Correlation and age of the Nugget Sandstone and Glen Canyon Group

Douglas A Sprinkel, Bart Kowallis

CORRELATION AND AGE OF THE NUGGET SANDSTONE AND GLEN CANYON GROUP, UTAH

Douglas A. Sprinkel[1], Bart J. Kowallis[2], and Paul H. Jensen[3]

ABSTRACT

In northeastern Utah, we propose to discontinue use of the term Glen Canyon Sandstone, and propose to instead use the term Nugget Sandstone for these rocks, which are exposed in the Uinta Mountains and have been drilled in most of the Uinta Basin. The Nugget Sandstone is also exposed and has been drilled throughout the Sevier thrust belt from northern Utah into central and southwestern Utah. The Glen Canyon Group, which consists of (in ascending order) the Wingate Sandstone/Moenave Formation, Kayenta Formation, and Navajo Sandstone, is exposed on the Colorado Plateau and has been drilled along the leading edge of the central and southwestern sectors of the Sevier thrust belt. The Nugget Sandstone is not included as a formation of the Glen Canyon Group, and thus two terms are used for strata above the Ankareh-Chinle Formations and below the Middle Jurassic formations. The term Nugget Sandstone is used where the Kayenta Formation is not recognized and the section consists predominantly of eolianite. Glen Canyon Group is used where the Kayenta is recognized.

Aetosaur and dinosaur tracks preserved in the newly applied Nugget Sandstone in the eastern Uinta Mountains and in exposures throughout the Glen Canyon Group include similar assemblages in approximately similar stratigraphic positions, strongly suggesting they are correlative. In addition, well log interpretation suggests that the Nugget Sandstone correlates with the entire Glen Canyon Group and that the Kayenta Formation either pinches out or transitions from fluvial to eolian deposition under the Uinta Basin and along the thrust belt in the Provo salient and south into southwestern Utah.

The age of the Nugget Sandstone is Late Triassic to Early Jurassic, which is similar to the Glen Canyon Group, and places the Triassic-Jurassic boundary within the formation/group and not at its base as previously thought.

INTRODUCTION

Upper Triassic to Lower Jurassic formations are exposed throughout Utah. In many places they form some of Utah's most spectacular scenery (figure 1). The rocks have also been drilled as primary targets for oil and gas in the Sevier thrust belt and in the northern Colorado Plateau, although in most wells they were drilled to reach deeper Paleozoic targets. Names for formations in Utah that lie above the Upper Triassic Ankareh and Chinle Formations and below Middle Jurassic strata include the Nugget Sandstone, the Glen Canyon Sandstone, and the Glen Canyon Group; the Glen Canyon Group consists of the Wingate Sandstone (Moenave Formation in southwestern Utah), Kayenta Formation, and Navajo Sandstone (Sprinkel, 1994; Hintze and Kowallis, 2009). The terms Nugget and Glen Canyon Sandstones were applied to the same package of thick eolianites with some minor interbedded fluvial-lacustrine beds. The Glen Canyon Group consists of a thick eolianite at its base (Wingate Sandstone) and at its top (Navajo Sandstone) separated by fluvial beds of the Kayenta Formation. The Moenave Formation consists of fluvial-lacustrine beds in southwestern Utah and intertongues with the Wingate Sandstone (Lucas and others, 2005). Geologists have long considered the Nugget and Glen Canyon Sandstones and the Glen Canyon Group to correlate to one another in a general sense because of their stratigraphic position and age control on the bounding formations. But the correlation between the formations of the Glen Canyon Group with the Nugget and Glen Canyon Sandstones has been uncertain. In addition, the age of the Nugget Sandstone has been reported as only Early Jurassic in some publications (e.g., Coogan and King, 2001) and Late Triassic to Early Jurassic in others (e.g., Bryant, 1990; Dover, 1995; Sprinkel, 2006, 2007).

Recent geologic mapping in northeastern Utah (Jensen, 2005; Sprinkel, 2006, 2007, 2009), age control on some of the poorly age-constrained formations from aetosaur and dinosaur tracks and newly discovered dinosaur bones (Lockley and others, 1992; 2004; Engelmann and others, 2010; Chambers and others, 2011; Engelmann and others, 2011; Lockley, 2011), and systematic interpretation of wells logs throughout Utah has shed light on the

[1]*Utah Geological Survey, P.O. Box 146100, Salt Lake City, UT 84114 Email: dsprinkel@gmail.com*
[2]*Department of Geological Sciences, Brigham Young University, Provo, UT 84602*
[3]*Arch Coal Company, P.O. Box 719, Helper, UT 84526*

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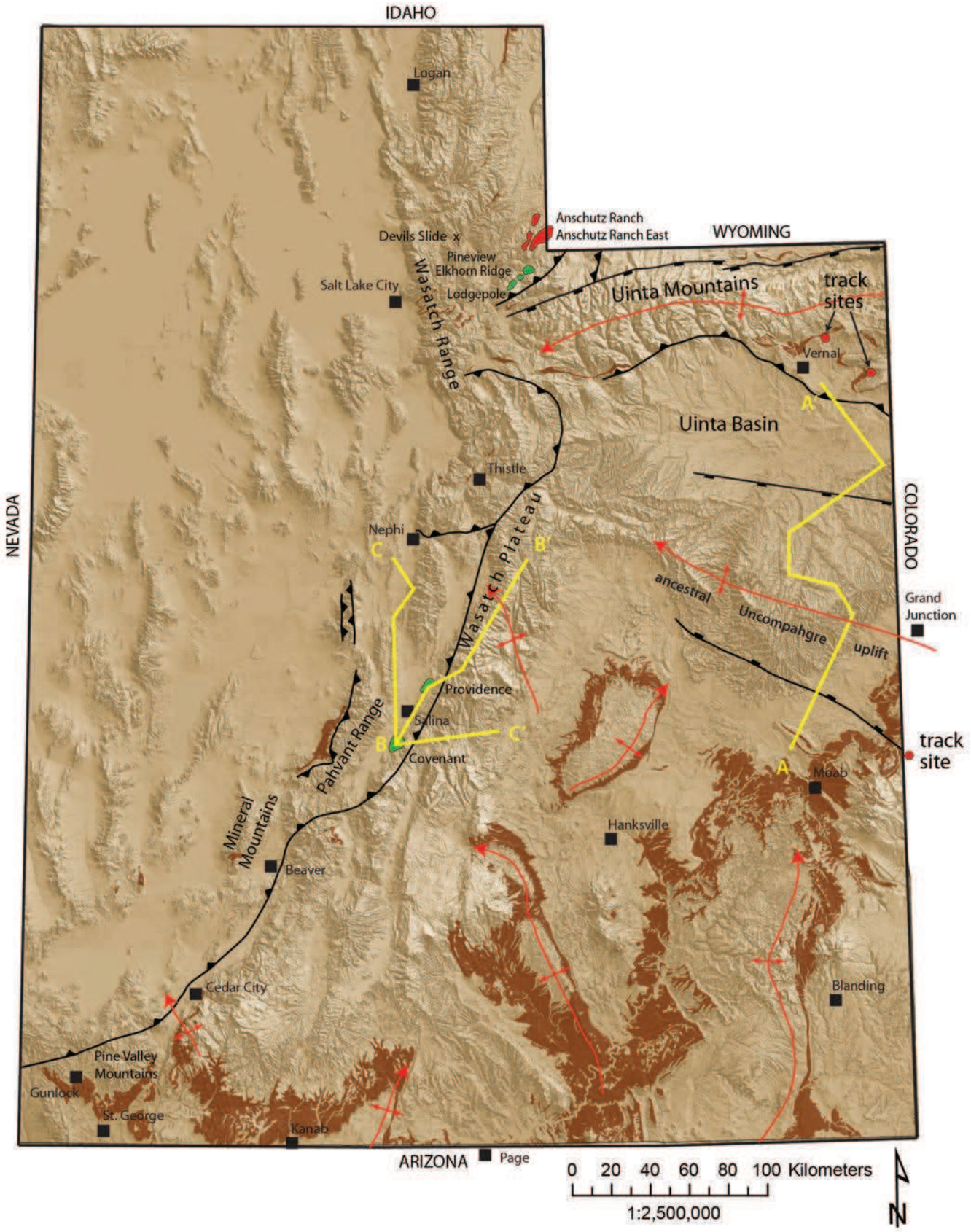


Figure 1. *Index map showing key geographic and geologic features mentioned in the article. (1) The Nugget and Glen Canyon Group outcrops are shown in darker brown; (2) the approximate axes of Ancestral Rocky Mountain and Laramide uplifts are in red; selected high-angle reverse faults are shown with solid boxes on up-thrown side; (3) oil fields are represented as irregular green polygons and gas fields are represented as irregular red polygons, and (4) the frontal edge and selected thrusts of the Sevier fold and thrust belt are shown with the barbs on the hanging wall.*

correlation and age of these formations. In this paper, we propose that: (1) the name Nugget Sandstone is the most appropriate name for the thick, massive-weathering, cross-bedded eolian sandstone exposed all around the Uinta Mountains and along parts of the Sevier fold and thrust belt, (2) the Nugget Sandstone is correlative to the entire Glen Canyon Group (Wingate Sandstone/Moenave Formation, Kayenta Formation, and Navajo Sandstone), and (3) the name Glen Canyon Sandstone, as proposed by Poole and Stewart (1964b) for northeastern Utah, be discontinued. We will discuss the distribution of and distinction between the Nugget Sandstone and Glen Canyon Group based on simple criteria, and provide evidence that both the Nugget Sandstone and Glen Canyon Group are Late Triassic to Early Jurassic in age.

REVIEW OF PREVIOUS STRATIGRAPHIC NOMENCLATURE

The name for the Upper Triassic to Lower Jurassic succession of mostly eolianites in Utah has changed several times. Powell (1876) used the name White Cliff Sandstone for the massive, white, cliff-forming sandstone found in both northern and southern Utah. This name was still in use in the eastern Uinta Mountains area in 1910 when Gale (1910) described it as a massive, light-gray to light-orange sandstone that "everywhere exhibits false *[cross-bedded]* stratification in many directions and many angles." To the north and west in Wyoming, however, the name Nugget Sandstone had entered the stratigraphic nomenclature for rocks of very similar age and character (Veatch, 1907; Gale and Richards, 1910; Boutwell, 1912).

In southern Utah, Arizona, and New Mexico, at about the same time, Gregory (1917) was proposing names for several Mesozoic formations. A number of workers studied these formations and it was generally accepted that the Nugget Sandstone in Wyoming and northern Utah was equivalent to all or part of Powell's White Cliff Sandstone and to a second formation called the Vermilion Cliff Sandstone in southern Utah and Arizona (Mansfield, 1920; Branson, 1927; Dobbin and Reeside, 1927; Lee, 1927; Mansfield, 1927; Reeside, 1929). Starting in the 1930s, however, workers began to restrict the correlation of the Nugget Sandstone in the north to just the Navajo Sandstone in the south (Gregory and Moore, 1931; Baker and others, 1936; Heaton, 1939; Kinney, 1955; Stokes and others, 1955).

It was also in the 1930s when the term Glen Canyon first entered the stratigraphic nomenclature (Baker and others, 1927). The Navajo Sandstone, along with strata called the Todilto(?) Formation, and the Wingate Sandstone were determined to be one conformable package of sedimentary rocks and they were grouped together into the Glen Canyon Group (Gregory and Moore, 1931). Rocks within the group called Todilto(?) were soon shown to not be equivalent to the type Todilto Limestone and were renamed the Kayenta Formation (Baker and others, 1936).

To the north, nomenclature in the Uinta Mountains was still in flux when Imlay (1952) recommended that the name Nugget Sandstone was more appropriate for the massive-weathering sandstone unit overlying the Chinle Formation, and that the name Navajo Sandstone should be restricted to areas south of the Uinta Basin. But, while mapping on the south flank of the Uinta Mountains, Kinney (1955) used the term Navajo Sandstone; however, he only applied this formation name to the upper part of the sandstone where large cross-bed sets were evident.

MacLachlan (1957) correlated the rocks mapped as Navajo Sandstone along the south flank of the Uinta Mountains in northeastern Utah with all or part of the Glen Canyon Group exposed to the south. Poole and Stewart 1964a, 1964b) renamed the rocks previously mapped as Navajo in the eastern Uinta Mountains as Glen Canyon Sandstone. They were uncertain, however, if their Glen Canyon Sandstone represented all formations within the Glen Canyon Group or only some formations. Interpretation of available well-log data at that time suggested that the Wingate Sandstone thickened northward from southern Utah as the Kayenta and Navajo thinned (Poole and Stewart, 1964a, 1964b). They speculated that if the thickness trend continued as suggested from the well-log interpretation, their Glen Canyon Sandstone probably correlated with the Wingate Sandstone and possibly a much thinned Navajo, with the Kayenta wedging out before the section surfaced along the eastern Uinta Mountains. Poole and Stewart (1964b) also considered that the Kayenta Formation and Navajo Sandstone may have been removed by a pre-Bajocian unconformity. They also stated that this new Glen Canyon Sandstone was equivalent to the Nugget Sandstone of the western Uinta and Wasatch Mountains, but chose not to use the name Nugget because "the name Nugget [was] opposed by many geologists because of lithologic differences between the Nugget in the type area in Wyoming and that in the Uinta Mountains." Unfortunately, Poole and Stewart (1964a, 1964b) did not provide references to show which geologists were opposed to the name Nugget Sandstone and did not outline in their paper what lithologic differences were problematic between the Nugget in the type area and the rocks they called the Glen Canyon Sandstone in the eastern Uinta Mountains.

The name Nugget Sandstone was never completely abandoned for these eastern Uinta Mountain rocks (e.g., High and Picard, 1975; Knapp, 1976; Doelger, 1987; Peterson, 1988), and recently it has been used in several published geologic reports and in presentations at professional geologic meetings (Jensen, 2005; Jensen and Kowallis, 2005; Jensen and others, 2005; Sprinkel and others, 2005; Hintze and Kowallis, 2009; Engelmann and others, 2010; Parry and Blamey, 2010; Chambers and others, 2011; Engelmann and others, 2011). The Nugget Sandstone has also been mapped from the western Uinta Mountains and northern Utah sector of the Sevier thrust belt eastward into the eastern Uinta Mountains (Bryant, 1990, 1992; Jensen, 2005; Sprinkel, 2006, 2007; Haddox and others, 2010a, 2010b).

We believe the lithologic similarities between the Glen Canyon Sandstone in the eastern Uinta Mountains and the Nugget Sandstone in its type locality in the Sevier thrust belt of southwestern Wyoming are strong and that the Nugget Sandstone can be easily mapped from there into northeastern Utah along the flanks of the Uinta Mountains. Thus, using another formation name for this fairly local area is unwarranted and the Nugget Sandstone is

preferred over the Glen Canyon Sandstone.

EVIDENCE FOR STRATIGRAPHIC CORRELATION

We agree with the evidence of McLachlan (1957) and Poole and Stewart (1964a, 1964b) supporting a correlation of the Nugget Sandstone with the Glen Canyon Group. In fact, aetosaur and dinosaur tracks preserved in the Nugget Sandstone around Dinosaur National Monument and in the Glen Canyon Group south of the Uinta Basin near Moab, Utah, as well as additional evidence from well logs presented in this paper (figure 2), further support the notion that the Nugget Sandstone in the eastern Uinta Mountains is indeed correlative to the Glen Canyon Group in total and not just part of the group.

The Nugget Sandstone contains key aetosaur and dinosaur tracks at several locations around Dinosaur National Monument, north and east of Vernal, Utah (Lockley and others, 1992; Hamblin and others, 2000; Engelmann and others, 2010; Lockley, 2011). The tracks are located near the base and in the upper half of the Nugget Sandstone. A well-preserved set of tracks identified as *Brachychirotherium* is located less than 10 meters above the base of Nugget Sandstone (Lockley and others, 1992; Lockley, 2011) (figure 3). A *Brachychirotherium* assemblage is also preserved in the Wingate Sandstone south of the Uinta Basin, which is evidence that at least this part of Nugget Sandstone is correlative with the Wingate (Lockley and others, 2004). The upper part of the Nugget Sandstone contains several track species including *Grallator, Otozoum,* and *Eubrontes* (Lockley and others, 1992; Lockley, 2011) (figure 4). This track assemblage is also preserved in the Kayenta Formation and Navajo Sandstone south of the Uinta Basin, and implies that the upper part of the Nugget Sandstone is correlative with that part of Glen Canyon Group (Lockley and others, 2004). In addition, *Otozoum* tracks were reported from the Nugget Sandstone in Wyoming (Kayser, 1964; Lockley, 2011).

Poole and Stewart (1964b) used well-log data to correlate between the formations above the Chinle and below the Carmel Formations on the northern Colorado Plateau and along the south flank of the Uinta Mountains, mostly in east-central to northeast Utah. By 1965, fewer than 30 wells had been drilled through the Nugget and Navajo Sandstones in their study area, with fewer than five wells located north of the Uncompahgre uplift. This represents a fairly limited data set to obtain a reasonable view of the correlation and predict thickness trends. Since 1965, nearly 100 wells have been drilled through the Nugget and Navajo Sandstones, and nearly 40 wells are located north of the Uncompahgre uplift. While this is still somewhat of a limited data set, we have also interpreted nearly 125 more wells throughout Utah, mostly south of the Uinta Mountains (figures 2). We interpreted only a few wells in the northern Utah thrust belt but plan to include significantly more wells to complete our work for a future, more comprehensive report.

Outcrops and drill holes near Moab, Utah, show that the Carmel Formation and the underlying Glen Canyon Group (Wingate Sandstone, Kayenta Formation, and Navajo Sandstone) thin northward across the buried ancestral Uncompahgre uplift. Both the Navajo Sandstone and Carmel Formation are missing on the crest of the uplift at Colorado National Monument, near Grand Junction, Colorado, where the Middle Jurassic Entrada Sandstone lies on the Kayenta Formation (Scott and others, 2001) (figure 5). The Uncompahgre uplift plunges to the northwest from Colorado National Monument and underlies the southernmost part of the Uinta Basin. Along the down-plunge axis and north of the crest of the uplift, the Navajo Sandstone is missing or too thin to identify with any confidence in wells, but the Wingate Sandstone and Kayenta Formation are preserved, even though regionally thin (figure 6). The Glen Canyon Group thickens northward under the Uinta Basin and likely northwestward toward the thrust belt, with the Navajo and Wingate Sandstones accounting for the increased thickness. The Kayenta continues to thin northward. Somewhere between Willow Creek and the subsurface trace of the Seep Ridge fault zone in the Seep Ridge 30' x 60' quadrangle (Sprinkel, 2009), the Kayenta either pinches out or changes from fluvial to eolian lithofacies and cannot be identified in geophysical logs (figure 6). The loss of the Kayenta strata is the criteria we use to define areas where the term Nugget Sandstone applies. Our interpretation is similar to that of Poole and Stewart (1964a, 1964b) except we believe the eolianite above the thinning Kayenta (the Navajo Sandstone) continues to thicken northward. The exact location of the transition from Glen Canyon Group to Nugget Sandstone is speculative because of limited well control; however, only the Nugget is recognized in subsurface from the northern part of the Seep Ridge quadrangle and in the adjoining Vernal quadrangle to the Uinta Mountains where it is exposed (Sprinkel, 2007). We recommend using the term Glen Canyon Group where the Kayenta can be recognized and Nugget where it cannot, and the unit as a whole is essentially a massive-weathering eolianite.

A similar stratigraphic relation exists between the Nugget Sandstone and Glen Canyon Group in the central and southwestern sectors of the Sevier thrust belt, and we recommend that the term Nugget be extended into central and southwestern Utah in areas where the Kayenta Formation cannot be recognized. Formations of the Glen Canyon Group (Wingate Sandstone, Kayenta Formation, and Navajo Sandstone) are not exposed in the central Utah sector of the Sevier thrust belt; however, they are identified in wells drilled along the frontal thrust faults (figure 7 and table 1). The Nugget Sandstone (no Kayenta) is sporadically exposed at several locations in the central Utah thrust belt from the Thistle area (Spanish Fork Canyon) southward to Nephi and along the west side of the Pahvant Range (figure 1, map showing outcrops and geography). In most published reports, Thistle was considered the dividing line between Nugget-Navajo nomenclature; the term Nugget was used north of Thistle and Navajo Sandstone was used south of Thistle (Hintze and Kowallis, 2009). But we have not identified the Kayenta Formation in any of the outcrops south of Thistle to the Pahvant Range and thus, we consider those rocks as the Nugget. The Nugget Sandstone is also identified in wells drilled in the central Utah thrust. The Nugget is exposed in the footwall of the Nebo and Pahvant thrust faults and on the hanging wall of the

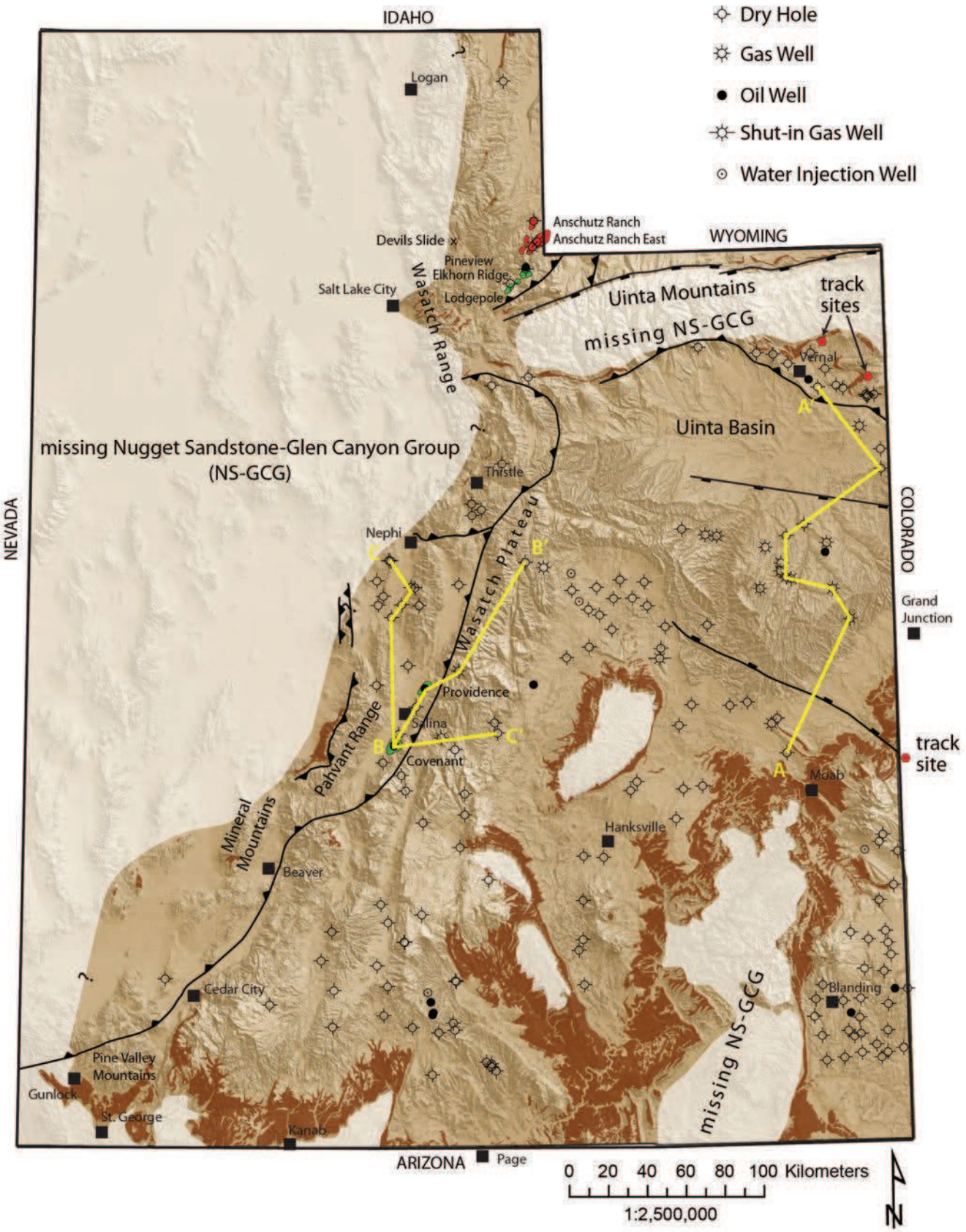


Figure 2. *Location and distribution of wells used to interpret the subsurface stratigraphic section between the Chinle-Ankareh Formations and Middle Jurassic formations. The Nugget Sandstone-Glen Canyon Group outcrops are shown in darker brown. The places identified on the map as having missing Nugget Sandstone-Glen Canyon Group are areas where the erosion has removed the Nugget Sandstone-Glen Canyon Group (and overlying formations). The eastern boundary of the area of no Jurassic in western Utah reflects the footwall cutoff of the Nugget Sandstone.*

Figure 3. *The Nugget Sandstone contains key aetosaur and dinosaur tracks that support the age and correlation with the Glen Canyon Group. At this site the tracks are: (A) preserved in a thin, horizontal-bedded unit (yellow arrow) that is within a few meters of the base of the Nugget Sandstone (the red line); (B) preserved on the underside of this horizontal-bedded unit, (C) identified as belonging to Brachychirotherium, which is a classic Triassic track, and (D) located east of Vernal, Utah, near Dinosaur National Monument. Another site not far from here also has this species of tracks that lie about 10 m above the base of the Nugget Sandstone. Brachychirotherium tracks are also found in the lower part of the Wingate Sandstone near Gateway, Colorado (see figure 1 for general location).*

Paxton thrust fault (for thrust fault locations, see Schelling and others, 2007). All formations of the Glen Canyon Group are recognized eastward on the Gunnison and Salina thrust faults. We believe the transition is similar to the transition in the southern Uinta Basin (figure 8 and table 1).

The Glen Canyon Group in the southwestern sector of the Sevier thrust belt consists of the Moenave Formation, Kayenta Formation, and Navajo Sandstone. The Moenave is restricted to southwestern and south-central Utah, is partially correlative to the Wingate Sandstone, and represents fluvial-lacustrine deposition (Clemmensen and others, 1989; Blakey, 1994; Peterson, 1994). Excellent and complete exposures of the Glen Canyon Group are in the St. George area, and attenuated sections are east of the Hurricane fault in the Cedar City area (figure 1) (Rowley and others, 2006; Biek and others, 2009). Outcrops of strata below the Carmel Formation are limited and incomplete west of the Hurricane fault in the Cedar City area, making it difficult to evaluate if these sections are Nugget or Glen Canyon Group. However, we do not recognize the Kayenta Formation in well logs from the few wells drilled in the area. Full sections of the strata between the Chinle and Carmel Formations are exposed in and around the Mineral Mountains east of Beaver, Utah, and the Kayenta Formation is not reported in those sections (Rowley and others, 2005). In addition, we have interpreted data from the few wells drilled in the same area and do not recognize the Kayenta in the subsurface. Thus, we consider the section above the Chinle and below the Carmel in those areas as the Nugget Sandstone.

AGE OF THE NUGGET SANDSTONE

As noted in the previous section, the Nugget Sandstone contains key aetosaur and dinosaur tracks and newly discovered dinosaur bones that help constrain its age. The lower part of the Nugget is Late Triassic in age based on the *Brachychirotherium* assemblage preserved near the base of the formation (Lockley and others, 1992). The upper part of the Nugget is considered Early Jurassic

Figure 4. *The Nugget Sandstone contains key aetosaur and dinosaur tracks that support the age and correlation with the Glen Canyon Group. At this site the dinosaur tracks are: (A) preserved in a fluvial lens that likely represents an interdunal wadi unit within the eolianite near the top of the Nugget Sandstone, (B), include Grallator and Eubrontes (pictured), both common Early Jurassic tracks, and (C) located along the shore of Red Fleet Reservoir, northeast of Vernal, Utah.*

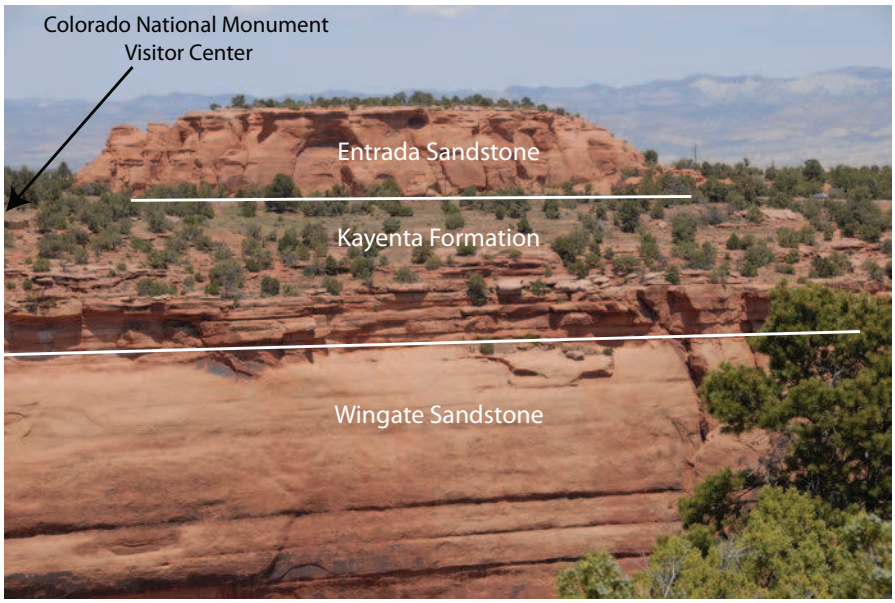
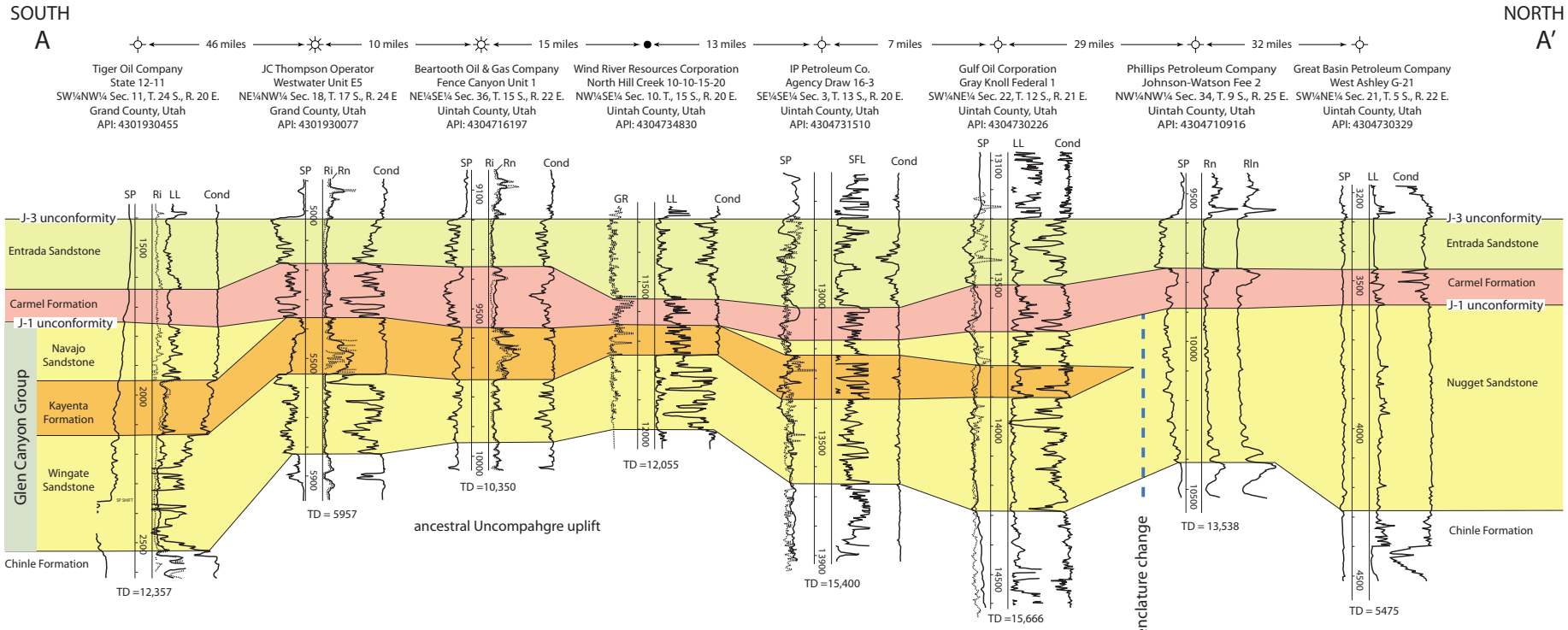


Figure 5. *The Uncompahgre uplift is a regional structural high that began to rise in Pennsylvanian time and affected Pennsylvanian, Permian, and Triassic deposition. This photograph shows the stratigraphic succession above the Chinle Formation exposed at Colorado National Monument. The Wingate Sandstone is overlain by the Kayenta Formation, which is typical throughout the Colorado Plateau; however, lying on the Kayenta is the Middle Jurassic Entrada Sandstone. Thus, the Navajo Sandstone and Carmel Formation are missing.*



Tiger Oil Company
State 12-11

Formation	Depth	Thick
Entrada Sandstone	1401	239
Carmel Formation	1640	110
Navajo Sandstone	1750	240
Kayenta Formation	1990	146
Wingate Sandstone	2136	394
Chinle Formation	2530	
Glen Canyon Group	1750	780

JC Thompson Operator
Westwater Unit E5

Formation	Depth	Thick
Entrada Sandstone	5028	148
Carmel Formation	5176	185
Kayenta Formation	5361	191
Wingate Sandstone	5552	272
Chinle Formation	5824	
Glen Canyon Group	5292	463

Beartooth Oil & Gas Company
Fence Canyon Unit 1

Formation	Depth	Thick
Entrada Sandstone	9194	166
Carmel Formation	9360	205
Kayenta Formation	9565	175
Wingate Sandstone	9740	216
Chinle Formation	9956	
Glen Canyon Group	9406	391

Wind River Resources Corporation
North Hill Creek 10-10-15-20

Formation	Depth	Thick
Entrada Sandstone	11,288	269
Carmel Formation	11,557	88
Kayenta Formation	11,645	105
Wingate Sandstone	11,750	262
Chinle Formation	12,012	
Glen Canyon Group	11,610	367

IP Petroleum Co.
Agency Draw 16-3

Formation	Depth	Thick
Entrada Sandstone	12,755	305
Carmel Formation	13,060	48
Navajo Sandstone	13,152	69
Kayenta Formation	13,221	74
Wingate Sandstone	13,370	495
Chinle Formation	13,865	
Glen Canyon Group	13,108	713

Gulf Oil Corporation
Gray Knoll Federal 1

Formation	Depth	Thick
Entrada Sandstone	13,299	226
Carmel Formation	13,525	155
Navajo Sandstone	13,680	107
Kayenta Formation	13,796	109
Wingate Sandstone	13,905	384
Chinle Formation	14,289	
Glen Canyon Group	13,637	609

Phillips Petroleum Company
Johnson-Watson Fee 2

Formation	Depth	Thick
Entrada Sandstone	9530	222
Carmel Formation	9752	60
Nugget Sandstone	9882	528
Chinle Formation	10,410	

Great Basin Petroleum Company
West Ashley G-21

Formation	Depth	Thick
Entrada Sandstone	3289	168
Carmel Formation	3457	121
Nugget Sandstone	3578	702
Chinle Formation	4280	

LOG CURVE ABBREVIATIONS
SP - Spontaneous Potential
Rn - Resistivity Normal
Rln - Resistivity Long Normal
Rl - Resistivity Lateral
Ri - Resistivity Induction
LL - Resistivity Laterolog
SFL - Spherically Focused Log
GR - Gamma Ray
Cond - Conductivity
All depths and thicknesses reported in feet

Figure 6. *Cross section A-A' shows the correlation of Middle Jurassic to Upper Triassic formations from near Moab, Utah, northward to near Vernal, Utah. It was drawn to highlight the change in nomenclature between Glen Canyon Group and the Nugget Sandstone based on regional changes of the petrophysical log signatures, supported by limited sample descriptions and cuttings. The Glen Canyon Group includes the Wingate Sandstone, Kayenta Formation, and Navajo Sandstone. The Wingate and Navajo are sandstone beds of predominantly eolian origin whereas the Kayenta is sandstone, siltstone, and minor limestone beds of fluvial-lacustrine origin. The Nugget Sandstone is predominantly of eolian origin. The cross section shows the Glen Canyon-Nugget interval thins over the ancestral Uncompahgre uplift, mostly at the expense of the Navajo Sandstone. In addition, the Kayenta thins northward and eventually pinches out. The nomenclatural change between Glen Canyon Group and Nugget Sandstone is where the Kayenta Formation is no longer identified in wells. The Kayenta Formation is characterized as having a more positive SP response and higher resistivity as compared to the overlying Navajo and underlying Wingate. The cross section datum is the J-3 unconformity at the top of the Entrada Sandstone. (click for larger view)*

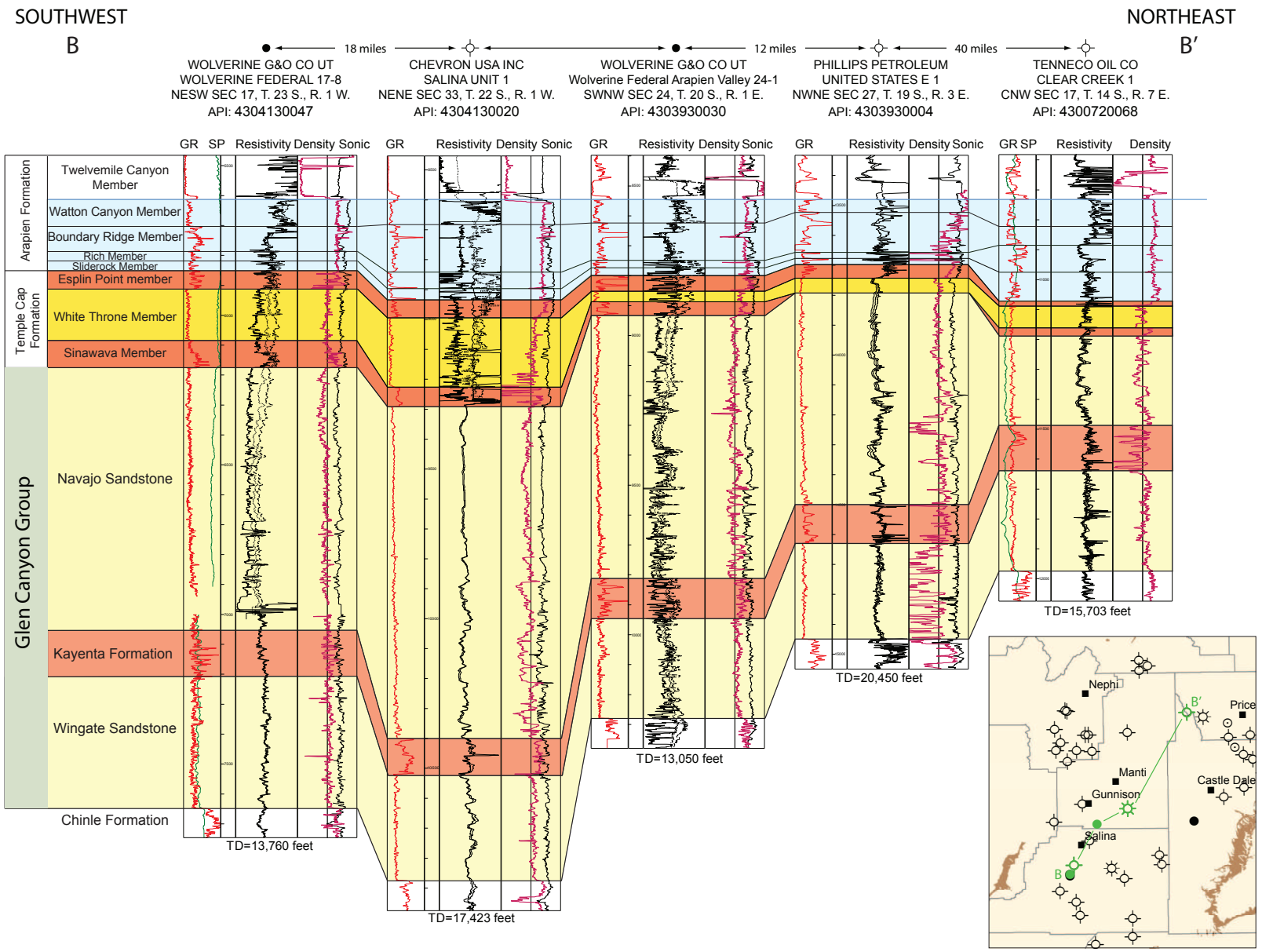


Figure 7. *Cross section B-B′ shows correlation of the Wingate Sandstone, Kayenta Formation, and Navajo Sandstone within the wells that parallel the fontal thrust faults of the Sevier thrust belt in central Utah. The Kayenta Formation is recognized in the wells using geophysical logs supported by sample descriptions and cuttings. Thus the term Glen Canyon Group is preferred. The cross section datum is the Watton Canyon Member of the Arapien Formation (equivalent to the Paria River Member of the Carmel Formation). (click for larger view)*

Table 1. *Tops and thickness of Nugget Sandstone and formations of the Glen Canyon Group from wells used in cross sections B-B' (figure 7) and C-C' (figure 8). Formation tops are reported as drilled depths and have not been corrected for well-bore deviation. Reported formation thickness is an apparent thickness as the values were not corrected for well-bore deviation or bedding attitude.*

API	Operator	Well Name	Top Navajo/ Nugget	Thick Navajo/ Nugget	Top Kayenta	Thick Kayenta	Top Wingate	Thick Wingate	Top Chinle/Ankareh
4302330007	Placid Oil Company	WXC-Howard 1A	11,042	1052	0	0	0	0	12,094
4302330004	Placid Oil Company	WXC-Barton 1	8812	706	0	0	0	0	9518
4302330009	American Quasar	Chicken Creek 16-34	7455	210	7665	65	7730	599	8329
4304111136	Skelly Oil Company	Emery Unit 1	5875	422	6297	298	6595	370	6965
4304130047	Wolverine Gas & Oil Company	Federal 17-8	6176	874	7050	162	7212	436	7648
4304130020	Chevron USA, Inc	Salina Unit 1	9300	1109	10,409	118	10,527	357	10,884
4303930030	Wolverine Gas & Oil Company	Fed Arapien Valley 24-1	8930	883	9813	137	9950	330	10,280
4303930004	Phillips Petroleum Company	United States E-1	13,790	712	14,502	138	14,640	313	14,953
4300720068	Tenneco Oil Company	Clear Creek 1	11,188	302	11,490	156	11,646	330	11,976

in age based on the *Grallator*, *Otozoum*, and *Eubrontes* assemblages (Lockley and others, 1992; Hamblin and others, 2000; Lockley, 2011). In addition, recent discoveries of *Brasilichnium* tracks on the slip faces of dune sets (Engelmann and others, 2010) and abundant bone fragments of a coelophysoid theropod (Chambers and others, 2011; Engelmann and others, 2011) in the Nugget Sandstone near Dinosaur National Monument are supportive evidence for the upper Nugget being Early Jurassic in age. This age range for the Nugget is similar to what is reported for the Glen Canyon Group (Lockley and others, 2004; Lucas and others, 2005; Cornet and Waanders, 2006; Kirkland and Milner, 2006; Lucas and Milner, 2006; Lockley, 2011). Thus, the Nugget in the Uinta Mountains is Late Triassic to Early Jurassic in age.

We assume that the Nugget Sandstone in the Sevier thrust belt is also Late Triassic to Early Jurassic, although no fossil evidence for a Late Triassic age has been reported. However, the contact and stratigraphic relations between the Nugget and the underlying formations (the Chinle and Ankareh Formations) in the Sevier thrust belt are the same as the Chinle-Nugget contact in the Uinta Mountains. The lithofacies and sedimentary features in the upper Chinle to the lower Nugget exhibit a general coarsening-up transition from predominately fluvial with some thin lacustrine beds to predominately eolian beds. This transition interval has been mapped as the formation of Bell Springs in the eastern Uinta Mountains (Jensen, 2005; Haddox and others, 2010a, 2010b) and is recognized elsewhere between Ankareh Formation and Nugget Sandstone (Brandley, 1988) and the Chinle Group and Glen Canyon Group (Lucas and others, 1997; Lucas and others, 2005) (see the discussion of formation of Bell Springs in the next section).

We do not see a regional unconformity at the basal Nugget contact in Utah that separates Triassic beds from Jurassic beds. Thus, the Triassic-Jurassic boundary is within the Nugget Sandstone and the J-0 unconformity of Pipiringos and O'Sullivan (1978) probably does not exist. The top of the Nugget and Navajo Sandstone of the Glen Canyon Group in the Sevier thrust belt of Utah is the regional J-1 unconformity (Pipiringos and O'Sullivan, 1978).

DISCUSSION OF FORMATION OF BELL SPRINGS

Underlying the Nugget Sandstone is a succession of beds that contains sedimentary features that indicate a transition from predominately fluvial-tidal flat deposition to predominately eolian deposition of the Nugget. This transitional unit has been recently mapped as the formation of Bell Springs in the eastern Uinta Mountains (Jensen, 2005; Haddox and others, 2010a, 2010b). The formation of Bell Springs resembles the Bell Springs Member of the Nugget (Pipiringos, 1968) in east-central Wyoming and had been previously included in the Chinle Formation (Kinney, 1955; Poole and Stewart, 1964b) or the Nugget Sandstone (High and others, 1969; Picard, 1977) in the Uinta Mountains. It is also similar to beds described in the Church Rock Member of the Chinle Formation (Stewart and others, 1972; Dubiel, 1992) and the Rock Point Formation

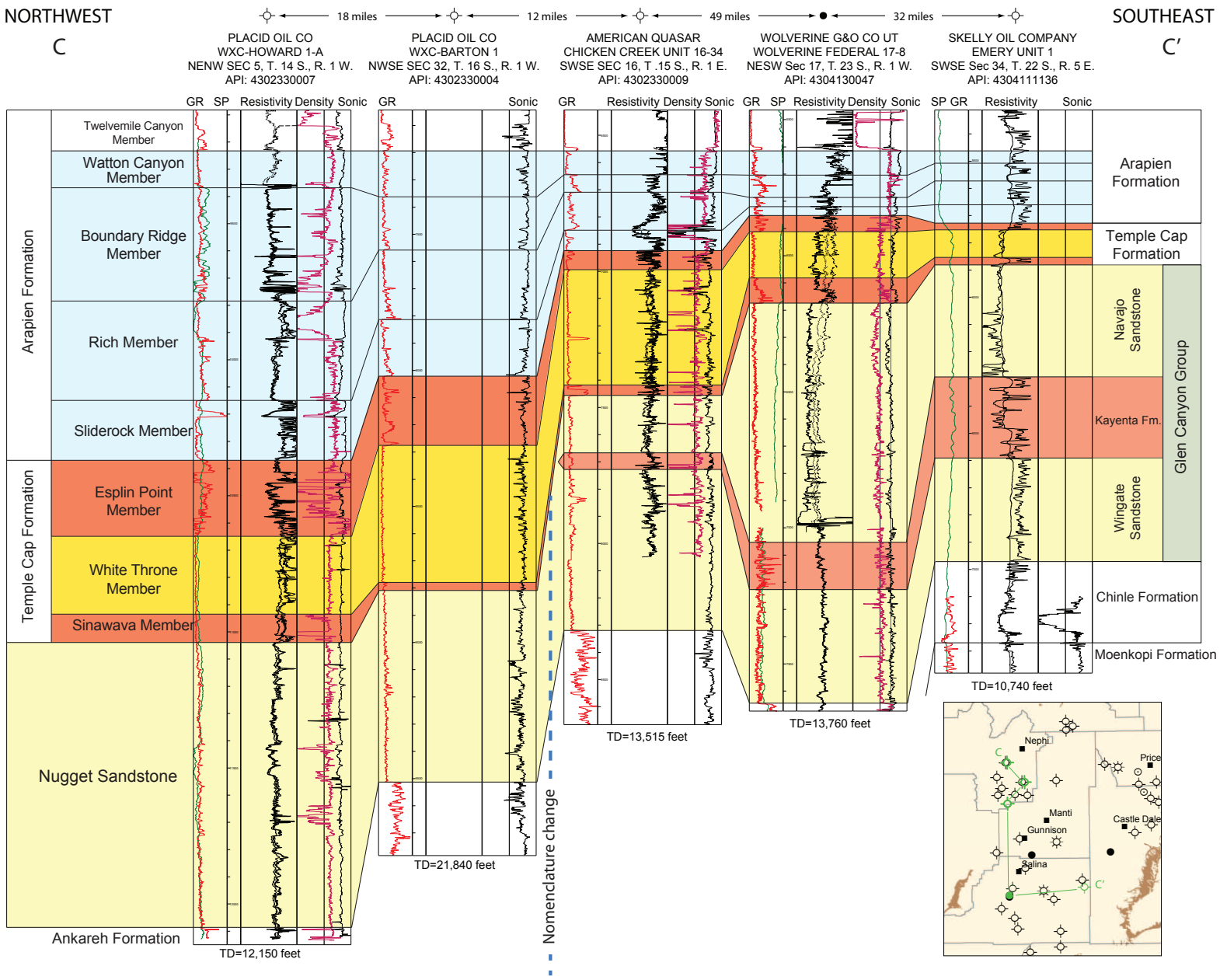


Figure 8. *Cross section C-C′ shows the correlation and stratigraphic relations between the Nugget Sandstone and formations of the Glen Canyon Group along the transport direction of thrusting in the Sevier fold and thrust belt in central Utah. The Glen Canyon Group is recognized where the Kayenta Formation is identified in wells using geophysical logs supported by sample descriptions and cuttings. The Kayenta Formation thins and either pinches or transitions to eolian lithofacies to the northwest. The term Nugget Sandstone is used where the Kayenta Formation is not recognized. This somewhat simple stratigraphic relation may be complicated in some wells by thrust faults. It is possible that in some wells, the Nugget Sandstone drilled on the hanging wall may overlie the Glen Canyon Group drilled in the footwall. The cross section datum is the Watton Canyon Member of the Arapien Formation (equivalent to the Paria River Member of the Carmel Formation). (click for larger view)*

of the Chinle Group in the Four Corners area (Lucas and others, 1997; Lucas and others, 2005). We only mention the formation of Bells Springs here in our discussion of the Nugget Sandstone-Glen Canyon Group correlation because we believe these beds: (1) are regionally recognizable, (2) show that stratigraphic relations between the upper Chinle-Ankareh Formations and lower Nugget are similar to those between the upper Chinle and Wingate Sandstone, (3) imply continuous deposition from Ankareh-Chinle Formation to Nugget Sandstone, and (4) corroborate a regional Late Triassic age for the Nugget.

In south-central Wyoming, near Rawlins, Pipiringos (1968) established the name Bell Springs Member of the Nugget Sandstone for a sequence of ripple-marked, red and gray sandstone, and red, green, and purple siltstone and shale beds. He also reported that the Bell Springs sat disconformably on top of the Popo Agie Formation (Chinle Formation equivalent), with the basal beds of the Bell Springs commonly containing rip-up pebbles of ocher-colored, analcime-rich mudstones from the underlying Popo Agie Formation. Pipiringos (1968) also pointed out that the Bell Springs Member of Wyoming correlated with the unnamed upper member of the Chinle Formation as described by Kinney (1955) and Poole and Stewart (1964a, 1964b) in northeastern Utah.

Picard (1975) also recognized two subdivisions in the Nugget Sandstone in northeastern Utah. He called the lower unit the "thinly-bedded facies" and discussed the possibility that this facies was equivalent to the Bell Springs Member of the Nugget in Wyoming. Lucas and others' (1997) work suggests that the Rock Point (Church Rock) Formation of the Chinle Group, near the Four Corners region, is correlative with formation of Bell Springs.

The lithofacies and thickness range of the Bell Springs Member in the eastern Uinta Mountains are quite consistent (figure 9). The first resistant sandstone overlying the upper red unit of the Chinle Formation is considered the basal bed of the Bell Springs. Where this contact can be clearly seen, it may be a local angular unconformity (figure 10) (High and others, 1969). This angular relationship is not observed in any other areas and most likely represents a deltaic clinoform in the lacustrine sediments of the Chinle rather than a regional erosion surface. Pipiringos (1968) reported a basal bed of pebbles in the Bell Springs, composed of ocher-colored analcime rocks derived from the Chinle along with chert and other lithics from an unidentified source. Conglomerate beds, although not found everywhere, do occur along the south flank of the Uinta Mountains and may mark a major unconformity or may be local channel gravels in the upper Chinle.

The lower half (approximately 15 meters) of the Bell Springs Member is composed of interbedded units of fine- to medium-grained sandstone and siltstone, usually 1 to 10 meters thick, and planar laminated mudstone that ranges from 0.5 to 2 meters thick. The sandstone is planar laminated and contains abundant ripple marks that vary from asymmetrical to symmetrical flaser ripples (figure 11). Mud drapes are thin (1 to 2 mm). The ripple marks are approximately 2.5 to 3 cm from crest to crest and 0.5 to 1 cm in amplitude. Rippled beds are multidirectional, but the crests average a slight southwest-northeast trend at 260º. Sandstone beds are commonly bioturbated and mottled. Mudcracks and small salt casts are also common (figures 12A and 12b). The mudstone and siltstone beds are mostly purple, red, and brown, and the sandstone layers vary in color from reddish-purple to orange to tan with yellow, white, and gray mottling. Siltstone beds are thinly bedded.

In the upper half of the Bell Springs Member, two sandstone beds, separated by fine-grained, ripple-marked siltstone and thin mudstone, are present. The two sandstone beds have well-rounded quartz grains and large, tabular cross-bedding and sigmoidal bedding, with some sets reaching amplitudes of 1 meter (figure 13A). The up-

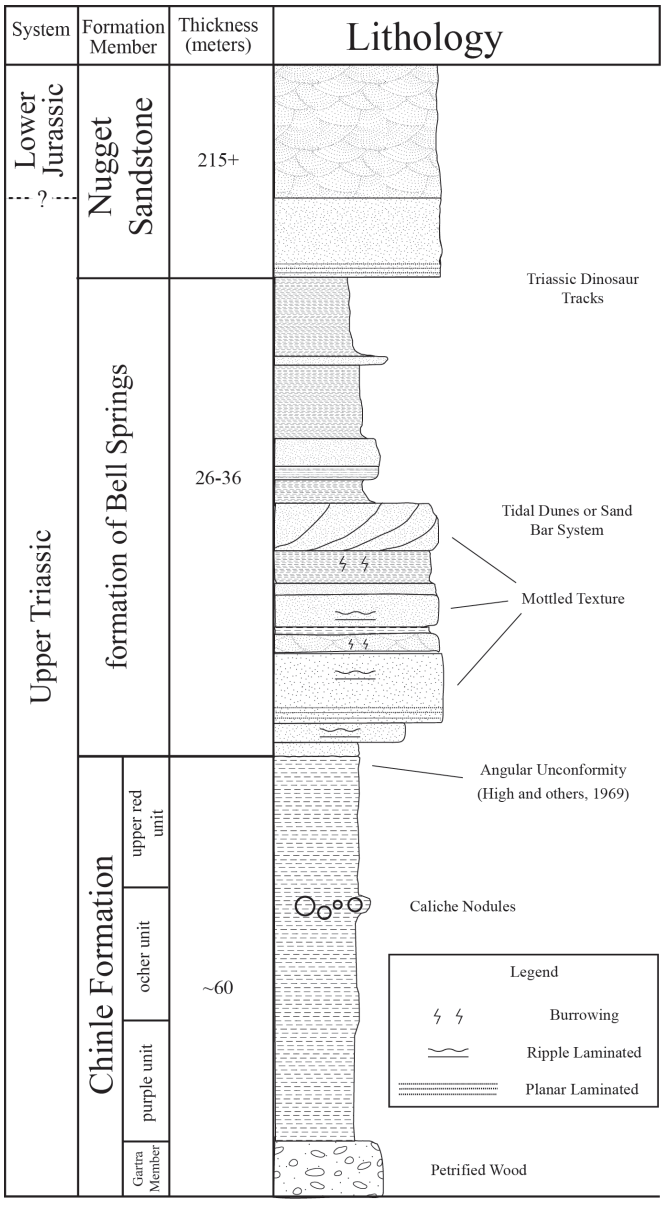


Figure 9. *Stratigraphic column of the Upper Triassic and Lower Jurassic formations in northeastern Utah. Sedimentary and bedding features identified in the formation of Bell Springs are interpreted as fluvial to tidal-flat deposition. In addition, it represents a transition from predominately fluvial to eolian deposition.*

Figure 10. *The angular unconformity that separates the upper red unit of the Chinle Formation and the overlying formation of Bell Springs is thought to represent structural warping before the deposition of the Bell Springs Member (High and others, 1969); however, this relationship has not been identified elsewhere in the region and it may represent a deltaic clinoform, unique only to this location. Photograph taken south of Squaw Springs (northwest of Vernal, Utah). Note the black Labrador retriever for scale.*

Figure 11. *Flaser ripples preserved in the lower part of the formation of Bell Springs. These sedimentary structures are characteristic of the moderate- to high-energy facies within the intertidal zone.*

per cross-bedded sandstone contains scoured channels filled by sand (figure 13B). From north to south in the Red Fleet area northeast of Vernal, Utah, the sandstone beds of the Bell Springs Member become less resistant and change from a sheer, cliff-forming sandstone to thinner, flaggy-bedded silty-sandstone beds over a distance of a few 100 meters. Based upon the sedimentary structures and bedding succession, Jensen (2005) interpreted the Bell Springs Member as a tidal deposit. Other studies on the Bell Springs Member of the Nugget Sandstone have also interpreted it as a tidal deposit (Pipiringos, 1968; Doelger and Steidtmann, 1982). In addition, equivalent beds of the upper Ankareh Formation in Spanish Fork Canyon, near Diamond Fork, Utah, have been interpreted as tidal flat deposits (Brandley, 1988). However, stratigraphically equivalent beds on the north flank of the Uinta Mountains, near Sheep Creek, Daggett County, Utah, appear to have been deposited in a deeper water system, as do the equivalent beds to the west near Hannah, Utah. The Bell Springs Member at the Nugget Sandstone type section, west of Kemmerer, Wyoming, also appears to have been deposited in relatively deeper water, given the abundant mudstone and siltstone beds, lack of sandstone beds, and planar lamination within the more competent beds in all of the deeper water sections. The strata at these localities are consistent with the overall regional setting and provide some control over the placement of the shoreline. Additional work is needed to determine if the formation of Bells Springs should be a member of the Nugget Sandstone (as established by Pipiringos, 1968), included in the Chinle Formation, or formalized as a new regional formation.

DISTRIBUTION OF NUGGET SANDSTONE AND GLEN CANYON GROUP

We have presented evidence to show that the Nugget Sandstone correlates with the Glen Canyon Group and that both are Late Triassic to Early Jurassic age. We have suggested that the term Nugget Sandstone should be used for strata that lie between the Ankareh-Chinle Formations and Jurassic formations where the Kayenta Formation is not recognized. The term Glen Canyon Group should be used where the Kayenta Formation is recognized. Thus, the Nugget is a thick eolianite with some minor interbedded fluvial-lacustrine beds, mostly near its base. The Glen Canyon Group contains a thick eolianite at its base (Wingate Sandstone) and at its top (Navajo Sandstone) separated by fluvial beds of the Kayenta Formation. The Moenave Formation consists of fluvial-lacustrine beds in southwestern Utah and intertongues with the Wingate Sandstone (Lucas and others, 2005).

Based on the criteria above, we have examined key sections exposed throughout Utah and interpreted about 150 well logs (to date) to determine Nugget versus Glen Canyon Group sections. We have mapped a preliminary nomenclature boundary based on their distribution (figure 14) In general, the Glen Canyon Group is restricted to much of the Colorado Plateau, on or south of the Uncompahgre Uplift, and into southwestern Utah. The Nugget Sandstone

is restricted to the Uinta Mountains, much of the Uinta Basin, and the Sevier thrust belt. The boundary in the central Utah sector of the thrust belt could be complicated by thrusting. In some areas, the Nugget Sandstone may be on the hanging wall of a thrust but the Glen Canyon Group may be on the underlying footwall.

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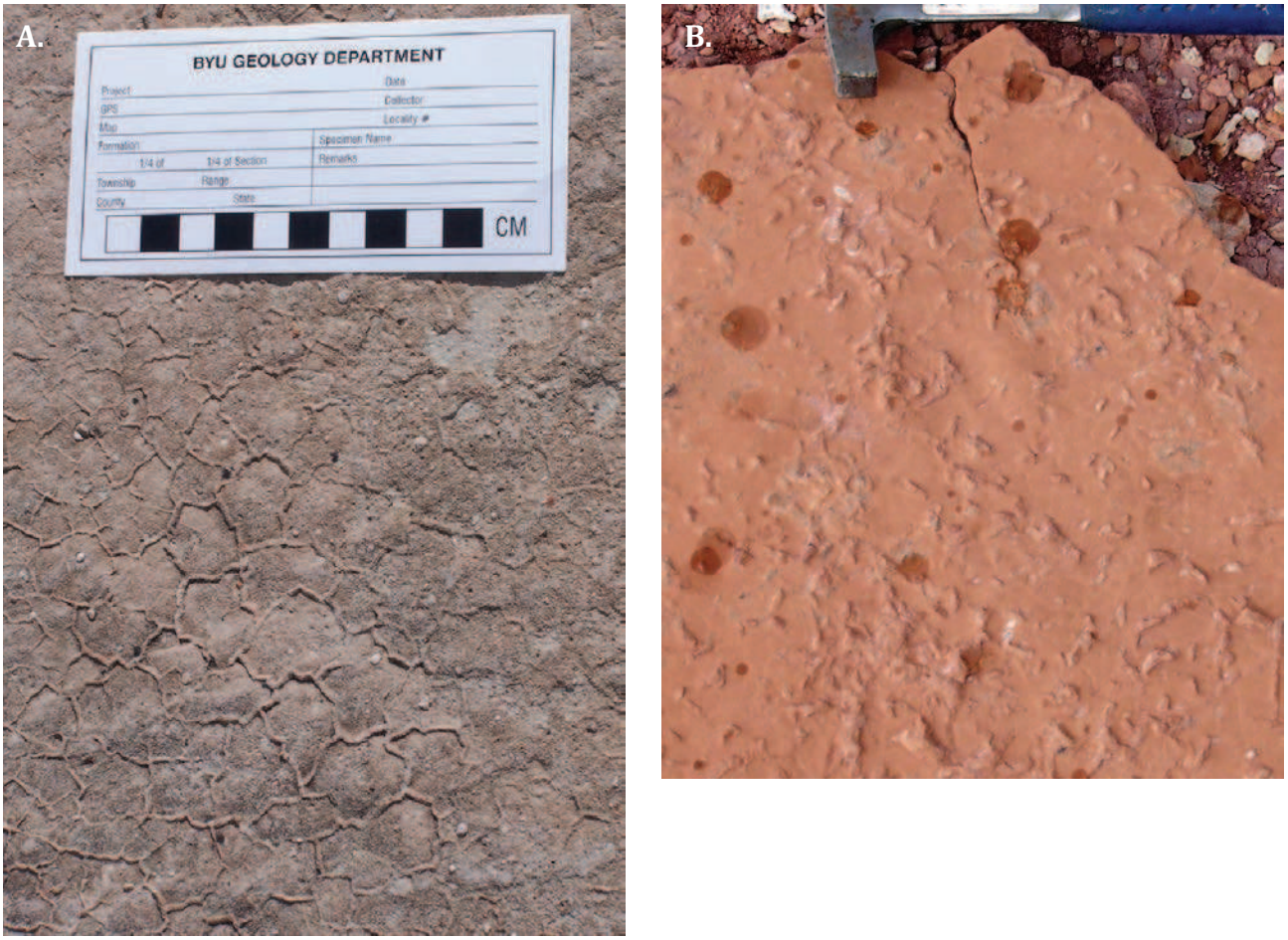

Figure 12. *Sedimentary features preserved in the lower part of the formation of Bell Springs include: (A) mudcracks and (B) salt crystal casts. These features denote periods of subaerial exposure, typical of a tidal-flat system.*

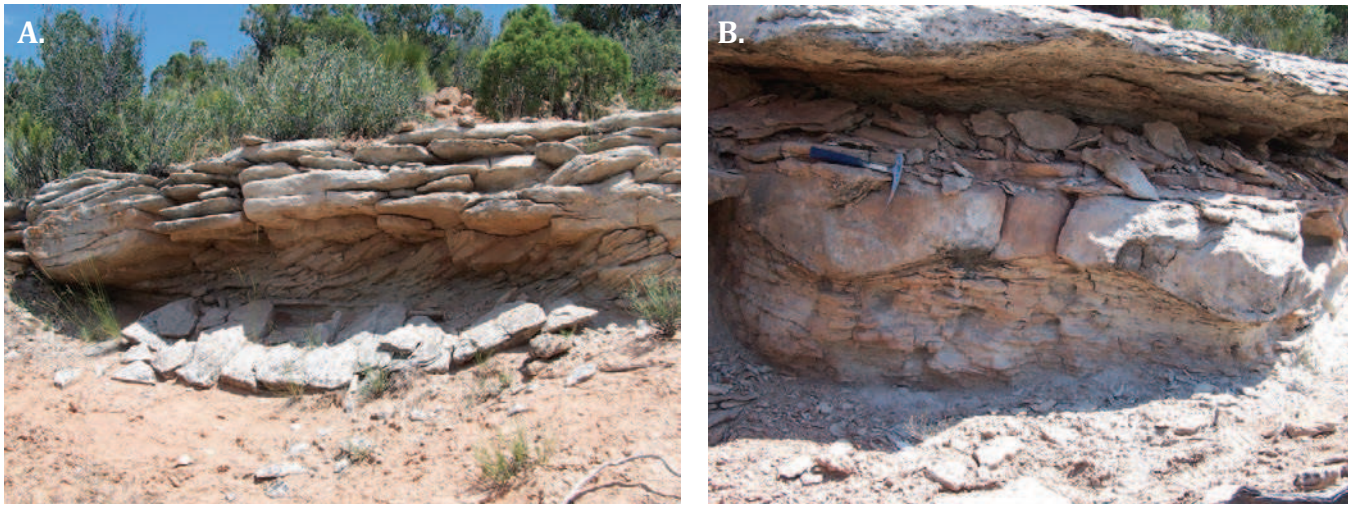

Figure 13. *Sedimentary features in sandstone beds in the upper part of the formation of Bell Springs include: (A) sigmoidal beds and cross-bedding from offshore sand bars, and (B) scour and fill from migrating sand bars.*

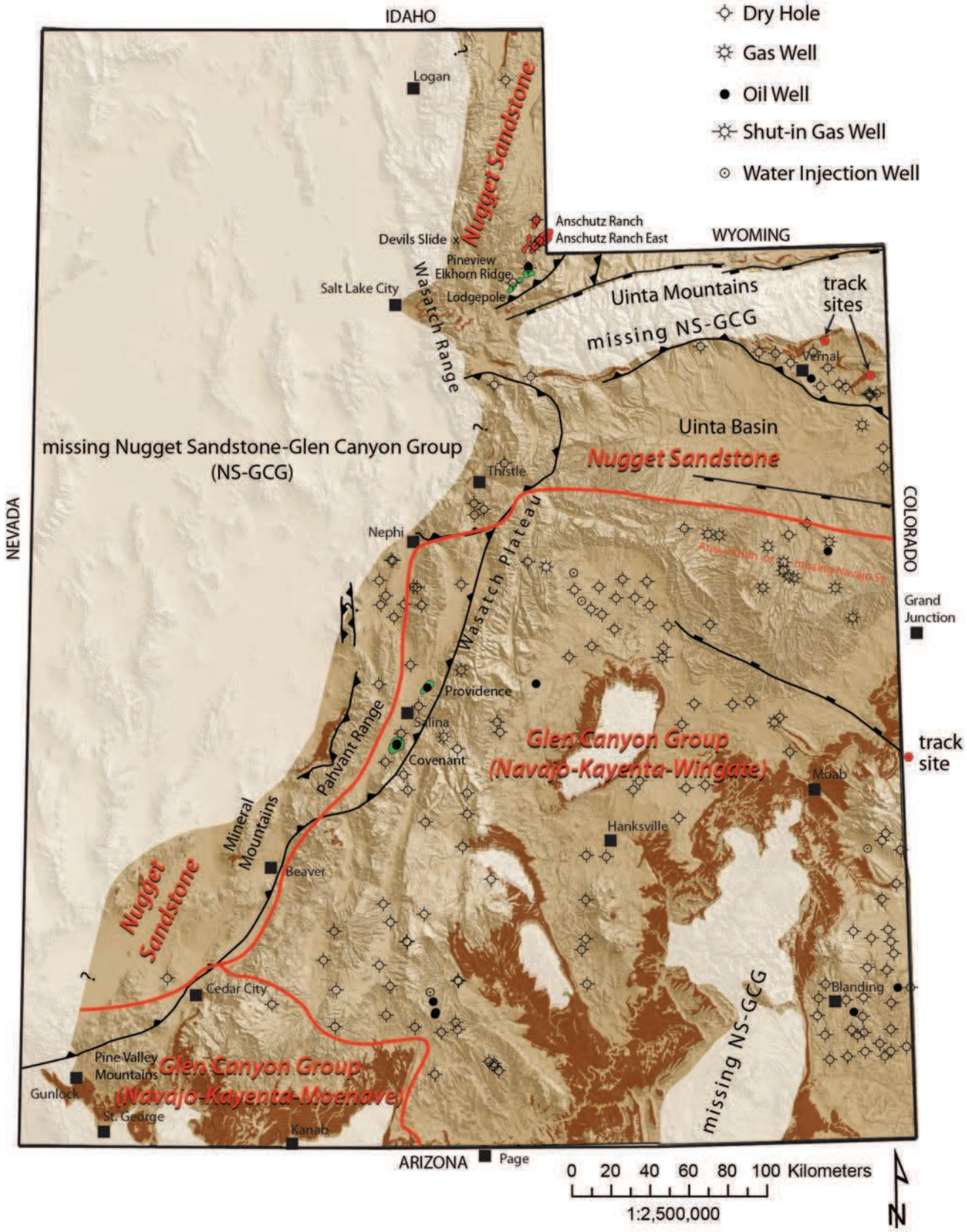

Figure 14. *Distribution of Nugget Sandstone-Glen Canyon Group nomenclature. The rock that overlies the Chinle-Ankareh Formations and underlies the Middle Jurassic units in Utah includes the Nugget Sandstone and Glen Canyon Group. The Glen Canyon Group contains the Wingate Sandstone (and intertonguing Moenave Formation), Kayenta Formation, and Navajo Sandstone. Areas where the Kayenta Formation is not recognized, the term Nugget Sandstone is used. The places identified on the map as having missing Nugget Sandstone-Glen Canyon Group are areas where the erosion has removed the Nugget-Glen Canyon (and overlying formations). The eastern boundary of the area of no Jurassic in western Utah reflects the footwall cutoff of the Nugget.*

Natural History Museum State Park) for taking Sprinkel to the track site near Dinosaur National Monument. We are very grateful to Grant Willis (Utah Geological Survey) for his careful review of the manuscript and figures. The manuscript and figures are greatly improved because of his work. We also thank Robert Ressetar (Utah Geological Survey) for his technical review. Finally, this project was supported by the Utah Geological Survey and the U.S. Geological Survey, National Cooperative Geologic Mapping Program, through USGS STATEMAP award numbers 06HQAG0037, 07HQAG0141, and 08HQAG0096. Some support was also provided by the USGS EDMAP program, award numbers 03HQAG0034, 04HQAG0055, and 05HQAG0049 to Brigham Young University.

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