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U.S. Department of the Interior
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By E.A. Merewether, W.A. Cobban, and R.W. Tillman

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Abstract

In the Bighorn Basin of north-central Wyoming and south-central Montana, the Frontier Formation of early Late Cretaceous age consists of siliciclastic, bentonitic, and carbonaceous beds that were deposited in marine, brackish-water, and continental environments. Most lithologic units are laterally discontinuous. The Frontier Formation conformably overlies the Mowry Shale and is conformably overlain by the Cody Shale. Molluscan fossils collected from outcrops of these formations and listed in this report are mainly of marine origin and of Cenomanian, Turonian, and Coniacian ages.

The lower and thicker part of the Frontier in the Bighorn Basin is of Cenomanian age and laterally equivalent to the Belle Fourche Member of the Frontier in central Wyoming. Near the west edge of the basin, these basal strata are disconformably overlain by middle Turonian beds that are the age equivalent of the Emigrant Gap Member of the Frontier in central Wyoming. The middle Turonian beds are disconformably overlain by lower Coniacian strata. Cenomanian strata along the south and east margins of the basin are disconformably overlain by upper Turonian beds in the upper part of the Frontier, as well as in the lower part of the Cody; these are, in turn, conformably overlain by lower Coniacian strata.

Thicknesses and ages of Cenomanian strata in the Bighorn Basin and adjoining regions are evidence of regional differential erosion and the presence of an uplift during the early Turonian centered in northwestern Wyoming, west of the basin, probably associated with a eustatic event. The truncated Cenomanian strata were buried by lower middle Turonian beds during a marine transgression and possibly during regional subsidence and a eustatic rise. An uplift in the late middle Turonian, centered in north-central Wyoming and possibly associated with a eustatic fall, caused the erosion of lower middle Turonian beds in southern and eastern areas of the basin as well as in an adjoining region of north-central Wyoming. Similarly, in east-central Wyoming and an adjacent area to the south, Cenomanian strata are disconformably overlain by upper middle and lower upper Turonian strata that probably reflect uplift and erosion in that region during the interim period of middle Turonian time.

During later subsidence and a marine transgression, upper Turonian deposits buried Cenomanian beds in areas along the south and east margins of the Bighorn Basin and buried lower middle Turonian beds in much of northern Wyoming. Upper Turonian and lower Coniacian strata are apparently conformable in eastern and southern areas of the basin as well as near Riverton, Kaycee, and Casper in central Wyoming. Upper Turonian strata are absent on the west flank of the Bighorn Basin and in outcrops west of the basin, where middle Turonian beds are disconformably overlain by lower Coniacian beds . The conformable upper Turonian and lower Coniacian beds apparently transgressed an eroded middle Turonian surface in the region, but only Coniacian strata overlie middle Turonian beds on the west side of the basin and areas farther west. Coniacian strata onlap the truncated lower middle Turonian surface west of the basin, indicating a region that had higher elevation possibly resulting from tectonic uplift.

In east-central Wyoming and an adjoining region to the south, upper middle Turonian and lower upper Turonian strata are disconformably overlain by lower and middle Coniacian beds. That region apparently was uplifted and eroded during the latest Turonian.

Introduction

The Frontier Formation in the Bighorn Basin (fig. 1) of Wyoming and Montana is composed of shale, siltstone, sandstone, conglomerate, and bentonite of early Late Cretaceous age (Cenomanian, Turonian, and Coniacian Stages) that were deposited in marine, brackish-water, and continental environments. Most of the lithologic units are laterally discontinuous. The formation includes flooding surfaces and unconformities. Thicknesses are as much as 640 ft at outcrops on the west flank of the basin and as much as 860 ft at outcrops on the east flank. Isopach and overburden maps for the formation in the basin have been prepared by M.A. Kirschbaum (written commun., 2008). The Frontier Formation conformably overlies the

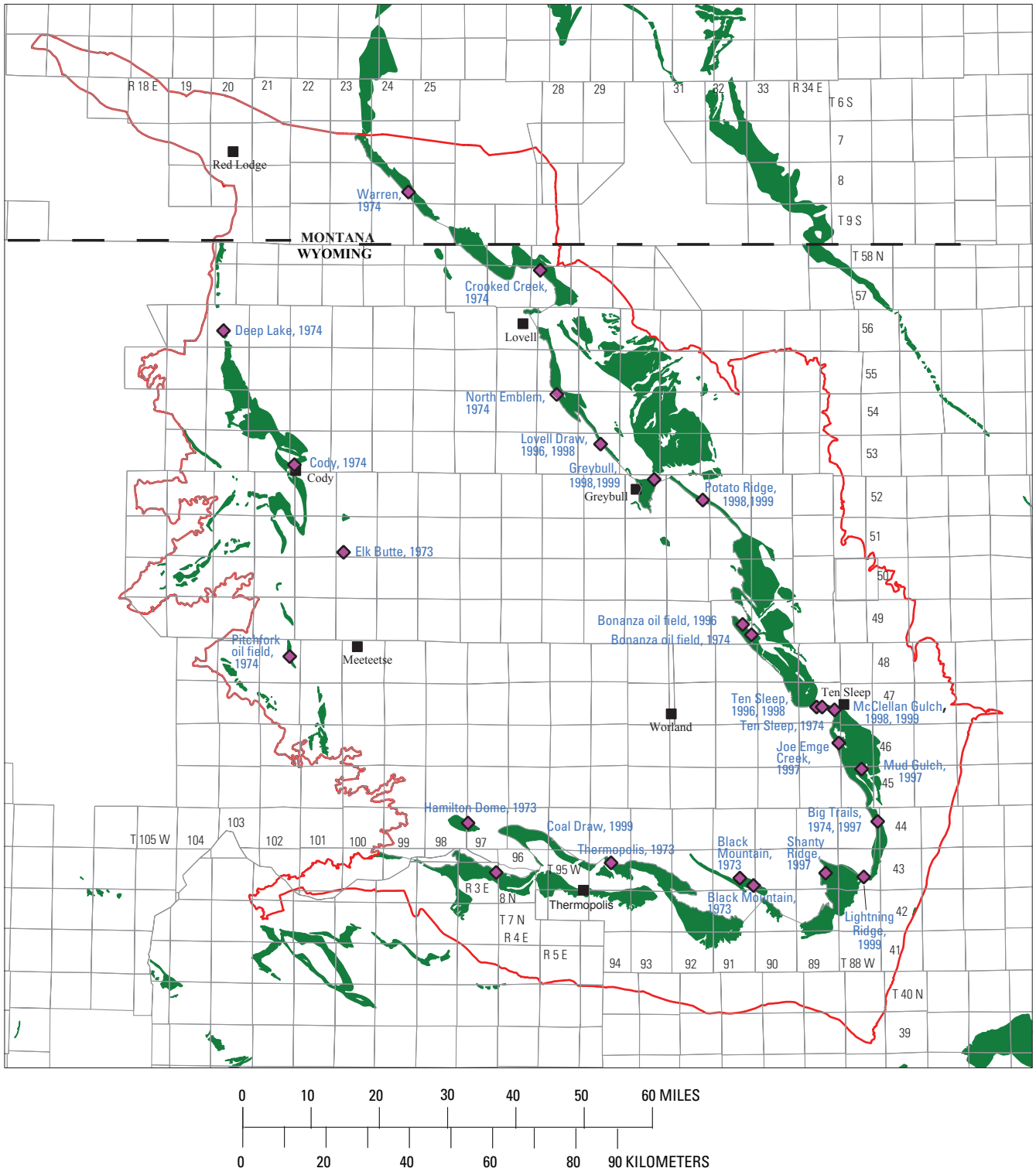

Figure 1. North-central Wyoming and south-central Montana showing locations of towns in the region (black squares), outline of the Bighorn Basin (red), locations of outcrops of the Frontier Formation (green), and outcrop sites examined for this report (red diamonds), with names and dates of original description (blue) as referenced in text.

Mowry Shale and is conformably overlain by the Cody Shale, both of which are marine formations. At the top of the Mowry in most of this region is a bed of bentonite that is informally named the Clay Spur.

Outcrops at 20 localities near the margins of the Bighorn Basin were examined and described by the authors of this report during the years 1973–1974 and 1996–1999. The dates of those periods of field work are not necessarily the same as the dates of related publications. Several of those outcrops are herein correlated with the geophysical logs of nearby boreholes. Horizons designated on the geophysical logs in this report were traced throughout the subsurface of the Bighorn Basin by M.A. Kirschbaum (written commun., 2008).

Several beds in the Mowry, Frontier, and Cody of this region contain molluscan fossils of Cenomanian, Turonian, and Coniacian ages, which were collected by personnel of the U.S. Geological Survey (USGS) and identified by W.A. Cobban (table 1). The species named in this report are from fossil faunas designated by USGS collection numbers, for example: D9259. Important fossils are listed and assigned informal zone numbers in figure 2. A zone includes the listed species and can include several other species. Most of the Frontier in the Bighorn Basin is Cenomanian (fig. 2, Zone 6 through Zones 14, 15, 16, 17, or 18) and is approximately equivalent in age to the Belle Fourche Member (BFM) of the Frontier in central Wyoming (figs. 3, 4).

At outcrops of the Frontier within the town limits of Cody, Wyo., near the west edge of the basin, Cenomanian strata are disconformably overlain by middle Turonian strata (fig. 2, Zones 29 and 30) that are equivalent in age to the upper part of the Emigrant Gap Member of the Frontier (Merewether, 1996) near Casper in east-central Wyoming. Near the south and east margins of the basin, Cenomanian strata are disconformably overlain by upper Turonian strata (fig. 2, Zones 36 and 37) that are the age-equivalent of part of the Wall Creek Member of the Frontier at outcrops a few miles west of Casper.

Middle Turonian beds (equivalent in age to an upper part of the Emigrant Gap Member) on the west side of the Bighorn Basin are disconformably overlain by lower Coniacian beds. Near the south and east edges of the basin, where middle Turonian beds are absent, upper Turonian beds (equivalent in age to parts of the Wall Creek Member) are conformably overlain by lower Coniacian beds.

Outcrops near Deep Lake, Wyoming

Outcrops of the Frontier in the vicinity of Deep Lake (figs. 1, 5), as described by Merewether and others (1975), consist of strata that originated in marine and nonmarine depositional environments. Sandstones range in grain size from very fine to very coarse and commonly enclose thin beds of conglomerate. At this locality, the formation is 630 ft thick and comprises, in ascending order, 338 ft of marine strata, about 200 ft of nonmarine strata, and 92 ft of marine strata. The nonmarine sequence is much thicker here than at other outcrops examined for this report.

Near Deep Lake, molluscan fossils of early Coniacian age — D9259, *Cremnoceramus deformis dobrogensis* (fig. 2, Zone 40), and D9258, *Cremnoceramus crassus inconstans* (fig. 2, Zone 41) (table 1)—were collected from the uppermost sandstone of the Frontier and from the overlying basal Cody Shale, respectively. The age of the lower marine sequence and the overlying nonmarine sequence is probably Cenomanian. Most of the marine sequence in the upper part of the Frontier could be of middle Turonian age. The contact between the nonmarine strata and the overlying marine strata could be a disconformity that represents the latest Cenomanian and the early Turonian. The basal contact of the uppermost sandstone of the Frontier could be a disconformity that represents late Turonian time.

Outcrops near Cody, Wyoming

The outcropping Frontier in northern Cody (fig. 1) was described by Merewether and others (1975) and Siemers (1975). It is recorded on geophysical logs and by cores from boreholes in that area (fig. 6). The Frontier at these outcrops consists of siliciclastic and bentonitic strata and minor conglomerate, carbonaceous beds, and lignite deposited in marine and continental environments. Most sandstones are very fine or fine grained. The marine strata commonly contain burrows and a few contain molluscan fossils (fig. 7). In this area, the formation is about 600 ft thick and includes two disconformities as well as several flooding surfaces.

At the outcrops in Cody (figs. 1, 6), the Frontier comprises three depositional units: (1) a lower 450-ft-thick sequence of mostly marine siliciclastic and bentonitic strata of apparent Cenomanian age; (2) a middle 30-ft-thick sequence of nonmarine sandstone, carbonaceous shale, and lignite probably also of Cenomanian age; and (3) an upper 115-ft-thick sequence of marine siliciclastic and bentonitic strata that lies disconformably on the underlying unit (fig. 6). Fossils (fig. 7) collected from near the middle of this upper sequence include *Inoceramus howelli* (D8997) of early middle Turonian age (fig. 2, Zones 29 and 30). The lacuna (a gap in the stratigraphic record) between the nonmarine unit and the overlying marine sequence could encompass much of late Cenomanian and all of early Turonian time.

The upper marine sequence at the top of the Frontier is capped by an 8-ft-thick pebble-bearing marine sandstone that might rest disconformably on middle Turonian strata. This unit is overlain by marine shale of the basal Cody Shale, about 15 ft of which is exposed at this outcrop and which contains the fossil *Cremnoceramus deformis* (D8996) of early Coniacian age (fig. 2, Zone 40). A hiatus at either the base or the top of the uppermost Frontier sandstone might represent late middle and late Turonian time.

Table 1. Late Cretaceous molluscan fossils collected by the U.S. Geological Survey in the Bighorn Basin, north-central Wyoming and south-central Montana. Locations are in Wyoming unless indicated otherwise.

USGS number	County	Locality	Section	Township	Range	Representative fossil	Age	Formation
D13651	Big Horn	Bonanza oil field	NW 1/4 31	49 N.	90 W.	*Plesiacanthoceras wyomingense*	Cenomanian, Middle	Frontier
D9253	Big Horn	Bonanza oil field	NW 1/4 15	49 N.	91 W.	*Cremnoceramus deformis erectus*	Coniacian, Early	Cody Shale
D9254	Big Horn	Bonanza oil field	W 1/2 15	49 N.	91 W.	*Gastropod*	Coniacian, Early	Cody Shale
D8992	Big Horn	Bonanza oil field	SW 1/4 15	49 N.	91 W.	*Plesiacanthoceras wyomingense*	Cenomanian, Middle	Frontier
D8993	Big Horn	Bonanza oil field	SW 1/4 15	49 N.	91 W.	*Mytiloides* cf. *M. incertus*	Turonian, Late	Cody Shale
D9267	Big Horn	Bonanza oil field	SE 1/4 25	49 N.	91 W.	*Dunveganoceras pondi*	Cenomanian, Late	Frontier
D9268	Big Horn	Bonanza oil field	SE 1/4 25	49 N.	91 W.	*Mytiloides incertus*	Turonian, Late	Cody Shale
D9269	Big Horn	Bonanza oil field	SE 1/4 25	49 N.	91 W.	*Mytiloides incertus*	Turonian, Late	Cody Shale
D8994	Big Horn	Bonanza oil field	SE 1/4 16	49 N.	91 W.	*Cremnoceramus deformis dobrogensis*	Coniacian, Early	Cody Shale
D8847	Big Horn	Torchlight Dome	SW 1/4 19	51 N.	92 W.	*Plesiacanthoceras wyomingense*	Cenomanian, Middle	Frontier
D8848	Big Horn	Torchlight Dome	SW 1/4 19	51 N.	92 W.	*Plesiacanthoceras wyomingense*	Cenomanian, Middle	Frontier
D8849	Big Horn	Torchlight Dome	SW 1/4 19	51 N.	92 W.	*Plesiacanthoceras wyomingense*	Cenomanian, Middle	Frontier
D13731	Big Horn	Potato Ridge	NE 1/4 25	52 N.	92 W.	*Acanthoceras amphibolum*	Cenomanian, Middle	Frontier
D13919	Big Horn	Potato Ridge	NE 1/4 25	52 N.	92 W.	*Plesiacanthoceras wyomingense*	Cenomanian, Middle	Frontier
D13918	Big Horn	Potato Ridge	NE 1/4 25	52 N.	92 W.	*Dunveganoceras pondi*	Cenomanian, Late	Frontier
D13920	Big Horn	Potato Ridge	NW 1/4 25	52 N.	92 W.	*Dunveganoceras pondi*	Cenomanian, Late	Frontier
D13921	Big Horn	Potato Ridge	NW 1/4 25	52 N.	92 W.	*Metoicoceras frontierense*	Cenomanian, Late	Frontier
D9754	Big Horn	Devils Kitchen	SW 1/4 1	52 N.	93 W.	*Baculites yokoyamai*	Turonian, Late	Cody Shale
D13915	Big Horn	Devils Kitchen	SW 1/4 1	52 N.	93 W.	*Pycnodonte* aff. *P. kellumi*	Cenomanian, Late	Frontier
D9752	Big Horn	Devils Kitchen	SE 1/4 2	52 N.	93 W.	*Dunveganoceras pondi*	Cenomanian, Late	Frontier
D9753	Big Horn	Devils Kitchen	SE 1/4 2	52 N.	93 W.	*Pycnodonte* aff. *P. kellumi*	Cenomanian, Late	Frontier
D13916	Big Horn	Devils Kitchen	SE 1/4 2	52 N.	93 W.	*Dunveganoceras pondi*	Cenomanian, Late	Frontier
D13729	Big Horn	Greybull	NW 1/4 14	52 N.	93 W.	*Inoceramus* sp.	Cenomanian	Frontier
D13730	Big Horn	Greybull	NW 1/4 14	52 N.	93 W.	*Dunveganoceras pondi*	Cenomanian, Late	Frontier
D13652	Big Horn	Greybull	NE 1/4 16	52 N.	93 W.	*Lingula subspatulata*	Cenomanian	Frontier
D9278	Big Horn	Greybull	SE 1/4 22	52 N.	93 W.	*Plesiacanthoceras wyomingense*	Cenomanian, Middle	Frontier
D13728	Big Horn	Greybull	SE 1/4 34	52 N.	93 W.	*Dunveganoceras pondi*	Cenomanian, Late	Frontier
D13229	Big Horn	Greybull	SE 1/4 24	53 N.	93 W.	*Neogastroplites haasi*	Cenomanian, Early	Thermopolis Shale
D13230	Big Horn	Greybull	NE 1/4 24	53 N.	93 W.	*Neogastroplites haasi*	Cenomanian, Early	Thermopolis Shale
D13917	Big Horn	Lovell Draw	SE 1/4 10	53 N.	94 W.	*Dunveganoceras conditum*	Cenomanian, Late	Frontier
D9276	Big Horn	North Emblem	3	54 N.	95 W.	*Inoceramus ginterensis*	Cenomanian, Late	Frontier
D9277	Big Horn	North Emblem	3	54 N.	95 W.	*Baculites* sp.	Turonian ?	Cody Shale

Table 1. Late Cretaceous molluscan fossils collected by the U.S. Geological Survey in the Bighorn Basin, north-central Wyoming and south-central Montana. Locations are in Wyoming unless indicated otherwise.—Continued

USGS number	County	Locality	Section	Township	Range	Representative fossil	Age	Formation
D9270	Big Horn	North Emblem	SW 1/4 10	54 N.	95 W.	*Pycnodonte* n. sp.	Cenomanian, Late	Frontier
D9271	Big Horn	North Emblem	NE 1/4 15	54 N.	95 W.	*Dunveganoceras albertense*	Cenomanian, Late	Frontier
D1430	Big Horn	Crooked Creek	SW 1/4 32	56 N.	94 W.	*Dunveganoceras albertense*	Cenomanian, Late	
D9272	Big Horn	Crooked Creek	N 1/2 5	57 N.	95 W.	*Metoicoceras muelleri*	Cenomanian, Late	Frontier
D9273	Big Horn	Crooked Creek	N 1/2 5	57 N.	95 W.	*Cremnoceramus* cf. *C. deformis*	Coniacian, Early	Cody Shale
D1727	Hot Springs	Black Mountain	NE 1/4 17	42 N.	90 W.	*Dunveganoceras* ?	Cenomanian, Late	Frontier
D1728	Hot Springs	Black Mountain	NW 1/4 17	42 N.	90 W.	*Acanthoceras* ? *wyomingense*	Cenomanian, Middle	Frontier
D1728	Hot Springs	Black Mountain	NW 1/4 17	42 N.	90 W.	*Inoceramus ginterensis*	Cenomanian, Late	
D1730	Hot Springs	Blue Springs	NE 1/4 16	42 N.	92 W.	*Dunveganoceras pondi*	Cenomanian, Late	Frontier
D1726	Hot Springs	Warm Spring Creek	SE 1/4 3	42 N.	94 W.	*Neogastroplites haasi*	Cenomanian, Early	Thermopolis Shale
D8953	Hot Springs	Black Mountain	SW 1/4 25	43 N.	91 W.	*Mytiloides scupini*	Turonian, Late	Frontier
D8954	Hot Springs	Black Mountain	SW 1/4 25	43 N.	91 W.	*Mytiloides scupini*	Turonian, Late	Frontier
D8955	Hot Springs	Black Mountain	SW 1/4 25	43 N.	91 W.	*Scaphites* cf. *S. nigricollensis*	Turonian, Late	Frontier
D13914	Hot Springs	Black Mountain	SW 1/4 25	43 N.	91 W.	*Cremnoceramus* cf. *C. deformis*	Coniacian, Early	Cody Shale
D13648	Hot Springs	Black Mountain	NE 1/4 26	43 N.	91 W.	*Unio* sp.	?	Frontier
D13649	Hot Springs	Black Mountain	SE 1/4 26	43 N.	91 W.	*Brachidontes arlingtonanus*	Cenomanian, Middle	Frontier
D1679	Hot Springs	Black Mountain	SW 1/4 26	43 N.	91 W.	*Pteria (Oxytoma)* sp.	Cenomanian	
D8843	Hot Springs	Black Mountain	NE 1/4 27	43 N.	91 W.	*Conlinoceras gilberti*	Cenomanian, Middle	Frontier
D8844	Hot Springs	Black Mountain	NE 1/4 27	43 N.	91 W.	*Plesiacanthoceras wyomingense*	Cenomanian, Middle	Frontier
D8846	Hot Springs	Black Mountain	NE 1/4 27	43 N.	91 W.	*Mytiloides scupini*	Turonian, Late	Frontier
D8842	Hot Springs	Black Mountain	NE 1/4 27	43 N.	91 W.	*Forresteria* sp.	Coniacian, Early	Cody Shale
D8843	Hot Springs	Black Mountain	NW 1/4 28	43 N.	91 W.	*Conlinoceras tarrantense*	Cenomanian, Middle	Frontier
D13822	Hot Springs	Black Mountain	NW 1/4 28	43 N.	91 W.	*Baculites mariasensis*	Coniacian, Early	Cody Shale
D8845	Hot Springs	Lake Creek oil field	NW 1/4 14	43 N.	92 W.	*Mytiloides scupini*	Turonian, Late	Frontier
D9314	Hot Springs	Lake Creek oil field	NW 1/4 14	43 N.	92 W.	*Cremnoceramus deformis dobrogensis*	Coniacian, Early	Cody Shale
D9315	Hot Springs	Blue Springs	NE 1/4 33	43 N.	92 W.	*Dunveganoceras pondi*	Cenomanian, Late	Frontier
D9316	Hot Springs	Blue Springs	NE 1/4 33	43 N.	92 W.	*Inoceramus perplexus* ?	Turonian, Late	Frontier
D9317	Hot Springs	Blue Springs	NE 1/4 33	43 N.	92 W.	*Inoceramus perplexus*	Turonian, Late	Frontier
D9318	Hot Springs	Blue Springs	NE 1/4 33	43 N.	92 W.	*Cremnoceramus* cf. *C. deformis erectus*	Coniacian, Early	Cody Shale
D1729	Hot Springs	Blue Springs	NE 1/4 33	43 N.	92 W.	*Calycoceras canitaurinum*	Cenomanian, Late	Frontier
D9750	Hot Springs	Thermopolis	NE 1/4 9	43 N.	94 W.	*Cremnoceramus deformis dobrogensis*	Coniacian, Early	Frontier

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USGS number	County	Locality	Section	Township	Range	Representative fossil	Age	Formation
D8951	Hot Springs	Thermopolis	SE 1/4 9	43 N.	94 W.	*Cremnoceramus crassus inconstans*	Coniacian, Early	Frontier
D9770	Hot Springs	Hamilton Dome	18	44 N.	97 W.	*Cremnoceramus deformis dobrogensis*	Coniacian, Early	Frontier
D9771	Hot Springs	Hamilton Dome	18	44 N.	97 W.	*Cremnoceramus crassus inconstans*	Coniacian, Early	Cody Shale
D9262	Park	Wood River	NE 1/4 15	47 N.	101 W.	*Cremnoceramus deformis dobrogensis*	Cenomanian, Early	Cody Shale
D9265	Park	Pitchfork	SE 1/4 2	48 N.	102 W.	*Cremnoceramus deformis dobrogensis*	Coniacian, Early	Frontier
D9266	Park	Pitchfork	SW 1/4 11	48 N.	102 W.	*Neogastroplites americanus*	Cenomanian, Early	Mowry Shale
D9263	Park	Pitchfork	14	48 N.	102 W.	*Neogastroplites americanus*	Cenomanian, Early	Mowry Shale
D9264	Park	Pitchfork	14	48 N.	102 W.	*Lingula* sp.	Cenomanian	Frontier
D9818	Park	Pitchfork	14	48 N.	102 W.	*Metengonoceras* sp.	Cenomanian	Frontier
D11916	Park	Elk Butte	NW 1/4 32	51 N.	100 W.	*Inoceramus howelli*	Turonian, Middle	Frontier
D8998	Park	Elk Butte	SE 1/4 31	51 N.	100 W.	*Inoceramus howelli*	Turonian, Middle	
D8999	Park	Elk Butte	NE 1/4 31	51 N.	100 W.	*Cremnoceramus deformis erectus*	Coniacian, Early	Frontier
D11917	Park	Elk Butte	SW 1/4 29	51 N.	100 W.	*Cremnoceramus inconstans*	Coniacian, Early	Cody Shale
D8997	Park	Cody	N 1/2 31	53 N.	101 W.	*Inoceramus howelli*	Turonian, Middle	Frontier
D8996	Park	Cody	N 1/2 31	53 N.	101 W.	*Cremnoceramus deformis dobrogensis*	Coniacian, Early	Cody Shale
D9259	Park	Deep Lake	W 1/2 21	56 N.	103 W.	*Cremnoceramus deformis dobrogensis*	Coniacian, Early	Frontier
D9258	Park	Deep Lake	W 1/2 21	56 N.	103 W.	*Cremnoceramus deformis deformis*	Coniacian, Early	Cody Shale
D9002	Park	Frannie oil field	SE 1/4 23	58 N.	98 W.	*Cremnoceramus deformis dobrogensis*	Coniacian, Early	Cody Shale
D9001	Park	Frannie oil field	SE 1/4 23	58 N.	98 W.	*Metoicoceras mesabiensis*	Cenomanian, Late	Frontier
D9000	Park	Frannie oil field	SE 1/4 23	58 N.	98 W.	*Metoicoceras* sp.	Cenomanian, Late	Frontier
D9006	Washakie	No Wood Ranch	3	42 N.	89 W.	*Cremnoceramus waltersdorfensis*	Turonian, Late	Cody Shale
D9251	Washakie	No Wood Ranch	NE 1/4 10	42 N.	89 W.	*Inoceramus perplexus*	Turonian, Late	Frontier
D13828	Washakie	Shanty Ridge	NW 1/4 26	43 N.	89 W.	*Dunveganoceras pondi*	Cenomanian, Late	Frontier
D13827	Washakie	Shanty Ridge	NW 1/4 26	43 N.	89 W.	*Dunveganoceras pondi*	Cenomanian, Late	Frontier
D9252	Washakie	Big Trails	SW 1/4 24	44 N.	88 W.	*Cremnoceramus deformis erectus*	Coniacian, Early	Cody Shale
D13823	Washakie	Mud Gulch	SW 1/4 4	45 N.	88 W.	*Plesiacanthoceras wyomingense*	Cenomanian, Middle	Frontier
D13824	Washakie	Mud Gulch	SW 1/4 4	45 N.	88 W.	*Scaphites impendicostatus*	Coniacian, Early	Cody Shale
D13825	Washakie	Joe Emge Creek	SW 1/4 13	46 N.	89 W.	*Metoicoceras mosbyense*	Cenomanian, Late	Frontier
D13228	Washakie	Joe Emge Creek	SW 1/4 13	46 N.	89 W.	*Scaphites preventricosus*	Coniacian, Early	Cody Shale
D13650	Washakie	Ten Sleep area	SE 1/4 22	47 N.	89 W.	*Inoceramus eulessanus*	Cenomanian, Middle	Frontier
D9009	Washakie	Ten Sleep area	SE 1/4 22	47 N.	89 W.	*Plesiacanthoceras wyomingense*	Cenomanian, Middle	Frontier

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USGS number	County	Locality	Section	Township	Range	Representative fossil	Age	Formation
D13732	Washakie	Ten Sleep area	SE 1/4 22	47 N.	89 W.	*Dunveganoceras* sp.	Cenomanian, Late	Frontier
D13910	Washakie	McClellan Gulch	NW 1/4 25	47 N.	89 W.	*Plesiacanthoceras wyomingense*	Cenomanian, Middle	Frontier
D13911	Washakie	McClellan Gulch	NW 1/4 25	47 N.	89 W.	*Inoceramus* sp.		
D13908	Washakie	McClellan Gulch	NW 1/4 25	47 N.	89 W.	*Placenticeras pseudoplacenta*	Turonian, Middle or Late	Frontier
D13909	Washakie	McClellan Gulch	SW 1/4 25	47 N.	89 W.	*Plesiacanthoceras wyomingense*	Cenomanian, Middle	Frontier
D13734	Washakie	Ten Sleep area	NE 1/4 27	47 N.	89 W.	*Cremnoceramus deformis dobrogensis*	Coniacian, Early	Cody Shale
D8956	Washakie	Ten Sleep area	NE 1/4 27	47 N.	89 W.	*Mytiloides scupini*	Turonian, Late	Cody Shale
D8957	Washakie	Ten Sleep area	NE 1/4 27	47 N.	89 W.	*Mytiloides scupini*	Turonian, Late	Cody Shale
D13242	Washakie	Ten Sleep area	NE 1/4 27	47 N.	89 W.	*Inoceramus* sp.	Turonian, Late	Cody Shale
D13913	Washakie	Ten Sleep area	NW 1/4 27	47 N.	89 W.	*Placenticeras pseudoplacenta*	Turonian, Middle or Late	Frontier
D13733	Washakie	Ten Sleep area	NW 1/4 27	47 N.	89 W.	*Inoceramus* sp.	Coniacian	Cody Shale
D9751	Washakie	Ten Sleep area	NE 1/4 27	47 N.	89 W.	*Placenticeras* sp.	Turonian, Middle or Late	Frontier
D13912	Washakie	McClellan Gulch	NW 1/4 36	47 N.	89 W.	*Mytiloides scupini*	Turonian, Late	Cody Shale
D9274	Carbon (MT)	Warren	25	8 S.	24 E.	*Metoicoceras defordi*	Cenomanian, Late	Frontier
D9275	Carbon (MT)	Warren	25	8 S.	24 E.	*Cremnoceramus* cf. *C. deformis*	Coniacian, Early	Frontier

SERIES	Stages	Informal substages	Western Interior ammonite age spans and radiometric ages (MY)	Zone nos.	Western Interior inoceramid age spans
UPPER CRETACEOUS (part)	Santonian (part)	lower	*Clioscaphites saxitonianus*	45	*Cladoceramus undulatoplicatus*
	Coniacian	upper	*Scaphites depressus* 87.14 ± 0.39	44	*Magadiceramus crenelatus* *Magadiceramus subquadratus*
		middle	*Scaphites ventricosus*	43	*Volviceramus involutus*
				42	*Volviceramus koeneni*
		lower	88.55 ± 0.59	41	*Cremnoceramus crassus crassus* *Cremnoceramus crassus inconstans*
			Scaphites preventricosus	40	*Cremnoceramus deformis dobrogensis*
				39	*Cremnoceramus deformis erectus*
	Turonian	upper	*Scaphites mariasensis*	38	*Cremnoceramus waltersdorfensis*
			Prionocyclus germari	37	*Mytiloides scupini*
			Scaphites nigricollensis	36	*Mytiloides incertus*
			Scaphites whitfieldi	35	*Inoceramus dakotensis*
				34	*Inoceramus perplexus*
		middle	*Scaphites ferronensis*	33	*Inoceramus dimidius*
			Scaphites warreni	32	
			Prionocyclus macombi 90.60 ± 0.46	31	
			Prionocyclus hyatti 92.46 ± 0.58	30	*Inoceramus howelli*
			Collignoniceras praecox	29	
			Collignoniceras woollgari	28	*Mytiloides hercynicus* *Mytiloides subhercynicus*
		lower	*Mammites nodosoides*	27	*Mytiloides mytiloides*
			Vascoceras birchbyi 93.48 ± 0.58	26	*Mytiloides kossmati*
			Pseudaspidoceras flexuosum 93.19 ± 0.42	25	
			Watinoceras devonense	24	*Mytiloides puebloensis*
	Cenomanian	upper	*Nigericeras scotti*	23	*Mytiloides hattini*
			Neocardioceras juddii 93.32 ± 0.38 93.82 ± 0.30	22	*Inoceramus pictus*
			Burroceras clydense	21	
			Euomphaloceras septemseriatum 93.99 ± 0.57	20	
			Vascoceras diartianum	19	
			Dunveganoceras conditum	18	*Inoceramus ginterensis*
			Dunveganoceras albertense	17	
			Dunveganoceras problematicum	16	
			Dunveganoceras pondi 94.71 ± 0.49	15	*Inoceramus prefragilis*
		middle	*Plesiacanthoceras wyomingense*	14	
			Acanthoceras amphibolum 94.96 ± 0.50	13	*Inoceramus rutherfordi*
			Acanthoceras bellense	12	*Inoceramus arvanus*
			Plesiacanthoceras muldoonense	11	*Inoceramus eulessanus*
			Acanthoceras granerosense	10	
			Conlinoceras tarrantense 95.73 ± 0.51	9	
		lower		8	
			(Gap in biostratigraphic record)	7	
				6	
			Neogastroplites maclearni	5	
			Neogastroplites americanus	4	
			Neogastroplites muelleri 98.88 ± 0.35	3	
			Neogastroplites cornutus	2	*Inoceramus maclearni*
			Neogastroplites haasi	1	
			99.6 ± 0.9		

Figure 2. Molluscan fossil zones, informal zone numbers, fossil-ranges, and radiometric ages for marine strata for Cenomanian, Turonian, Coniacian, and Santonian Stages (Upper Cretaceous) in the Western Interior, United States (modified after Cobban and others, 2006).

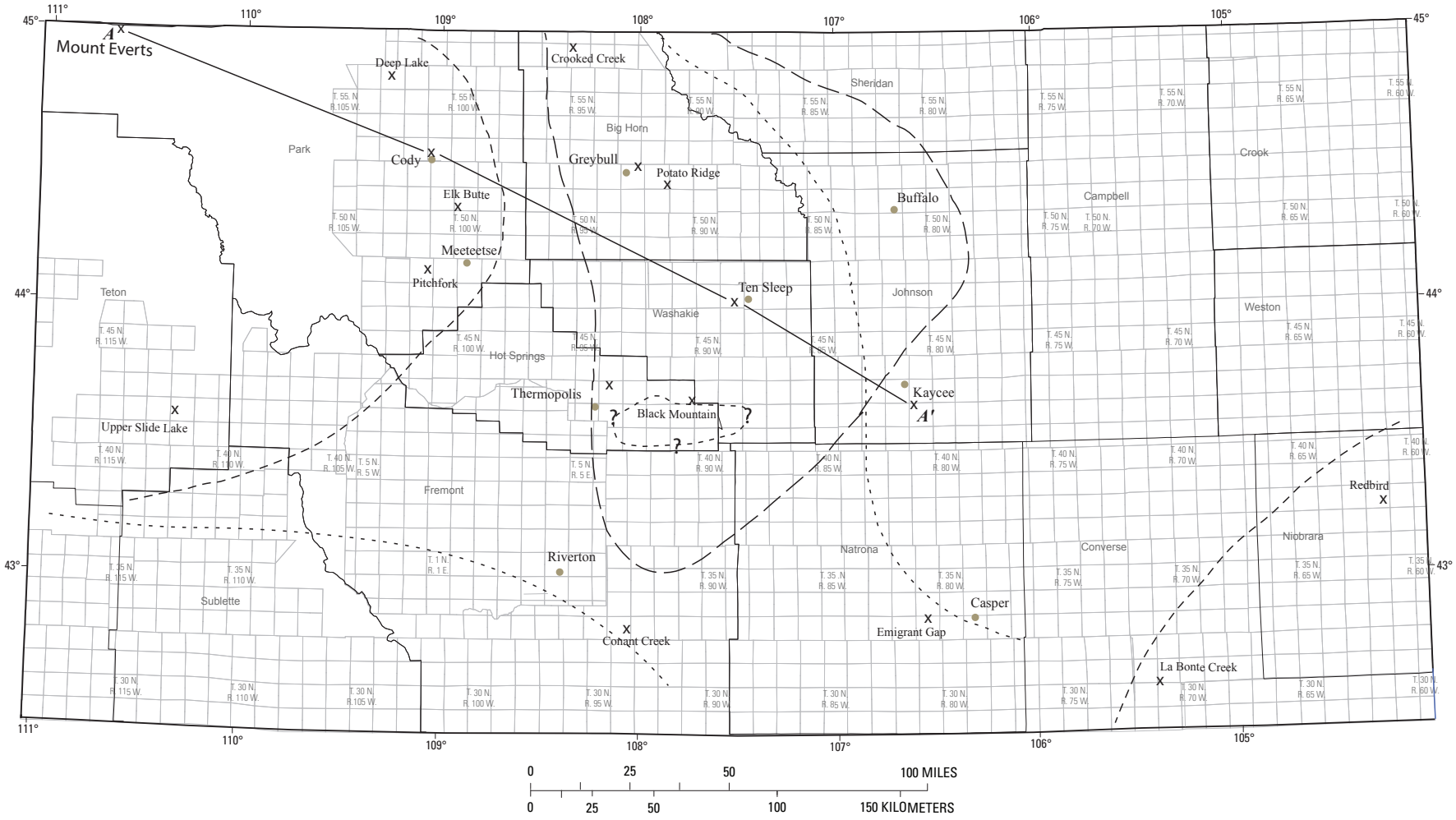


Figure 3. (facing page) Northern Wyoming showing locations of selected outcrops of the Frontier Formation (x) and equivalent strata. Long dashed line is approximate boundary of a region in north-central Wyoming where lower Middle Turonian (fig. 2, Zones 28–31) strata are absent. Short dashed lines are the approximate boundaries of regions in northwestern and east-central Wyoming where Lower or Middle Coniacian strata disconformably overlie Turonian strata. Dotted lines are the approximate boundaries enclosing a region in northwestern and central Wyoming where lower Upper Turonian (fig. 2, Zones 34–35) strata are absent, except for the small area near Black Mountain bounded by the dotted line with question marks, in which these rocks are present. A—A', location of regional cross-section (fig. 32) of the Frontier Formation and lower beds of the overlying Cody Shale. Brown dots mark towns in the region.

SERIES	UPPER CRETACEOUS (part)						
Stages	Cenomanian			Turonian			Coniacian (part)
Informal substages	lower	middle	upper	lower	middle	upper	lower
Fossil zones	1 2 3 4 5 6 7 8	9 10 11 12 13 14	15 16 17 18 19 20 21 22 23	24 25 26 27	28 29 30 31 32 33	34 35 36 37 38	39 40 41

Locality	Units (oldest to youngest, fossil zones 1–41)						
Mount Everts–Park Co.	Mowry Shale ?	Frontier Form-ation ?	hiatus	Frontier Formation	hiatus	Cody Shale (part)	
Upper Slide Lake–Teton Co.	Mowry Shale ?	Frontier Form-ation ?	hiatus	Frontier Formation	hiatus	Frontier Formation	Cody Shale (part)
Cody area–Park Co.	Mowry Shale	Frontier Formation	hiatus	Frontier Formation	hiatus	Frontier Formation	Cody Shale (part)
Greybull area–Big Horn Co.	Mowry Shale	Frontier Formation	hiatus	Cody Shale (part)			
Ten Sleep area–Washakie Co.	Mowry Shale	Frontier Formation	hiatus	Frontier Formation	Cody Shale (part)		
Black Mountain–Hot Springs Co.	Mowry Shale	Frontier Formation	hiatus	Frontier Formation	Cody Shale (part)		
Riverton area/Conant Creek–Fremont Co.	Mowry Shale	Frontier Formation	hiatus	Frontier Formation	hiatus	Frontier Formation	Cody Shale (part)
Casper area/Emigrant Gap–Natrona Co.	Mowry Shale	Frontier Formation (Belle Fourche Member)	hiatus	Frontier Formation (Emigrant Gap Member)	hiatus	Frontier Formation (Wall Creek Member)	Cody Shale (part)
Redbird area–Niobrara Co.	Mowry Shale	Belle Fourche Shale	Greenhorn Formation	Carlile Shale (part)	hiatus	Carlile Shale (part)	hiatus
Fossil zones	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41						

Figure 4. Formations and members of early Late Cretaceous ages and corresponding fossil zones (fig. 2) for selected localities in northern Wyoming.

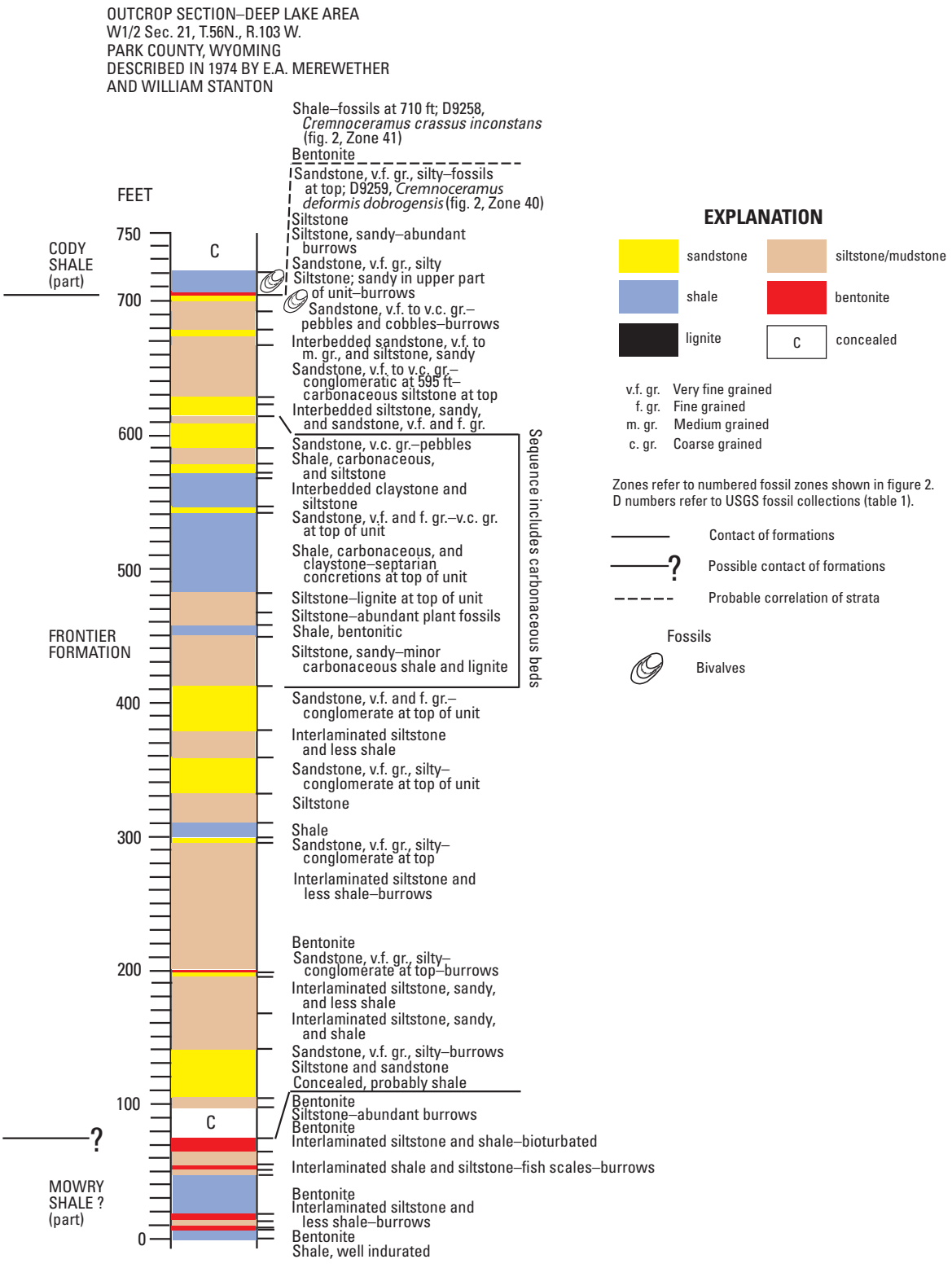


Figure 5. Columnar section and lithologic description of Frontier Formation in outcrops near Deep Lake, northwestern Bighorn Basin (fig. 1).

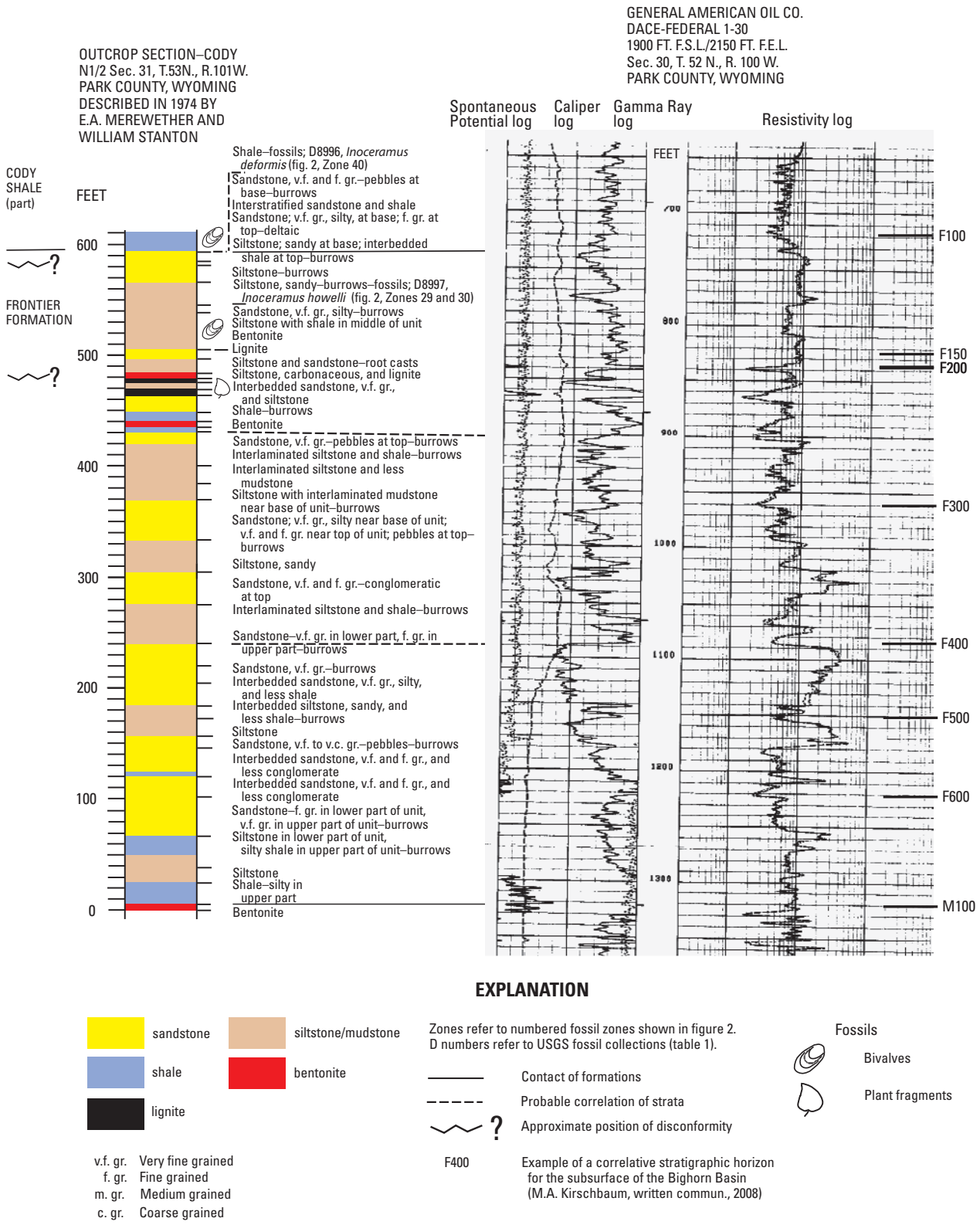


Figure 6. Columnar section and lithologic description of Frontier Formation in outcrops near Cody, western Bighorn Basin (fig. 1). Also shown are surface-to-subsurface correlations with a nearby borehole. This section is modified from the version published in Kirschbaum and others (2009).

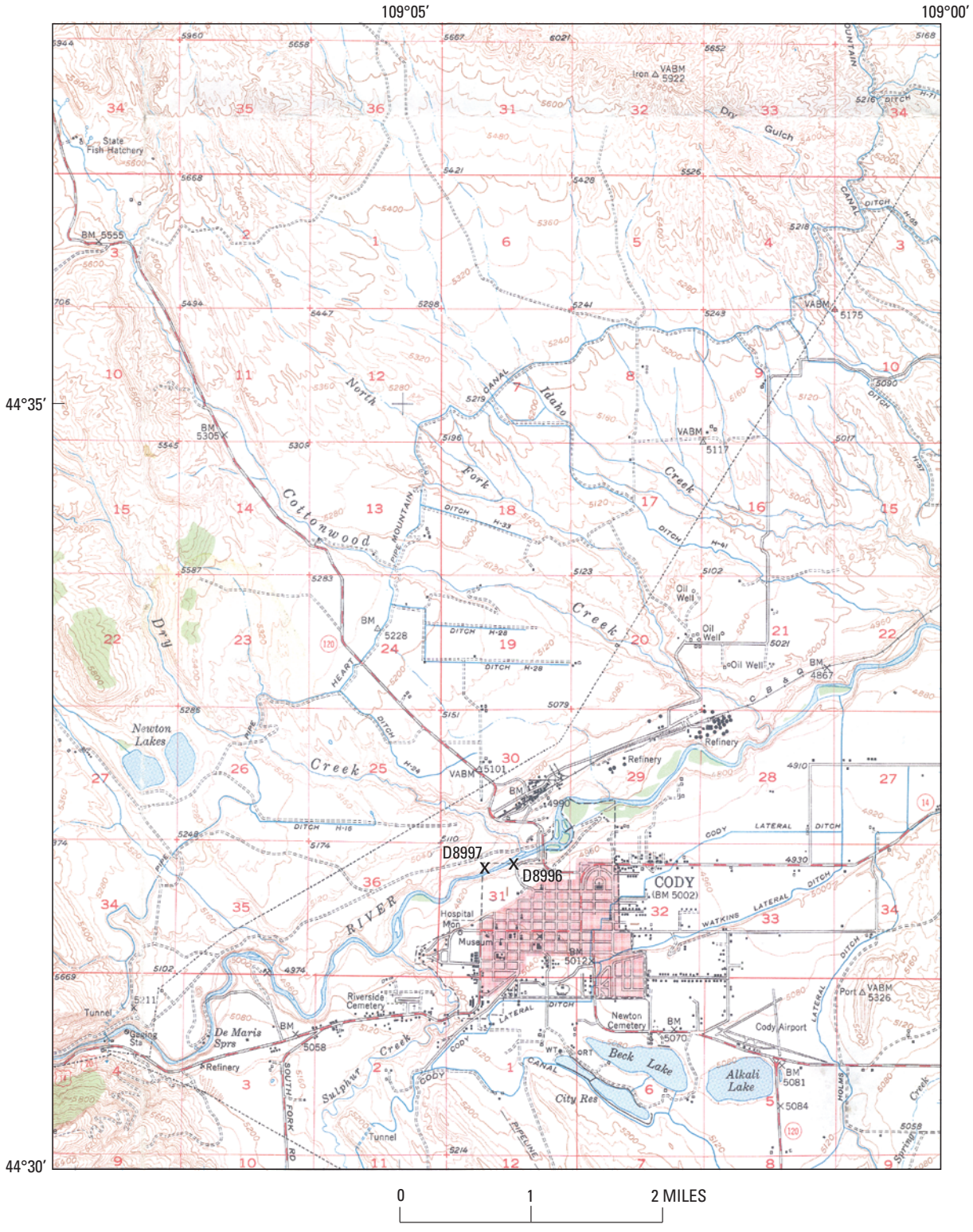


Figure 7. Fossil localities near Cody in the Cody quadrangle (15-minute, 1949), Park County, Wyoming. D numbers refer to USGS fossil collections (table 1).

Outcrops near Elk Butte, Wyoming

In outcrops near Elk Butte, about 14 mi southeast of Cody and about 13 mi north of Meeteetse (fig. 1), only an upper part of the Frontier is well exposed. It was not described in detail (Merewether and Cobban made an unpublished partial description in 1973), but the entire formation is recorded on geophysical logs from nearby boreholes (fig. 8). A slightly carbonaceous mudstone in these outcrops is overlain by very fine and fine grained sandstones at least 30 ft thick. The lower part of this sandstone sequence contains the fossil bivalve *Inoceramus howelli* (D11916; fig. 2, Zones 29 and 30; fig. 9) of early middle Turonian age.

Near the top of the Frontier, the Turonian sandstones are disconformably overlain by about 20 ft of a darker, coarse grained sandstone that is conglomeratic at the top (figs. 8, 10). Fossils from the upper part of this darker sandstone include *Cremnoceramus deformis erectus* (D8999; fig. 2, Zone 39) of earliest Coniacian age. The lacuna between the two sandstones (fig. 10) probably spans late middle and late Turonian time. Conformably overlying the Frontier is the Cody Shale, which contains the fossil *Cremnoceramus crassus inconstans* (D11917; fig. 2, Zones 40 and 41; fig. 9) of late early Coniacian age, 22 ft above the base.

Outcrops in the Pitchfork Oil Field, Wyoming

The Frontier is exposed in the Pitchfork oil field, about 10 mi west of Meeteetse (fig. 1), where it was described by Merewether and others (1975). It is recorded on geophysical logs from boreholes in the area (fig. 11). The formation consists of siliciclastic and bentonitic beds that were deposited mainly in shallow-marine environments. Many of these strata contain burrows and a few contain molluscan fossils. The Frontier in this area is at least 520 ft thick, comprises several stratigraphic sequences, and includes one or two disconformities.

In the oil field, the Frontier overlies the Mowry Shale, the upper 95 ft of which comprises sandstone, siltstone, shale, and bentonite. The sandstones and siltstones commonly contain burrows but *Ophiomorpha* are rare. An ammonite of early Cenomanian age (*Neogastroplites americanus*, D9263; fig. 2, Zone 4) was collected from sandstone near the middle of this sequence (figs. 11, 12).

The overlying Frontier is composed of very fine and fine grained sandstone, siltstone, shale, and bentonite. Most of these strata were deposited in marine environments, although fossil bivalves (D9264) that lived in brackish water were found in one of the lower beds (fig. 11). A long-ranging ammonite, *Metengonoceras* sp. (Albian and early Cenomanian, D9818), was also found in a lower part of the formation. The Frontier in these outcrops commonly contains marine burrows. However, a few beds near the top of the formation, including carbonaceous shale, are nonmarine. The ages of these strata are Cenomanian and probably Turonian. Strata of these ages might be separated by a disconformity.

The main part of the Frontier is disconformably overlain by a 20-ft-thick sandstone at the top of the formation that is very fine to very coarse grained and contains pebbles. It also contains marine burrows, including *Ophiomorpha*, and fossil bivalves, including *Cremnoceramus deformis* (D9265; fig. 2, Zone 40). The age of this uppermost Frontier and of a basal part of the overlying Cody Shale is early Coniacian. At this disconformity, the lacuna might include the uppermost middle and upper Turonian and the lowest Coniacian.

Outcrops at Hamilton Dome, Coal Draw, and near Thermopolis, Wyoming

The Frontier in outcrops near the southwestern margin of the basin (figs. 1, 13), at Hamilton Dome and near Thermopolis, Wyo., were described by Merewether and others (1975). Outcrops at Coal Draw were described by R.W. Tillman and R. Bottjer (written commun., 1999). Sandstones at these localities are mainly very fine grained; rarely are they coarse grained or contain pebbles. The formation is at least 560 ft thick, and the strata are mostly of marine origin but contain a few carbonaceous beds at Coal Draw and near Thermopolis. Burrows are common in the marine beds.

The age of the lower part of the Frontier probably is Cenomanian. Sandstones at the top at Hamilton Dome and near Thermopolis contain molluscan fossils (D9770 and D8951, respectively) of early Coniacian ages (fig. 2, Zones 40 and 41). Regional correlations in the Bighorn Basin indicate that these outcrops enclose several flooding surfaces as well as a disconformable contact that separates Cenomanian from Turonian beds.

Outcrops at Black Mountain, Wyoming

At Black Mountain (fig. 1), which is about 24 mi east of Thermopolis, Wyo., outcrops of the Frontier were described by W.A. Cobban, (written commun., 1973), Merewether and others (1975, 1998), and R.W. Tillman and R. Bottjer (written commun., 1999). In this area, the formation is 665 ft thick and consists of siliciclastic and bentonitic strata deposited in a variety of marine environments. The lower and main part, 620-ft thick, is separated from the upper 45 ft by a disconformity (fig. 14). Sandstones in the lower part are generally very fine or fine grained, although several are medium grained and contain pebbles.

Burrows are common in these strata and molluscan fossils have been collected from beds near the top (figs. 15, 16). Ammonites of earliest middle Cenomanian age,

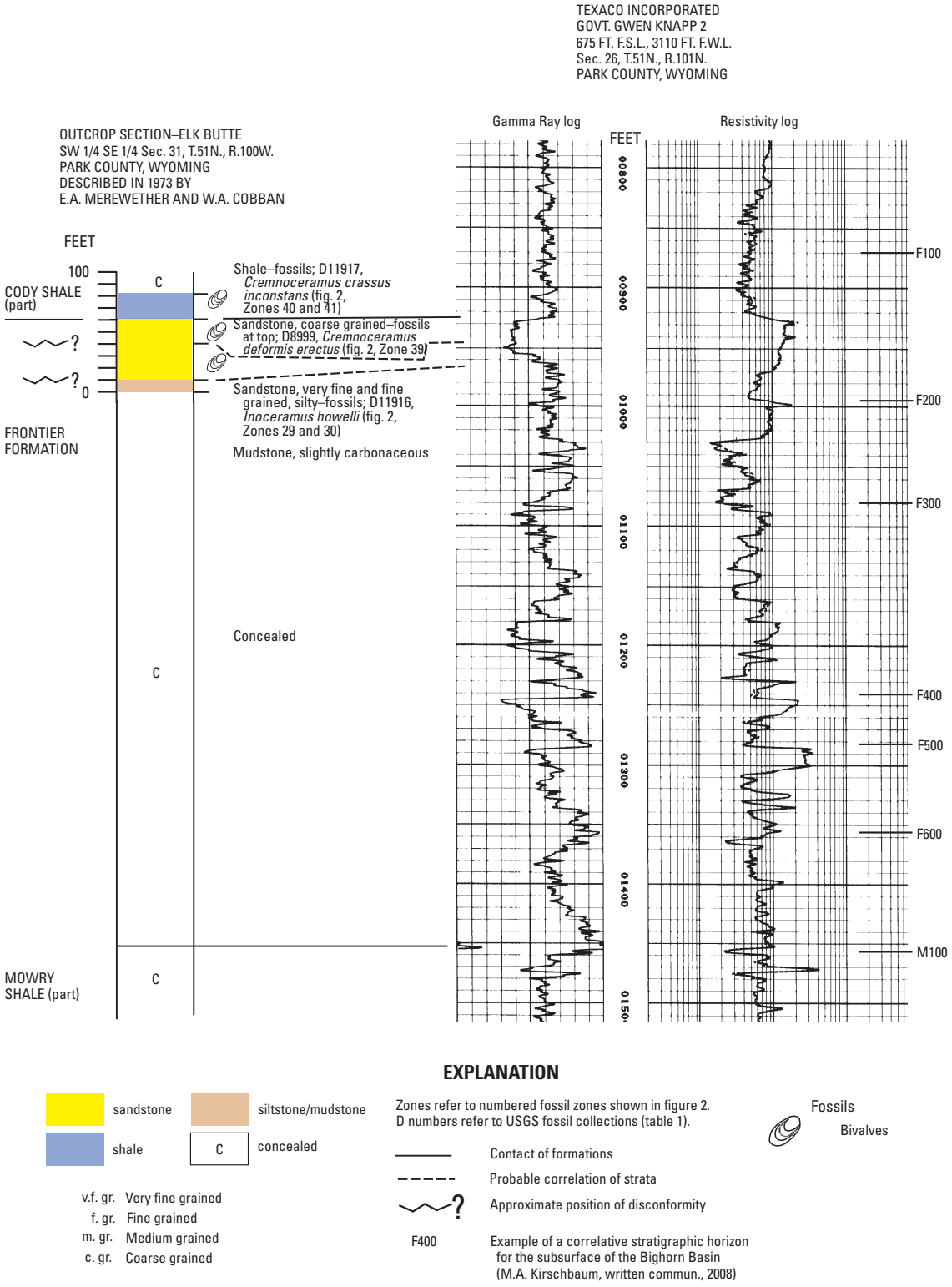


Figure 8. Columnar section and lithologic description of Frontier Formation in outcrops near Elk Butte, western Bighorn Basin (fig. 1). Also shown are surface-to-subsurface correlations with a nearby borehole.

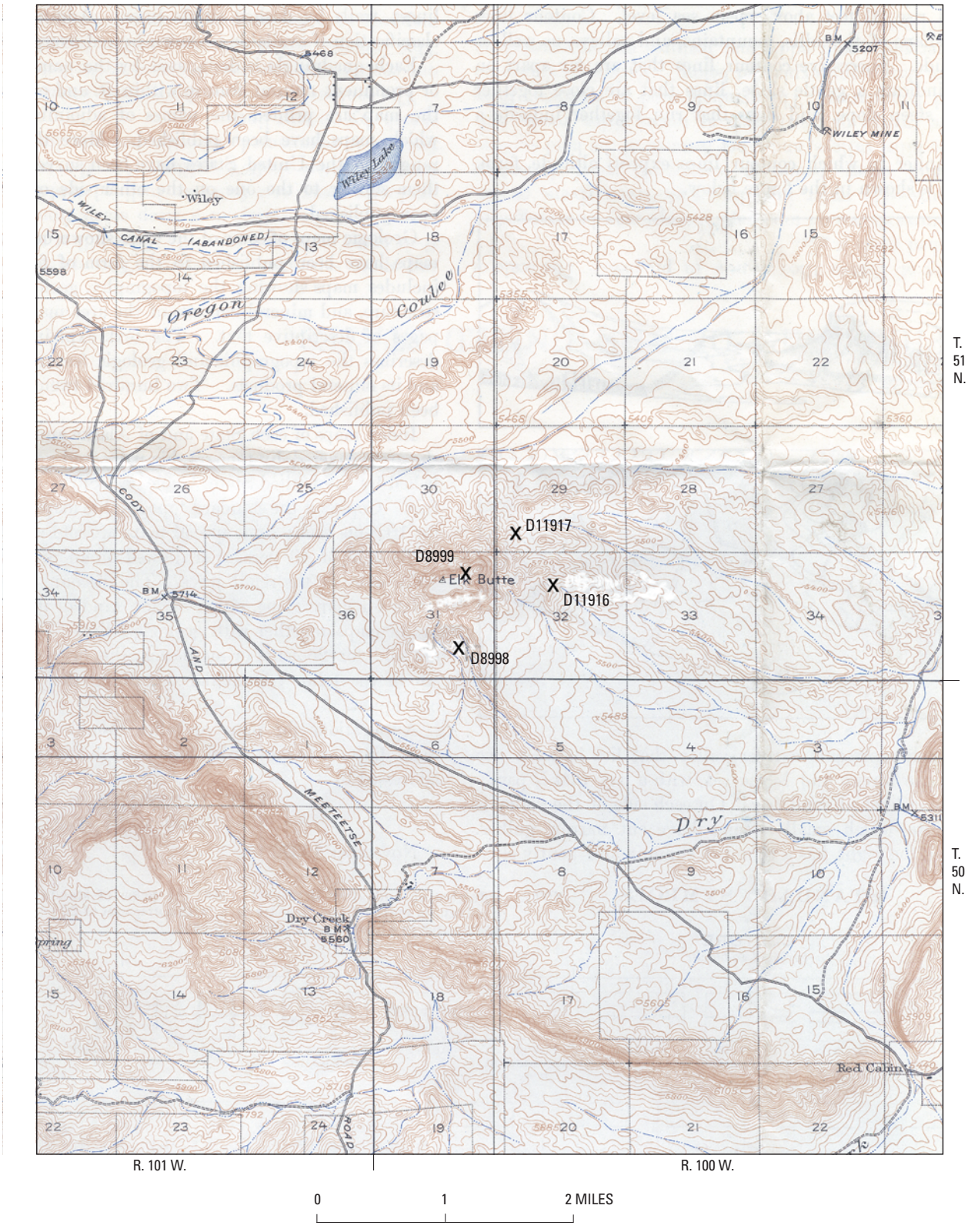


Figure 9. Fossil localities near Elk Butte in the Oregon Basin quadrangle (15-minute, 1913), Park County, Wyoming. D numbers refer to USGS fossil collections (table 1).

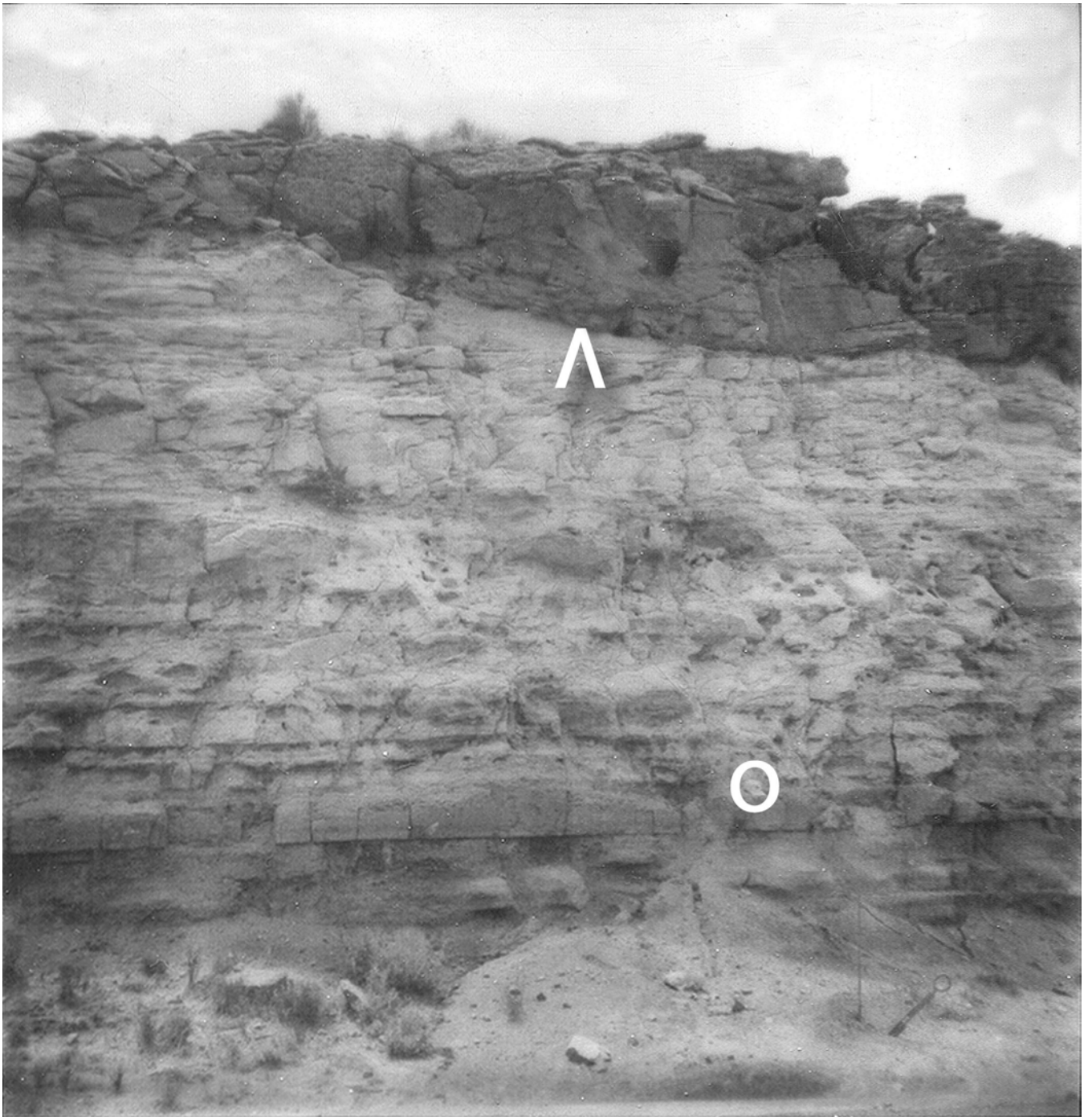


Figure 10. Middle Turonian sandstone disconformably overlain by a lower Coniacian sandstone near Elk Butte, western Bighorn Basin (fig. 1). Pointer indicates location of disconformity. Fossils collected from ledges near O included *Inoceramus howelli* (fig. 2, Zones 29 and 30).

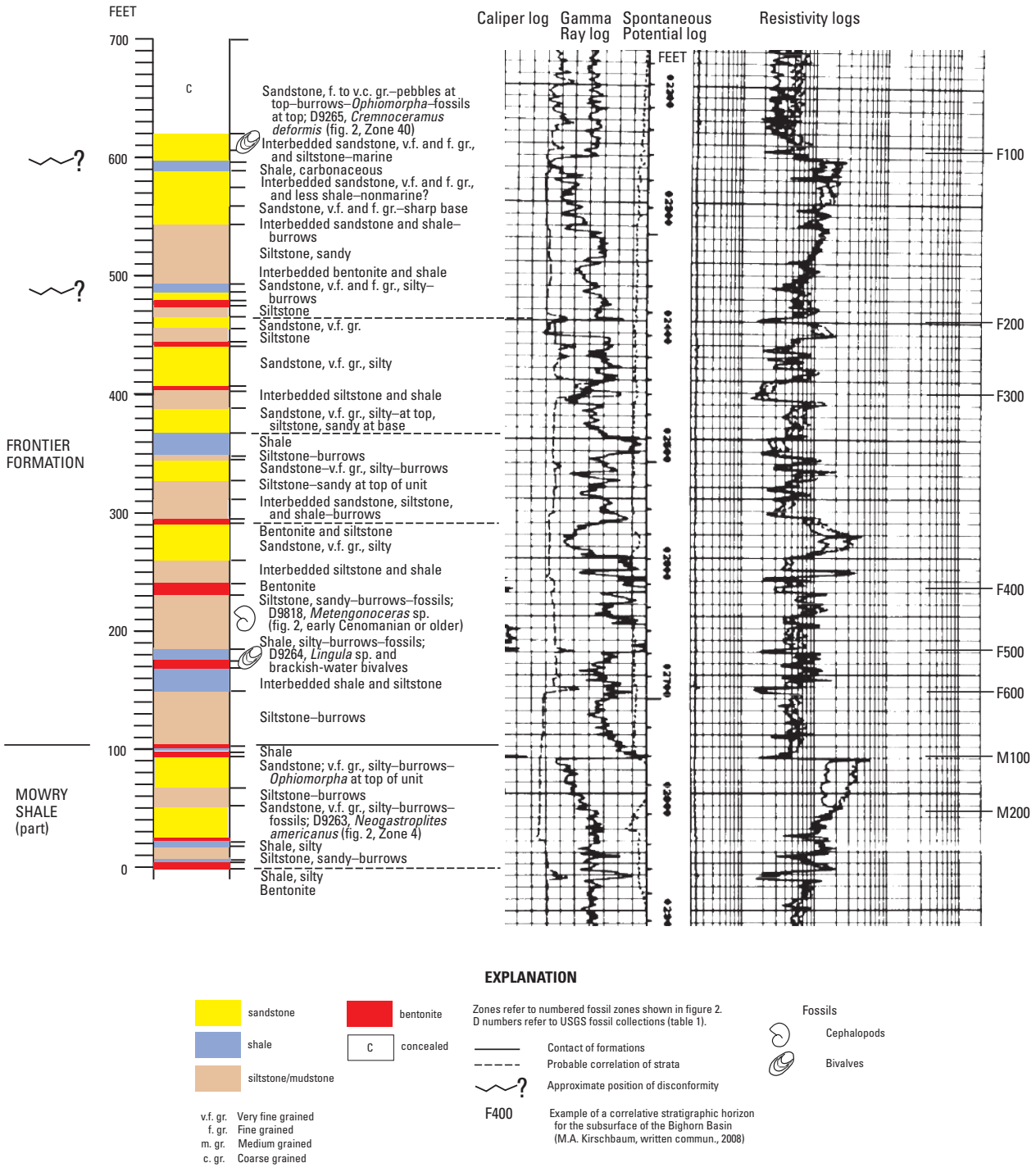


Figure 11. Columnar section and lithologic description of Frontier Formation in outcrops near Pitchfork, western Bighorn Basin (fig. 1). Also shown are surface-to-subsurface correlations with a nearby borehole.

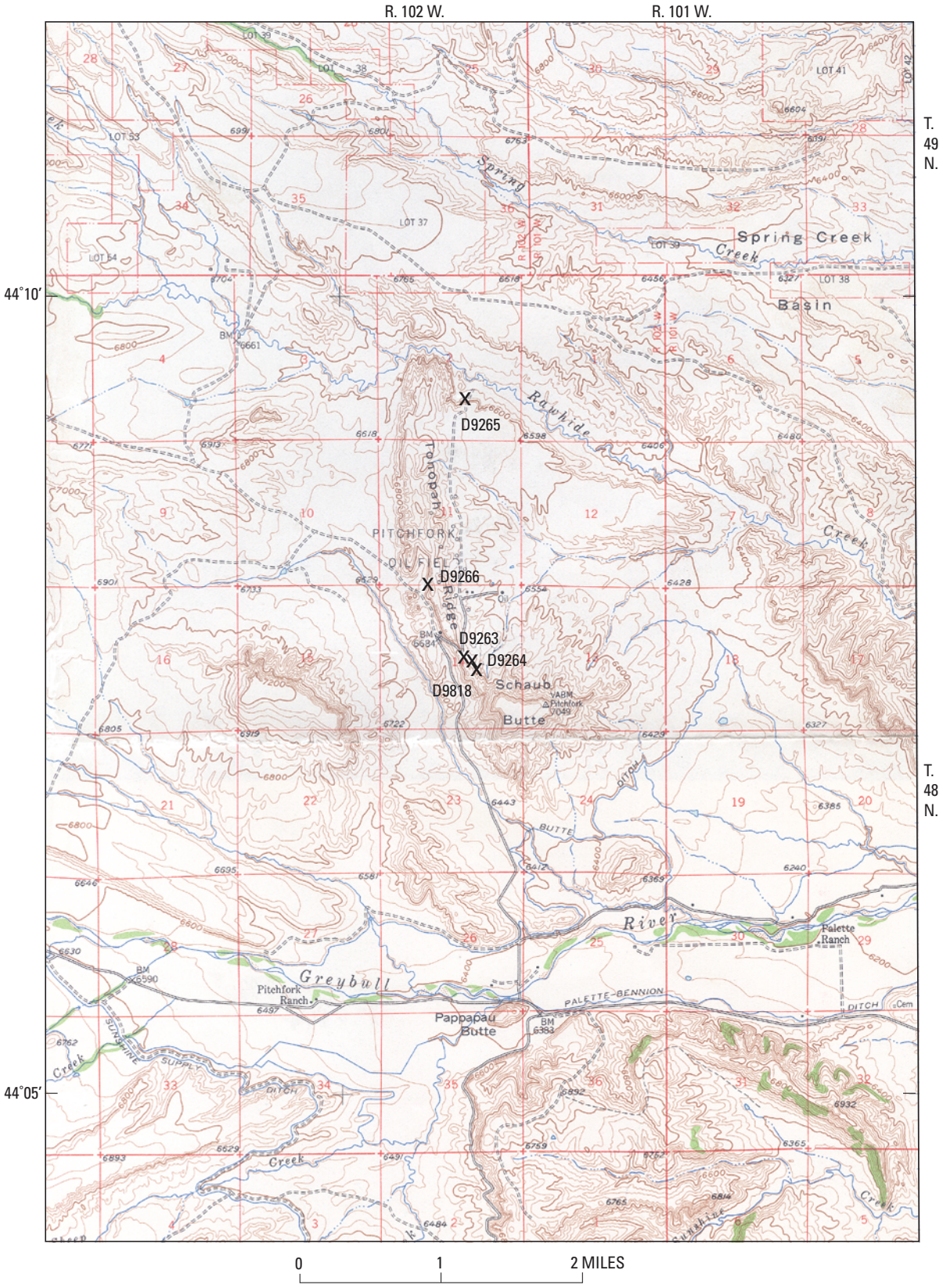


Figure 12. Fossil localities near Pitchfork oil field in the Sunshine Reservoir quadrangle (15-minute, 1957), Park County, Wyoming. D numbers refer to USGS fossil collections (table 1).

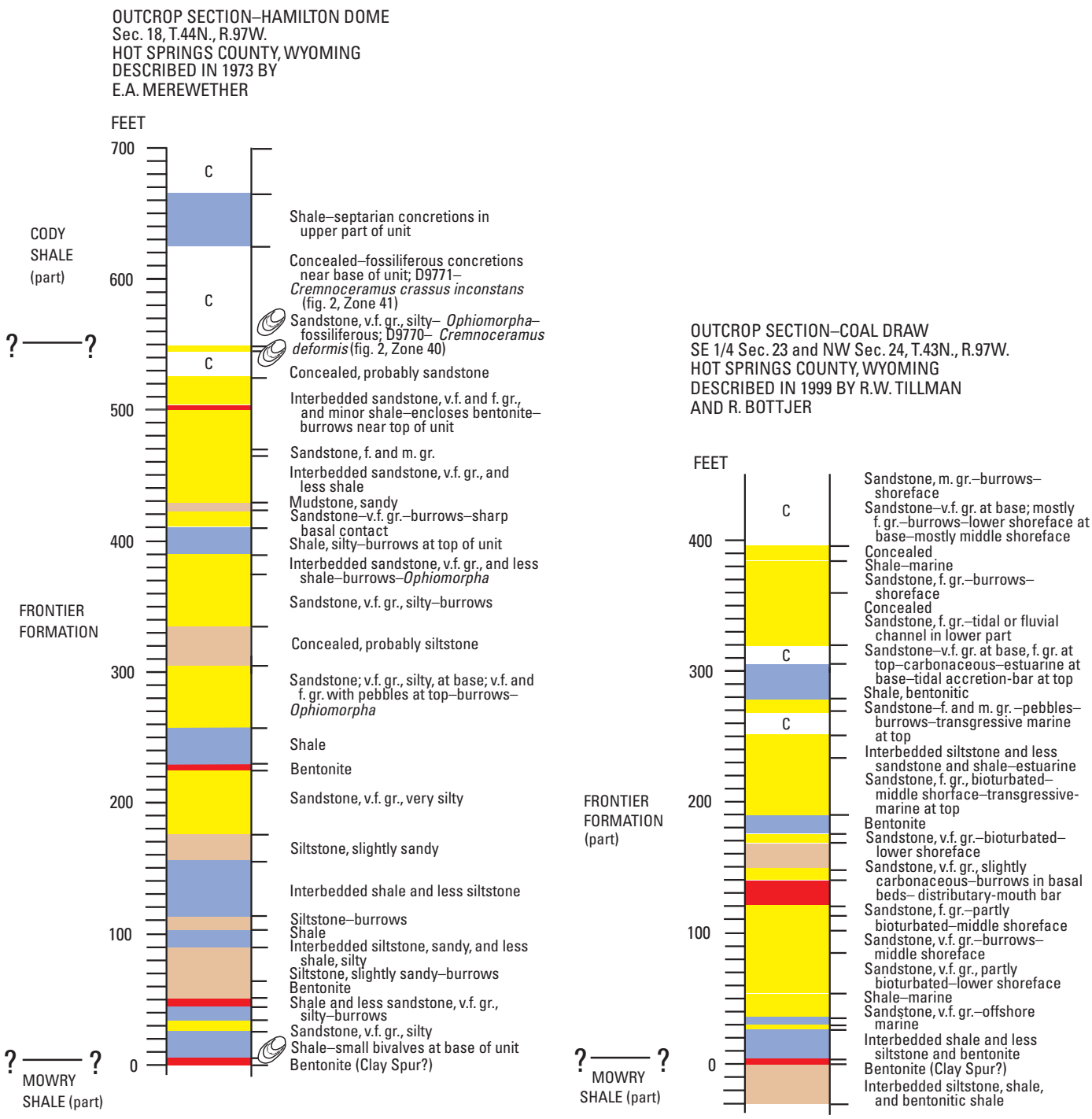
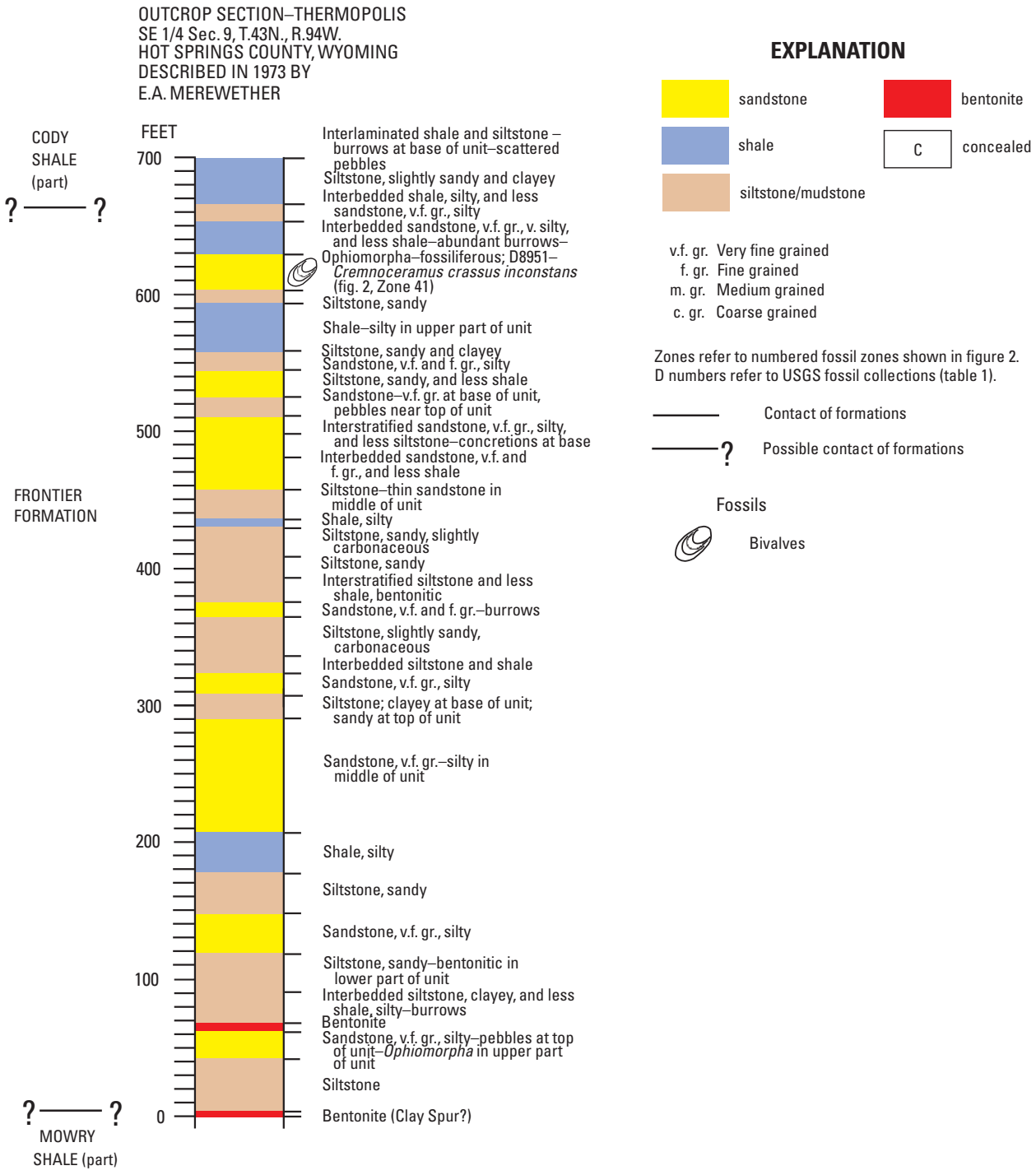


Figure 13. Columnar sections and descriptions of Frontier Formation in outcrops at Hamilton Dome, Coal Draw, and near Thermopolis, southern Bighorn Basin (fig. 1).



EXPLANATION

sandstone

shale

siltstone/mudstone

bentonite

C concealed

v.f. gr. Very fine grained
f. gr. Fine grained
m. gr. Medium grained
c. gr. Coarse grained

Zones refer to numbered fossil zones shown in figure 2.
D numbers refer to USGS fossil collections (table 1).

Contact of formations

? Possible contact of formations

Fossils

Bivalves

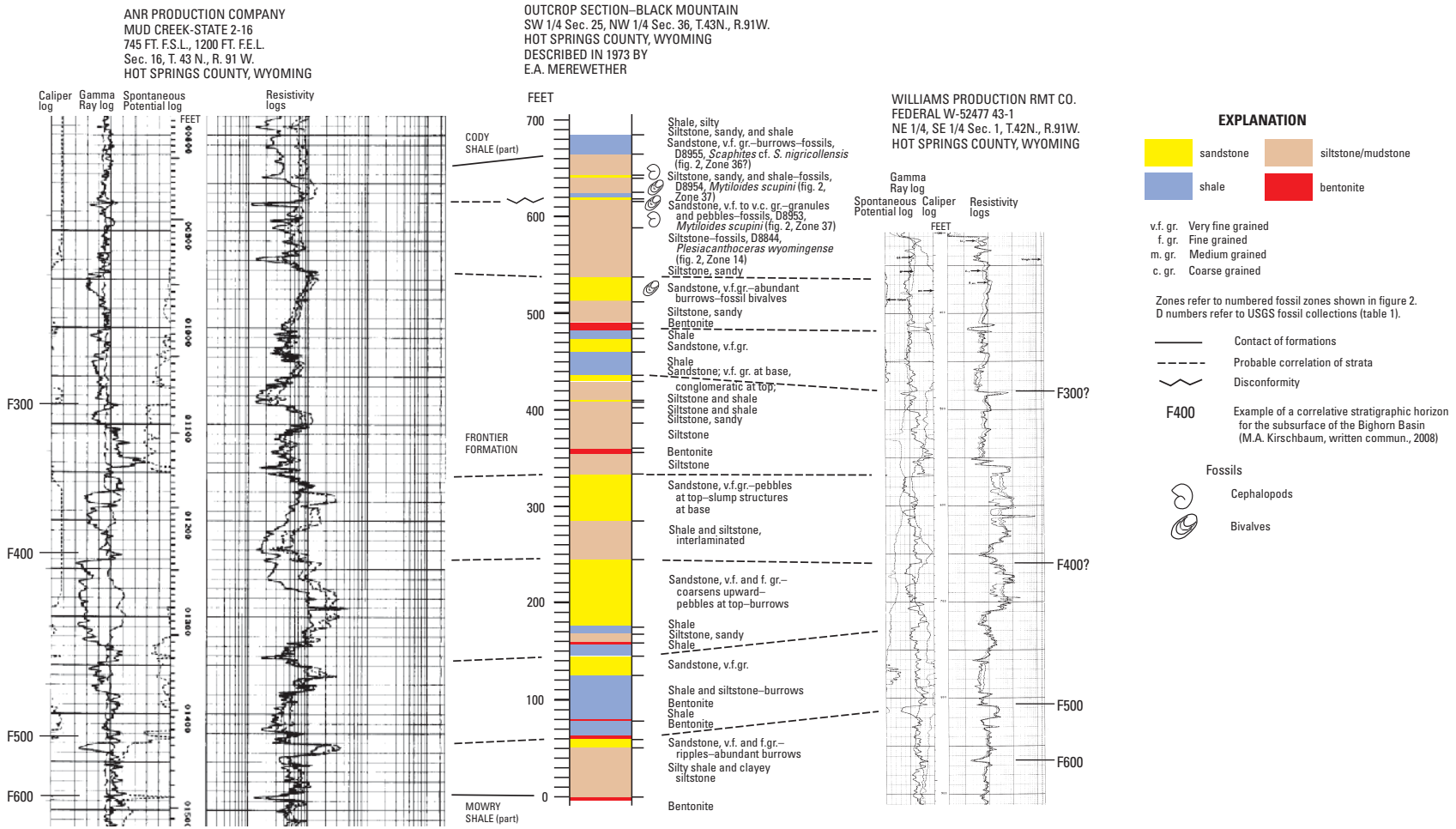


Figure 14. Columnar section and lithologic description of Frontier Formation in outcrops near Black Mountain, southern Bighorn Basin (fig. 1). Also shown are surface-to-subsurface correlations with nearby boreholes.

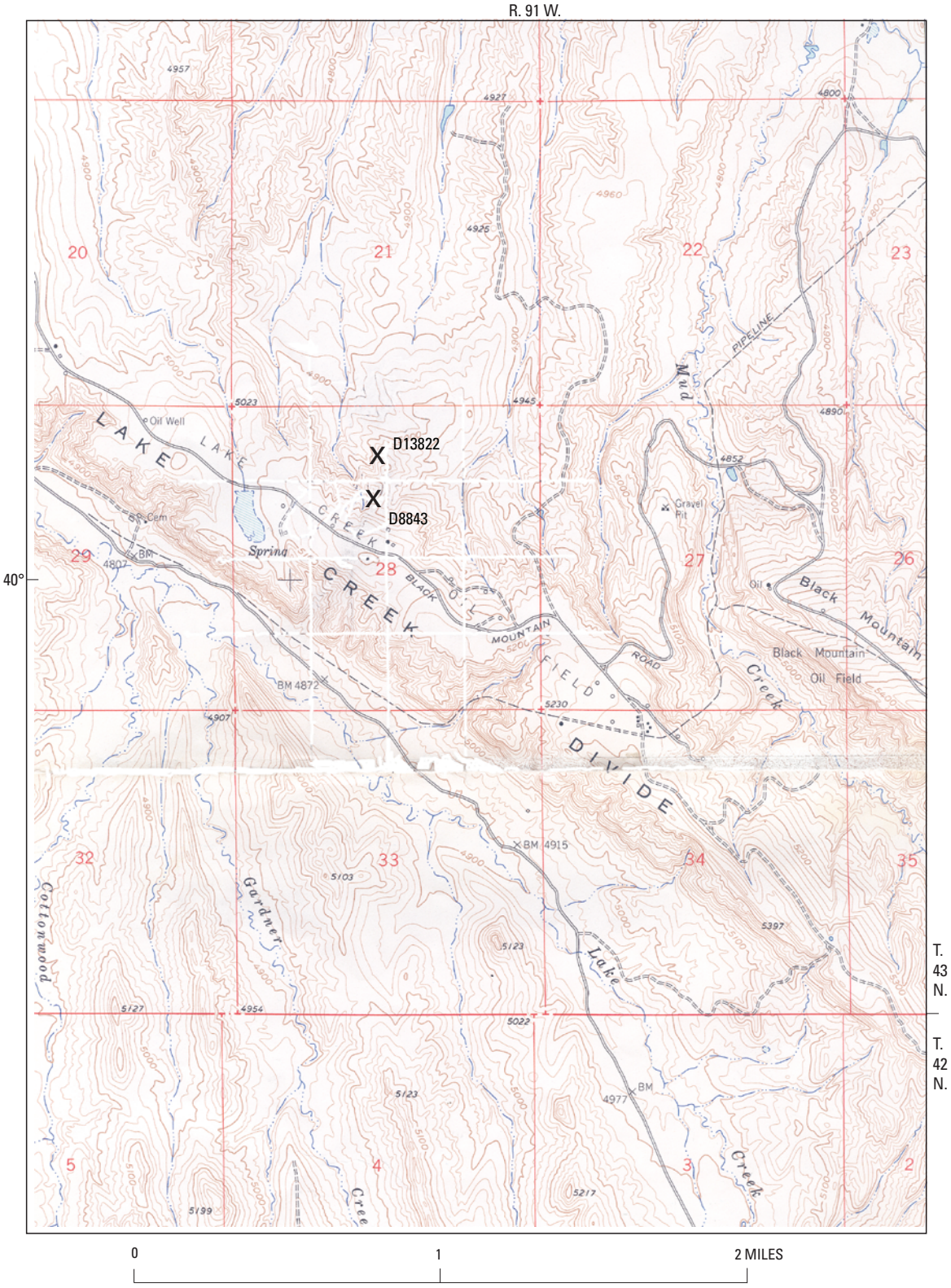


Figure 15. Fossil localities near Black Mountain in the Packsaddle Creek quadrangle (7.5-minute, 1960), Hot Springs County, Wyoming. D numbers refer to USGS fossil collections (table 1).

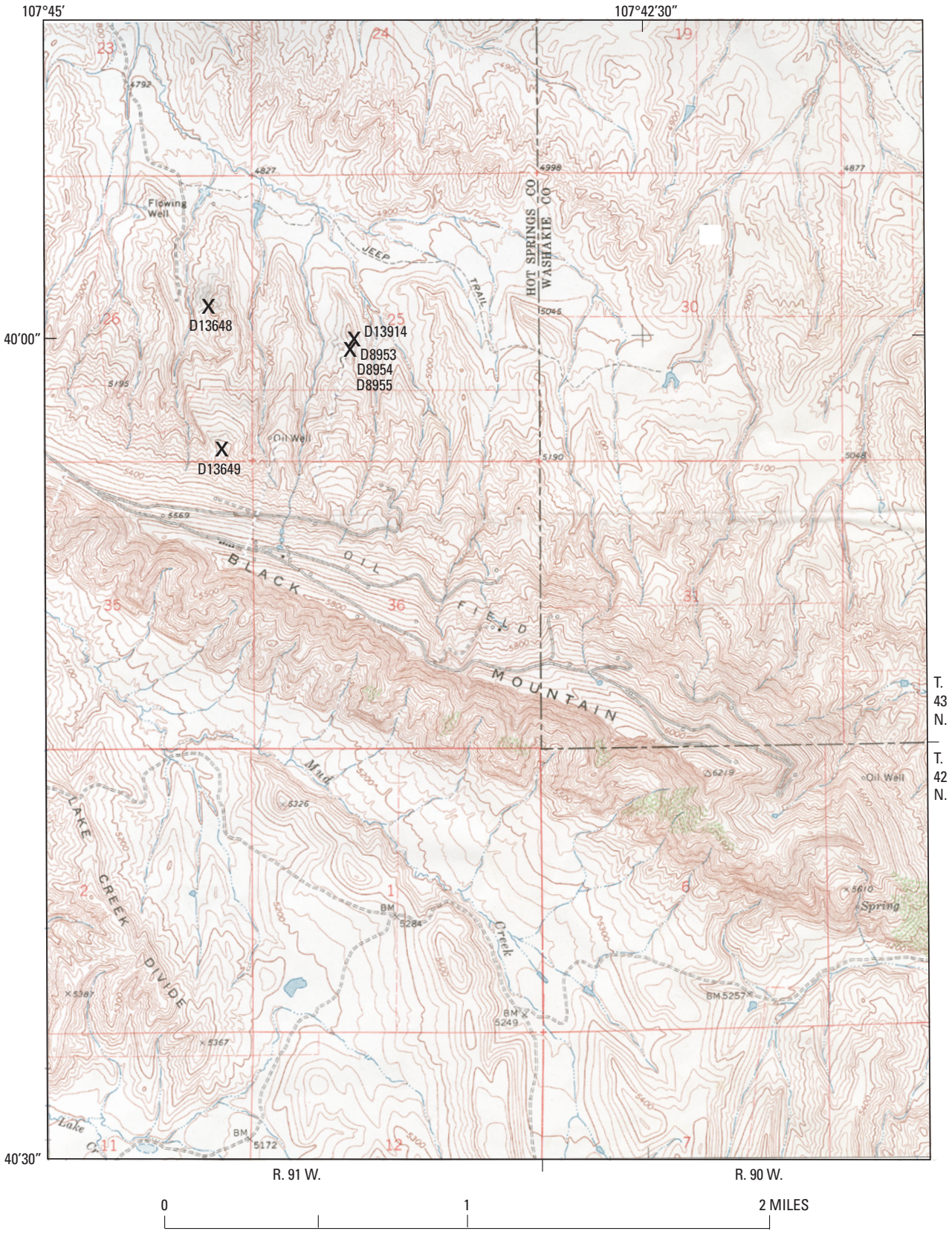


Figure 16. Fossil localities near Black Mountain in the Bader Draw quadrangle (7.5-minute, 1960), Hot Springs County, Wyoming. D numbers refer to USGS fossil collections (table 1).

Conlinoceras tarrantense (D8843; fig. 2, Zone 9; table 1), were found from 100 to 120 ft below the top. Ammonites of latest middle Cenomanian age, *Plesiacanthoceras wyomingense* (D8844; fig. 2, Zone 14), are in the uppermost 20 ft of this lower sequence.

The upper sequence consists of a basal fine to very coarse grained sandstone that contains granules and pebbles, a sandy siltstone, and an upper very fine grained sandstone. These strata, 15- to 65-ft thick, enclose marine bivalves of late Turonian age (D8845, D8846, D8953, and D8954, *Mytiloides scupini*, fig. 2, Zone 37; table 1). The lacuna between the lower and upper sequences of the Frontier in this area spans late Cenomanian and early and middle Turonian time. In contrast, an outcrop of the upper part of the Frontier about 6 mi west of Black Mountain, between Black Mountain and Thermopolis (fig. 1), contains an early late Turonian bivalve, *Inoceramus perplexus* (D9317; fig. 2, Zone 34).

Overlying the Frontier is marine shale of the Cody Shale, the lower beds of which contain molluscan fossils of early Coniacian age: D8842, *Forresteria* sp., and D13822, *Baculites mariasensis* (fig. 2, Zones 39–41). The contact of the Frontier and the Cody in this area could be either conformable or a disconformity that represents a minor lacuna.

Outcrops near Shanty Ridge and Big Trails, Wyoming

Outcrops near the southeastern margin of the basin (figs. 1, 17) were described by Merewether and others (1975, 1998). In this area, several parts of the Frontier are concealed and the stratigraphy is probably complicated by faulting. Thickness a few miles east of Shanty Ridge could be as much as 855 ft. Sandstones in these outcrops range from very fine to medium grained and a few contain pebbles. Marine beds containing burrows are common; however, several beds were deposited probably in estuarine environments. Fossils collected from the upper part of the Frontier near Shanty Ridge (D13827 and D13828) include *Dunveganoceras pondi* of earliest late Cenomanian age (fig. 2, Zone 15).

At outcrops about 3 mi south of Shanty Ridge, fossils from the upper part of the Frontier include the early late Turonian bivalve, *Inoceramus perplexus* (D9251; fig. 2, Zone 34). Outcrops of the lower part of the Cody Shale, about 2 mi south of Shanty Ridge, contain the latest Turonian bivalve, *Cremnoceramus waltersdorfensis* (D9006; fig. 2, Zone 38).

Outcrops at Mud Gulch and Joe Emge Creek, Wyoming

South of Ten Sleep (fig. 1), near the southeastern margin of the Bighorn Basin, the Frontier at two localities (fig. 18) was described by Merewether and others (1998) and was examined further by Tillman and Merewether in 1999. Sandstones in these sequences are mostly very fine and fine grained and rarely medium grained and pebble-bearing. The formation includes flooding surfaces and transgressive beds and was deposited in environments that ranged from offshore marine to estuarine and possibly fluvial. It is as much as 860 ft thick.

The Frontier at these outcrops probably is entirely of Cenomanian age and is disconformably overlain by upper Turonian strata of the basal Cody Shale. Ammonites in the upper part of the Frontier are *Plesiacanthoceras wyomingense* (D13823) of the latest middle Cenomanian (fig. 2, Zone 14) and *Metoicoceras mosbyense* (D13825) of the early late Cenomanian (fig. 2, Zone 17). Molluscan fossils of early Coniacian age in the lower part of the Cody Shale include *Scaphites preventricosus* (D13228; fig. 2, Zones 39–41; table 1) and *Scaphites impendicostatus* (D13824; fig. 2, Zone 40; table 1). The disconformable contact of the Cenomanian and Coniacian strata apparently represents latest Cenomanian and most of Turonian time.

Outcrops near Ten Sleep, Wyoming

About 3 mi west of Ten Sleep (fig. 1), outcrops of the Frontier were examined by Merewether and others (1975, 1998) and additionally by Tillman and Merewether in 1996. The Frontier is faulted in parts of that area. Sequences of the exposed strata can be correlated with those penetrated in nearby boreholes (fig. 19). Where described, the formation is as much as 860 ft thick and consists of siliciclastic and bentonitic beds that were deposited in marine and estuarine environments. A disconformity in the upper part separates strata of Cenomanian and Turonian ages.

The lower part of the Frontier, of Cenomanian age, is at least 620 ft thick. Sandstones in these strata are mostly very fine or fine grained and rarely medium to very coarse grained and pebble-bearing. Thin beds of conglomerate are associated with a few of the sandstone beds. This sequence was deposited mainly in nearshore and estuarine environments but rarely in channels. Many of the beds contain burrows and those near the top of the sequence contain fossil bivalves and ammonites (figs. 19, 20, 21): D13911, *Inoceramus* sp., and D9009 and D13910, *Plesiacanthoceras wyomingense* of latest middle Cenomanian age (fig. 2, Zone 14).

The upper part of the Frontier, 140–170 ft thick, is mostly siliciclastic strata that accumulated in marine and estuarine depositional environments. This sequence includes a disconformity that separates middle Cenomanian strata from upper Turonian strata. A sandstone at the top of the Frontier apparently is of late Turonian age and is conformably overlain by the Cody Shale. Marine shale composing the lowermost Cody is about 40 ft thick and contains fossiliferous concretions. Collections of fossil bivalves from the basal Cody, D8956 and D8957, include *Mytiloides scupini* of late Turonian age (fig. 2, Zone 37). Another collection, D13734, from overlying beds,

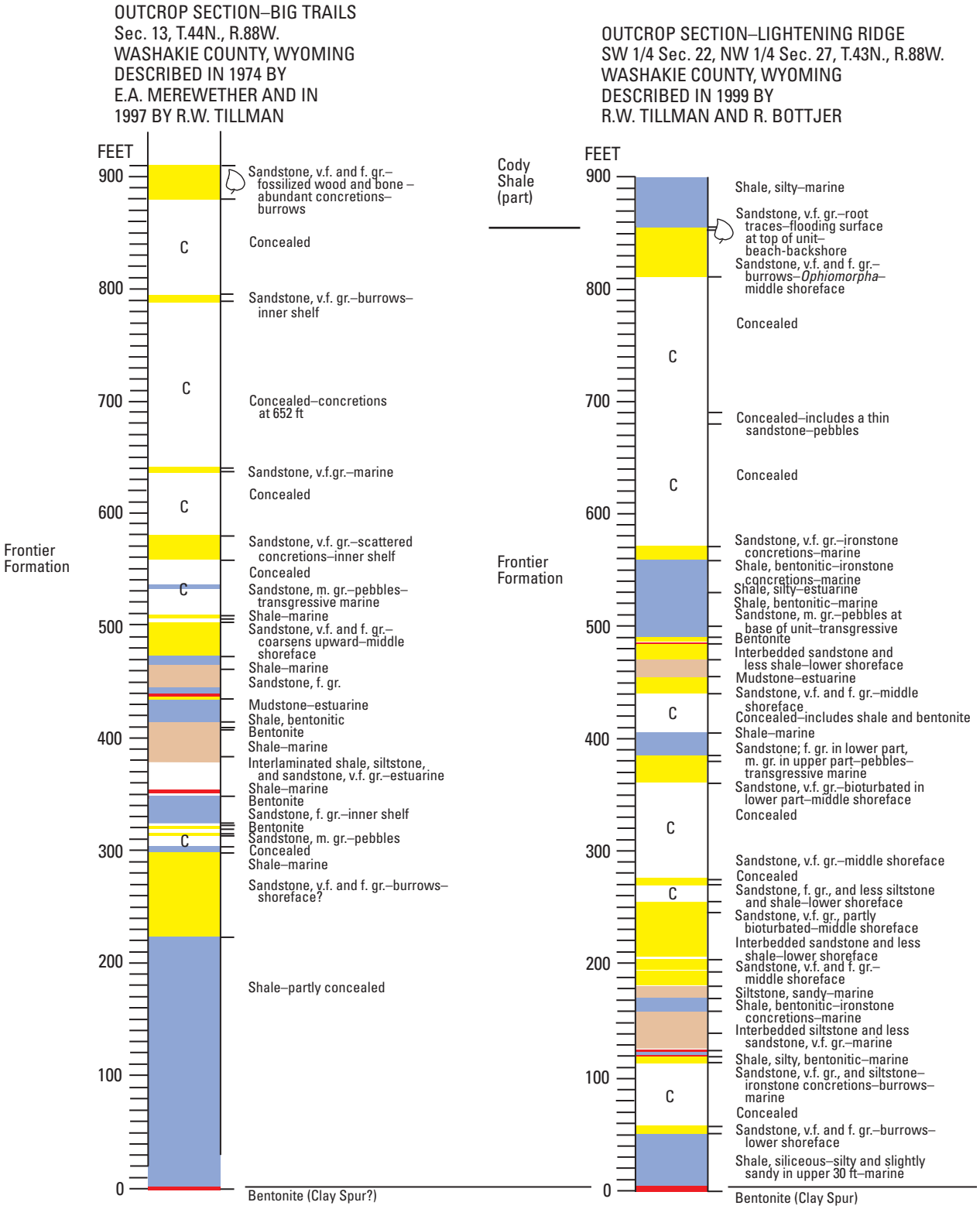
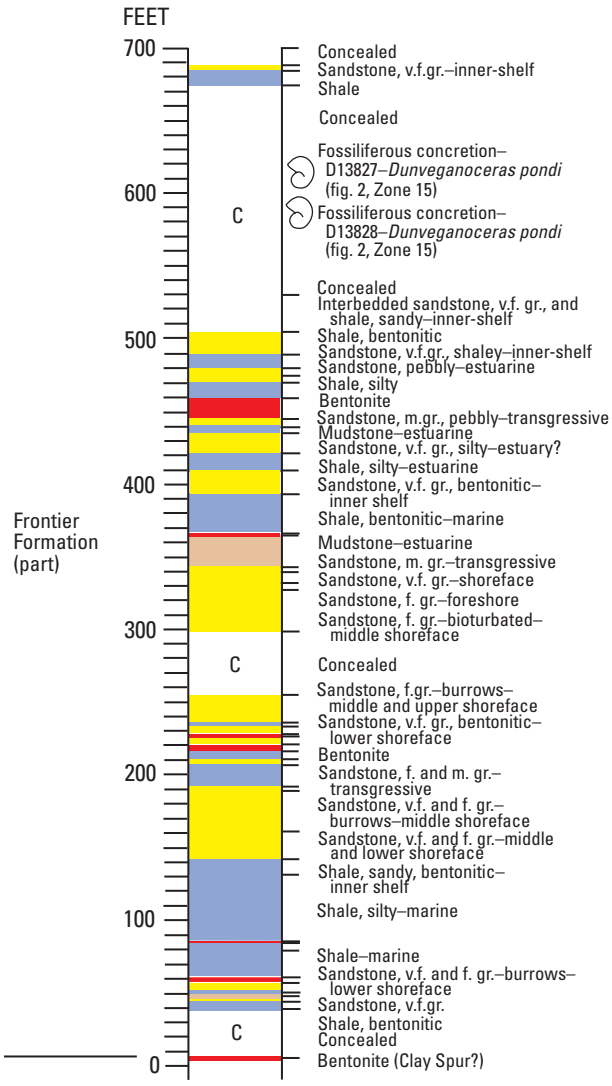


Figure 17. Columnar sections and lithologic descriptions of Frontier Formation in outcrops near Big Trails and Shanty Ridge, southeastern Bighorn Basin (fig. 1).

OUTCROP SECTION–SHANTY RIDGE DRAW
SE 1/4, NW 1/4 Sec. 26, T.43N., R.89W.
WASHAKIE COUNTY, WYOMING
DESCRIBED IN 1997 BY
R.W. TILLMAN AND
E.A. MEREWETHER



EXPLANATION

sandstone
shale
siltstone/mudstone
bentonite
C concealed

v.f. gr. Very fine grained
f. gr. Fine grained
m. gr. Medium grained
c. gr. Coarse grained

Zones refer to numbered fossil zones shown in figure 2.
D numbers refer to USGS fossil collections (table 1).

Contact of formations

Fossils

Cephalopods

Plant fragments

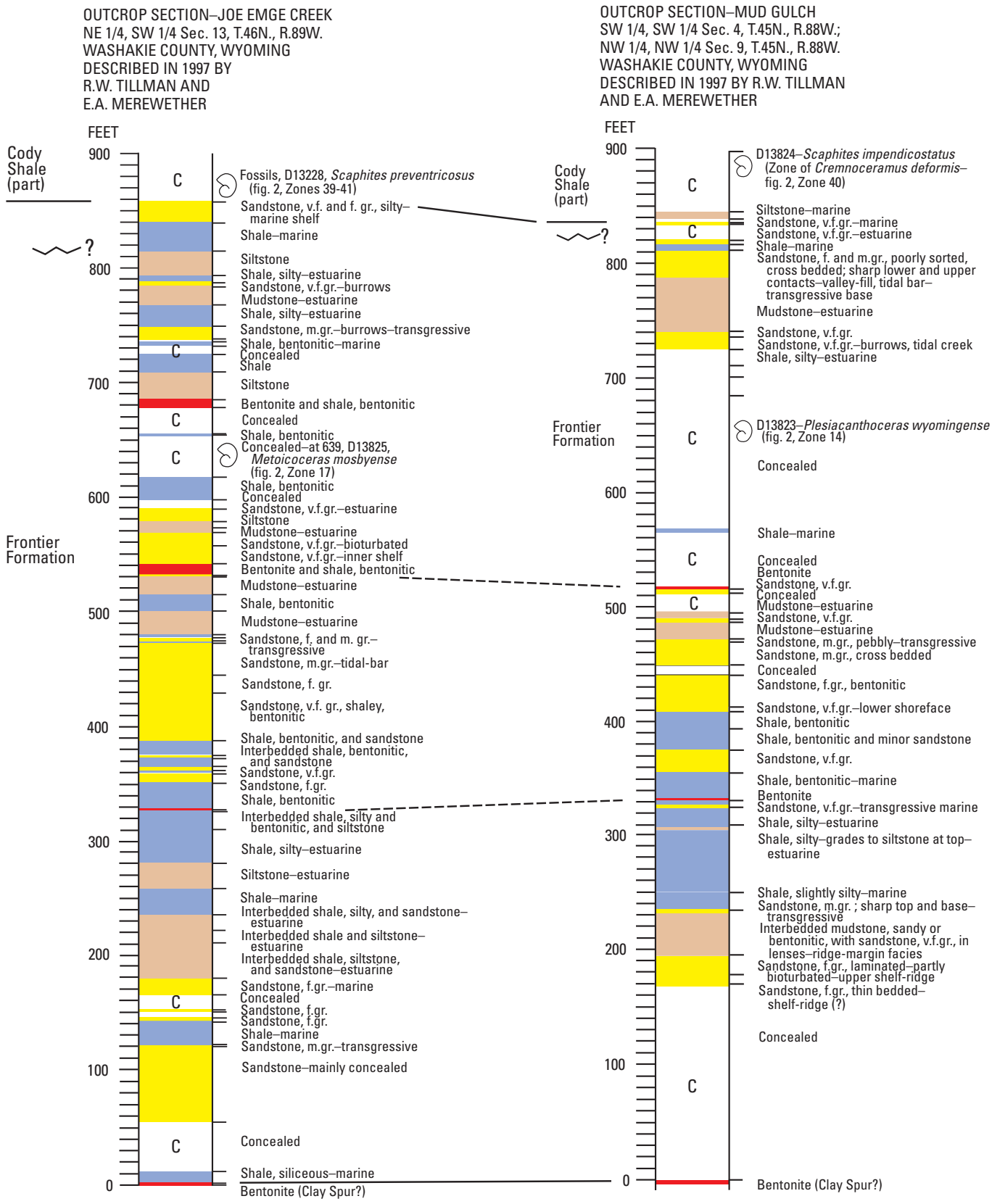
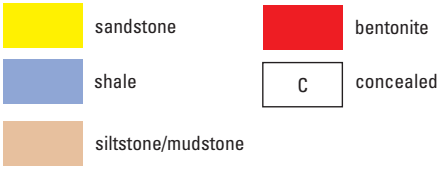


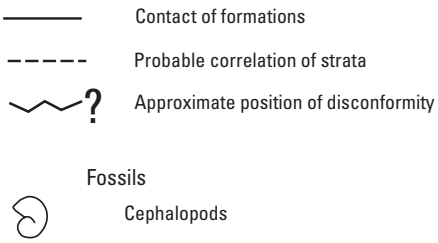
Figure 18. Columnar sections and lithologic descriptions of Frontier Formation in outcrops at Joe Emge Creek and Mud Gulch, southeastern Bighorn Basin (fig. 1).

EXPLANATION



v.f. gr. Very fine grained
f. gr. Fine grained
m. gr. Medium grained
c. gr. Coarse grained

Zones refer to numbered fossil zones shown in figure 2.
D numbers refer to USGS fossil collections (table 1).



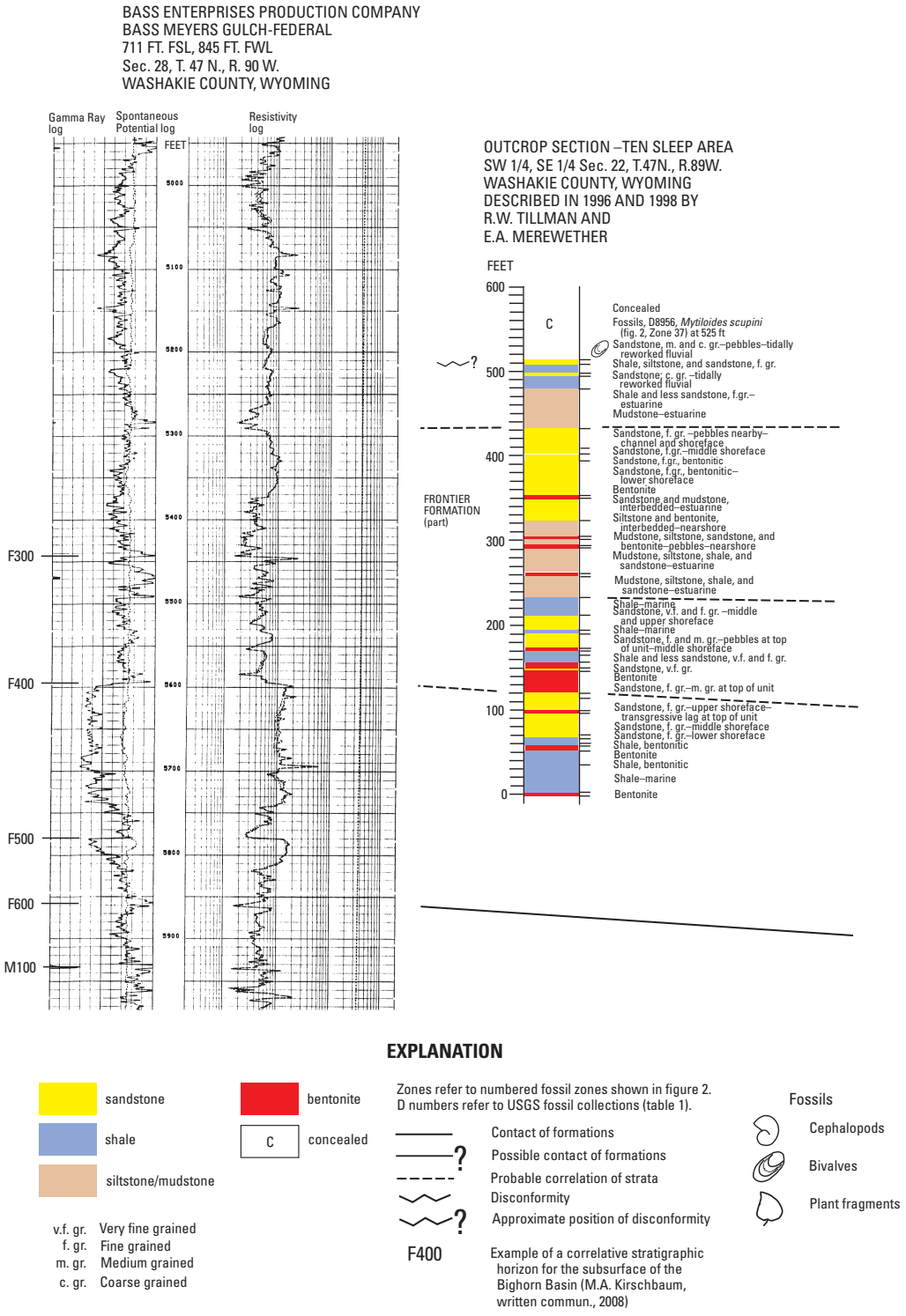
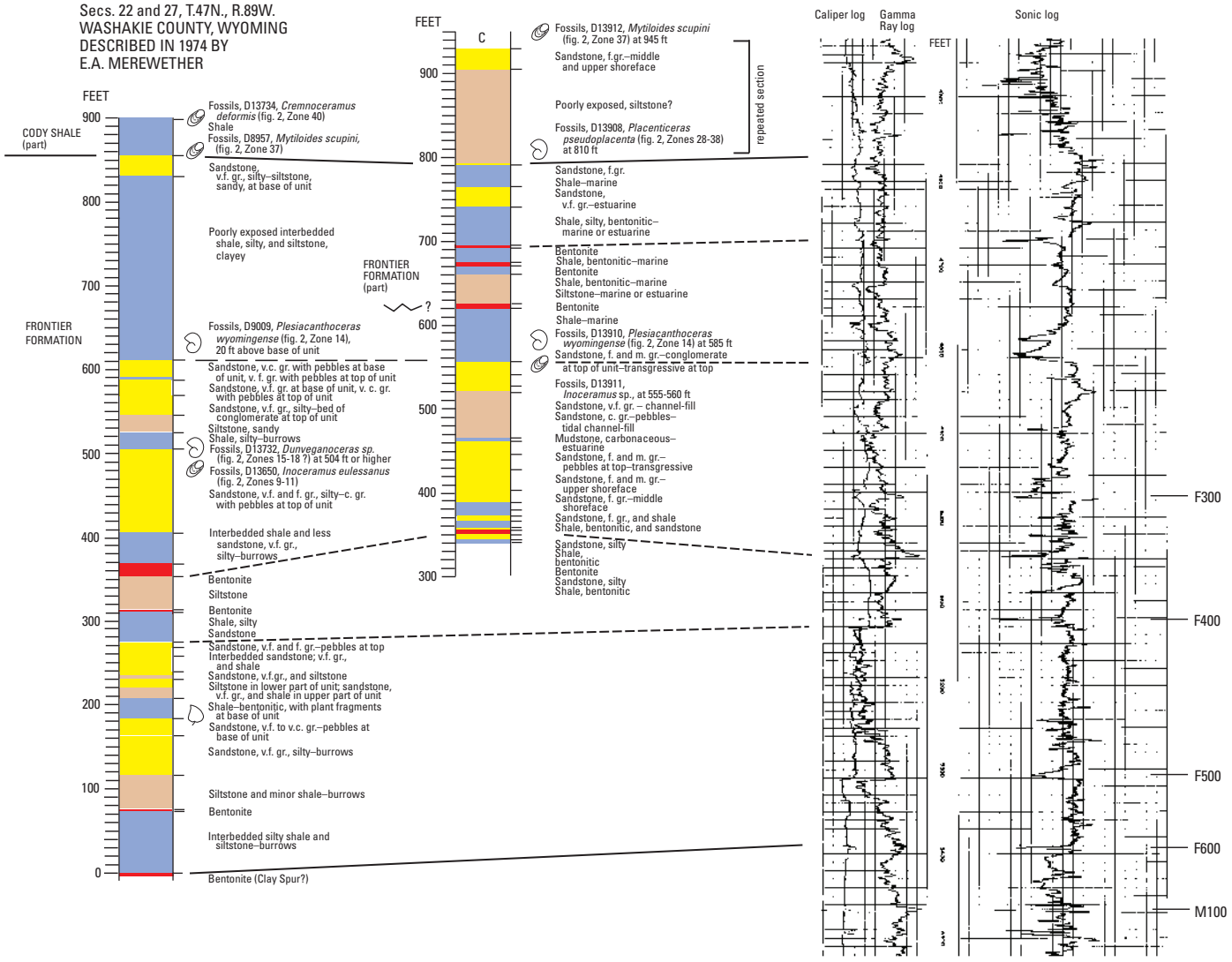


Figure 19. Columnar sections and lithologic descriptions of Frontier Formation in outcrops near Ten Sleep, southeastern Bighorn Basin (fig. 1). Also shown are surface-to-subsurface correlations with nearby boreholes.

OUTCROP SECTION –TEN SLEEP AREA
Secs. 22 and 27, T.47N., R.89W.
WASHAKIE COUNTY, WYOMING
DESCRIBED IN 1974 BY
E.A. MEREWETHER

OUTCROP SECTION –McCLELLAN GULCH
SE 1/4, NW 1/4 Sec. 25, T.47N., R.89W.
WASHAKIE COUNTY, WYOMING
DESCRIBED IN 1998 AND 1999
BY R.W. TILLMAN

CHORNEY RAYMOND
SHOAL UNIT 2
2180 FT. FSL, 616 FT. FWL
Sec. 6, T. 46 N., R. 89 W.
WASHAKIE COUNTY, WYOMING



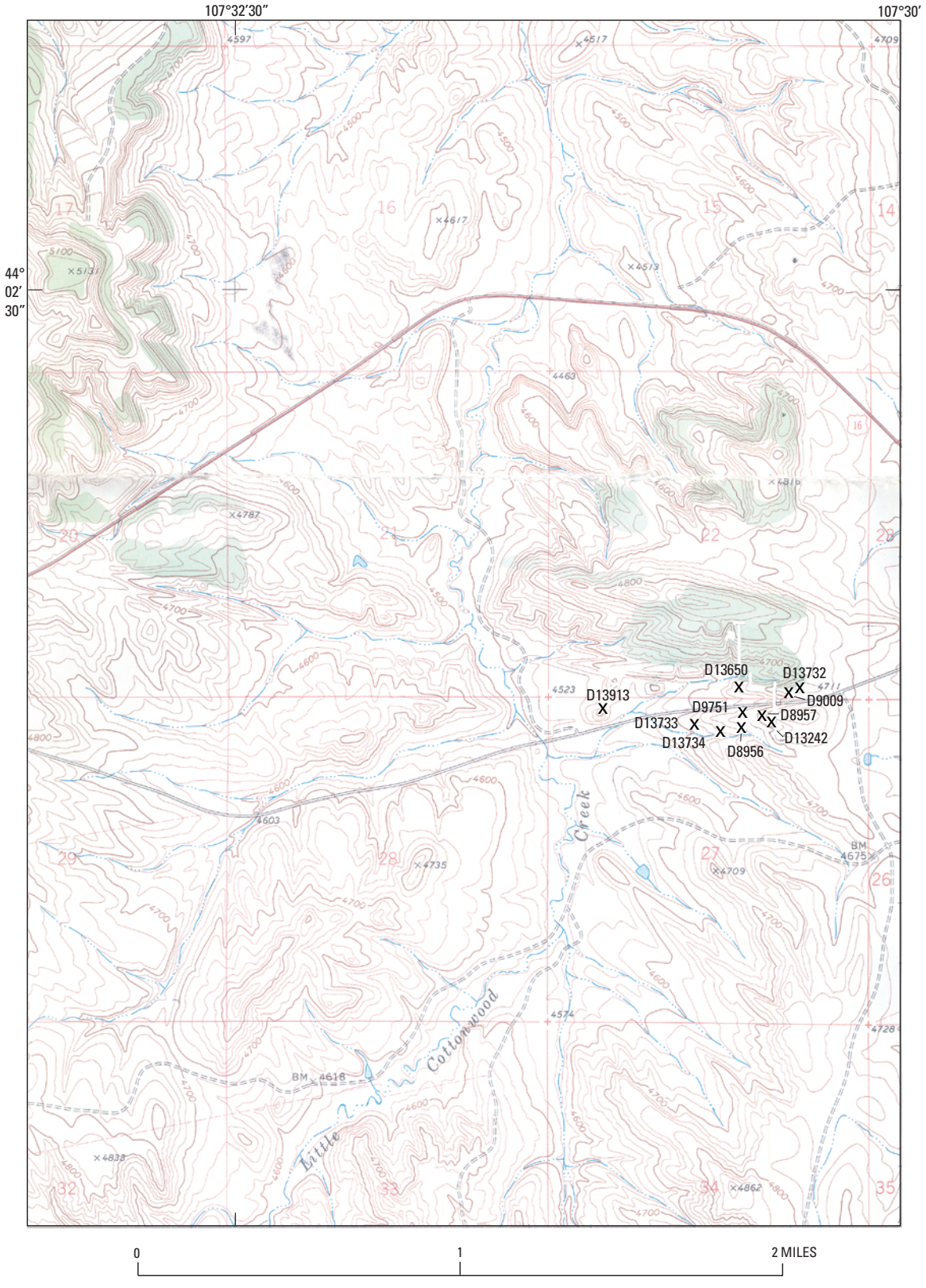


Figure 20. Fossil localities near Ten Sleep in the Wild Horse quadrangle (7.5-minute, 1967), Washakie County, Wyoming. D numbers refer to USGS fossil collection (table 1).

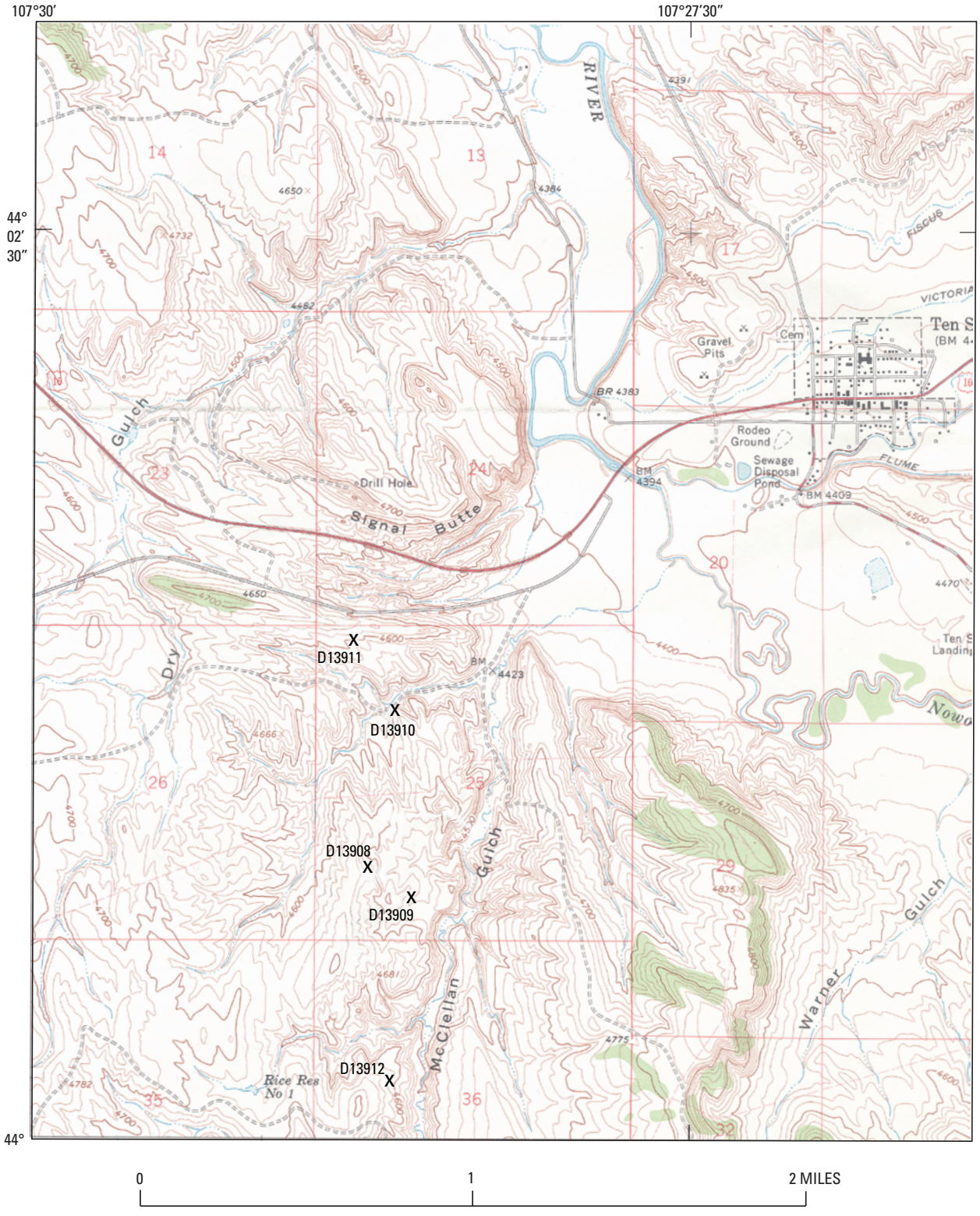


Figure 21. Fossil localities near McClellan Gulch in the Ten Sleep quadrangle (7.5-minute, 1967), Washakie County, Wyoming. D numbers refer to USGS fossil collections (table 1).

contains *Cremnoceramus deformis* of early Coniacian age (fig. 2, Zone 40).

The time span of the lacuna represented by the disconformity in the Frontier in this area probably includes the late Cenomanian, the early and middle Turonian, and an early part of the late Turonian.

Outcrops at Bonanza Oil Field, Wyoming

The Bonanza oil field is about 18 mi northwest of Ten Sleep, Wyo., and about 25 mi southeast of Greybull, Wyo. (fig. 1). Outcrops of the Frontier in this area (fig. 22) were discussed by Merewether and others (1975), and examined further by Tillman and Merewether in 1996. The Frontier is at least 745 ft thick and consists mainly of sandstone, siltstone, and shale deposited in marine and estuarine environments. The sandstones are mainly very fine to fine grained and are rarely conglomeratic.

Many beds in the Frontier at the Bonanza locality contain burrows, and several beds in the upper part contain molluscan fossils (figs. 22, 23, 24) including *Plesiacanthoceras wyomingense* of latest middle Cenomanian age (D8992; fig. 2, Zone 14) and *Dunveganoceras pondi* of earliest late Cenomanian age (D9267; fig. 2, Zone 15). Fossils in basal strata of the overlying Cody Shale include *Mytiloides incertus* of late Turonian age (D9268 and D9269; fig. 2, Zone 36) and *Cremnoceramus deformis dobrogensis* of early Coniacian age (D8994; fig. 2, Zone 40).

Outcrops near Greybull, Wyoming

Outcrops of the Frontier about 3 mi northeast of Greybull, Wyo. (figs.1, 25), were described by Merewether and others (1975) and examined further by Tillman and Merewether in 1998 and 1999. Outcrops about 10 mi southeast of Greybull, near Potato Ridge (fig. 1), were also described by the authors in 1998 and 1999. The strata were deposited in offshore, nearshore, and brackish-water environments. The sandstones are mostly very fine and fine-grained; a few are medium-grained and contain pebbles. In this area, the Frontier is about 715 ft thick, although in a few places thickness measurements might reflect some faulting. As shown in figure 25, correlations can be made with equivalent sequences in nearby boreholes.

Collections of fossils from localities northeast of Greybull (figs. 26, 27) include D13652, *Lingula subspatulata* (possibly a brackish-water species), from the top of the thick sandstone in the lower part of the Frontier (the Peay Sandstone Member). Collections of ammonites from the upper part of the Frontier in that area are: D9278, *Plesiacanthoceras wyomingense* of latest middle Cenomanian age (fig. 2, Zone 14), and D9752 and D13916, *Dunveganoceras pondi* of earliest late Cenomanian age (fig. 2, Zone 15). In that area, the Frontier is disconformably overlain by marine shale of the Cody Shale. A collection of fossils from the basal Cody, D9754, contains *Baculites yokoyamai* of late Turonian age (fig. 2, Zones 34–39; table 1). The lacuna at or near the Frontier-Cody contact spans most of the upper Cenomanian as well as the lower and middle Turonian.

At the outcrops southeast of Greybull near Potato Ridge (fig. 28), the lower part of the Frontier is at least 535 ft thick and is of Cenomanian age. Collections of molluscan fossils from that area include: D13731, *Acanthoceras amphibolum* of late middle Cenomanian age (fig. 2, Zone 13); D13919, *Plesiacanthoceras wyomingense* of latest middle Cenomanian age (fig. 2, Zone 14); D13920, *Dunveganoceras pondi* of earliest late Cenomanian age (fig. 2, Zone 15); and D13921, *Metoicoceras frontierense* of early late Cenomanian age (fig. 2, Zone 16; table 1).

Outcrops at Lovell Draw and North Emblem, Wyoming

Outcrops of the Frontier Formation between Greybull and Lovell, Wyo. (figs. 1, 29), were examined at Lovell Draw in 1996 and 1998 and at North Emblem by Merewether and others (1975). The formation, where exposed in this area, is 670 ft thick and of Cenomanian age. Sandstones in these exposures are generally very fine or fine grained and are rarely medium grained and pebble-bearing. Most of the strata at these localities were deposited in nearshore-marine environments. Many beds contain burrows and a few near the top of the formation enclose molluscan fossils.

Fossils include the ammonite *Dunveganoceras conditum* (D13917) of middle late Cenomanian age (fig. 2, Zone 18). Mollusks from near the top of the formation at North Emblem include the bivalve *Inoceramus ginterensis* (D9276) of early late Cenomanian age (fig. 2, Zones 16–18). Outcrops about 2 mi south of North Emblem contain the early late Cenomanian ammonite *Dunveganoceras albertense* (D9271; fig. 2, Zone 17). At North Emblem, concretions about 100 ft above the base of the overlying Cody Shale contain *Baculites* sp. of Turonian age (D9277). A disconformity separating beds of middle late Cenomanian age in the Frontier from beds of Turonian age in the Cody probably spans the uppermost Cenomanian and the lower and middle Turonian.

Outcrops at Crooked Creek, Wyoming

Outcrops of the Frontier and the lower part of the Cody at Crooked Creek, Wyo. (figs. 1, 30), about 8 mi north of Lovell, Wyoming, were described by Merewether and others (1975). These strata, about 760 ft thick, can be traced into

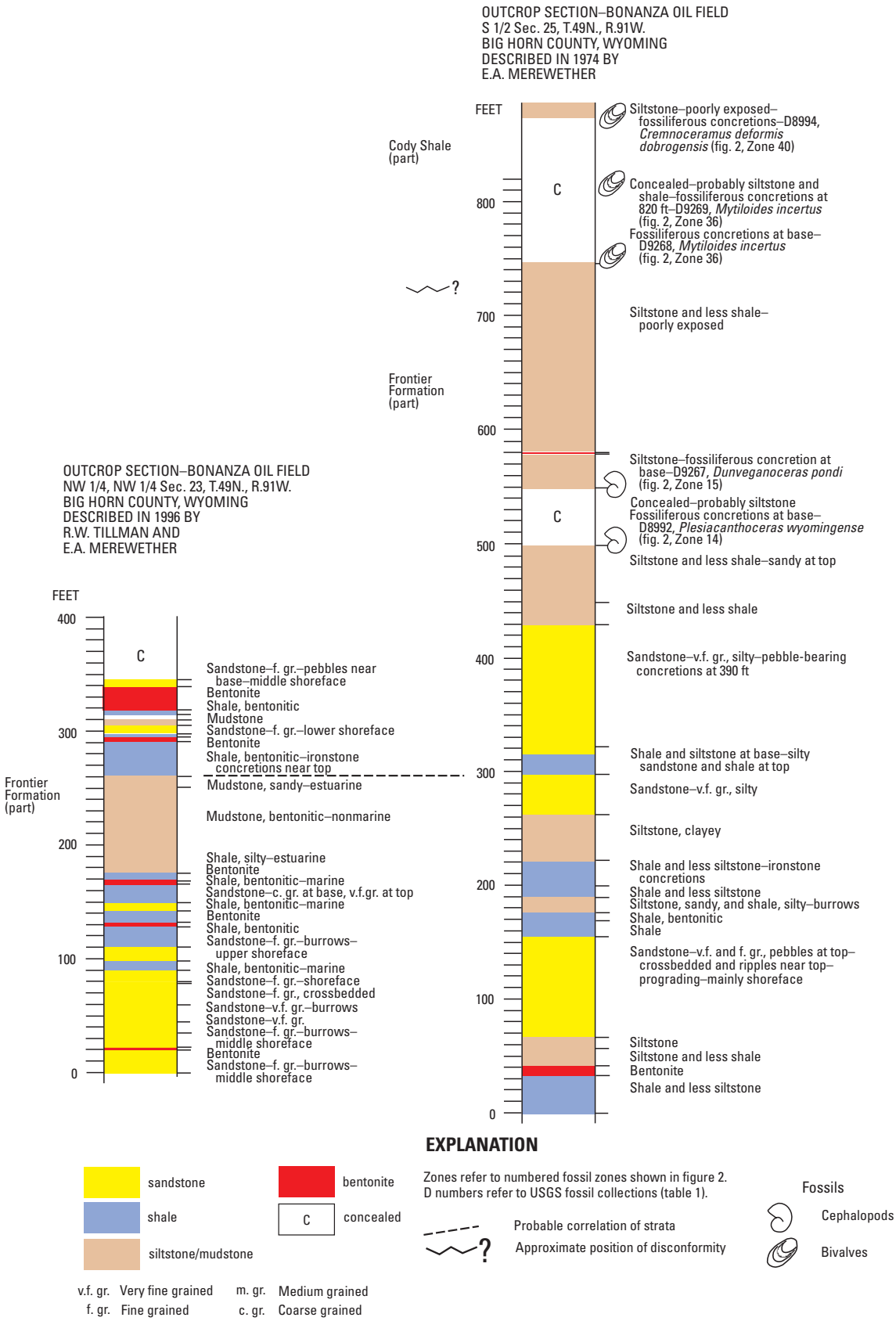


Figure 22. Columnar sections and lithologic descriptions of Frontier Formation in outcrops in the Bonanza oil field, eastern Bighorn Basin (fig. 1).

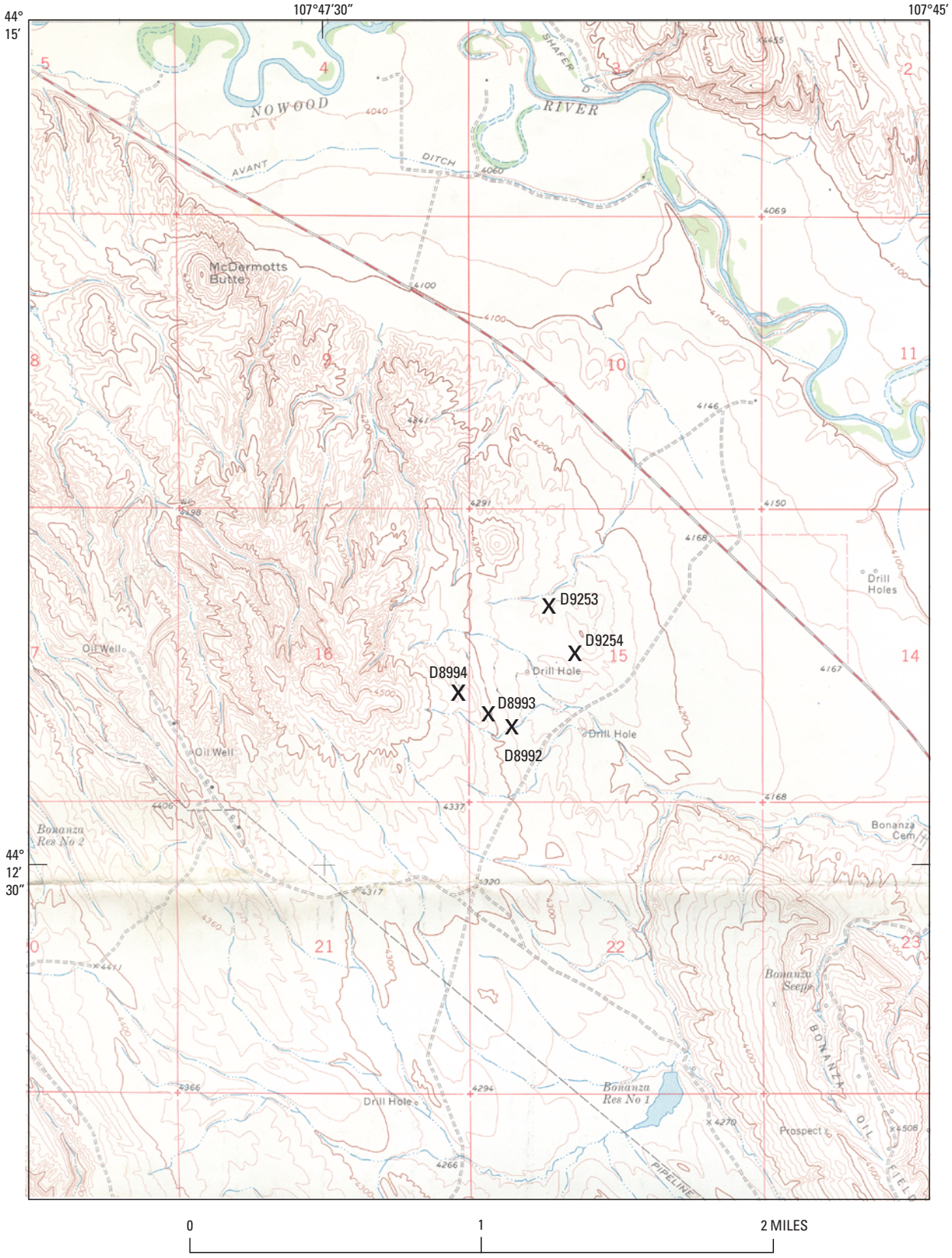


Figure 23. Fossil localities near the Bonanza oil field in the McDermotts Butte quadrangle (7.5-minute, 1967), Big Horn County, Wyoming. D numbers refer to USGS fossil collections (table 1).

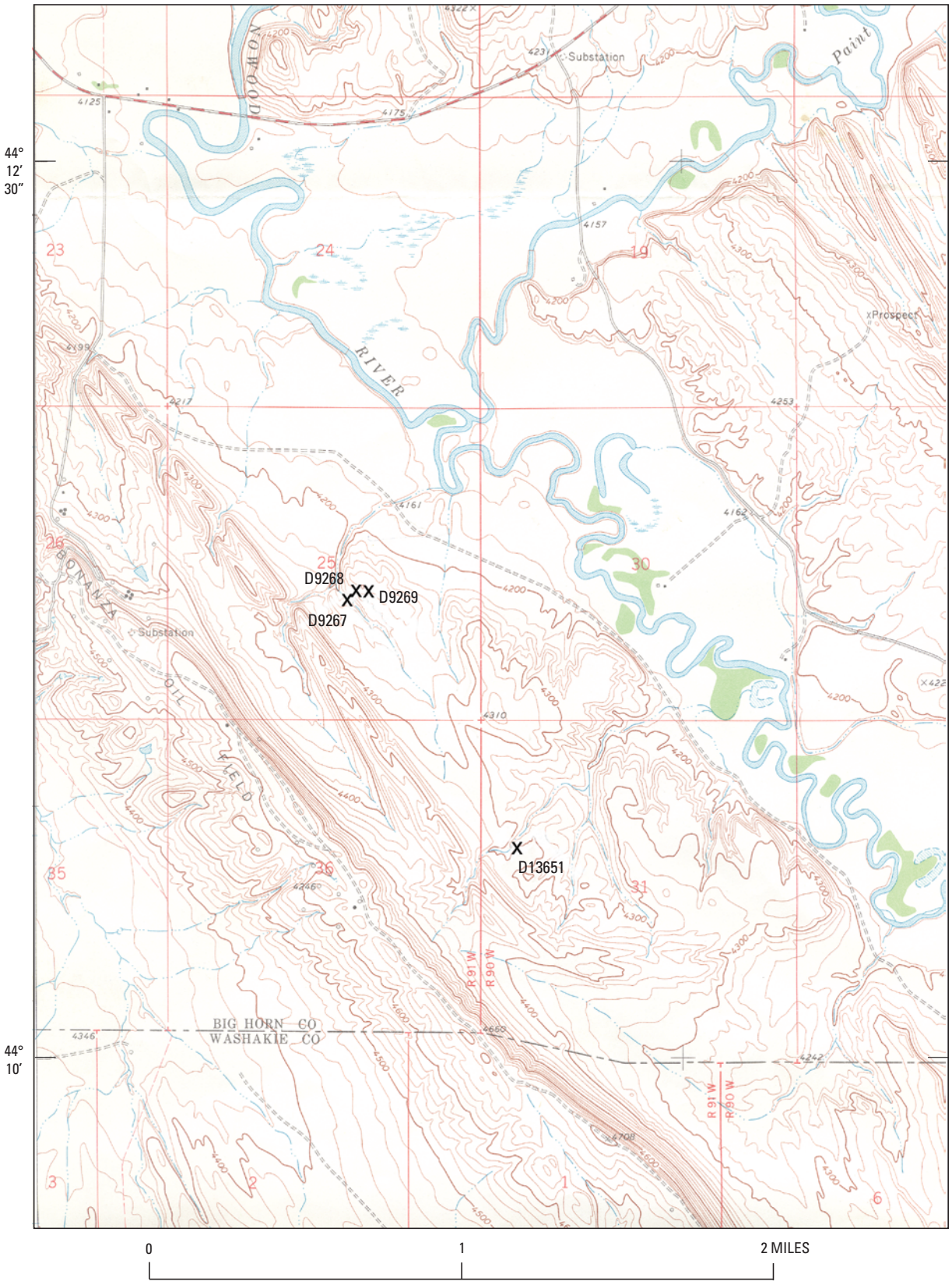


Figure 24. Fossil localities near the Bonanza oil field in the Weintz Draw quadrangle (7.5-minute, 1967), Big Horn County, Wyoming. D numbers refer to USGS fossil collections (table 1).

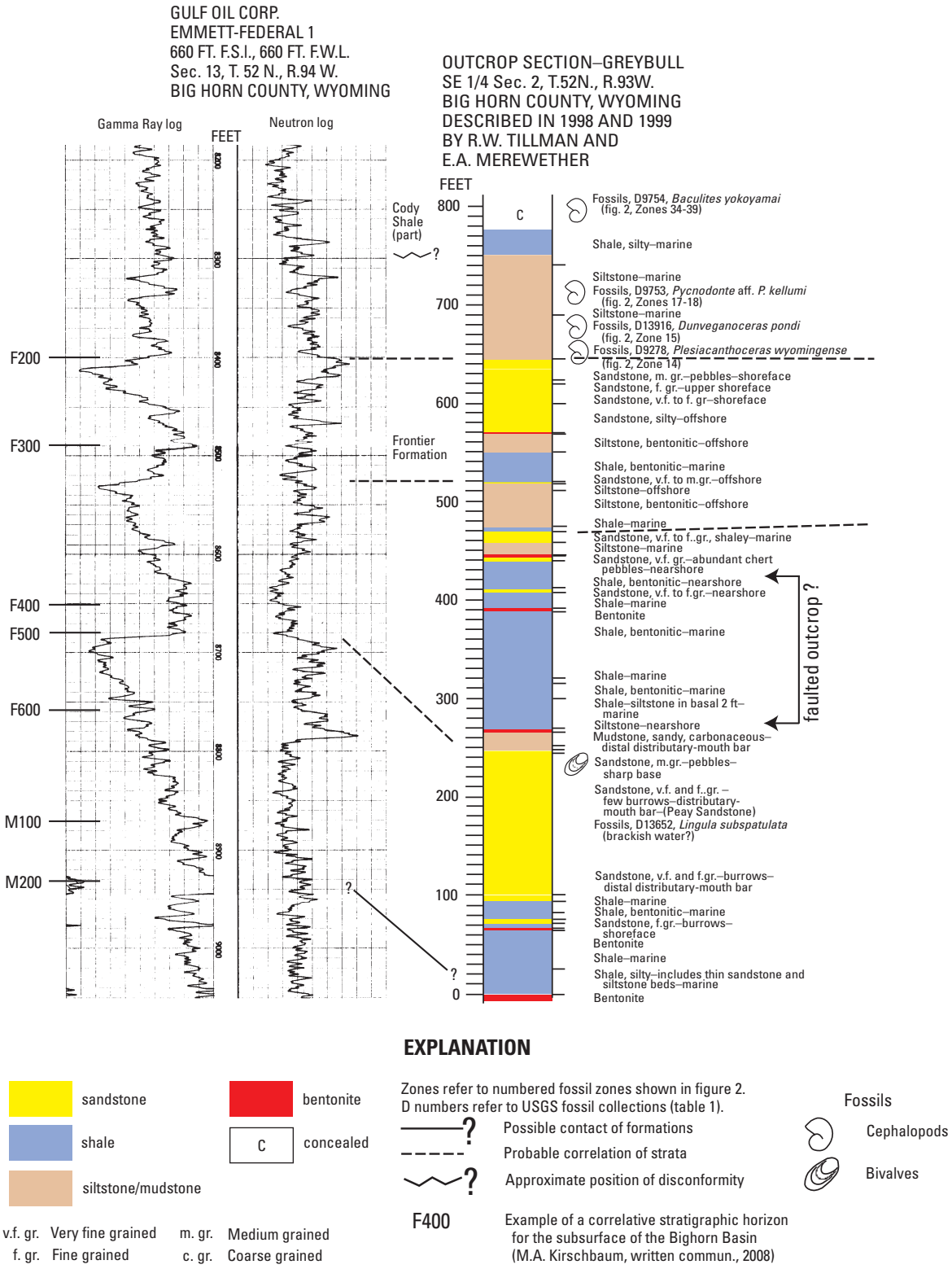
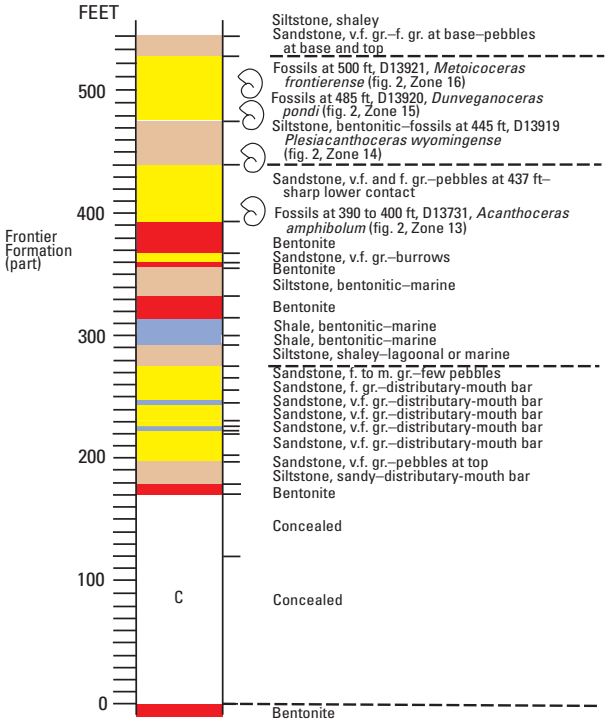
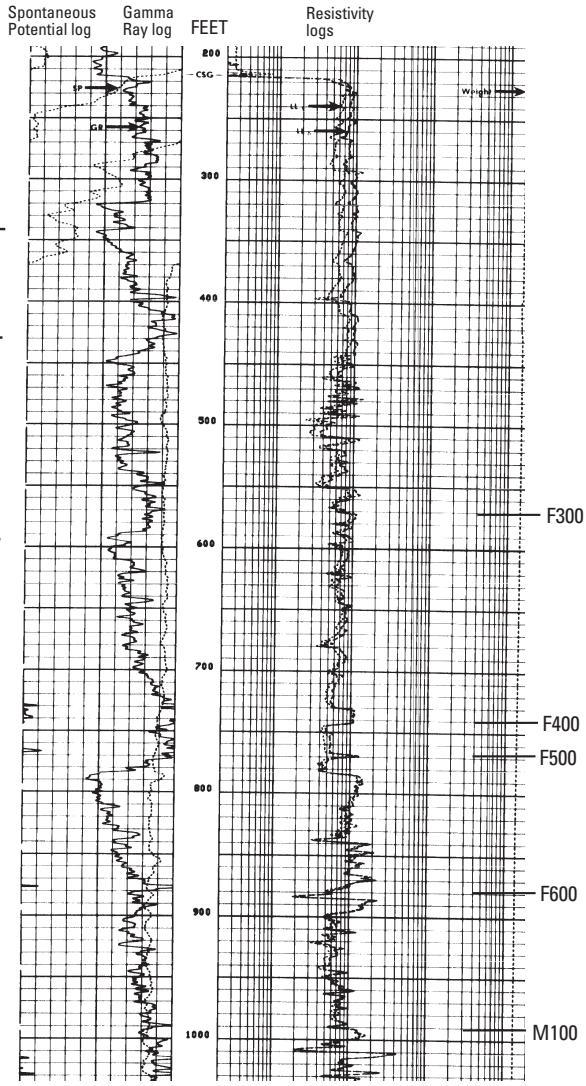


Figure 25. Columnar sections and lithologic descriptions of Frontier Formation in outcrops near Greybull and Potato Ridge, eastern Bighorn Basin (fig. 1). Also shown are surface-to-subsurface correlations with nearby boreholes. This section is modified from the version published in Kirschbaum and others (2009).

OUTCROP SECTION–POTATO RIDGE
NW 1/4, NW 1/4 Sec. 25, T.52N., R.92W.
BIG HORN COUNTY, WYOMING
DESCRIBED IN 1998 AND 1999 BY
R.W. TILLMAN AND
E.A. MEREWETHER



DATA BIG HORN BASIN
DATA 43-6
NE 1/4, SE 1/4 Sec. 6, T.51N., R.91W.
BIG HORN COUNTY, WYOMING



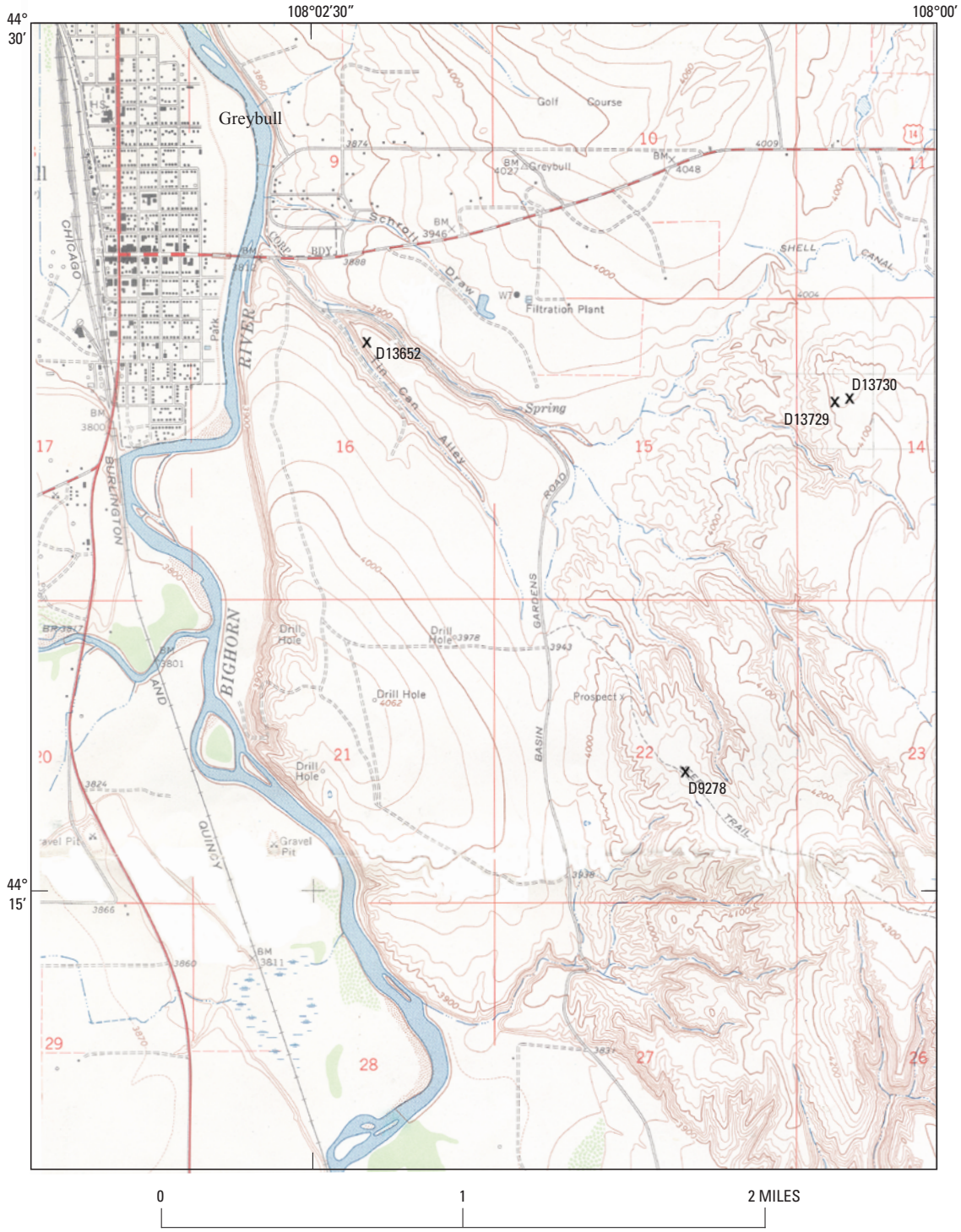


Figure 26. Fossil localities near Greybull in the Greybull South quadrangle (7.5-minute, 1966), Big Horn County, Wyoming. D numbers refer to USGS fossil collections (table 1).

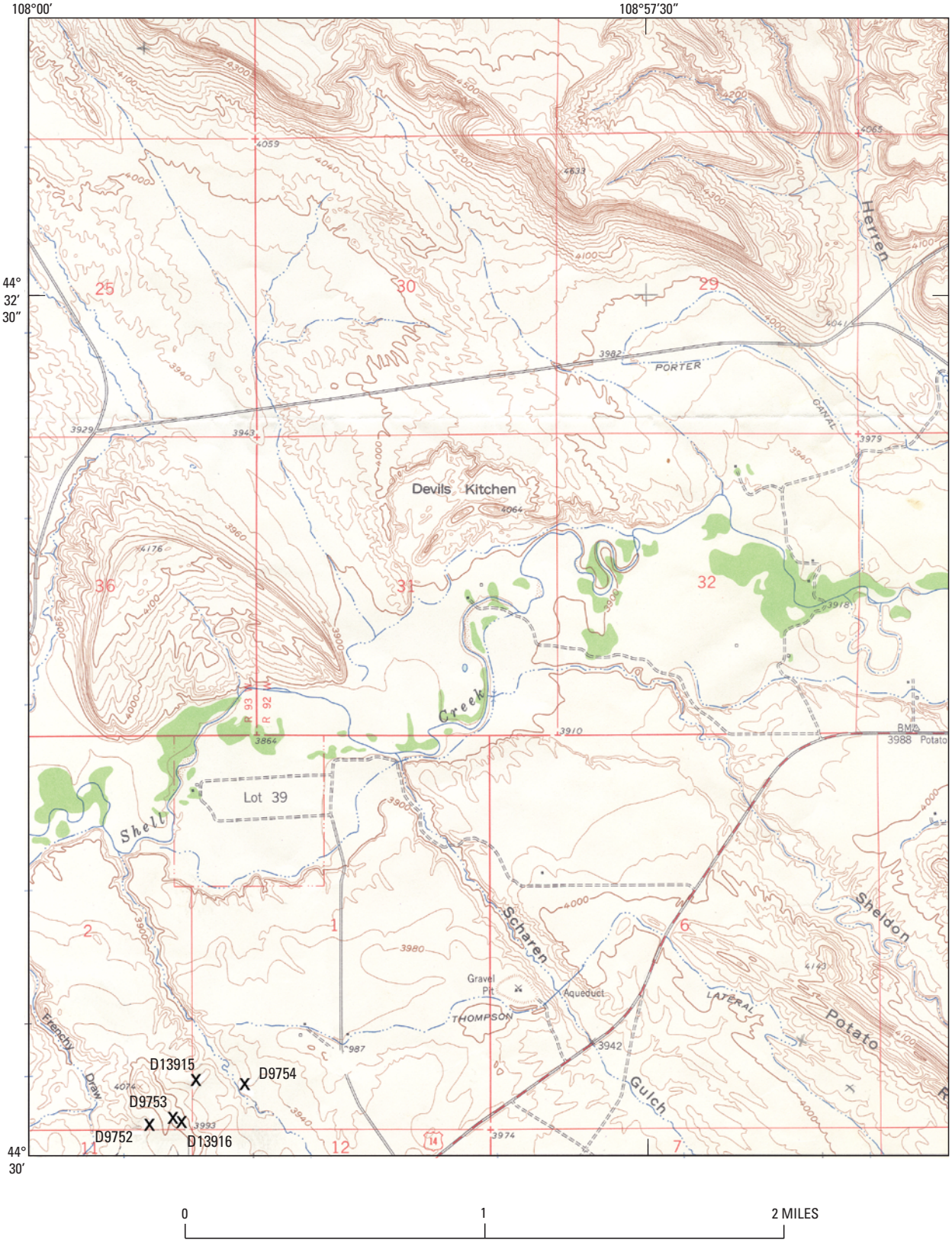


Figure 27. Fossil localities near Greybull in the Devils Kitchen quadrangle (7.5-minute, 1960), Big Horn County, Wyoming. D numbers refer to USGS fossil collections (table 1).

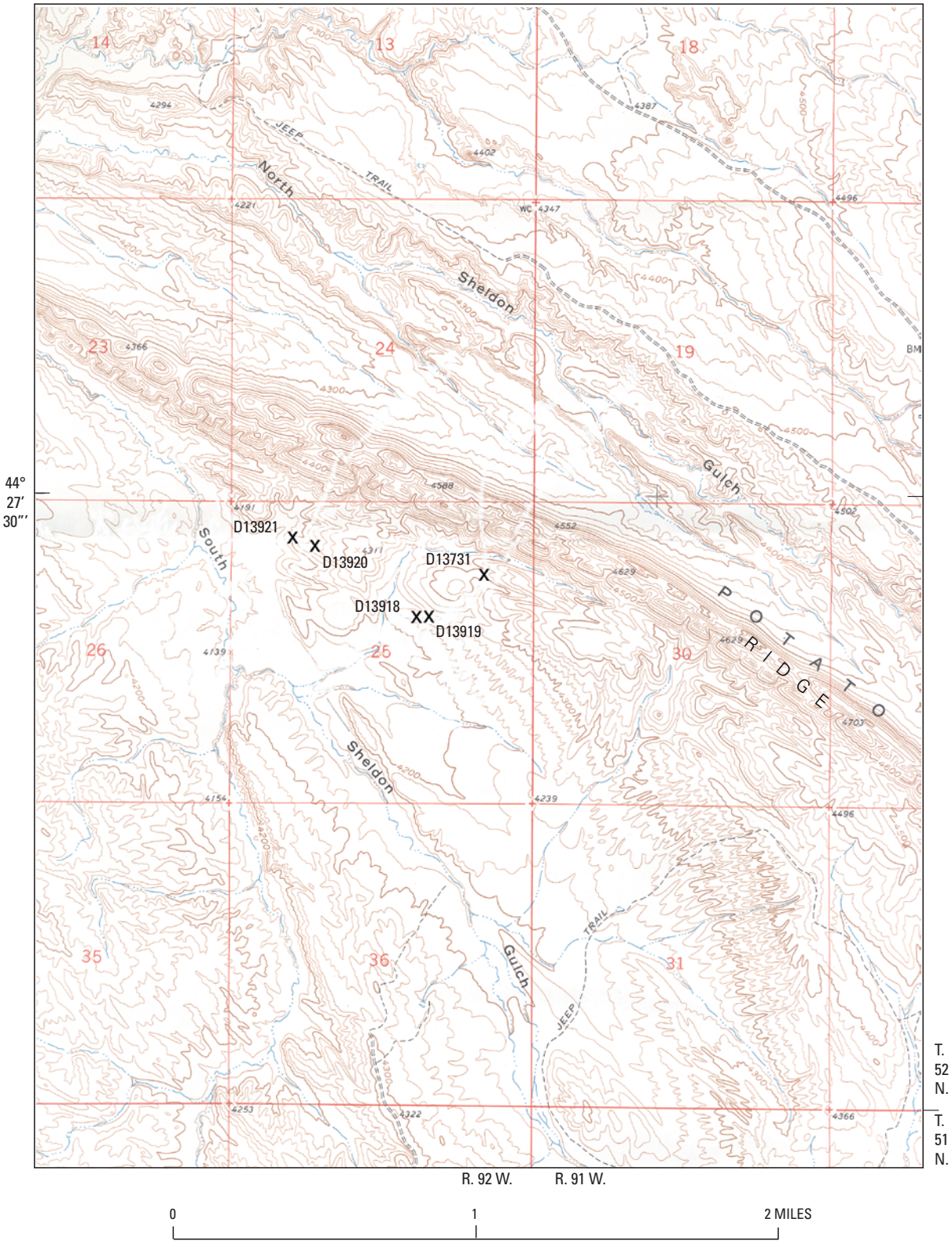


Figure 28. Fossil localities near Potato Ridge in the Manderson NE quadrangle (7.5-minute, 1960), Big Horn County, Wyoming. D numbers refer to USGS fossil collections (table 1).

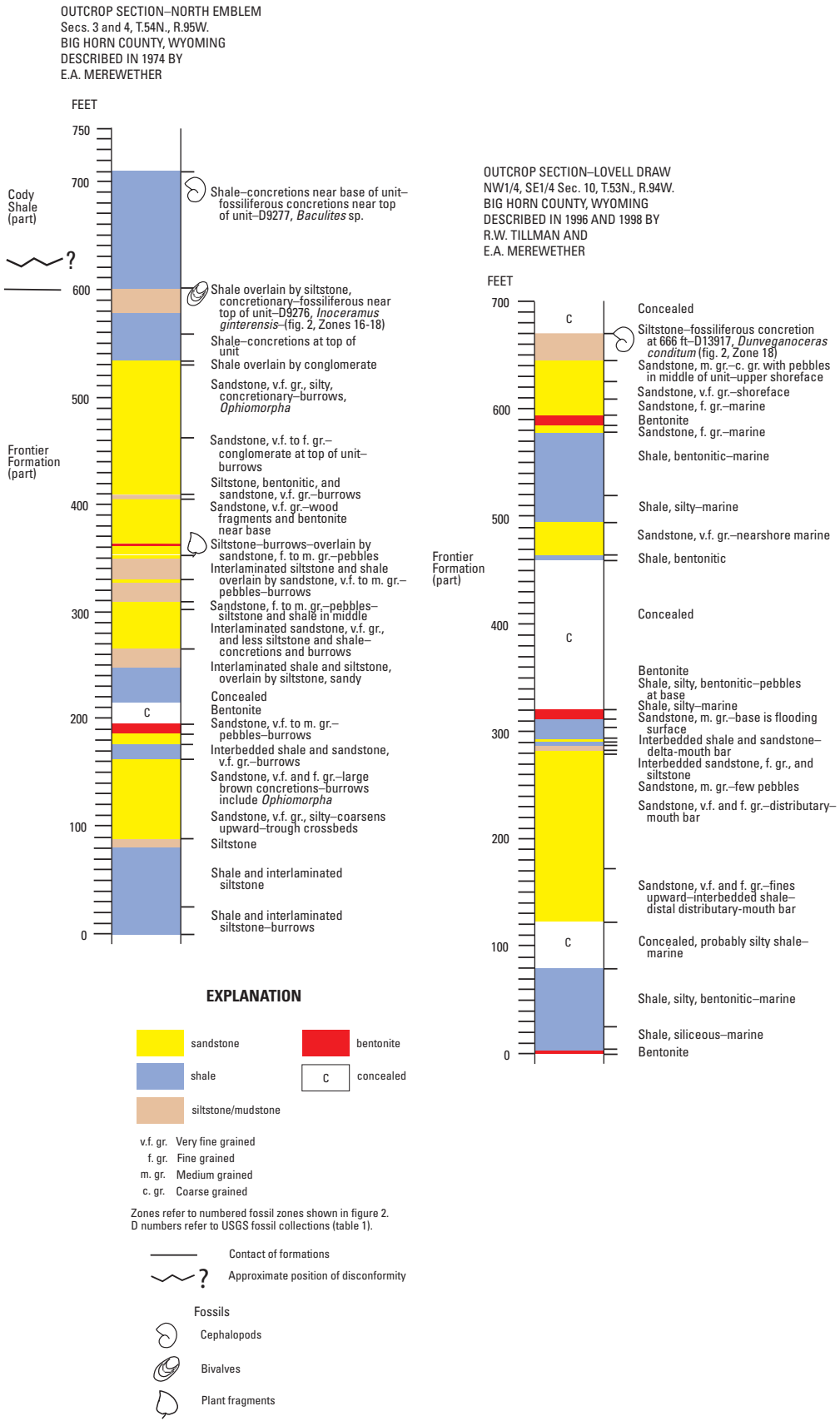


Figure 29. Columnar sections and lithologic descriptions of Frontier Formation in outcrops near North Emblem and Lovell Draw, eastern Bighorn Basin (fig. 1).

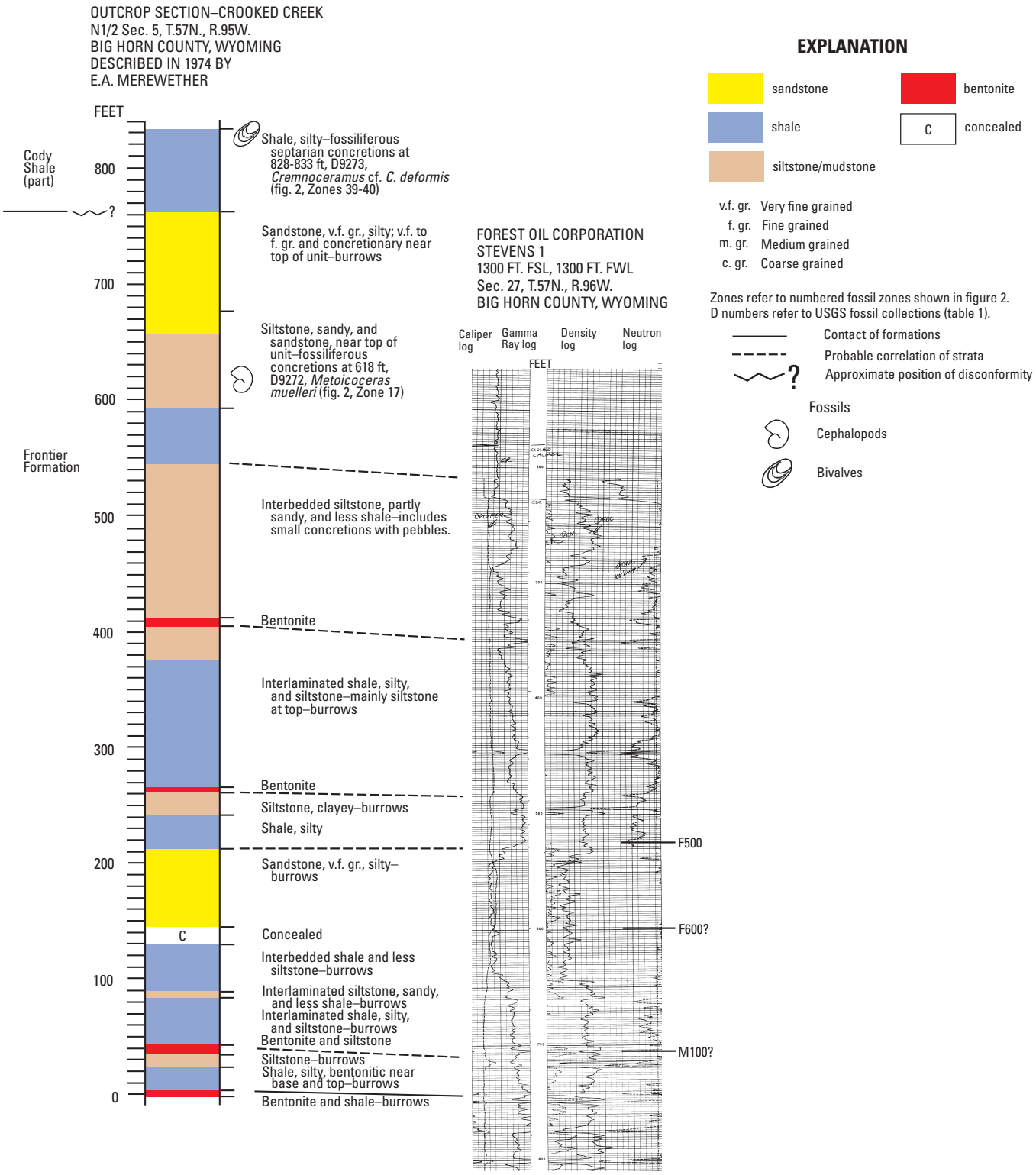


Figure 30. Columnar section and lithologic description of Frontier Formation in outcrops near Crooked Creek, eastern Bighorn Basin (fig. 1). Also shown are surface-to-subsurface correlations with a nearby borehole.

the subsurface on geophysical logs of boreholes in the area. The Frontier sandstones in these outcrops are mainly very fine grained, and accumulated mostly in nearshore-marine environments.

Many beds contain burrows, and a siltstone in the upper part of the formation encloses the ammonite *Metoicoceras muelleri* (D9272) of early late Cenomanian age (fig. 2, Zone 17). Concretions in the overlying Cody, 65 to 70 ft above the Frontier, contain the bivalve *Cremnoceramus* cf. *C. deformis* (D9273) of early Coniacian age (fig. 2, Zones 39 or 40). Strata between a fossiliferous siltstone in the Frontier and the fossiliferous shale in the Cody in this area enclose a disconformity that probably represents latest Cenomanian and early and middle Turonian time.

Outcrops near Warren, Montana

About 25 mi northwest of Lovell near Warren, Mont. (figs. 1, 31), outcrops of the Frontier and basal strata of the overlying Cody were described by Merewether and others (1975). Sandstones in the Frontier are mostly very fine grained; they rarely include medium- or coarse-grained and pebble-bearing beds. The strata in the Frontier commonly display burrows and contain fossils near the middle and at the top of the formation. They were deposited probably in nearshore-marine environments. Formation thickness is about 620 ft.

Fossils collected from near the middle of the Frontier include the ammonite *Metoicoceras defordi* (D9274) of early late Cenomanian age (fig. 2, Zone 17). Fossil bivalves from a sandstone at the top of the Frontier consist of *Cremnoceramus* cf. *C. deformis* (D9275; fig. 2, Zones 39–40) of the lower Coniacian. The Cenomanian strata in these outcrops are disconformably overlain by beds of Turonian age, as at outcrops to the southeast. The lacuna at the disconformable contact spans most of the upper Cenomanian, the lower and middle Turonian, and most of the upper Turonian.

Interpretations and Conclusions

Outcropping beds of the Frontier Formation near the margins of the Bighorn Basin (fig. 1) are mainly siliciclastic and bentonitic and most were deposited in marine and brackish-water environments. However, outcropping strata along the northwest flank of the basin near Deep Lake and Cody include carbonaceous beds that accumulated in continental environments.

The lower and thickest part of the Frontier Formation in the Bighorn Basin, including the nonmarine beds, is herein assigned a Cenomanian age. Those strata are approximately correlative with outcropping Cenomanian beds at Conant Creek near Riverton (fig. 3; Merewether and Cobban, 2007) and with the Belle Fourche Member of the Frontier near Kaycee and Casper (figs. 3, 4; Merewether and others, 1976, 2007). The Cenomanian strata are 480 ft thick at Cody and 680–690 ft thick near Ten Sleep. Detailed thicknesses of the Frontier in the Bighorn Basin have been presented by Kirschbaum (written commun., 2008).

Molluscan fossils of Cenomanian age have been collected from outcrops at Pitchfork, Black Mountain, and near Shanty Ridge, and from other outcrops on the east flank of the basin (fig. 1, table 1). The oldest Cenomanian fossils (fig. 2, Zone 4) were collected in the Mowry Shale at Pitchfork. The youngest (fig. 2, Zone 18) were collected in the Frontier at Lovell Draw; outcrops northwest of that locality might also be of that age. However, to the southeast, the youngest Cenomanian outcrops are somewhat older—Zone 17 at Joe Emge Creek, Zone 16 at Potato Ridge, possibly Zone 15 near Shanty Ridge, and Zone 14 at Black Mountain. Along the east flank of the basin, the top of the Cenomanian strata apparently is an irregular truncated surface that increases in age toward the south.

In north-central Wyoming, east of the Bighorn Basin (fig. 3), the age of the top of the Belle Fourche Member of the Frontier Formation increases southward, ranging from Zones 21 or 22 of the late late Cenomanian near Buffalo to Zones 16 or 17 of the early late Cenomanian in the vicinity of Casper. The irregular but progressive southward truncation of Cenomanian strata between Buffalo and Casper and on the east flank of the Bighorn Basin indicates differential uplift and erosion of parts of that region during the early Turonian. Within the Bighorn Basin, vertical movement evidently was largest at the south end, near Black Mountain, but uplift apparently was most pronounced in the region of Mount Everts and Upper Slide Lake in northwestern Wyoming, west of the basin (fig. 3). At those localities, strata overlying the Mowry Shale and underlying middle Turonian beds are interpreted to be middle Cenomanian or older and laterally equivalent to a lower part of the Cenomanian sequences in the Bighorn Basin. These strata at Mount Everts and Upper Slide Lake are also appreciably thinner (180–260 ft thick) than those in the Bighorn Basin (fig. 32). The early Turonian uplift might have been accompanied by a eustatic sea-level fall (Haq and others, 1987).

Deposition on the eroded surfaces of Cenomanian sequences in the Bighorn Basin and elsewhere in northern Wyoming (figs. 3, 4) evidently began with a marine transgression during early middle Turonian time (fig. 2, Zones 28–30). The disconformable contact between Cenomanian and middle Turonian strata at Cody (figs. 1, 6), near the western margin of the basin, could represent most of the late Cenomanian and all of early Turonian time. Middle Turonian strata were identified in the basin only at Cody, where they are 115 ft thick, and at Elk Butte (fig. 2, Zones 29 and 30), although they probably extend north at least to Deep Lake and south to Pitchfork. They are correlative with middle Turonian beds in the Frontier south of the Bighorn Basin, at Conant Creek (Merewether and Cobban, 2007), and with an upper part of the middle Turonian Emigrant Gap Member of the Frontier southeast of the basin near Casper (fig. 4). Slightly older middle Turonian fossils, representing Zone 28 (fig. 2), were collected from outcrops

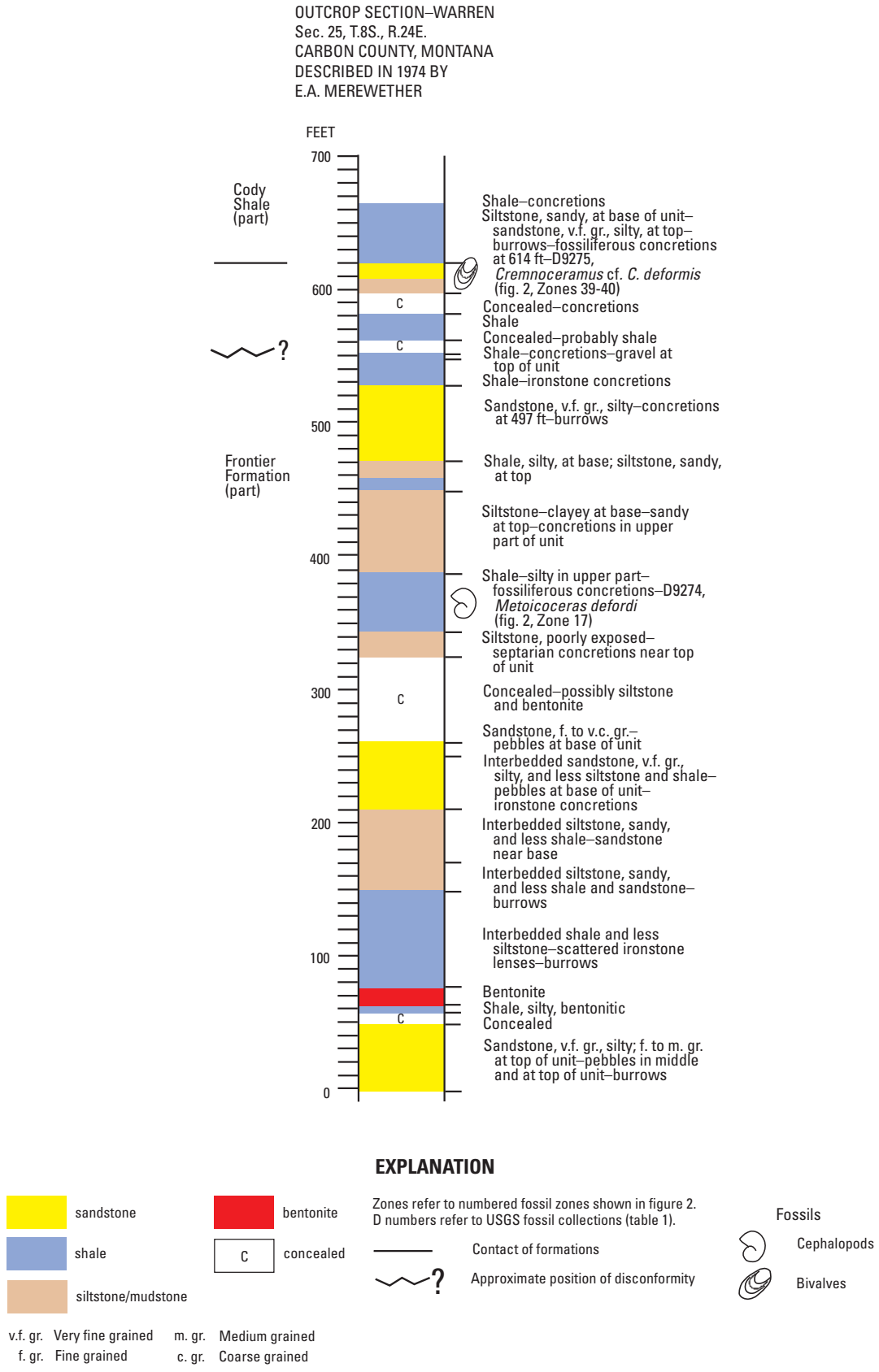


Figure 31. Columnar section and lithologic description of Frontier Formation in outcrops near Warren, eastern Bighorn Basin (fig. 1).

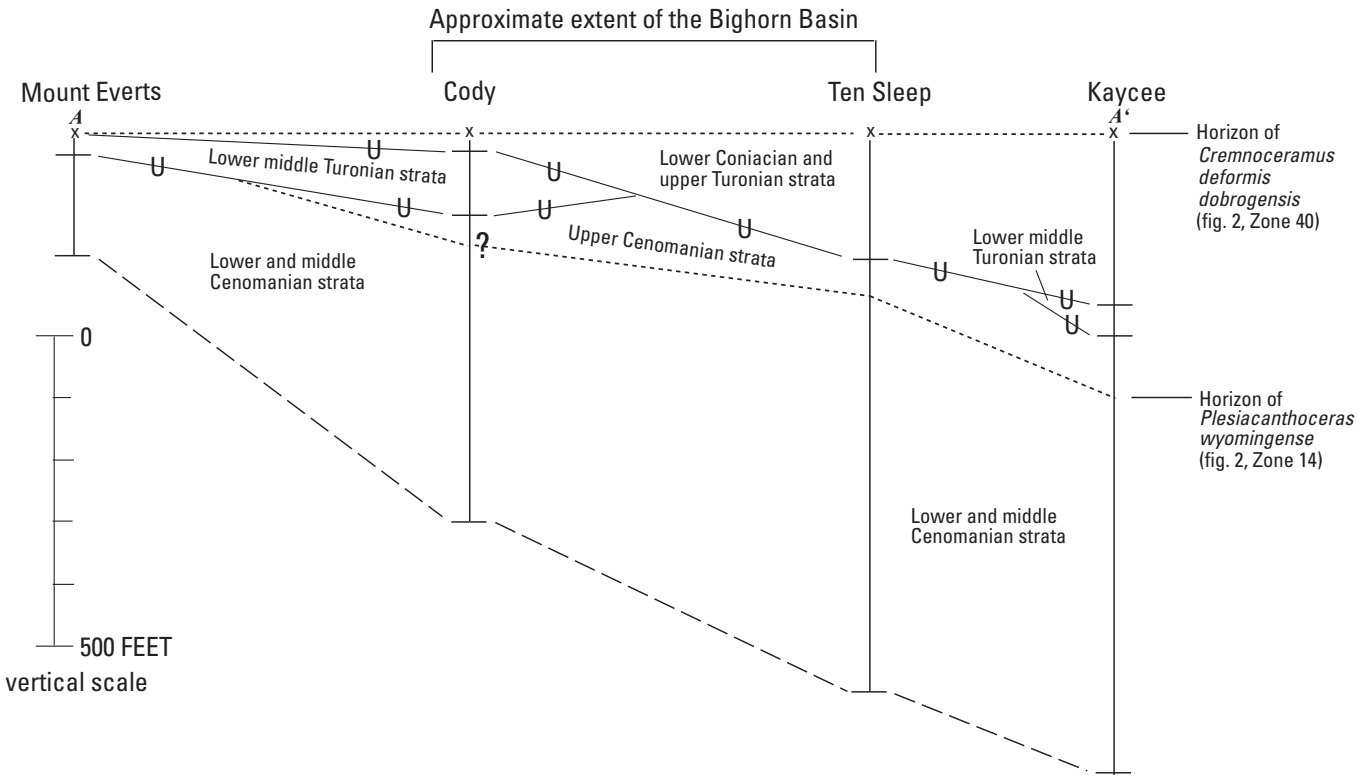


Figure 32. Stratigraphic cross section of Frontier Formation and lower beds of the overlying Cody Shale in northwestern Wyoming (line *A–A′*, fig. 3). Dashed line marks contact with the underlying Mowry Shale. Dotted lines are horizons of two molluscan index-fossils. U indicates disconformable contact.

east of the basin in the vicinity of Kaycee and from the lower part of the Emigrant Gap Member near Casper, as well as from outcrops at Mount Everts and Upper Slide Lake in northwestern Wyoming (fig. 3).

Early middle Turonian fossils of Zones 28–31 (fig. 2) are absent in part of north-central Wyoming (fig. 3; Merewether and Cobban, 1986, their figs. 11 and 12), which indicates an uplift in that region and possibly another eustatic fall (Haq and others, 1987) during the late middle or early late Turonian. Similarly, in east-central Wyoming and in an adjacent area to the south, Cenomanian strata are disconformably overlain by upper middle and lower upper Turonian strata that probably reflect uplift and erosion in that region (Weimer, 1984) during the middle Turonian.

A conformable sequence of upper middle Turonian, upper Turonian, and lower Coniacian strata disconformably overlies beds as old as middle Cenomanian and as young as early middle Turonian in much of northern Wyoming. Outcropping Cenomanian sequences in southern and eastern areas of the Bighorn Basin are disconformably overlain by strata containing late Turonian fossils that represent Zone 34 between Thermopolis and Black Mountain, Zone 37 on Black Mountain, Zone 34 near Shanty Ridge, Zone 37 near Ten Sleep, and Zone 36 at the Bonanza oil field. These Turonian beds are 140–170 ft thick near Ten Sleep and as much as 65 ft thick at Black Mountain.

At Black Mountain, this mid-Frontier disconformity spans all of the late Cenomanian and the early and middle Turonian. At the Bonanza oil field, it represents most of the late Cenomanian, the early and middle Turonian, and an early part of the late Turonian. The lacuna at the disconformity between the Cenomanian and upper Turonian sequences near the south and east margins of the Bighorn Basin represents two periods of erosion that correspond to two lacuna elsewhere in the Frontier, notably at the Conant Creek and Emigrant Gap localities in central Wyoming (fig. 4).

Middle Turonian strata in the upper part of the Frontier, which are present at Cody and Elk Butte (fig. 1) and probably north and south of those localities, are disconformably overlain by beds of early Coniacian age (fig. 2, Zones 39–41). At most outcrops near the west edge of the basin, the uppermost Frontier sandstone is early Coniacian in age, but at outcrops near the east margin, sandstone of Coniacian age was identified only near Warren (fig. 1). Middle Turonian beds

and overlying lower Coniacian beds at Cody are comparable in age to strata at Conant Creek in central Wyoming and at Mount Everts and Upper Slide Lake in northwestern Wyoming (fig. 4). Correlative beds near Casper are within the Emigrant Gap Member of the Frontier and a lower part of the Cody Shale. At this disconformity near Cody, the lacuna apparently includes the late middle Turonian and the late Turonian indicating a single erosional episode. The tectonic history of northern Wyoming during the early Late Cretaceous, which contains middle Turonian strata disconformably overlain by Coniacian beds, was described and interpreted by White and others (2002).

At outcrops of the uppermost Frontier Formation and the basal Cody Shale near the east and south edges of the Bighorn Basin, beds of late Turonian age (fig. 2, Zones 37 and 38) appear to be conformably overlain by beds of early Coniacian age (fig. 2, Zones 39 and 40); if there is a disconformity, it is insignificant. Those beds are correlative with conformable strata of the Wall Creek Member of the Frontier and a lower part of the overlying Cody Shale near Casper. Because they are probably conformable, an earlier interpretation by Merewether and others (2007, their figs. 20 and 21) that a lacuna exists at the base of lower Coniacian beds in nearly all of northern Wyoming seemingly is incorrect.

The collections of fossils from northern Wyoming that were compiled and studied for this report are more numerous than those used for the publication by Merewether and others (2007). Consequently, a few of the sedimentologic and tectonic interpretations in that publication (particularly those illustrated by the maps in their figs. 20 and 21) should be modified. The disconformable contact of the Turonian and Coniacian strata in north-central Wyoming indicated by those maps is not confirmed by data in the present report. That contact along the eastern flank of the Bighorn Basin and in adjoining areas south and east of the basin apparently is conformable.

The biostratigraphy of the Frontier Formation and the lower part of the Cody Shale in the Bighorn Basin and surrounding areas is evidence of the tectonic history of the region (White and others, 2002) and of possible eustatic events (Haq and others, 1987) during the Turonian (fig. 32). Truncated sequences of Cenomanian strata overlain by middle Turonian beds on the west flank of the basin and elsewhere in northern Wyoming reflect a withdrawal of the sea and associated erosion that were caused partly by regional uplift of most of northern Wyoming during the early Turonian (Merewether and Cobban, 1986). The amount of this uplift and erosion apparently was greatest in northwestern Wyoming, west of the Bighorn Basin. Later in the early Turonian, subsidence and probably a eustatic rise allowed a marine transgression and the deposition of lower middle Turonian (fig. 2, Zones 28–30) strata throughout the basin and elsewhere in northern Wyoming.

The absence of middle Turonian strata near the south and east margins of the Bighorn Basin, as well as in adjoining areas to the east (fig. 3; see also Merewether and Cobban, 1986, their figs. 11 and 12), indicates uplift and the erosion of those strata possibly in late middle Turonian time. Thereafter, upper Turonian strata accumulated on Cenomanian strata in the southern and eastern parts of the basin during a marine transgression. These upper Turonian strata are overlain with apparent conformity by lower Coniacian beds along the southern and eastern flanks of the basin and elsewhere in northern Wyoming.

However, lower Coniacian beds were deposited on middle Turonian (EGM) beds near the west edge of the basin and farther to the west. The ages and thicknesses of the middle Turonian, upper Turonian, and lower Coniacian strata in northwestern Wyoming are interpreted to indicate that higher elevations existed on the west side of the basin and west of the basin during a late Turonian and early Coniacian marine transgression.

In east-central Wyoming (fig. 3) and in an adjoining area to the south, lower Coniacian beds disconformably overlie either upper middle Turonian or middle upper Turonian beds. This area was uplifted and eroded for a second time (Weimer, 1984), probably in the late Turonian.

Summary

The areal and temporal distributions of molluscan index fossils of Cenomanian, Turonian, and Coniacian ages in outcrops of the Bighorn Basin and adjoining areas provide evidence of several depositional and tectonic events. Significant lacunae are proposed for two horizons, at the contact of Cenomanian and lower middle Turonian strata and at the contact of lower middle Turonian with upper Turonian or lower Coniacian strata. The extensive and variable lacuna between Cenomanian and middle Turonian strata indicates uplift and erosion centered in northwestern Wyoming during the early Turonian. In that region and elsewhere in northern Wyoming, the erosion was followed by deposition during a marine transgression in the early middle Turonian. Thereafter, the lacunae between Cenomanian and upper Turonian strata as well as between middle Turonian and lower Coniacian strata in the Bighorn Basin indicate that topographic relief, resulting from differential uplift, induced erosion in the region during the latest middle Turonian. This uplift and the higher terrain appears to have been centered in north-central Wyoming, east of the basin, and was followed by a marine transgression in the late Turonian. In north-central and northwestern Wyoming, marine strata transgressed northwestward during the late Turonian and early Coniacian, onlapping a truncated and irregular surface composed of Cenomanian beds on the east flank of the Bighorn Basin and of middle Turonian beds on the west flank of the basin.

In east-central Wyoming and an adjoining region to the south, upper middle Turonian and lower upper Turonian strata are disconformably overlain by lower and middle Coniacian beds. That region apparently rose and was eroded during the latest Turonian.

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In 2007, a regional study of the Frontier Formation by M.A. Kirschbaum of the U.S. Geological Survey (USGS) provided an opportunity for a comprehensive investigation of the biostratigraphy of the formation and associated strata in the Bighorn Basin. Molluscan fossils collected in the basin during 1957 and 1958 by George H. Horn, Robert L. Rioux, and John R. Dyni of the USGS are named and included in table 1 of this report. Assistance with descriptions of outcrops in the region was provided by William Stanton in 1974 and R. Bottjer in 1999. In 2008, S.M. Condon prepared the map showing outcrops of the Frontier Formation in the Bighorn Basin as well as the locations of outcrops described in this report (fig. 1). Comprehensive reviews of the manuscript were provided in 2009 by R.B. O'Sullivan, W.R. Keefer, D.J. Nichols, and M.S. Ellis of the USGS. The administrative and technical support provided by the preceding geologists were important contributions and are gratefully acknowledged.

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