Spectacular Crinkled Crust—A Detachment Fold Train in the Carmel Formation, Western San Rafael Swell, Utah

Thomas C. Chidsey, Jr.[1], and Paul B. Anderson[2]
[1]Utah Geological Survey, PO Box 146100, Salt Lake City, Utah 84114-6100, tomchidsey@utah.gov
[2]Geologic Consultant, PO Box 101, Emery, Utah 84522

Utah Geosites
2019
Utah Geological Association Publication 48
M. Milligan, R.F. Biek, P. Inkenbrandt, and P. Nielsen, editors

Cover image: *Typical fold core showing contorted bedding, brecciation, and heterogeneous lithic component.*

INTRODUCTION

Imagine slipping on a small rug overlying a hardwood floor. In the process of sliding along the floor the rug produces a series of small folds and the rug moves forward from its original position. The same could be said for the "crinkled crust," or folded layers of rocks in a detachment fold train. A spectacular detachment fold train, consisting of over 100 small, regularly spaced convex-upward folds called anticlines in gypsum-rich rock layers of the Middle Jurassic (about 168 million years ago [Ma]) Carmel Formation, is exposed immediately north of Interstate 70 (I-70) in the San Rafael Swell of east-central Utah (figures 1 and 2). The San Rafael Swell, a large anticlinal uplift, is an icon for everything that makes the Colorado Plateau dramatically scenic and geologically classic. However, the fold train is located in drab-colored, relatively featureless rock layers of the Carmel Formation in an area called Reed Wash along the gently dipping west flank of the Swell. After passing magnificent canyons, buttes, and mesas both to the east and west along I-70, the fold train typically goes unnoticed by not only the average tourist but geologists as well. Once the fold train is pointed out, the geologic observer is immediately struck with awe at this large, well-exposed, complex structural feature.

Literally hundreds of classic geologic sites are well displayed in the San Rafael Swell; many are easily accessed overlooks and viewpoints. The detachment fold train, by contrast, is chosen as a geosite for its geologic uniqueness, educational instruction, and research opportunities in structural geology.

HOW TO GET THERE

The detachment fold train is about 190 miles (300 km) or a 3-hour drive from Salt Lake City, Utah, via I-15 and U.S. Highway 6 to State Highway 10. Stay southbound on State Highway 10, past the town of Ferron for 5.3 miles (8.5 km) and make a left turn towards the town of Moore onto Moore Road. Follow the road until a "T" in the road (about 3.6 miles [5.8 km]), turn left (east) and stay on the paved road (County Road 803) until it intersects with I-70, about 16.5 miles (26.6 km) beyond the "T." Enter I-70 heading westbound for about 4.6 miles (7.4 km) to the best of several views (to the north) of the detachment fold train (38°50'49" N., 110°59'57" W., elevation 6325 feet [1928 m]) (figure 1). The fold train geosite is about 46 miles (74 km) west of the junction of U.S. Highway 6 and I-70 near the town of Green River, Utah (figure 2).

Upon approaching the Reed Wash area (there is no sign so use the odometer or the GPS coordinates) carefully slow down with flashers on and pull off the interstate to the right as far as possible. Depending on the exact location, the view area may require climbing up a small but steep hill adjacent to the interstate. The majority of the lands in the Reed Wash area are public and overseen by the U.S. Bureau of Land Management, with some owned by the State of Utah School and Institutional Trust Lands Administration, and therefore access to examine the fold train up close is open to the public; however, there are no trails; the terrain is rugged and requires negotiating a fence designed to keep livestock and wildlife from the interstate.

GEOLOGIC SUMMARY OF THE SAN RAFAEL SWELL

The San Rafael Swell is a broad, asymmetric, north-south- to southwest-northeast-trending anticlinal structure, about 75 miles (120 km) long and 35 miles (56 km) wide, that formed in response to compressional forces of the Laramide orogeny (a regional mountain-building event) between latest Cretaceous time (about 70 Ma) and the Eocene (about 40 Ma) (Hintze and Kowallis, 2009 and references therein) (figures 3 and 4). Uplift and erosion have made it a showcase of Colorado Plateau geology with a colorful array of sedimentary rocks over 7000 feet (2100 m) thick, ranging in age from Permian to Cretaceous (299–66 Ma) and exposed in spectacular cliffs along cuestas, mesas, and deep canyons (figure 5 represents those on the west flank of the Swell where Reed Wash is located).

Figure 1. *Spectacular detachment fold train in the Winsor Member of the Middle Jurassic Carmel Formation in the Reed Wash area on the west-dipping flank of the San Rafael Swell; view north from I-70. Photograph by Michael Chidsey, Sqwak Productions Inc.*

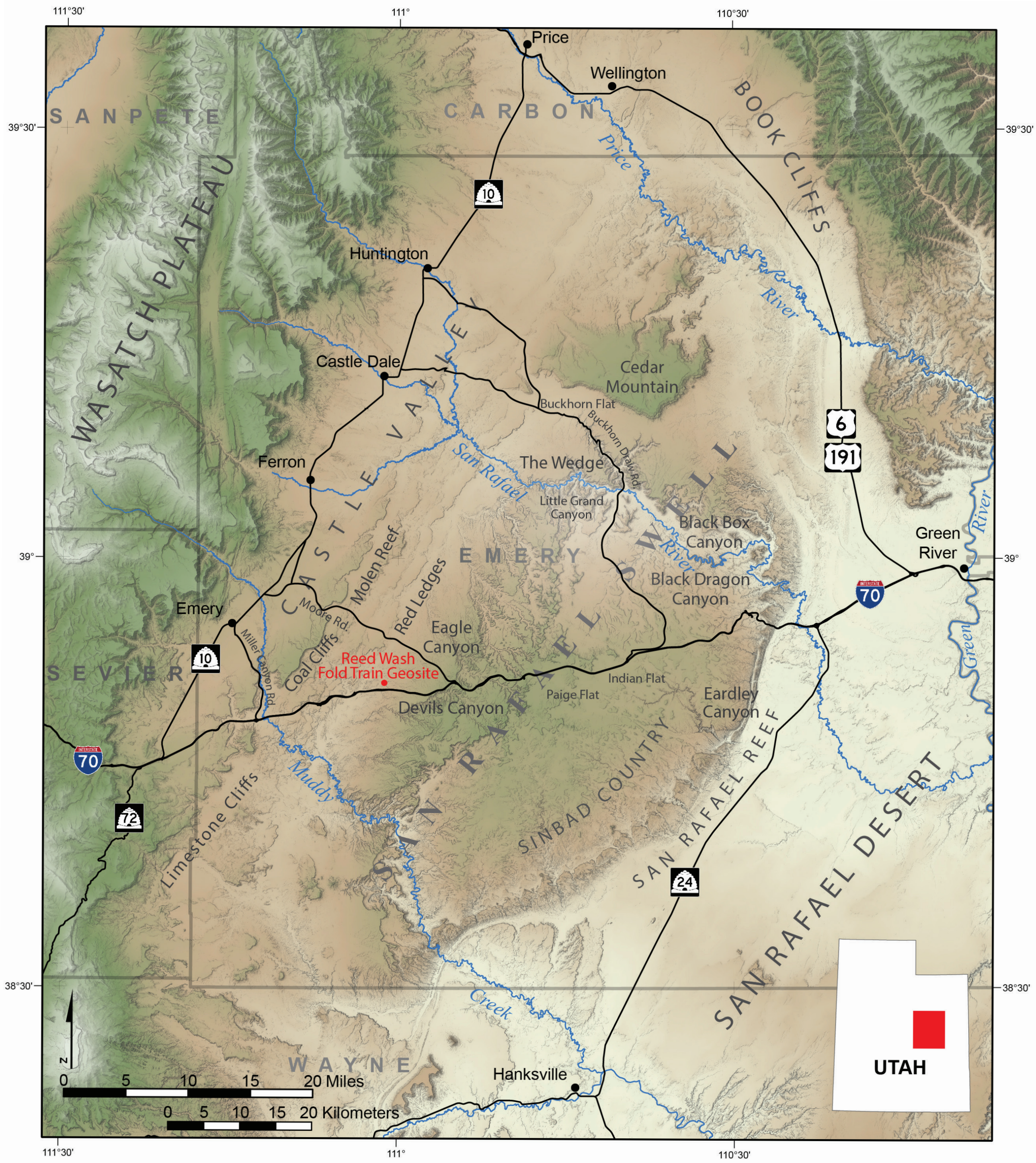

Figure 2. The San Rafael Swell and vicinity, east-central Utah, showing the location of the detachment fold train geosite as well as major physiographic features, surrounding towns, and highways.

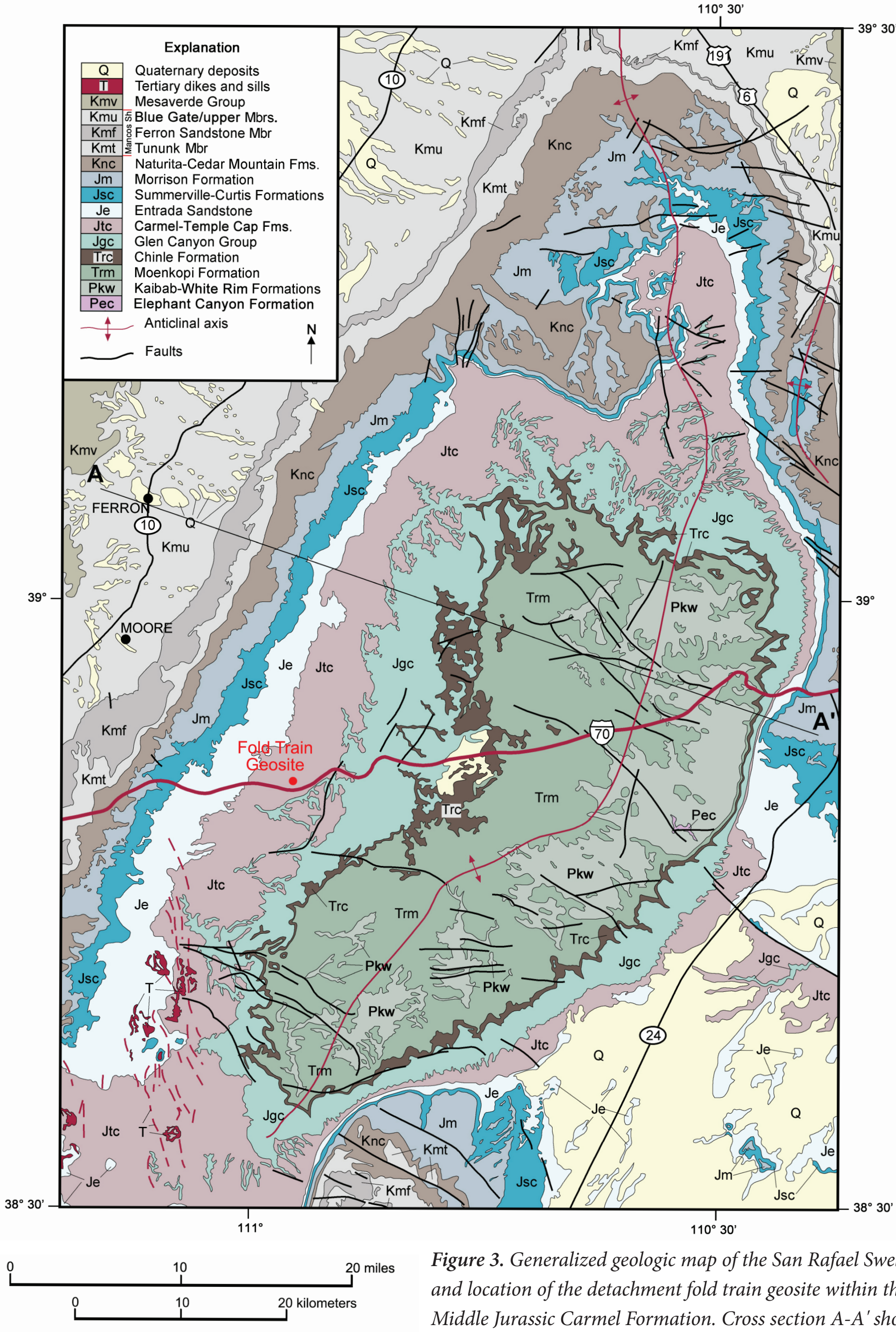

Figure 3. Generalized geologic map of the San Rafael Swell and location of the detachment fold train geosite within the Middle Jurassic Carmel Formation. Cross section A-A' shown on figure 4. After Doelling and Hylland (2002).

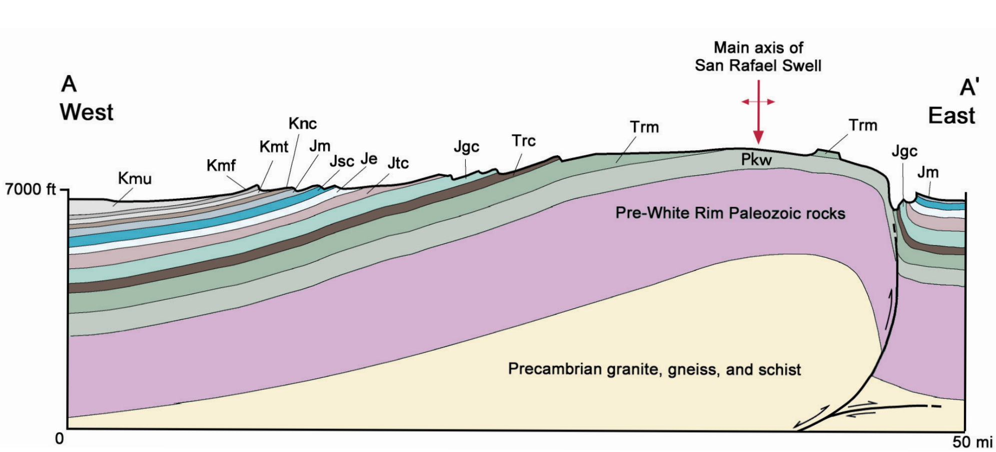

Figure 4. Diagrammatic cross section across the middle of the San Rafael Swell. The cross section is not drawn to scale, but the vertical dimension is exaggerated about eight times relative to the horizontal; the horizontal length of the cross section covers about 50 miles (80 km). Symbols and colors of geologic formations correspond to those shown on figure 3; location of cross section also shown on figure 3. After Doelling and Hylland (2002).

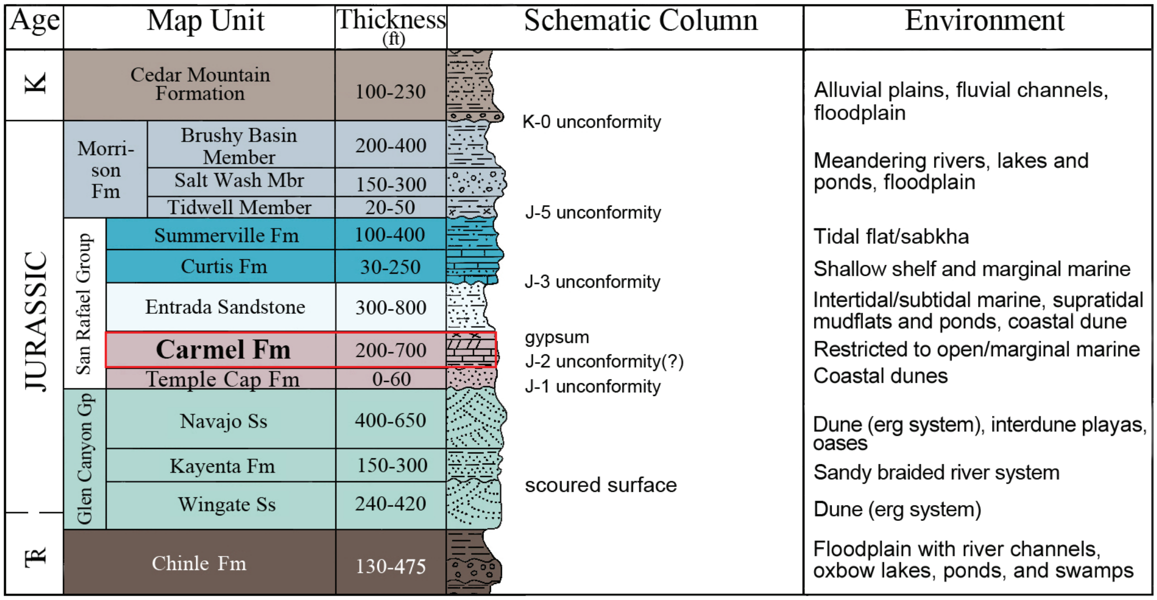

Figure 5. *Stratigraphic column of exposed rocks along the west flank of the San Rafael Swell, including age, thickness, lithology, weathering profile, and depositional environment. Modified from Hintze and Kowallis (2009).*

The sedimentary formations and their many members exposed in the San Rafael Swell were deposited in a wide range of environments including eolian (windy desert), floodplain, stream, deltaic, swamp, tidal flat, and shallow and restricted marine (figure 5). Several major unconformities represent significant periods of erosion or non-deposition. Pliocene-age igneous rocks are present in the form of dikes, conduits, and sills intruded into exposed Triassic to Cretaceous sedimentary strata (figure 3).

The rocks in the San Rafael Swell are folded, faulted, jointed, fractured, and uplifted. The major uplift and deformation of the San Rafael Swell was likely controlled by a large, blind (buried), basement-involved reverse fault (up on the west side) bounding the east flank of the structure (figure 4). Three sets of high-angle normal faults are mapped on the surface: (1) northwest-southeast striking, (2) east-west striking, and (3) north-south to northeast-southwest striking (figure 3). Two styles of reverse faulting are identified in the San Rafael Swell: (1) west-directed, blind reverse faults on the east flank, and (2) east-directed, ramp-style thrusting. Sandstone beds are quartz rich and brittle, and when folded or bent, produce prominent joints and fractures.

Uranium, oil and gas, carbon dioxide, helium, coal, and industrial minerals (gypsum, bentonite clay, and humate) are found within the San Rafael Swell. Gypsum ($CaSO_4{\cdot}2H_2O$) was produced from one mine in the Carmel Formation near the detachment fold train and was used for manufacturing wallboard (sheetrock) and plaster (Gloyn and others, 2003). The Carmel contains an estimated 7.3 million tons of minable gypsum (Lupton, 1913). Cumulative gypsum production in the San Rafael Swell since 1990 is about 1.8 million tons; there is one active mine on the north end of the structure (verbal communication, Andrew Rupke, Utah Geological Survey, 2018).

STRATIGRAPHY: MIDDLE JURASSIC CARMEL FORMATION

The detachment fold train at Reed Wash is within the Winsor Member of the Middle Jurassic (Bajocian through Callovian [170.3 through 161.2 Ma]) Carmel Formation. The Carmel creates a major but gentle dip slope along the west flank of the San Rafael Swell and ranges from steep to nearly flat lying on the east flank (figures 3 and 4). It is divided into four members, which in ascending order are: Co-op Creek Limestone (or equivalent Judd Hollow), Crystal Creek, Paria River, and Winsor (figure 6). The Carmel ranges from 280 to as much as 1100 feet (85–330 m) thick in the San Rafael Swell (Witkind, 1988; Doelling and Kuehne, 2008, 2016; Doelling and others, 2015). However, all four members are not always present. Doelling and Kuehne (2008) suggested a possible unconformity (angular) separates the Crystal Creek and Paria River Members. The members of the Carmel in the San Rafael Swell were mapped, measured, and described by Doelling and Kuehne (2008) and Sprinkel, Doelling, and Chidsey (Utah Geological Survey, unpublished measured sections).

Winsor Member

The Winsor Member (Bathonian and lower Callovian, based on palynomorphs [Anderson and Lucas, 1994; Sprinkel and others, 2011]) ranges in thickness from 190 to 380 feet (58–120 m). It consists of two main informal units: the lower gypsiferous and the upper banded. The gypsiferous unit consists of interbedded red, red-brown, green-gray, or light-gray sandstone, calcarenite, calcisiltite, and siltstone, and white alabaster gypsum and a few limestone beds. Sandstone is friable, fine grained, well sorted, and cemented with calcite or iron oxide. Calcarenite is very fine grained, well sorted, and laminated to thin bedded with well-developed ripple marks and some bioturbation. Calcisiltite appears shaly and weathers into small plates. Siltstone is coarse grained,

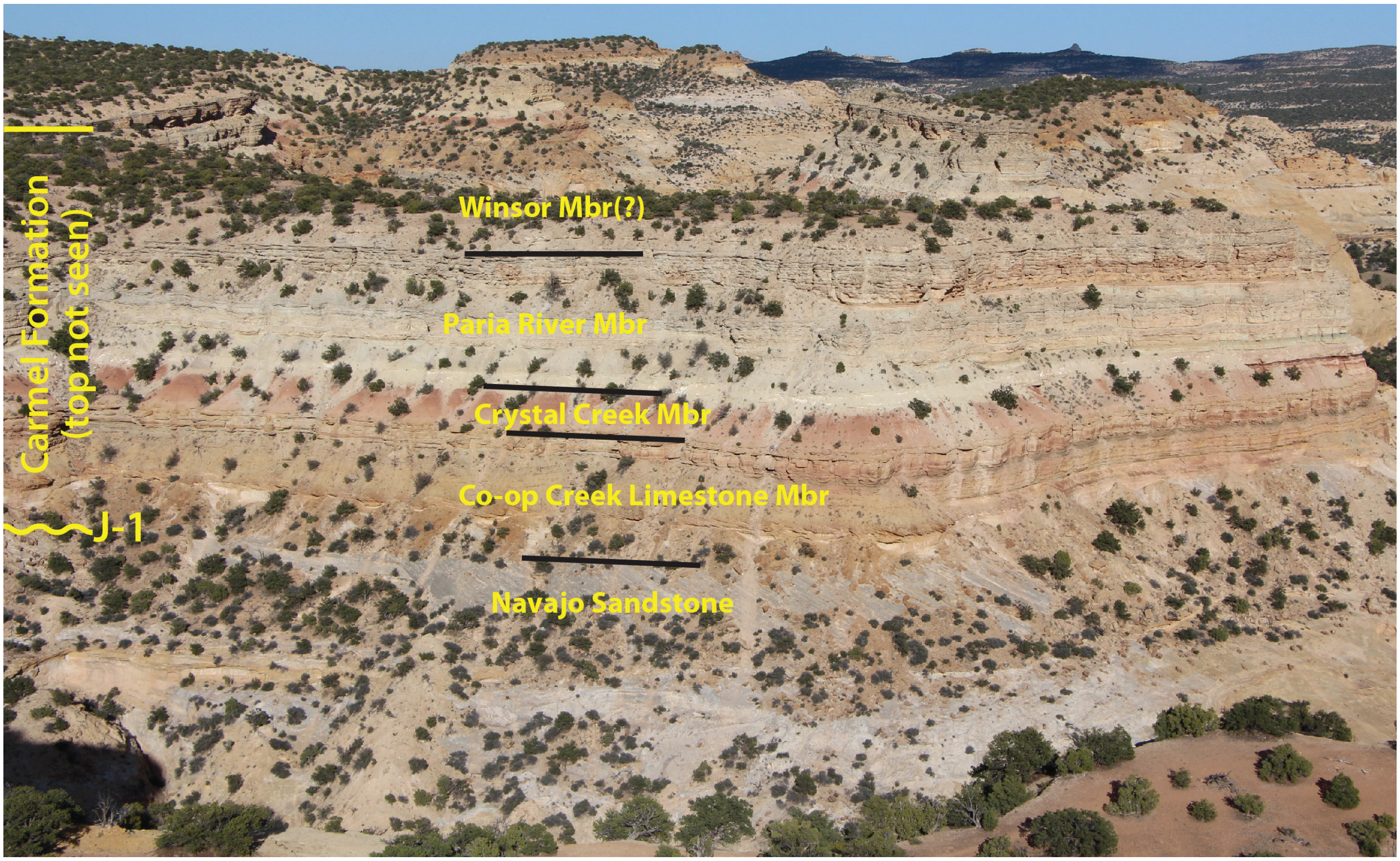

Figure 6. Excellent exposure of Middle Jurassic Carmel Formation, San Rafael Group, west flank of the San Rafael Swell, Devils Canyon south of I-70, view to the east. The Co-op Creek, Crystal Creek, Paria River, and part of the Winsor Members are shown. The Carmel is in direct contact with the underlying Navajo Sandstone represented by the J-1 unconformity. Photograph by Michael Chidsey, Sqwak Productions Inc.

gypsiferous (often with fine laminae of gypsum), and contains small lenses of calcarenite. Sandstone and siltstone beds form steep, earthy slopes. The Winsor contains six to nine gypsum beds ranging in thickness from 1 to 20 feet (0.3–6 m); total thickness of gypsum ranges from 50 to 90 feet (15–30 m) in outcrops along the west flank of the San Rafael Swell. Gypsum is silty and forms ledges as much as 20 feet (6 m) thick. The banded unit consists of interbedded sandstone, calcarenite, siltstone, and mudstone that displays colored bands of red and gray in various shades, and white gypsum. These rocks have characteristics similar to those in the underlying gypsiferous unit. Gypsum veins crisscross the clastic rocks. Gypsum beds produce frothy "popcorn-like" or sugary weathering on sparsely vegetated surfaces and drape into drainages (Rigby and others, 1974).

Depositional Environment

The Carmel Formation is the result of deposition during the transgression of the shallow marine Sundance Sea, which extended south from Canada into a narrow embayment or arm (called the Utah-Idaho trough) through northern, central, and southwestern Utah (figure 7) (Blakey and Ranney, 2008; Hintze and Kowallis, 2009). Shoreline fluctuations produced variations between restricted- and more open- to marginal-marine conditions, causing significant changes in lithology. This was especially the case along the eastern margin of the marine embayment, which is now exposed on the San Rafael Swell. The Co-op Creek and Paria River Members correspond to marine transgressions and the Crystal Creek and Winsor Members represent regressions (Doelling and others, 2010). The Winsor was deposited in restricted, muddy, hypersaline marine and coastal environments during a second major regression of the Sundance Sea (Blakey and Ranney, 2008).

GEOLOGIC DESCRIPTION AND POSSIBLE ORIGINS OF THE DETACHMENT FOLD TRAIN

The detachment fold train in the Reed Wash area was described by Royse (1996), Vickye (2004), and Chidsey (2013) (figure 8). The fold train consists of over 100 repeated, regularly spaced anticlines (and intervening troughs called synclines [concave-downward folds]) confined to a 62-foot-thick (19 m) gypsum-bearing interval within the Winsor Member of the Carmel Formation. The anticlines are unfaulted between the floor and roof detachments surfaces, show a gentle northward plunge to no plunge, and have axes that strike south-southwest to north-northeast. Some of the anticlines are moderately asymmetric with an eastward vergence.

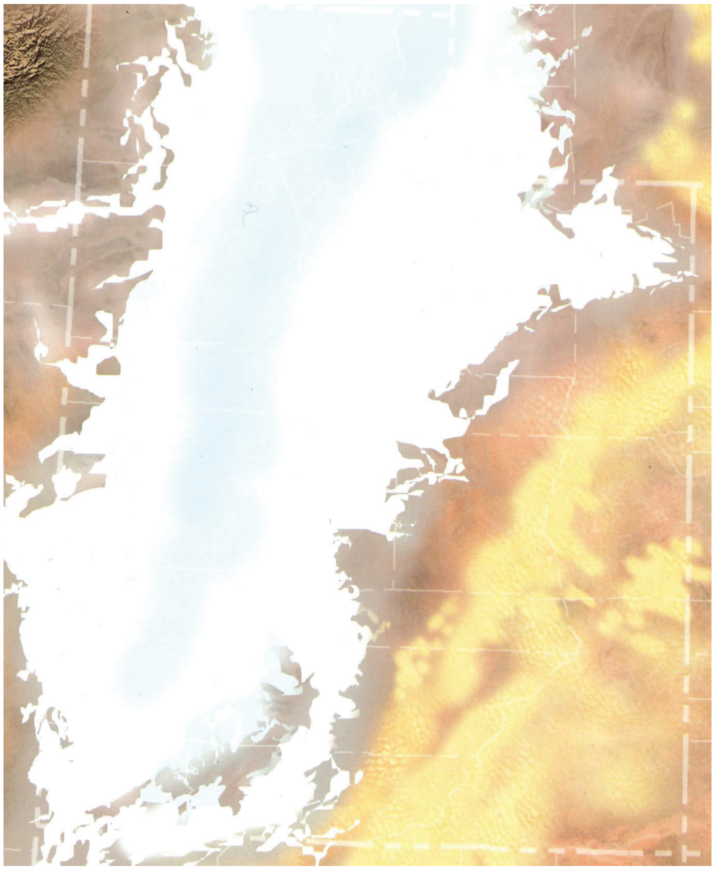

Figure 7. Paleogeographic map of Utah during deposition of the Middle Jurassic (170 Ma) Carmel Formation. Modified from Blakey and Ranney (2008).

In the western part of the fold train before continuing into the subsurface, they display chevron-like shapes with detached, rounded crests, whereas in the middle the anticlines have round, box, or isoclinal shapes with vertical or slightly overturned flanks (figures 8A through 8C). At the eastern end of the fold train, the anticlinal limbs have low to moderate dips (Royse, 1996). The fold cores consist of contorted bedding, breccia, and heterogeneous lithic components (figure 8D). Amplitudes of these folds are about 30 feet (9 m), but decrease on the eastern end of the fold train (Vickye, 2004). The distance between anticlinal hinges ranges from 15 to 85 feet (5–26 m). The floor of the entire fold train is a single detachment zone in a 2-foot-thick (0.6 m) claystone, whereas the roof has multiple detachments in a 32-foot-thick (9.8 m) gypsum unit (Royse, 1996).

There are two possible origins of this unusual detachment fold train. One is thought to be an easternmost manifestation of the Sevier thrust faulting in central Utah (Royse, 1996; Vickye, 2004). In that case the compressive forces responsible for its formation are similar to those that produced the east-directed, ramp-style thrusting mapped on the surface near Cedar Mountain and at Farnham anticline (Morgan, 2007; Chidsey, 2013). These folds may have formed as the result of two compressive structural processes: limb rotation and hinge migration (Vickye, 2004). An alternative origin of the detachment fold train, which we prefer, may be that of a gravity slide block off the San Rafael Swell. Such a

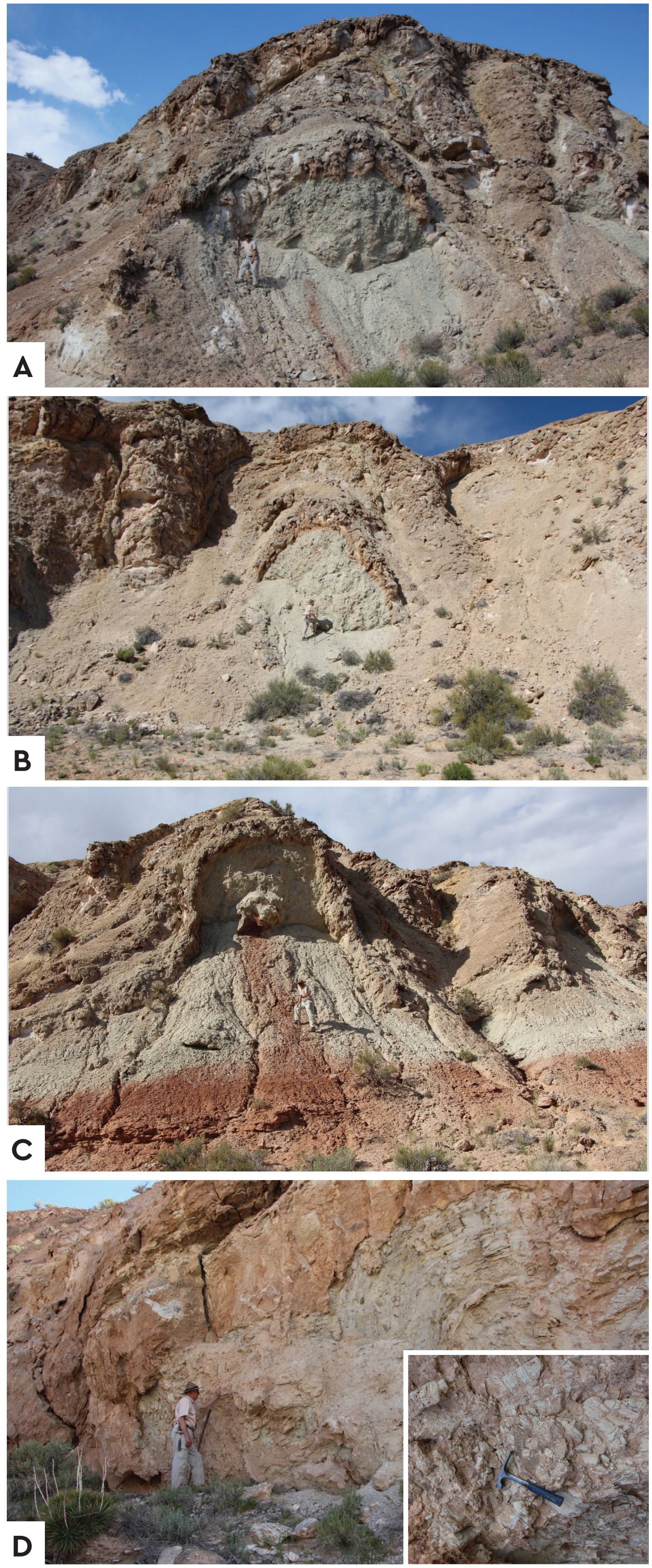

*Figure 8. Fold styles and other characteristics of the detachment fold train: **A** – round-shaped anticline, **B** – chevron-shaped anticline, **C** – box-shaped anticline, and **D** – typical fold core showing contorted bedding, brecciation, and heterogeneous lithic components (see inset for close-up view). Photographs by Michael Chidsey, Sqwak Productions Inc.*

slide would post-date the 70 to 40 Ma Laramide-age structure and may have formed following the erosion of several thousand feet of sedimentary rocks from regional uplift of the Colorado Plateau beginning during the Miocene (23 Ma) (Hunt, 1956; Lucchitta, 1979; Hintze and Kowallis, 2009). Perhaps after much of the overlying thick section of rocks was removed, the Carmel Formation was able to naturally slide off the crest of the Swell. In any case, calcium sulfate-bearing water within the lower detachment zone may have helped “grease” the incompetent claystone beds, thus assisting with the movement of the fold train (Royse, 1996).

ACKNOWLEDGMENTS

Support for this paper was provided by the Utah Geological Survey (UGS). Cheryl Gustin and Jay Hill of the UGS drafted figures. This paper was carefully reviewed by Michael D. Vanden Berg, Stephanie M. Carney, Michael D. Hylland, and Bill Keach of the UGS, along with the editors of this publication. Their suggestions and constructive criticism greatly improved the manuscript.

REFERENCES

Anderson, O.J., and Lucas, S.G., 1994, Middle Jurassic stratigraphy, sedimentation and paleogeography in the southern Colorado Plateau and southern High Plains, *in* Caputo, M.V., Peterson, J.A., and Franczyk, K.J., editors, Mesozoic systems of the Rocky Mountain region, USA: Rocky Mountain Section SEPM (Society for Sedimentary Geology), p. 299–314.

Blakey, R., and Ranney, W., 2008, Ancient landscapes of the Colorado Plateau: Grand Canyon, Arizona, Grand Canyon Association, 156 p.

Chidsey, T.C., Jr., 2013, Geology of the San Rafael Swell, east central Utah, *in* Morris, T.H., and Ressetar, R., editors, The San Rafael Swell and Henry Mountains Basin—geologic centerpiece of Utah: Utah Geological Association Publication 42, p. 1–73.

Doelling, H.H., Blackett, R.E., Hamblin, A.H., Powell, J.D., and Pollock, G.L., 2010, Geology of Grand Staircase-Escalante National Monument, *in* Sprinkel, D.A., Chidsey, T.C., Jr., and Anderson, P.B., editors, Geology of Utah’s parks and monuments (3rd edition): Utah Geological Association Publication 28, p. 193–235.

Doelling, H.H., and Hylland, M.D., 2002, San Rafael Swell proposed as site of new national monument: Utah Geological Survey, Survey Notes, v. 34, no. 2, p. 9–11.

Doelling, H.H., and Kuehne, P.A., 2008, Interim geologic map of the Temple Mountain quadrangle, Emery County, Utah: Utah Geological Survey Open-file Report 541, scale 1:24,000, 7 p., 1 plate.

Doelling, H.H., and Kuehne, P.A., 2016, Interim geologic map of the eastern half of the Salina 30' x 60' quadrangle, Emery, Sevier, and Wayne Counties, Utah: Utah Geological Survey Open-file Report 642DM, scale 1:62,500, 2 plates.

Doelling, H.H., Kuehne, P.A., Willis, G.C., and Ehler, B., 2015, Geologic map of the San Rafael Desert 30' x 60' quadrangle, Emery and Grand Counties, Utah: Utah Geological Survey M-267DM, 24 p., scale 1:100,000, 2 plates.

Gloyn, R.W., Tabet, D.T., Tripp, B.T., Bishop, C.E., Morgan, C.D., Gwynn, J.W., and Blackett, R.E., 2003, Energy, mineral, and ground-water resources of Carbon and Emery Counties, Utah: Utah Geological Survey Bulletin 132, 161 p.

Hintze, L.F., and Kowallis, B.J., 2009, Geologic history of Utah: Provo, Utah, Brigham Young University Geology Studies Special Publication 9, 225 p.

Hunt, C.B., 1956, Cenozoic geology of the Colorado Plateau: U.S. Geological Survey Professional Paper 279, 99 p.

Lucchitta, I., 1979, Late Cenozoic uplift of the southwestern Colorado Plateau and adjacent Colorado River region: Tectonophysics, v. 61, p. 63–95.

Lupton, C.T., 1913, Gypsum along the west flank of the San Rafael Swell, Utah, *in* Contributions to economic geology (short papers and preliminary reports), 1911, part 1 – metals and non-metals except fuels: U.S. Geological Survey Bulletin 530, p. 221–231.

Morgan, C.D., 2007, Structure, reservoir characterization, and carbon dioxide resources of Farnham Dome field, *in* Willis, G.C., Hylland, M.D., Clark, D.L., and Chidsey, T.C., Jr., editors, 2007, Central Utah—diverse geology of a dynamic landscape: Utah Geological Association Publication 36, p. 297–310.

Rigby, J.K., Hintze, L.F., and Welsh, S.L., 1974, Geologic guide to the northwest Colorado Plateau, studies for students No. 9: Provo, Utah, Brigham Young University Geology Studies, v. 21, pt. 2, p. 53–93.

Royse, F., Jr., 1996, Detachment fold train, Reed Wash area, west flank, San Rafael Swell, Utah—an example of a limb-lengthening, roll-through folding process on the eastern margin of the Sevier thrust belt: The Mountain Geologist, v. 33, no. 2, p. 45–64.

Sprinkel, D.A., Kowallis, B.J., and Jensen, P.H., 2011, Correlation and age of the Nugget Sandstone and Glen Canyon Group, Utah, *in* Sprinkel, D.A., Yonkee, W.A., and Chidsey, T.C., Jr., editors, The Sevier thrust belt—northern and central Utah and adjacent areas: Utah Geological Association Publication 40, p. 131–149.

Vickye, V., 2004, Geometric analysis of the Reed Wash detachment fold train, west flank of San Rafael Swell, Utah: American Association of Petroleum Geologists Datapages Achives, 14 p.

Witkind, I.J., 1988, Geologic map of the Huntington 30' x 60' quadrangle, Carbon, Emery, Grand, and Uintah Counties, Utah: U.S. Geological Survey Miscellaneous Investigations Series Map I-1764, scale 1:100,000, 5 plates.