UPPER CRETACEOUS MARINE AND BRACKISH WATER STRATA AT GRAND STAIRCASE-ESCALANTE NATIONAL MONUMENT, UTAH
GEOLOGICAL SOCIETY OF AMERICA FIELD TRIP ROAD LOG, MAY 2002

Slick Rock Bench. This view north toward Wiggler Wash shows steep dip of Entrada through Straight Cliffs Formations in Kaibab anticline. Canaan Peak and Table Cliff Plateau can be seen on the far horizon

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INTRODUCTION

Mid-Cretaceous strata in southwestern Utah (figures 1 and 2) are transitional from shelf to nonmarine rocks in the foreland basin along the tectonically active western margin of the Western Interior basin. Predominantly nonmarine western sequences (Beaver Dam Mountains near Gunlock, Utah; Cedar Canyon near Cedar City, Utah; and at Parowan Gap near Parowan, Utah) are difficult to correlate with other rocks because they lack a representative suite of marine megafauna. Rocks in Grand Staircase-Escalante National Monument, are mostly marine, but have not been thoroughly sampled for datable fossils; thus correlations within the marine sequence are generally imprecise. Furthermore, correlations with key reference sections in the central part of the Western Interior basin are not well defined. Better correlations will help in establishing the timing of transgressive and regressive depositional events throughout the basin.

This field trip will familiarize geologists and non-geologists alike with the mid-Cretaceous sequence in Grand Staircase-Escalante National Monument, with emphasis on the fossiliferous marine units. We discuss the physical stratigraphy of key rock units, biostratigraphic correlations, and general environments of deposition. Characterization of the regional timing of transgressive and regressive stages of the Tropic sea will be made using new fossil collections of Cobban and others (2000) and Dyman and others (2000). We also include general explanations of other Mesozoic stratigraphic units along the field trip route. The field trip was designed as a one-day event in order to reduce participant costs and accommodate tight schedules. We have examined excellent marine sections farther to the east in the Monument, but have selected our stops as the best within existing logistical limitations.

Mid-Cretaceous strata in the Monument include the Cenomanian Dakota Formation, the Cenomanian to Turonian Tropic Shale, and the Turonian lower part of the Straight Cliffs Formation. At Tropic, Utah, and Cottonwood Wash, along the route of the trip, marine rocks associated with the Tropic transgression extend from near the upper part of the Dakota Formation through the Tibbet Canyon Member of the Straight Cliffs Formation (figure 2).

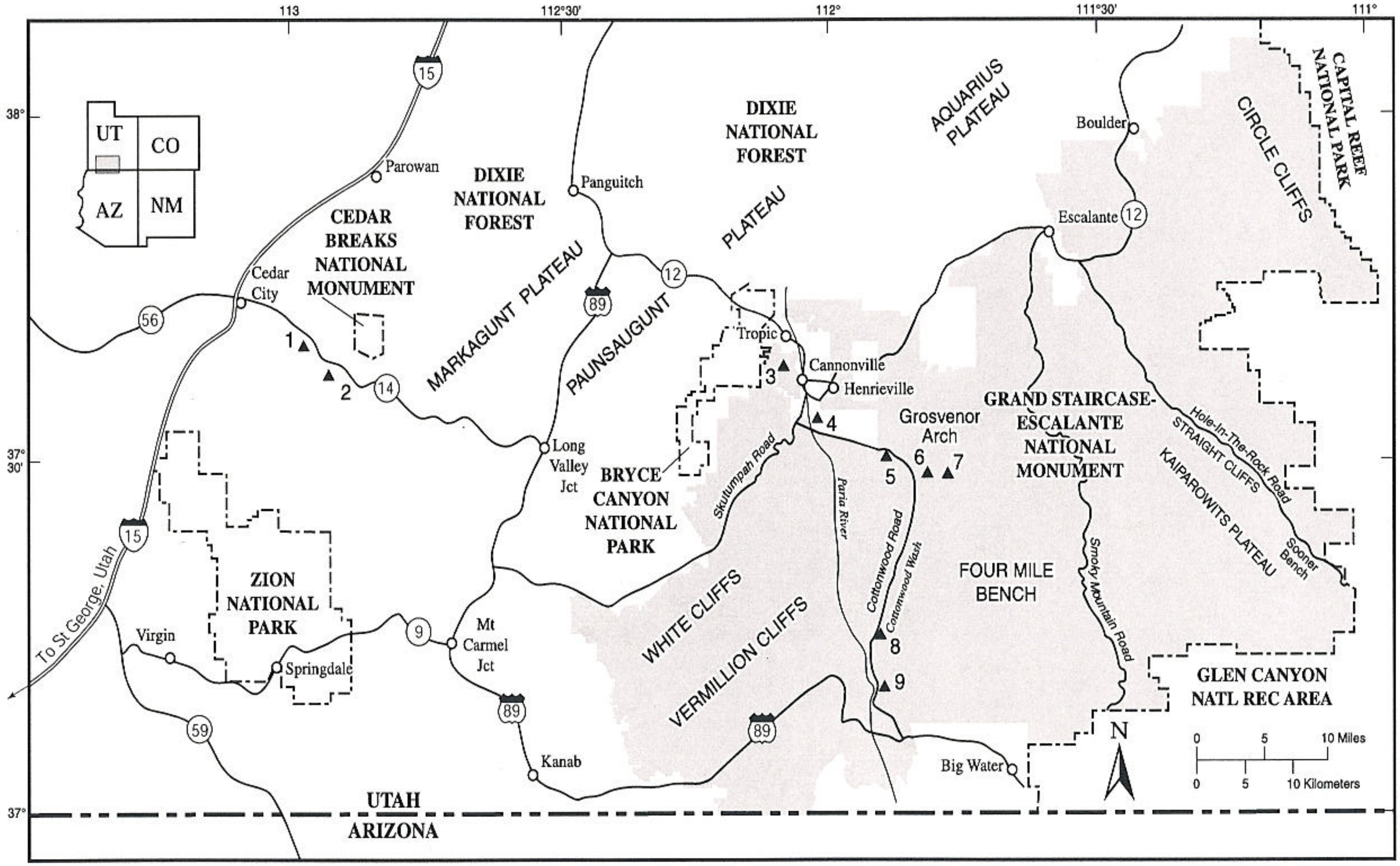

Figure 1. Index map of southwestern Utah, including the Cedar City area and Grand Staircase-Escalante National Monument, illustrating major geographic features, highways, and towns. Field trip stops 1-9 identified by numbered black triangles.

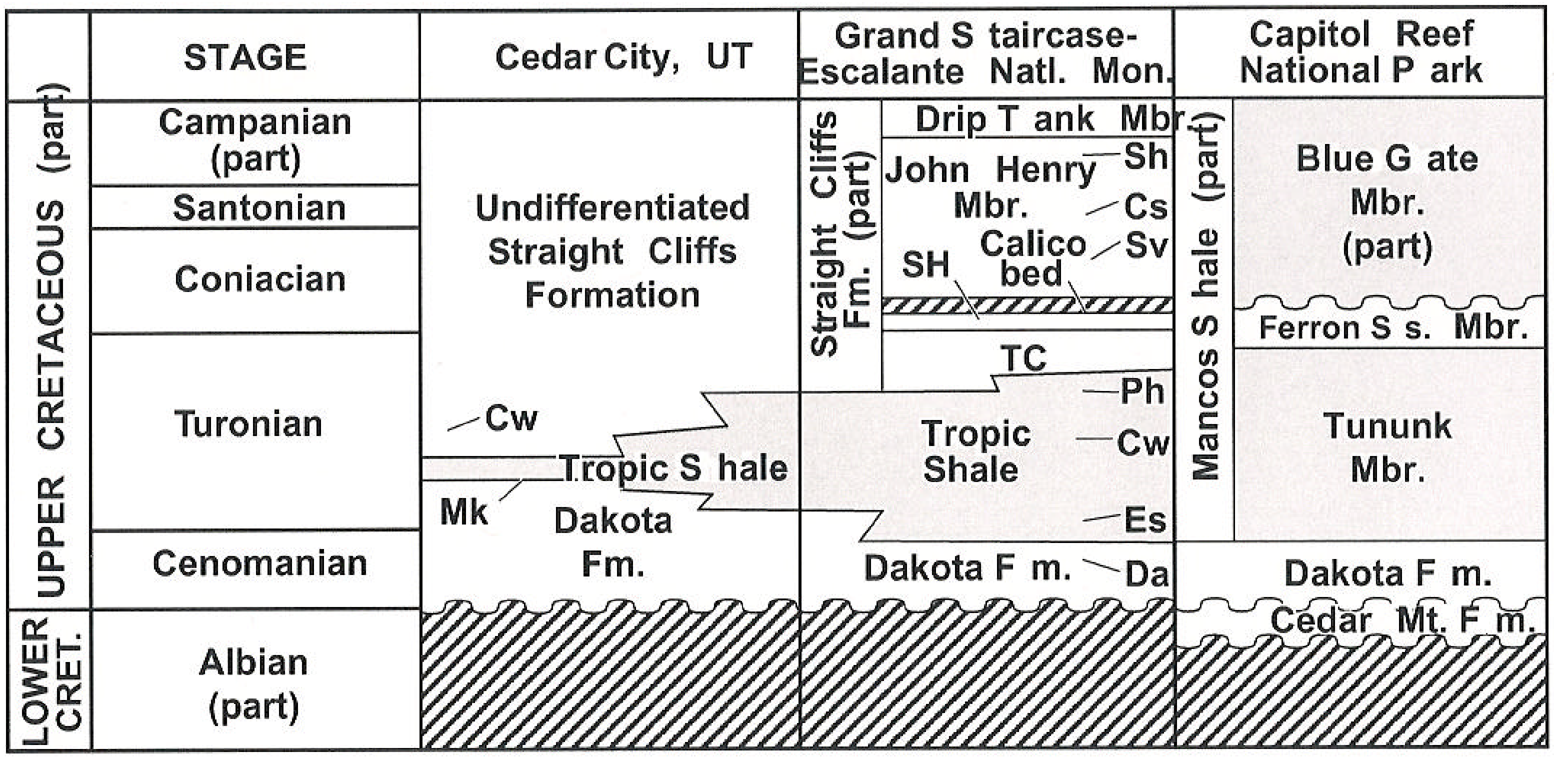

Figure 2. Generalized stratigraphic correlation chart illustrating marine Cretaceous rock units of late Cenomanian through early Campanian age in Grand Staircase-Escalante National Monument, the Cedar City area, and the Capitol Reef National Park area. Hatchured pattern indicates unconformities. Abbreviations show the stratigraphic location of marine Cretaceous ammonite biozones, associated inoceramids, and stratigraphic units as follows: Cw, Collignoniceras woollgari; Cs, Clioscaphites vermiformis; Da, Dunveganoceras albertense; Es, Euomphaloceras septemseriatum; Ph, Prionocyclus hyatti; Sv, Scaphites ventricosus; SH, Smoky Hollow Member of Straight Cliffs Formation; TC, Tibbet Canyon Member of Straight Cliffs Formation.

Farther east, near Escalante, Utah, marine rocks extend upward into the upper part (John Henry Member) of the Straight Cliffs Formation.

Fossil descriptions and supporting information for marine invertebrate collections from the Monument are available as a digital Microsoft EXCEL file in Dyman and others (2000) (Any use of trade, product, or firm names is for descriptive purposes only and does not imply endorsement by the U.S. Government). The fossil collections are stored at the U.S. Geological Survey in Denver, Colo. The authors wish to acknowledge Russell Tysdal and Carol Molnia, U.S. Geological Survey, Denver, Colo., and Bill Lund, Utah Geological Survey, Cedar City, Utah, for their critical reviews of the manuscript.

STRATIGRAPHY AND AGE

Figure 2 is a generalized correlation chart illustrating the stratigraphic position of Upper Cretaceous rocks in the Monument, adjacent to the eastern boundary of the Monument in Capitol Reef National Park, and in areas farther to the west in southwestern Utah. This chart presents a regional stratigraphic perspective. Within the Monument, as previously stated, marine rock units include the upper part of the Dakota Formation, the Tropic Shale, and the lower part of the Straight Cliffs Formation. At Capitol Reef National Park, marine rocks include most of the Dakota Formation and the overlying Mancos Shale Group. Figure 3 is a biostratigraphic chart showing Upper Cretaceous stages, formations and members in the Monument, informal stratigraphic units, Western Interior ammonite zones, and localities of biostratigraphically significant fossil collections from Cobban and others (2000) and Dyman and others (2000).

Dakota Formation

The upper part of the Dakota Formation contains the oldest marine rocks in the Monument. Near the town of Tropic (field trip stop 3), and southeastward at Grosvenor Arch and Cottonwood Wash (field trip stops 6, 8, 9), the Dakota is about 200-300 feet thick and is composed of sandstone, conglomerate, mudstone, siltstone, and coal. The Dakota thins in the eastern part of the Monument, where it averages less than 150 feet thick. The base of the Dakota consists of a coarse pebble and cobble conglomerate that persists throughout most of the region (figure 4). Clasts consist of quartzite, dark-gray chert, and various lithic fragments, including sandstone, conglomerate, and mudstone. Where the conglomerate is absent, the basal Dakota consists of carbonaceous mudstone, coal, and sandstone. The basal strata overlie a widespread regional unconformity above Jurassic rocks. The conglomeratic unit is time-equivalent to the Cedar Mountain Formation in central Utah (Doelling and others, 2000), based on an Early Cretaceous age of palynomorphs from interbedded siltstones.

The lower, middle, and upper parts of the Dakota contain several distinctive coally carbonaceous zones. Sandstones are generally fine to medium grained and lithic rich. The Dakota was deposited in coastal, floodplain, and shallow marine depositional environments at Cottonwood Wash. The Dakota Formation-Tropic Shale contact near the town of Tropic is sharp and marks an abrupt change in lithology from predominantly sandstone to shale.

The oldest marine fossils are in the uppermost beds of the Dakota, which are clearly of late Cenomanian age at the Monument (figure 3). Ammonites are scarce, but recent collecting has yielded specimens of *Dunveganoceras problematicum natronense*, *Dunveganoceras* cf. *D. albertense*, and *Metoicoceras* cf. *M. frontierense* from a channel-fill sandstone bed in the lower part of the upper sequence. *Inoceramus* cf. *I. prefragilis,* indicating the zone of *Calycoceras canitaurinum* (also ,zone of *Dunveganoceras pondi),* has also recently been collected from the lowermost marine shale, and the highest sandstones have yielded a *Vascoceras diartianum* assemblage, indicating that a nearly complete upper Cenomanian marine biostratigraphic sequence exists. At most localities, the top of the Dakota contains an extensive fauna of bivalves characterized by the oyster *Exogyra (Costagyra)*

Cretaceous Stages		Formations and Members		Informal Stratigraphic Units	Ammonite Zones	Fossil Localities
Santonian	Upper	Straight Cliffs Formation (part)	John Henry Member	Gss, Fss Coal zones	*Desmoscaphites bassleri*	
				Ess, Dss UMMT	*Desmoscaphites erdmanni*	
					Clioscaphites choteauensis	
	Middle			Css, Bss Coal zones	*Clioscaphites vermiformis*	125, 141
	Lower				*Clioscaphites saxitonianus*	
Coniacian	Upper			Ass LMMT	*Scaphites depressus*	106, 108, 109, 114, 120, 123, 129, 135, 150, 152, 159
	Middle		Smoky Hollow Member	Calico bed	*Scaphites ventricosus*	62, 113, 139, 158, 160
				barren zone	*Forresteria alluaudi*	
	Lower				*Forresteria peruana*	
Turonian	Upper				*Prionocyclus germari*	
					Scaphites nigricollensis	
					Scaphites whitfieldi	
					Scaphites ferronensis	
				?	*Scaphites warreni*	
				coal zone	*Prionocyclus macombi*	140
	Middle		Tibbet Canyon Mbr	lower ss	*Prionocyclus hyatti*	5, 15, 16, 55, 56, 59, 60, 78, 96, 105, 107, 110, 126, 164
		Tropic Shale		noncalcareous shale	*Collignoniceras praecox*	
				calcareous shale	*Collignoniceras woollgari*	4, 20, 54, 58, 77, 79, 83, 147, 155
	Lower				*Mammites nodosoides*	28, 47-50
					Vascoceras birchbyi	} 9, 10, 23, 30, 42-46, 52, 53
					Pseudaspidoceras flexuosum	
					Watinoceras devonense	26
Cenomanian (part)	Upper				*Nigericeras scotti*	
					Neocardioceras juddii	3, 131
					Burroceras clydense	
					Euomphaloceras septemseriatum	2, 7, 8, 12, 19, 22, 25, 36, 38, 39, 51, 80, 85-86, 89-91, 93-95, 100-101, 148
		Dakota Formation		upper member	*Vascoceras diartianum*	6, 12, 17, 18, 21, 24, 27, 29, 31, 33, 34, 37, 70-72, 81, 82, 84, 87, 88, 92, 99, 134, 137, 161
					Dunveganoceras conditum	} 14, 32, 41
					Dunveganoceras albertense	
					Dunveganoceras problematicum	
					Dunveganoceras pondi	
	Middle			? middle and lower members	*Plesiacanthoceras wyomingense*	
					Acanthoceras amphibolum	
					Acanthoceras bellense	
					Acanthoceras muldoonense	
					Acanthoceras granerosense	
					Conlinoceras tarrantense	

Figure 3. Biostratigraphic chart showing Upper Cretaceous stages, formations and members in the Grand Staircase-Escalante National Monument, informal stratigraphic units, Western Interior ammonite zones (modified from Cobban, in Obradovich, 1993), and localities of fossil collections in Dyman and others (2000). Upper part of informal stratigraphic units modified from Peterson (1969). LMMT and UMMT are lower and upper marine mudstone tongues, and A through G are sandstone tongues of the John Henry Member of Straight Cliffs Formation. Each number corresponds to the appropriate invertebrate fossil collection in Dyman and others (2000).

Figure 4. Henrieville Sandstone-Dakota Formation contact in upper Henrieville Valley east of Henrieville, Utah. Hammer for scale.

olisiponensis Sharpe and *Flemingostrea prudentia* (White). At one locality (Cobban and others, 2000; Dyman and others, 2000), we found *Metoicoceras mosbyense* with *E. olisiponensis,* which suggests that the *E. olisiponensis* assemblage lies at the top of the range of *M. mosbyense* (figure 5). Inasmuch as the highest specimens of *M. mosbyense* occur in the zone of *Vascoceras diartianum*, we assigned the highest beds of the Dakota to this zone. The presence of *M. mosbyense* lower in the upper part of the Dakota suggests assignment to one of the *Dunveganoceras* zones, such as *D. conditum* or *D. albertense*.

Using methods reported in Obradovich (1993), J.D. Obradovich recently obtained a new date for the middle part of the Dakota Formation in the Tropic area (field trip stop 3) by $^{40}Ar/^{39}Ar$ laser fusion dating of sanidine crystals. Several bentonite beds in the Dakota Formation contain sanidine. Obradovich took a sample from the middle part of the Dakota, 120 feet from the top of the unit, and isolated the sanidine by disaggregation and magnetic and heavy liquid separation, similar to methods used by Hicks and others (1995). Obradovich analyzed the samples using the GLM continuous laser system at the U.S. Geological Survey isotope facility at Menlo Park, California (Dalrymple, 1989) and presented the date as an unweighted mean as 95.97 +/-0.22 Ma which identifies the sample as early Cenomanian.

Tropic Shale

Gregory and Moore (1931) first described the Tropic Shale near the town of Tropic, Utah. It is about 700 to 900 feet thick in the Monument and composed of medium- to dark-gray fissile shale with local thin siltstone and sandstone lenses (figure 6). The lower part of the formation is generally calcareous and contains several distinctive concretionary zones. The lowermost limestone concretionary zone, which forms a distinct horizon about 15 to 20 feet above the base of the formation, contains the straight-shelled ammonite *Sciponoceras gracile* and associated fauna of the middle upper Cenomanian *Euomphaloceras septemseriatum* biozone (figure 3; field trip stops 8 and 9; Cobban and others, 2000; Dyman and others, 2000). A second horizon, not far above the first, contains a fauna characteristic of the *Neocardioceras juddii* biozone. A third horizon about 150 feet above the base of the formation contains fauna of the *Vascoceras birchbyi* biozone of early Turonian age. A fourth horizon has septarian concretions with large ammonites of the *Mammites nodosoides* biozone. A fifth horizon, containing the early middle Turonian ammonite *Collignoniceras woollgari* is located about 250 feet above the base of the Tropic. About 700 feet above the base, at a distinct color change from light gray calcareous to dark gray noncalcareous shale, is the approximate first appearance of the ammonite *Prionocyclus hyatti* of late middle Turonian age (field trip stop 8). This ammonite is also found in the overlying Tibbet Canyon Member of the Straight Cliffs Formation. A similar sharp color change has been recognized as far east as west-central Kansas, where it marks the contact of the stratigraphically equivalent Fairport and overlying Blue Hill Members of the Carlile Shale.

At the Cenomanian-Turonian boundary reference section near Pueblo, Colorado, we recognize the middle Turonian *Prionocyclus hyatti* biozone in the upper part of the Blue Hill Member of the Carlile Shale and in the overlying Codell Sandstone Member of the Carlile Shale. At Pueblo, these strata are unconformably overlain by upper Turonian and Coniacian limestones of the Fort Hays Limestone Member of the Niobrara Formation (Cobban and Scott, 1972).

The upper part of the Tropic Shale in the Monument is gradational with the overlying Tibbet Canyon Member of the Straight Cliffs Formation. Sandstones increase in abundance upward in the upper part of the Tropic until sandstone is the dominant lithology. The Tropic-Straight Cliffs contact is usually placed where sandstone becomes more abundant than shale (Peterson, 1969).

Figure 5. Upper part of Dakota Formation at field trip stop 6 (The Reservoir). The upper part of the Dakota Formation forms a coarsening upward cycle capped by sandstone and conglomeratic sandstone. Marine and brackish water invertebrates illustrated here include Inoceramus mesabiensis, Exogyra olisponensis, Ostrea sp., and the ammonite Metoicoceras mosbyense (see Dyman and others (2000) for a complete list of invertebrate fossils at this locality).

Figure 6. The Cockscomb along Cottonwood Wash (near field trip stop 8) looking south with views, from left to right, of the upper part of the Dakota Formation, Tropic Shale, and lower part of the Straight Cliffs Formation.

Bentonite beds are abundant throughout the Tropic. Four widely distributed beds of bentonite, lettered A to D, are present in the Bridge Creek Member of the chronostratigraphically equivalent Greenhorn Limestone at Pueblo, Colorado (Elder and Kirkland, 1985). Elder (1985) traced the four beds across the Western Interior basin from Pueblo to Black Mesa in northeastern Arizona. Obradovich (1993) dated bentonite A, which lies in the upper Cenomanian biozone of *Euomphaloceras septemseriatum*, at 93.49 +/- 0.89 Ma. Obradovich dated bentonite B, which lies higher in the upper Cenomanian biozone of *Neocardioceras juddii*, at 93.59 +/- 0.58 Ma. He dated bentonite C, which may lie in the lower Turonian biozone of *Pseudaspidoceras flexuosum*, at 93. 25 +/- 0.55 Ma. Bentonite D, in the lower Turonian biozone of *Vascoceras birchbyi*, was dated at 93.40 +/- 0.63 Ma. Elder (1991) described these bentonite beds from Black Mesa in Arizona to Wahweap Creek in the northern part of the Monument.

Refer to Obradovich (1993) for a detailed list of all dated bentonites within the middle Cretaceous of the Western Interior basin. Refer also to Zelt (1985) and Leithold (1994) for an alternative zonation for these bentonites and for bentonites higher in the stratigraphic section.

Straight Cliffs Formation

Gregory and Moore (1931) named the Straight Cliffs Formation for exposures along the eastern edge of the Kaiparowits Plateau near Fifty-Mile Mountain in the Monument. The formation represents the final regressive phase of the Tropic sea. Lithologic descriptions of drill core by Hettinger (1995) show the clastic-rich formation is lithologically diverse. It contains four named members designated by Peterson (1969). They are: the Tibbet Canyon, Smoky Hollow, John Henry, and Drip Tank Members (figures 2 and 3). Only the Tibbet Canyon and John Henry Members are known to contain marine invertebrate fauna (field trip stop 7).

Tibbet Canyon Member: The Tibbet Canyon, the lowest member of the Straight Cliffs Formation, is composed of gray-brown, fine- to medium-grained sandstone and interbedded mudstone and shale. Peterson (1969) identified the base of the Tibbet Canyon in the southeastern Kaiparowits Plateau, where sandstone becomes the dominant lithology above the Tropic Shale. The Tibbet Canyon Member is comprised of marine shoreface sandstone and contains the middle Turonian guide fossil *Prionocyclus hyatti*. At several localities, the Tibbet Canyon contains beds with abundant *Inoceramus howelli*, an inoceramid that occurs within the zone of *P. hyatti* (figure 7; field trip stop 7; Cobban and others, 2000; Dyman and others, 2000). The member ranges in thickness from about 70 to 200 feet in the Monument.

Smoky Hollow Member: The Smoky Hollow Member of the Straight Cliffs Formation is more lithologically and depositionally heterogeneous than the underlying Tibbet Canyon Member and is composed of interbedded sandstone, mudstone, carbonaceous mudstone, and coal. The base of the member consists of a zone of coal and carbonaceous mudstone that varies in thickness from 0 to 47 feet (Peterson, 1969) (field trip stop 7). The top of the member is composed of a yellow-brown iron-rich unit of quartz- and chert-rich sandstone and chert-pebble conglomerate. This unit is referred to as the Calico bed (Peterson, 1969) (figures 3 and 4) or the Calico sandstone or sequence (Hettinger, 1995). The Calico bed varies in thickness from 0 to about 50 feet and is in sharp contact with the overlying John Henry Shanley and others (1992) also placed the unconformity at the base of the Calico, and interpreted the sharp contact at the base of the overlying John Henry to represent a transgressive surface of erosion.

A late Turonian age is likely for most of the member (Peterson, 1969). Hettinger (1995, p. A6) noted the occurrence of an inoceramid bivalve identified as *Cremnoceramus deformis* (Meek) 12 feet below the top of the Smoky Hollow Member at a locality southwest of Escalante, just outside the Monument. The inoceramid is probably *Volviceramus involutus* (Sowerby) which is middle Coniacian in age. Cobban and others (2000) found middle

Figure 7. Sandstone slab taken near top of Tibbet Canyon Member of Straight Cliffs Formation from Alvey Wash about 3 miles south of Escalante, Utah, containing Inoceramus howelli. Inoceramus howelli is middle Turonian in age. Pen for scale.

Coniacian inoceramids at two localities in the Monument, but both are from the overlying John Henry Member.

John Henry Member: The John Henry Member varies in thickness from about 600 feet to more than 1,000 feet in the Monument and is composed of interbedded sandstone, siltstone, mudstone, carbonaceous mudstone, and coal (figure 8; field trip stop 7). Peterson (1969) placed the upper contact of the John Henry Member at the base of the lowest cliff-forming sandstone of the overlying Drip Tank Member. He also interpreted the John Henry-Drip Tank contact to be conformable, but Shanley and McCabe (1991) interpreted the contact to be unconformable.

In the southwestern third of the Monument, the John Henry Member seems to be entirely nonmarine, but in the central part of the Monument, thick marine sandstones intertongue with coal-bearing units, and farther east, two marine mudstone units intertongue with the sandstones. Peterson (1969) referred to the mudstone units as a "lower marine mudstone tongue" and an "upper marine mudstone tongue" (figure 3). The lower tongue commonly has pebbles at the base and rests on an unconformable surface above the Calico bed of the Smoky Hollow Member.

Ammonites and inoceramids date the lower tongue as late Coniacian. The upper tongue is not well dated, but has yielded a single fragment of an ammonite assigned to *Clioscaphites vermiformis* (Meek and Hayden) of middle Santonian age. Four major sandstone units separate the two mudstone tongues designated by Peterson (1969): A (lowest) to D (highest) (figure 3). Peterson collected an ammonite, *Baculites codyensis* Reeside, at the boundary of the B and C sandstones (Cobban and others, 2000; Dyman and others, 2000). It is a late Coniacian to middle Santonian species. Peterson collected the bivalve *Endocostea baltica* (Boehm) from the upper part of the upper mudstone tongue (Cobban and others, 2000; Dyman and others, 2000) as well as from the overlying G sandstone (Cobban and others, 2000; Dyman and others, 2000). This inoceramid has a range of late Santonian to early Campanian. Peterson also collected the late Santonian-early Campanian inoceramid *Sphenoceramus patootensiformis* (Seitz) from near the top of the G sandstone (Cobban and others, 2000; Dyman and others, 2000).

Another significant find by Peterson is a good collection of the inoceramids *Endocostea flexuosa* (Haenlein) and *E. flexibaltica* (Seitz) 350 feet below the top of the Straight Cliffs Formation just outside the Monument about 10 miles northwest of Escalante. According to Seitz (1967) *E. flexuosa* is found in rocks assigned to the lower Campanian in Germany, and *E. flexibaltica* has a range of late Santonian-early Campanian in Germany. Troeger (1987) shows *E. flexibaltica* as having a very narrow range straddling the late Santonian-early Campanian boundary. Until paleontologists discover diagnostic ammonites in the uppermost part of the Straight Cliffs, that part of the formation is herein regarded as of latest Santonian age, as also suggested by Eaton (1991, p. 52).

The Monument contains vast coal resources from the John Henry Member of the Straight Cliffs Formation. The original in-place coal resource for the entire Kaiparowits Plateau (figure 1) is more than 60 billion short tons, from coal zones primarily within the John Henry (Hettinger and others, 2000). The Utah Geological Survey (UGS) (in Petzet, 1997) estimated that the Kaiparowits coal field in the Monument contains nearly 12 billion tons of technically recoverable coal. The UGS assessment was in part derived from the U.S. Geological Survey assessment of Kirschbaum and others (2000).

Drip Tank Member: The Drip Tank is the uppermost member of the Straight Cliffs Formation and ranges from about 140 feet in thickness in the southern part of the Monument to more than 500 feet in the northern part. It is a cliff-forming, fine- to medium-grained, gray-brown, nonmarine sandstone with well-developed cross-stratification (figure 9).

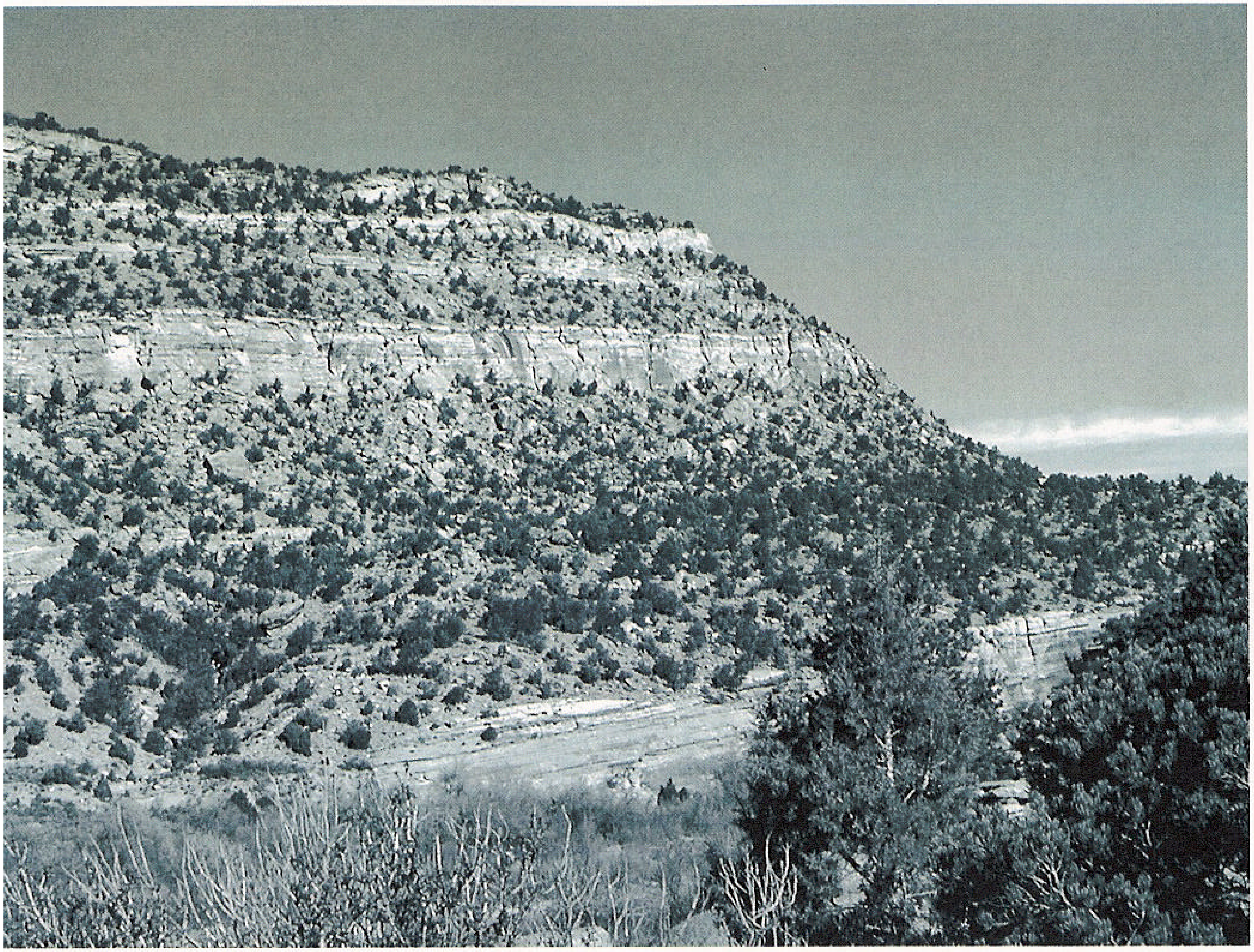

Figure 8. Smoky Hollow Member and lower part of John Henry Member of Straight Cliffs Formation in Alvey Wash, about 3 miles south of Escalante, Utah.

Figure 9. Upper part of John Henry Member and Drip Tank Member of Straight Cliffs Formation, looking north about 5 miles east of Henrieville, Utah.

ROAD LOG

MILEAGE

Int.	Cum.	Description
0.0	0.0	Field trip starting point, westernmost parking lot of Southern Utah University, also known as the Motor Pool, west side of Eccles Coliseum, Cedar City, Utah. Drive north on 1150 W, 200 S to stop sign. Turn east on Center Street and drive toward mountains.
1.0	1.0	Stop light is intersection of Main and Center streets. Continue east toward mountains on State Route (SR) 14.
0.2	1.2	Lower red and gray cliffs at 12:00 are composed of Moenkopi Formation (Triassic) (figure 10). These rocks have been exposed along the Hurricane fault zone.
0.6	1.8	Complex structural relationships in Triassic Moenkopi and Chinle Formations (figure 10) within zone of Sevier orogenic overprint.
0.7	2.5	Gray beds at 9:00 are clinkers from the former Utah Power and Light coal-fired electric generating plant located in space now occupied by Utah Wildlife Sanctuary.
0.3	2.8	Jurassic Navajo Sandstone-Carmel Formation contact (figure 10) on both sides of road. The strata are dipping steeply to the east, and the Navajo Sandstone is probably tectonically thinned. The overlying Carmel Formation is thickened above the contact and may be repeated.
1.2	4.0	Thrust anticlines visible within limestone unit of Carmel Formation.
1.8	5.8	Right Hand-Kolob Canyon turnoff. Continue east on SR 14.
0.7	6.5	Lower part of Cretaceous Dakota Formation at road level overlying Jurassic Carmel Formation. Good exposures of flat-lying beds along road for next mile.
1.4	7.9	Unnamed fault at 3:00.
0.8	8.7	**STOP 1—**CEDAR CANYON. Westernmost facies of Cretaceous Dakota, Tropic, and Straight Cliffs Formations on field trip, exposed on both sides of road along Coal Creek in Cedar Canyon. Excellent views of fault along Coal Creek, landslides along highway, and paleovalley-filling basalts on north side of road. Park on north side of SR 14 away from traffic. This stop is a general overview of western facies of the marine Cretaceous than is exposed in Grand Staircase-Escalante National Monument. The approximate position of the Dakota-Tropic contact is on the south side of the highway, but landslides have covered most exposures. Marine rocks comprise the upper part of the Dakota, the Tropic, and lower part of the Straight Cliifs at Cedar Canyon. W.A. Cobban identified the oldest marine rocks in the lower part of the Tropic Shale as part of the lower Turonian

AGE	Formations, members, and thicknesses in feet	
TERTIARY		Mt Dutton volcanics
	Claron Formation -1400	
	Pine Hollow Fm Grand Castle Fm Canaan Peak Fm 0-1300	
CRETACEOUS	Kaiparowits Formation 2000-3000	
	Wahweap Formation 1000-1500	
	Straight Cliffs Fm 900-1800	Drip Tank Mb
		John Henry Mb
		Smoky Hollow Mb
		Tibbet Canyon Mb
	Tropic Shale 500-750	
	Dakota & Cedar Mtn Fms 3-370	
JURASSIC	Morrison Fm / Henrieville Ss 0-950	
	Entrada Ss 0-1000	Escalante Mb
		Cannonville Mb
		Gunsight Butte Mb
	Carmel-Page Fms 180-1040	
	Navajo Sandstone 1300-1500	main body
		Tenney Canyon Tongue
		Lamb Point Tongue
	Kayenta Formation 150-350	
	Moenave Fm & Wingate Ss 100-350	
TRIASSIC	Chinle Fm 425-930	Petrified Forest Mb
		Shinarump Mb
	Moenkopi Fm 440-1150	
PERMIAN	Permian Fms 655+	

Figure 10. Generalized stratigraphic chart illustrating rock units along the field trip route. Modified from Doelling and others (2000).

Mytiloides kossmati biozone. The Tropic Shale is exposed for about 0.25 mi east along the highway and represents a Turonian-age western marine facies of the Tropic, although various other names have been used for these rocks. See Eaton and others (2001) for a detailed discussion of the various stratigraphic names used for Cretaceous rocks in Cedar Canyon and for a list of other fauna found in the area.

The overlying Straight Cliffs Formation forms the uppermost cliffs of the canyon and is at least 1,000 feet thick at this stop. It forms continuous ledges of fine- to medium-grained lithic-rich sandstone that can be attributed to a coastal origin. Marine fauna range up through the lower middle Turonain zone of *Collignoniceras woollgari*.

0.4 9.1 Exposures of marine Tropic Shale on right. Ashdown Canyon on left.

0.2 9.3 Massive coastal marine sandstones of the lower part of the Straight Cliffs Formation on both sides of road in middle lower Turonian zone of *Vascoceras birchbyi*.

0.3 9.6 Series of brackish-water coquina beds containing *Crassostrea soleniscus* in Straight Cliffs Formation. Alternating marine strata contain *Mytiloides mytiloides* and *M. labiatus*.

1.8 11.4 *C. soleniscus* and *Craginia coalvillensis* (gastropod) coquina beds in Straight Cliffs Formation on both sides of road.

0.4 11.8 Southern Utah University Mountain Center and field station.

0.3 12.1 Discontinuous exposures of nonmarine upper part of Straight Cliffs Formation.

0.3 12.4 Woods Ranch County Recreation Facility.

0.2 12.6 Dixie National Forest boundary.

0.4 13.0 Approximate contact of Straight Cliffs and overlying Wahweap Formations.

0.5 13.5 Sharp curves in road. **EXERCISE CAUTION**.

0.4 13.9 Beautiful exposures of concretionary sandstone in Cretaceous Wahweap and Kaiparowits Formations.

0.1 14.0 Exposures of nonmarine Paleocene-Eocene Claron Formation.

1.7 15.7 Websters Flat turnoff on right. Continue east on SR 14.

0.2 15.9 Excellent exposures of lacustrine facies of Claron Formation on left.

1.6 17.5 **STOP 2**—MARKAGUNT PLATEAU. Regional overview of structural and topographic features. Zion National Park, Kolob Terrace, and Pine Valley Mountains are visible to the south. Large southeast drainage is O'Neil Gulch. This overview parking area is on the western rim of the Markagunt Plateau. The Markagunt, which is bounded on the east by the Sevier fault and on the west by the Hurricane fault, represents the farthest western influence of structures associated with the Colorado Plateau region. The Markagunt Plateau dips northeastward, exposing older strata to the southwest. The Pine Valley Mountains, composed primarily of monzonite porphyry, represent the exposed core of an eroded lacolith, which is part of the great Tertiary (20-25 m.y.) intrusive event in southwestern Utah. The Pine Valley Mountains are on the downthrown side of the Hurricane fault and rest on the Paleocene-Eocene Claron Formation. Exposures of the Paleocene-Eocene Claron Formation (figure 10) on the north side of the road.

0.5	18.0	Bristlecone pine viewing area on right. Continue east on SR 14.
0.9	18.9	Midway intersection. Turnoff for Cedar Breaks National Monument. Cedar Breaks National Monument contains spectacular erosional features in the Claron Formation. Continue east on SR 14.
2.2	21.1	Tree-covered cinder cone at 11:00.
0.5	21.6	Quaternary flow basalts at 10:00.
0.2	21.8	“Lava flows” interpretive sign.
1.7	23.5	Kane County line. Volcanic flows on both sides of road.
1.5	25.0	Navajo Lake overlook.
1.3	26.3	Navajo Lake turnoff on right. Continue east on SR 14.
2.4	28.7	Duck Creek Campground on left. Continue east on SR 14.
1.8	30.5	Duck Creek Village.
1.5	32.0	Mammoth Creek turnoff. Continue east on SR 14.
1.5	33.5	Junction of Uinta Flat (left) and Strawberry Point (right) roads.
1.3	34.8	Exposures of Claron Formation on left.
0.8	35.6	Swains Creek road.
3.5	39.1	Exiting Dixie National Forest.
0.5	39.6	Cretaceous Kaiparowits and Wahweap rocks on both sides of road. Sharp curves. **EXERCISE CAUTION.**
1.7	41.3	Junction SR 14 and U.S. Highway 89 (US 89). Long Valley Junction. Turn north on US 89.
0.9	42.2	Paleocene-Eocene Claron Formation on both sides of road.
3.2	45.4	Garfield County line.

3.0	48.4	Cross Asay Creek.
3.3	51.7	Cross Mammoth Creek.
0.5	52.2	Junction with Fish Hatchery Road. Continue north on US 89.
1.1	53.3	Town of Hatch, Utah.
1.7	55.0	Sevier River. Pleistocene and Holocene valley-fill gravels on both sides of road.
0.7	55.7	Valley-fill volcanic rocks cap ledges on left.
6.1	61.8	Junction SR 12. Turn east (right) toward Bryce Canyon National Park. Cross Sevier River.
2.5	64.3	Entrance to Red Canyon. Trace of Sevier fault visible at 9:00. Late Tertiary basalt, which has been dated as 12 Ma (Hintze, 1993), is on downthrown west side of fault. Claron Formation on both sides of road. Short photo stop.
0.9	65.2	Red Canyon Visitors Center. Continue east on SR 12.
3.9	69.1	Crest of Paunsaugunt Plateau. The name "Paunsaugunt" is a Paiute word meaning home of the beaver. Mt. Dutton volcanic rocks at 9:00. These volcanic rocks date from 23-26 Ma (Hintze, 1993). Highway on Claron Formation.
1.8	70.9	Leaving Dixie National Forest. Summit marker 7,619 feet.
2.5	73.4	Cross East Fork of Sevier River. Powell Point (elevation 10,188 feet) at 12:00 on Table Cliff Plateau.
2.1	75.5	Junction SR 63. Entrance to Bryce Canyon National Park on right. Continue east on SR 12.
0.8	76.3	Begin descent on east side of Paunsaugunt Plateau. Bryce Canyon National Park to the left.
0.5	76.8	Wahweap Sandstone block and Claron Formation on right side of road. This structural block is part of the Rubys Inn thrust fault, a Laramide structure.
2.3	79.1	Mossy Cave trailhead.
0.4	79.5	Sharp contact of Claron Formation on left and underlying Cretaceous John Henry Member of the Straight Cliffs Formation on right. Trace of Paunsaugunt fault.
0.5	80.0	Tropic, Utah, city limit. Exposures of Tibbet Canyon and Smoky Hollow Members of Straight Cliffs Formation on left.

0.5	80.5	Highway descends into Cretaceous Tropic Shale of Bryce Valley.
2.3	82.8	Dougs Place, Tropic, Utah. Short break.
1.3	84.1	Continue south on Utah Highway 12 through lower Tropic Shale and Dakota Formation. Bentonites of lower part of Tropic Shale exposed on low bench at 9:00.
0.4	84.5	Upper part of Dakota Formation including beds of sandstone and coal in roadcut on right.
0.7	85.2	**STOP 3--** STAN MECHAM PROPERTY. Turn right on private drive and park near fresh shale cut on Stan Mecham property. Fresh exposure of middle and upper part of Dakota Formation. Rubys Inn recently excavated this outcrop for a source of bentonite to line a sewage pond. The upper 135 feet of the Dakota crops out here as a series of alternating beds of sandstone, siltstone, shale, and bentonite. Approximately 5 miles to the east in Henrieville Valley, the entire Dakota is about 210 feet thick. Lower Dakota beds are nonmarine, but sandstones in the upper Dakota contain a marine assemblage including *Exogyra olisponensis, Flemingostrea prudentia*, *Inoceramus mesabiensis*, and *Metoicoceras mosbyense*. See Cobban and others (2000) and Dyman and others (2000) for a complete list of invertebrate fossils at this and nearby localities. The uppermost part of the Dakota here contains coal beds, which are in turn overlain by gray shales of the Tropic Shale. About 1 mile to the south along Yellow Creek, these upper Dakota coal beds contain tree trunks in their original upright position. J.D. Obradovich dated a bentonite in the middle part of the Dakota Formation in the Tropic area by $^{40}Ar/^{39}Ar$ laser fusion dating of sanidine crystals. The date is 96.06 +/- 0.30 Ma which identifies the sample as early middle Cenomanian according to Obradovich (1993). Refer to the text section in this report on the Dakota Formation for more details.
0.3	85.5	Return to SR 12 and continue south.
0.8	86.3	Cannonville Member of Jurassic Entrada Formation on right. Dakota Formation-Henrieville Sandstone contact on left across Paria River. The Henrieville Sandstone is a Morrison Formation equivalent unit (figure 10).
1.0	87.3	Cannonville, Utah, city limit.
0.4	87.7	Turn right on Main Street (Grand Staircase-Escalante National Monument Road No. 400). Continue south toward Kodachrome Basin State Park.
0.4	88.1	Views of contact between lower Gunsight Butte and upper Cannonville Members of Entrada Formation. Note large sweeping cross beds in Gunsight Butte Member.
1.2	89.3	Promise Rock on right in Gunsight Butte Member. According to local folklore, Promise Rock was a sacred Paiute marriage-ritual site.

0.5 89.8 Contact of upper Gunsight Butte Member of Entrada Formation and lower Wiggler Wash Member of Carmel Formation.

0.5 90.3 Intersection with Sheep Flat Road and Yellow Creek. Continue south.

0.3 90.6 Intersection with Skutumpah Road. Continue south.

0.4 91.0 Cross bridge over Paria River.

2.0 93.0 **STOP 4--** SHEPHARD POINT. Park on left or right side of road. Views of sedimentary pipes in the Winsor Member of the Carmel Formation. Evidence suggests that the clastic sedimentary pipes exposed here and at Kodachrome Basin State Park are liquefaction features related to paleoearthquake events. Note numerous normal faults cutting the pipes.

2.0 95.0 Entrance to Kodachrome Basin State Park on left.

1.0 96.0 Cliffs to north capped by Dakota Formation. Dakota-Henrieville contact well exposed below.

0.6 96.6 Cross Dry Valley-Rock Springs Creek.

3.8 100.4 Begin ascent of steep hill. Excellent view of north-plunging end of Kaibab anticline at 10:00.

0.3 100.7 **STOP 5--** SLICK ROCK BENCH. Stop on crest of hill for regional stratigraphic overview. The view north toward Wiggler Wash shows steep dip of Entrada through Straight Cliffs Formations (figure 10) in Kaibab anticline. Canaan Peak and Table Cliff Plateau on far horizon.

The Upper Valley oil field is about 12 miles northeast of here, along the flank of the southeast-trending Upper Valley anticline. Hydrodynamic drive has forced hydrocarbons off the crest of the Upper Valley structure. Production occurs in dolomite reservoirs of the Permian Kaibab Formation and the Triassic Moenkopi Formation at depths ranging from about 6,300 to 7,600 feet. These reservoirs have produced more than 25 million barrels of oil since the field was discovered in 1964 (Petzet, 1997). The field is currently in a water-flood program in which reservoir water is re-injected to increase oil recovery. Because no long-distance pipelines exist in the area, produced oil is stored in local holding tanks and trucked to oil refineries in Salt Lake City. Potential new and deeper reservoirs in and near the Monument include the Mississippian Redwall Limestone, Cambrian Tapeats Sandstone, and Late Proterozoic Chuar Group.

Conoco recently sought to drill several deep exploration wells in the southern part of the Monument about 45 miles south of Escalante, to test the Cambrian Tapeats Sandstone and the Late Proterozoic Chuar Group. Conoco completed the first of these wells, but detailed information about prospective targets is not available. Conoco holds leases on more than 140,000 acres within the Monument (Petzet, 1997).

Other potential energy resources in the Monument include coal and coalbed gas from coal beds in the John Henry Member of the Straight Cliffs Formation. We will discuss these resources at STOP 7.

0.3 101.0 Distant views of Lower Jurassic Navajo Sandstone on right at 3:00. This section is part of the White Cliffs of the Grand Staircase.

0.7 101.7 Round Valley Draw. Cliffs on left in Upper Jurassic Henrieville Sandstone and capped by Cedar Mountain(?) and Dakota Formations.

0.4 102.1 Cliffs on left in Henrieville Sandstone.

0.5 102.6 Butler Valley.

1.9 104.5 Turn left on Monument Road No. 440 toward Grosvenor Arch. Road is in Carmel Formation.

1.0 105.5 Grosvenor Arch parking area. The base of this arch is in the Upper Jurassic Henrieville Sandstone. The upper part is in the Cretaceous Cedar Mountain(?) and Dakota Formations**. BATHROOM AND LUNCH STOP.**

0.3 105.8 Turn left on stock pond road.

0.1 105.9 **STOP 6--** DAKOTA FORMATION AT STOCK RESERVOIR. Park in open area to left of dam. The entire Dakota Formation crops out here along the east-dipping margin of the East Kaibab monocline. The Dakota is approximately 200 feet thick and is composed of three informal depositional units. The lower conglomeratic unit contains coarse sandstone and conglomerate clasts of quartzite, dark-gray chert, and limestone. The lower unit forms incised fluvial channels 1 to 3 feet thick with sharp scoured lower surfaces. This lower unit is equivalent in age to the Cedar Mountain Formation in central Utah, according to Doelling and others (2000), based on an Early Cretaceous age of palynomorphs from interbedded siltstones. The lower unit unconformably overlies the Jurassic Henrieville Sandstone. The middle unit is composed of carbonaceous mudstone, siltstone, sandstone, bentonite, and coal, and forms a coarsening upward depositional cycle with marine to coastal sandstones at the top. Thin sandstone beds in the middle of the unit contain iron-rich concretions up to 4 inches in diameter. A fine- to medium-grained lithic-rich sandstone bed forms the top of the unit and contains a marine invertebrate assemblage including *Metoicoceras mosbyense,* of late Cenomanian age. The upper unit forms another coarsening upward cycle of coal, carbonaceous mudstone, sandstone, and conglomeratic sandstone. Marine and brackish water invertebrates include *Inoceramus mesabiensis, Exogyra olisponensis, Ostrea* sp., and the ammonite *Metoicoceras mosbyense* (see Dyman and others (2000) for a complete list of invertebrate fossils at this locality).

The Dakota Formation-Tropic Shale contact is not well exposed here but represents a transgressive surface of erosion in which gray marine shales of the Tropic overlie coastal beds of the Dakota. All but the upper part of the Tropic Shale is covered between this stop and STOP 7.

Return to Monument Road No. 440 and turn left.

0.4 106.3 **STOP 7:** “THE GUT” AND STRAIGHT CLIFFS FORMATION. Park at crest of hill on left and right. Roadcuts continue for more than a half mile southeast. This stop provides an excellent opportunity to view the four named members of the Straight Cliffs Formation originally described by Peterson (1969) at an equivalent sequence southeast of The Gut on the Kaiparowits Plateau. The Tibbet Canyon is the lowest member and crops out at the parking area and immediately east of the road. It is gradational with the underlying Tropic Shale and forms a regressive marine depositional system. The Tibbet Canyon contains *Inoceramus howelli* and *Prionocyclus hyatti* of middle Turonian age.

The Tibbet Canyon Member is conformably overlain by the nonmarine Smoky Hollow Member. Note the abundant coal and carbonaceous mudstone in the Smoky Hollow. The Smoky Hollow is in turn overlain by a distinctive white-weathering unconformity-bounded nonmarine sandstone called the Calico bed (Hettinger, 1995). The Calico bed is time-equivalent to a widespread Coniacian unconformity observed throughout the Western Interior basin. Sandstones in the Calico bed contain nodules that weather out on outcrop to form distinctive surfaces.

The Calico bed is unconformably overlain by the John Henry Member. Farther east in the Monument, in the Straight Cliffs region southeast of Escalante, Utah, the John Henry contains marine fossils as young as Santonian, within the zone of *Clioscaphites vermiformis* (Cobban and others, 2000). Equivalent rocks at this locality (field trip stop 7) in the upper part of the John Henry contain a nonmarine fossil assemblage including *Unio* sp., *Proparraysia*? sp., turtle shells, and reptilian bones. An intermediate locality along SR 12 east of Henrieville (Dyman and others, 2000) contains a brackish water assemblage of oysters and clams.

The John Henry Member of the Straight Cliffs Formation has the potential for significant resources of coalbed gas and coal. The Kaiparowits coal field in the Monument is estimated to contain 2.6-10.5 trillion cubic feet of coalbed gas in place at depths less than 6,000 feet and nearly 12 billion tons of technically recoverable coal (Utah Geological Survey, in Petzet, 1997). The original in-place coal resource for the entire Kaiparowits Plateau (figure 1) is more than 60 billion short tons, from coal zones primarily within the John Henry (Hettinger and others, 2000).

The uppermost Drip Tank Member is an entirely nonmarine sandstone sequence resting sharply on the John Henry (figure 9). The Drip Tank is readily identifiable by its lighter color and distinctive reticulate fracture pattern on outcrop. The Drip Tank is, in turn, overlain by the nonmarine Wahweap and Kaiparowits Formations. These uppermost Cretaceous units can be seen on Monument Road No. 440 east of The Gut in the drainages of Wahweap Creek.

0.4 106.7 Turn around and continue past the stock dam and Grosvenor Arch. Return to Monument Road 400.

1.3 108.0 Turn south (left) on Monument Road 400.

1.9 109.9 Entering The Cockscomb along the west-dipping East Kaibab monocline in the valley of Cottonwood Creek.

0.6 110.5 Henrieville Sandstone on left.

1.3 111.8 Steeply dipping Carmel and Entrada Formations. Santa Claus Rock on left.

4.3 116.1 Pump Canyon Spring on right.

2.9 119.0 Views of Dakota, Tropic, and Straight Cliffs Formations. Brief photo stop.

3.8 122.8 Series of deep washes along road. Views of compressed stratigraphy along East Kaibab monocline.

2.0 124.8 **STOP 8:** THE COCKSCOMB. Park along either side of road. **EXERCISE CAUTION**. Spectacular views of upper part of Dakota Formation, Tropic Shale and overlying Straight Cliffs Formation. The Tropic Shale is about 700 feet thick at this locality but may be structurally compressed due to folding. The lower part of the formation is calcareous and contains several distinctive fossiliferous concretionary zones and bentonite beds. Bentonite beds A-D in the lower part of the Tropic Shale are well exposed along this road cut. Bentonite A lies in the upper Cenomanian biozone of *Euomphaloceras septemseriatum* and has been dated at 93.49 +/- 0.89 Ma (Obradovich, 1993). Bentonite B, which lies higher in the upper Cenomanian biozone of *Neocardioceras juddii*, was dated at 93.59 +/- 0.58 Ma (Obradovich, 1993). Bentonite C, which may lie in the lower Turonian biozone of *Pseudaspidoceras flexuosum*, was dated at 93.25 +/- 0.55 Ma, and bentonite D, in the lower Turonian biozone of *Vascoceras birchbyi*, was dated at 93.40 +/- 0.63 Ma (Obradovich, 1993).

The upper part of the lower Tropic calcareous unit contains *Collignoniceras woollgari* of early middle Turonian age. At the Cenomanian-Turonian boundary reference section near Pueblo, Colorado, *Collignoniceras woollgari* has been collected from the Fairport Member of the Carlile Shale (Cobban and Scott, 1972).

Note the sharp color change in the upper part of the Tropic Shale from underlying medium gray to overlying dark gray color. This distinct color change, from calcareous to noncalcareous shale, represents the approximate first appearance of the ammonite *Prionocyclus hyatti* of middle Turonian age which is also found in the overlying Tibbet Canyon Member of the Straight Cliffs Formation. We recognize a similar sharp color change as far east as west-central Kansas, where it marks the contact of the underlying Fairport and Blue Hill Members of the Carlile Shale which are stratigraphically equivalent to the Tropic Shale.

The Dakota-Tropic contact and the Tropic-Straight Cliffs contact are well exposed at this stop. Note the sharp transgressive surface separating the Dakota and Tropic, and the gradational upper Tropic-lower Straight Cliffs contact.

0.8 125.6 Cottonwood Wash begins to widen from here southward.

5.5 130.8 **STOP 9--** LOWER COTTONWOOD WASH. DAKOTA FORMATION-TROPIC SHALE CONTACT. Park along either side of the road. This stop offers an excellent opportunity to view the Dakota-Tropic contact and the various fossil horizons and bentonite horizons associated with this interval.

The oldest marine fossils associated with the Tropic transgression are in these uppermost beds of the Dakota. Ammonites, although scarce, are represented by the presence of *Metoicoceras mosbyense* and *M. defordi.* This suggests an assignment to one of the zones of *Vascoceras diartianum*, *Dunveganoceras conditum*, or *D. albertense* and indicates an early late

Cenomanian age for the Dakota. The top of the Dakota at this locality contains several bivalve coquina zones characterized by the oyster *Exogyra (Costagyra) olisiponensis* Sharpe and *Flemingostrea prudentia* (White). Also, we found *Metoicoceras mosbyense* with *E. olisiponensis*, at this locality, which suggests that the *E. olisiponensis* assemblage lies at the top of the range of *M. mosbyense.* Inasmuch as the highest *M. mosbyense* occurs in the zone of *Vascoceras diartianum*, the highest beds of the Dakota here are assigned to this zone.

At the Cenomanian-Turonian boundary reference section near Pueblo, Colorado, the oldest marine fauna above the Dakota are in the lower middle Cenomanian *Conlinoceras terrantense* biozone in the Thatcher Limestone Member of the Graneros Shale. The lower upper Cenomanian *Metoicoceras mosbyense* biozone is in the lower part of the Hartland Shale Member of the Greenhorn Limestone (Cobban and Scott, 1972). Correlating these biozones provides valuable insight into the significant facies changes that occur within the mid-Cretaceous from the western to central parts of the Cretaceous Western Interior basin.

The lowermost concretionary zone of the overlying Tropic, which forms a distinct horizon about 15 to 20 feet above the base of the formation at this locality, contains the ammonite *Sciponoceras gracile* and associated fauna of the middle upper Cenomanian *Euomphaloceras septemseriatum* biozone.

This concludes our discussion of Cretaceous marine and brackish water strata of Grand Staircase-Escalante National Monument. The rocks and fossils along the fieldtrip route are a small but interesting part of the natural history of this unique and very scenic area.

1.1 131.9 Road continues south along Dakota-Tropic contact.

5.2 137.1 **END OF ROAD LOG.** Turn right on US 89 and continue west to Kanab and then north to Long Valley Junction (80 miles), and then west to Cedar City on Utah Highway 14 (41 miles).

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