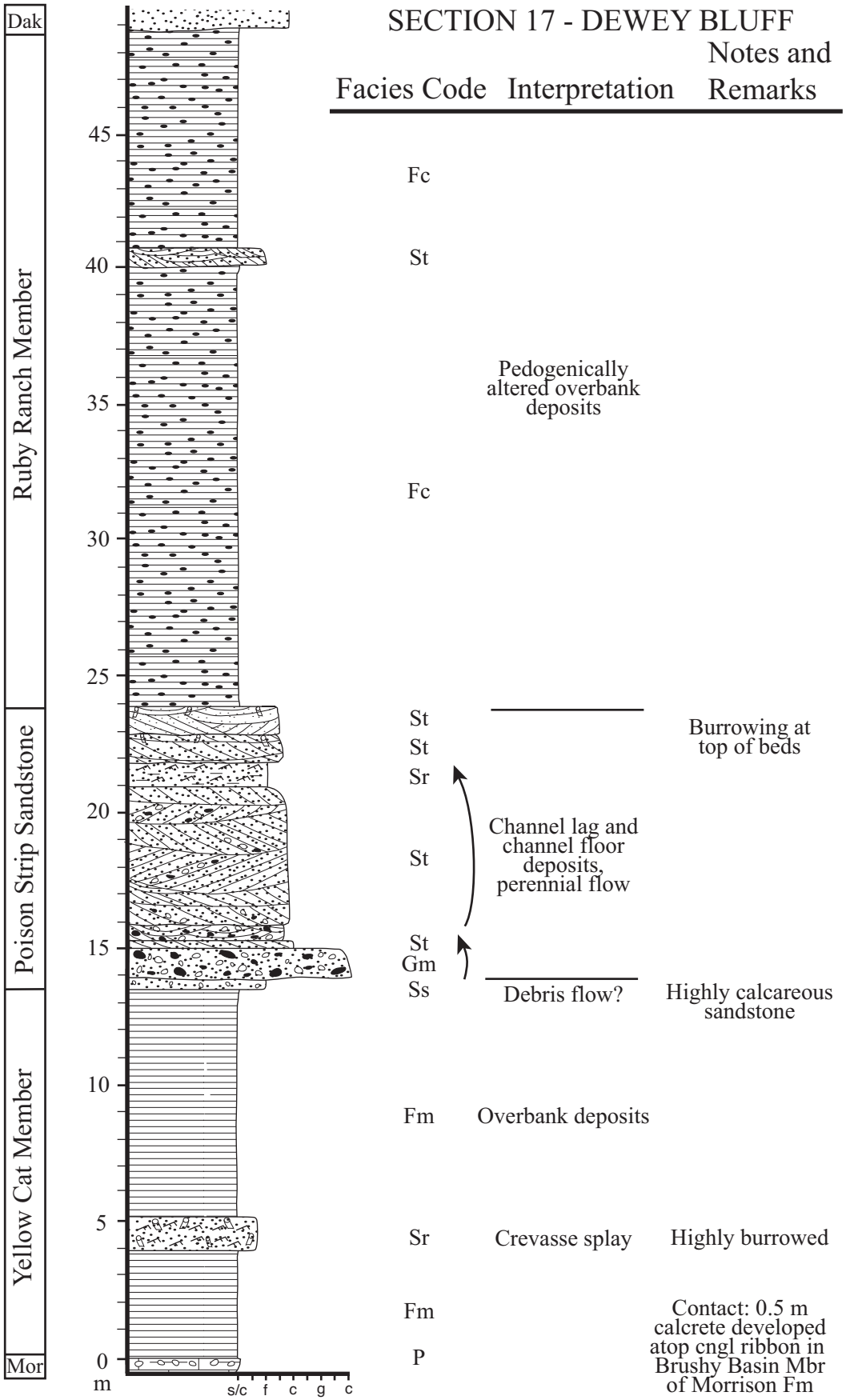
SECTION 15 - YELLOW CAT SPRING

Facies Code	Interpretation	Notes and Remarks
		Scale break
Fc	Pedogenically altered overbank deposits	
St Gs Gm St Fm Sla St Gm St Gs	Gravelly bedload braided fluvial channels, ephemeral flow	* 18.6 m
Fc		
Sr/Ss	Lake-margin debris flow?	Rippled to contorted, some cobble-size carb. nodules
Fc	Pedogenically or hydrogeologically altered overbank deposits	Sparse carb. nodule horizons
P		Contact: 4.0 m thick calcrete of coarsening-upward nodules

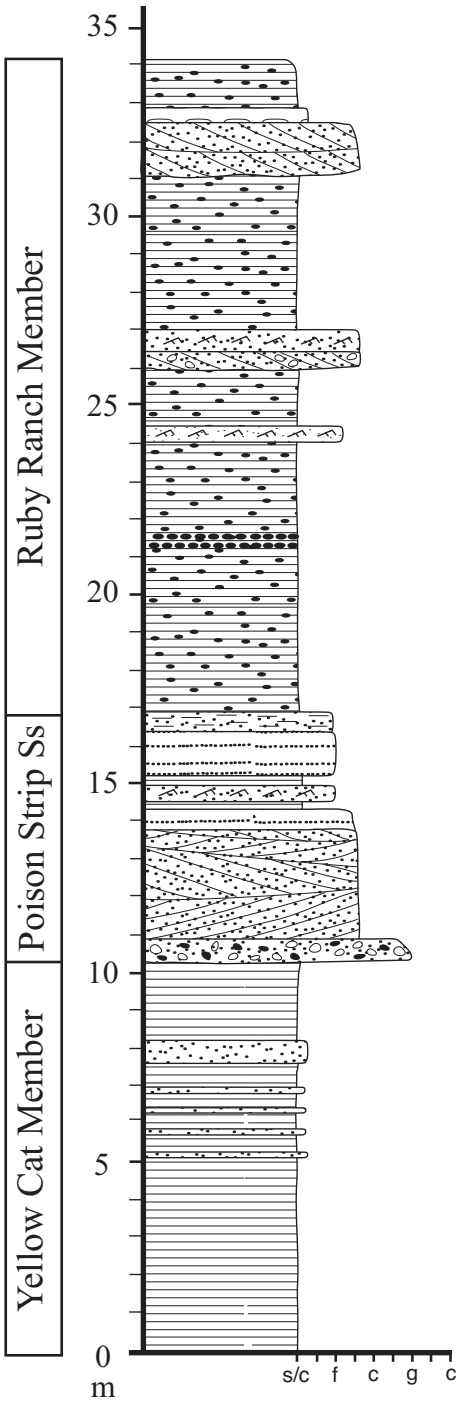


SECTION 16 - PIPELINE

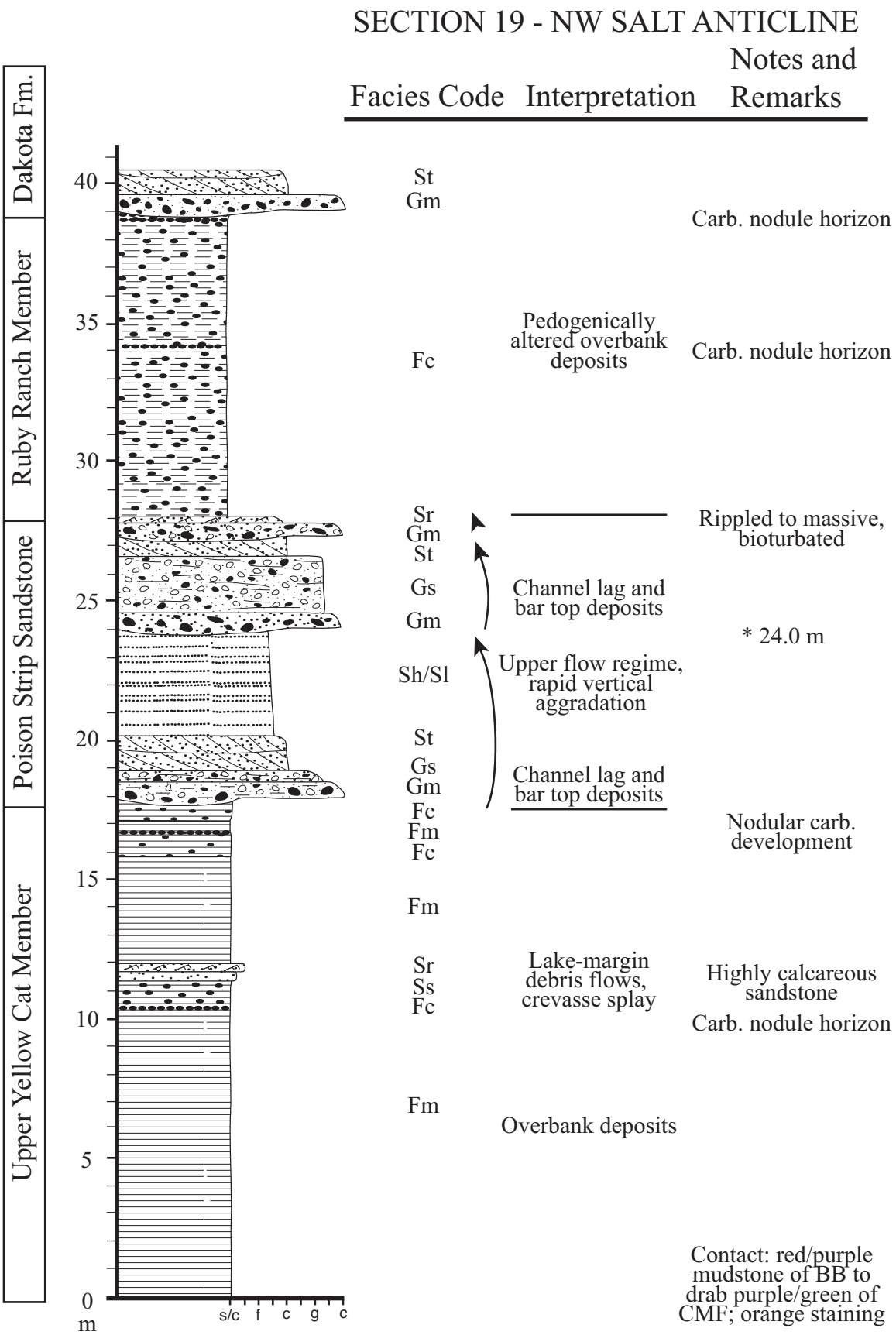
Facies Code	Interpretation	Notes and Remarks
Fc	Pedogenically altered overbank deposits	
		Some thin green silcrete horizons
Sr	Lower flow regime	Bioturbated
Sh/Sl ?		Massive
St	Shallow channels, ephemeral flow	
St		
St		
Gm		
Fl	Proximal floodplain	
Fm	Overbank deposits	
Sr	Crevasse splay	
Fm	Overbank deposits	
Ss		Contorted, bioturbated
		Contact: large carb. nodules; red/purple mudstone of BB to drab purple/green of CMF; orange staining

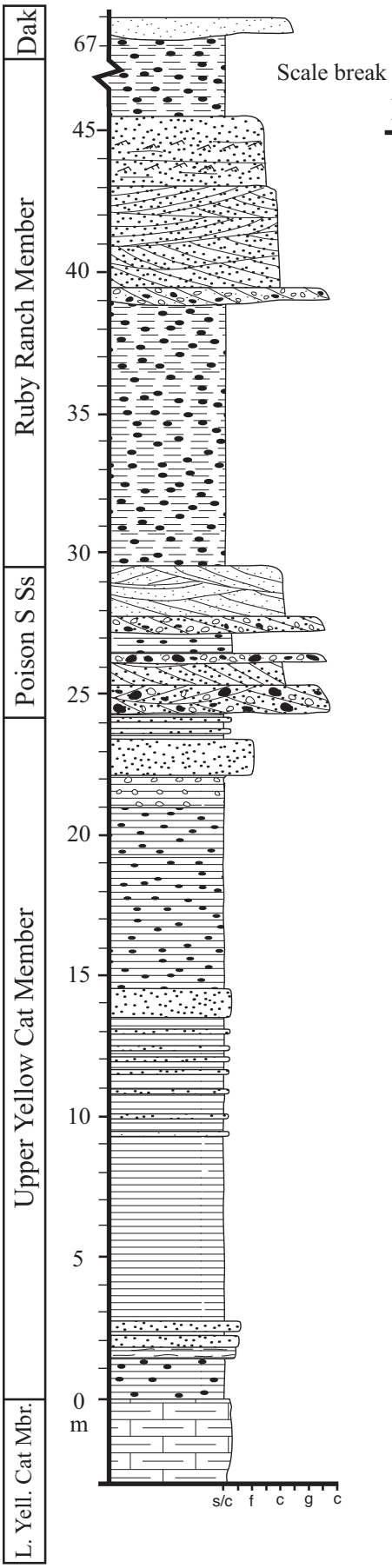

SECTION 17 - DEWEY BLUFF
Facies Code
Interpretation
Notes and Remarks
Dak
Ruby Ranch Member
Poison Strip Sandstone
Yellow Cat Member
Mor
45
40
35
30
25
20
15
10
5
0
m
s/c f c g c
Fc
St
Pedogenically altered overbank deposits
Fc
St
St
Sr
Burrowing at top of beds
Channel lag and channel floor deposits, perennial flow
St
St
Gm
Ss
Debris flow?
Highly calcareous sandstone
Fm
Overbank deposits
Sr
Crevasse splay
Highly burrowed
Fm
P
Contact: 0.5 m calcrete developed atop cngl ribbon in Brushy Basin Mbr of Morrison Fm

SECTION 18 - KOKOPELLI TRAIL



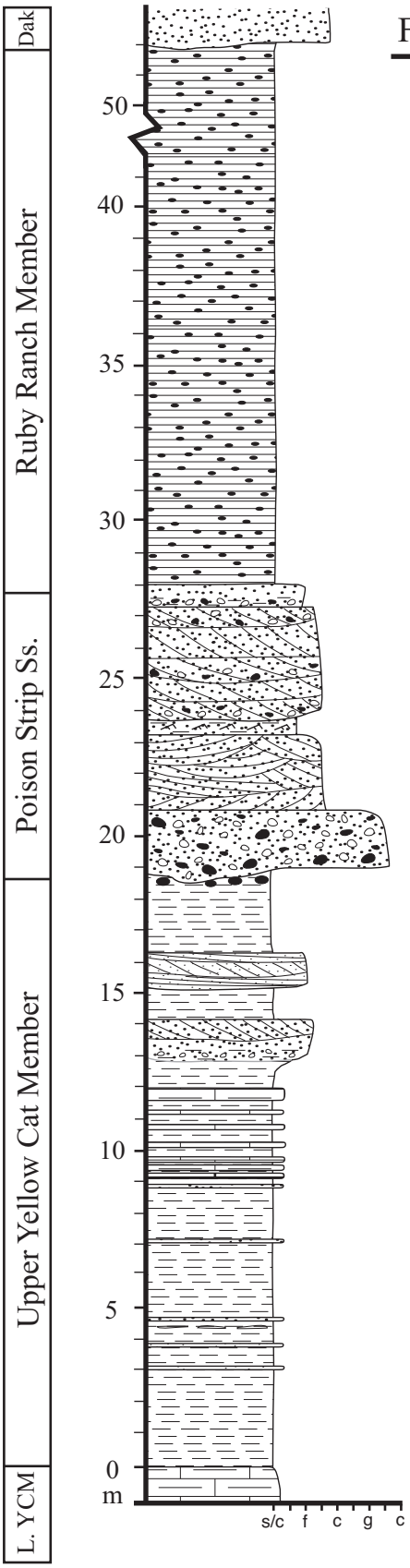
Facies Code	Interpretation	Notes and Remarks
		Mesa top, no Dakota Fm
		Green/black chert layer
Sp	Lower flow regime, ephemeral flow	
Fc		
Sr St	Lower flow regime	
Sr		
		Carb. nodule horizon
Fc	Pedogenically altered overbank deposits	
Sr ? Sh/Sl	Falling stage, shallow flow	Rippled to massive, bioturbated
Sr Sh/Sl		
St	Channel lag and dune deposits, ephemeral flow	
Gm		
Fm		
Ss	Debris flow?	
Fl	Proximal floodplain	Bioturbated, muddy sand bodies
Fm	Overbank deposits	Sparse chert pebble layers, orange staining
		Contact: no CMF mudstone banding; top of BB cngl ribbon, similar to section 17


SECTION 19 - NW SALT ANTICLINE
Facies Code
Interpretation
Notes and Remarks
Dakota Fm.
Ruby Ranch Member
Poison Strip Sandstone
Upper Yellow Cat Member
40
35
30
25
20
15
10
5
0
m
s/c f c g c
St
Gm
Carb. nodule horizon
Pedogenically altered overbank deposits
Fc
Carb. nodule horizon
Sr
Gm
St
Rippled to massive, bioturbated
Gs
Gm
Channel lag and bar top deposits
* 24.0 m
Sh/Sl
Upper flow regime, rapid vertical aggradation
St
Gs
Gm
Fc
Fm
Fc
Channel lag and bar top deposits
Nodular carb. development
Fm
Sr
Ss
Fc
Lake-margin debris flows, crevasse splay
Highly calcareous sandstone
Carb. nodule horizon
Fm
Overbank deposits
Contact: red/purple mudstone of BB to drab purple/green of CMF; orange staining



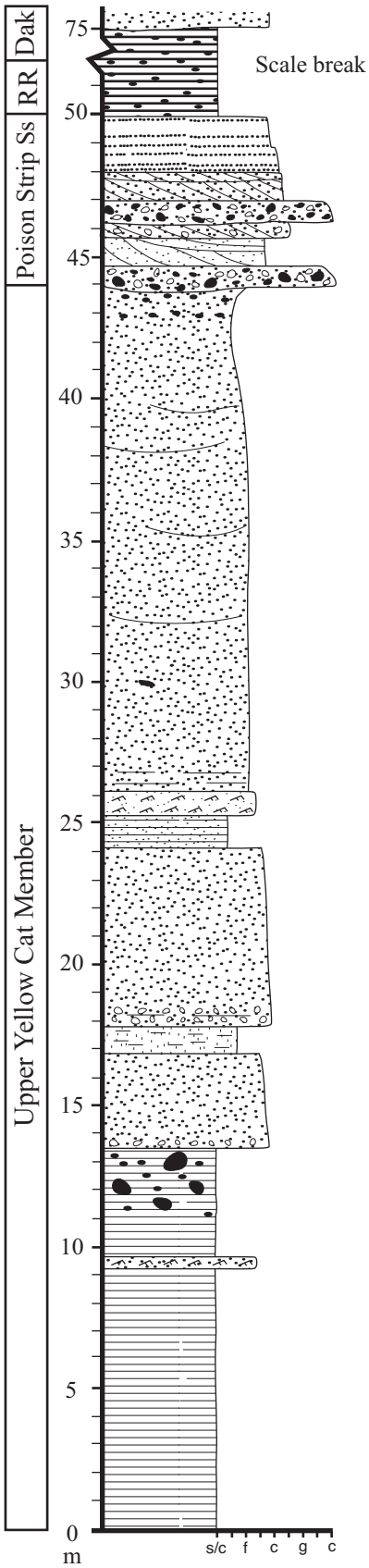
SECTION 20 - YELLOW CAT WASH

Facies Code	Interpretation	Notes and Remarks
Sh/Sl/Sr	Lower flow regime	Top massive, bioturbated
St	3-D dunes	Ribbon to restricted sheet
Gs		
Fc	Pedogenically altered overbank deposits	
St		
Gs		
Fc	Gravelly, bedload braided fluvial system, ephemeral flow	Vert. fragment as clast
Gm		
St		
Gs		
Fl	Lake-margin debris flows? crevasse splay?	
Ss		
Fm		Spheroidal weathering, gastroliths
Fc		14.5-20.9 m nodular, calc. mudstone, some extremely contorted zones
Ss	Lake-margin debris flows? crevasse splay?	Bioturbated
Fl	Proximal floodplain	Laterally continous tan siltstones
Fm	Overbank deposits	
Ss		Contorted bedding, bioturbated
Ss		
Fc		Sparse white carb. nodules
P	Pedogenic calcrete	Contact: 3.0 m calcrete; banded red/purple mudstone to drab purple/green mudstone



SECTION 21 - LONG VALLEY EAST

Facies Code	Interpretation	Notes and Remarks
		scale break
Fc	Pedogenically altered overbank deposits	
Sr ?		Structureless, bioturbated
St/Sp	2-D dunes or bar foresets	* 24.1 m
Sr	3-D dunes, lower flow regime, perennial flow	Abundant wood debris, transitions laterally to Sla
St		
Gm	Channel lag	
Fm		
St/Sh		
Fm	Ephemeral, shallow channels	
St		
L/Fc	Lacustrine limestone	
L/Fm		
	Proximal floodplain deposits	Thin, rippled sand beds
Fm		
		Disarticulated vert. remains
P		Contact: 1.2 m tan/gray calcrete, some floating chert pebbles and green/purple mud matrix



SECTION 22 - NE SALT ANTICLINE

Facies Code	Interpretation	Notes and Remarks
Fc	Pedogenically altered overbank deposits	50-75 m green mudstone w/ carb. nodules
Sh/Sl St Gm Sp St Gm	Channel lag and dune deposits, frequent channel switching, ephemeral flow	
		Carbonate nodules Silt content increase
		Scours trend N80W - S80E
Ss	Lake-margin debris flow ? crevasse splay ?	
		Gastrolith
Sr Fm	Crevasse splay	Solitary ripple marks Spheroidal weathering
Ss	Lake-margin debris flow ? crevasse splay ?	
		Massive, crude basal horiz. strat
Ss		Spheroidal weathering
Ss	Lake-margin debris flow ? crevasse splay ?	Massive
Fc		Carb. nodules, chert pebbles including red chert; abundant red/white agate
Sr	Crevasse splay	
Fm	Overbank deposits	
		Contact: equivocal, banded smectitc BB mudstone to unbanded CMF mudstone; orange staining from 0-2.9 m