

APPENDIX A: STRATIGRAPHIC DATA FOR SUBSIDENCE ANALYSIS

The geologic time scale used comes from Gradstein et al. (2012). Cretaceous Western Interior ammonite biozones are those defined by Cobban et al. (2006) with modifications made by Scott (2014). Stratigraphic correlation of units in Wyoming are those of Gill et al. (1970), Roberts et al. (2005b), and the Wyoming Geological Association (WGA, 2014).

Paleowater depth scale is defined as inner shelf (0–50 m), middle shelf (50–100 m), outer shelf (100–200 m), upper slope (200–300 m), coastal plain (i.e., fluvial system is tied to a known shoreline) (0 to –50 m), fluvial (–50 to –200 m). Water depth assignment is made primarily on lithofacies and sedimentology as described in the literature or, in rare cases, where indicative benthic fossils are found (e.g., Hill and Heller, 1988).

Stratigraphic thicknesses for most wells come from the Colorado Oil and Gas Commission or the Wyoming Oil and Gas Commission.

Overall water depth information comes from lithofacies and sedimentology descriptions. More specific age and water depth information come from references listed below.

Bighorn Basin—Sellers Draw well (API 49-029-20489)

Thicknesses from Roberts et al. (2008).

Formation	Top (m)	Water Depth min (m)	Water Depth max (m)	Age of top (Ma)
Tatman and Willwood	0	–200	100	51
Fort Union	1549	–200	0	55
Lance	3814	–100	0	65.4
Meeteetse	4195	0	50	69.4
Teapot Ss.	4578	0	50	72
unconformity	4619			73
Mesaverde	4619	0	50	78
Cody Sh.	4936	50	200	83
Frontier	5680	0	50	88.5
Mowry Sh.	5808	30	200	97.2
Muddy Ss.	5965	0	50	99.5
unconformity	5979			101

Denver-Julesburg Basin—Wyoming Calco Morton King #1 well

Thickness from <http://coloradostratigraphy.com>. Ages from Hattin (1975), Kauffman (1977), Cobban (1984) and Scott and Cobban (1986).

Formation	Top (m)	Water Depth min (m)	Water Depth max (m)	Age of top (Ma)
unconformity	0	–200	0	50
Laramie	0	–200	0	66
Fox Hills	314	0	50	67
upper Pierre	392	50	200	69
Richards Ss.	1007	0	100	72
Larimer/Rocky Ridge	1042	0	100	72.5
Pierre Sh.	1188	100	200	73.5
Terry Ss.	1264	0	100	74
Pierre Sh.	1323	100	200	74.5
Hygiene Ss.	1436	0	100	75
lower Pierre Sh.	1513	100	200	80
Niobrara	2090	100	300	84
Carlile/Codell Ss.	2177	0	100	87
Greenhorn	2197	100	300	91
Graneros	2280	50	200	95
J Ss (Muddy)	2343	0	50	99

Denver-Julesburg Basin—south of Denver

Combined thickness from J.S. Abercrombie State #1 well from
<http://coloradostratigraphy.com> and Castle Pines Core (Raynolds and Johnson, 2003)

Ages from Hattin (1975), Kauffman (1977), Cobban (1984), Scott and Cobban (1986) and Raynolds and Johnson (2003).

Formation	Top (m)	Water Depth min (m)	Water Depth max (m)	Age of top (Ma)
<i>Castle Pines:</i>				
unconformity	125			56.3
P3 upper D1	208	-200	0	60.5
P2 upper D1	313	-200	0	62.3
P1 upper D1	399	-200	0	62.4
upper lower D1 (Lancian)	480	-200	0	65.5
lower D1	697	-100	0	67
Laramie	833	-50	0	68.2
Fox Hills	927	0	50	68.5
<i>Abercrombie:</i>				
Pierre	1029	100	200	69
Niobrara (Smoky Hill, Ft Hays)	2900	30	300	83.5
Codell Ss	3020	0	100	90
GreenHorn	3042	100	300	91
Graneros	3100	50	200	95
J Ss (Muddy)	3136	0	50	99

Great Divide Basin—British American Oil Govt. 1 well (API 49-013-05023)

Thickness data from Reynolds (1976).

Formation	Top (m)	Water Depth min (m)	Water Depth max (m)	Age of top (Ma)
Ft. Union	0	-50	0	60
Lance	518	-50	0	65.5
Fox Hills	1414	0	50	69
Lewis Sh.	1497	50	200	70
Mesaverde	2875	0	50	73
Cody Sh.	3437	50	200	79
<i>Baculites</i> zone beds	3563	0	50	80
Blair	3767	50	100	80
Steele Sh.	3836	50	200	81
Baxter Sh.	3837	30	100	84
Frontier	4834	0	50	89
Mowry Sh.	5060	50	200	97
Muddy Ss.	5221	0	50	99.5

Green River Basin—Dagger Unit 1 (API 49-037-21958)

-Ages and water depth from Gill et al. (1970), Merewether and Cobban (1986), Finley (1992), Martinsen et al. (1999), Merewether et al. (2007), Kieft et al. (2011) and Gonzalez and Birgenheier (2014).

Formation	Top (m)	Water Depth min (m)	Water Depth max (m)	Age of top (Ma)
Ft Union	0	-50	0	55
Lance	2498	-50	0	65.5
Lewis Sh.	2579	50	200	70
Almond	2748	0	50	71
Ericson	2817	-30	30	73
Rock Springs	2892	0	50	80
Blair	3288	50	100	81
Baxter Sh.	3696	30	100	84
Frontier	4960	0	50	89
Mowry Sh.	5027	50	200	97
Muddy Ss.	5134	0	50	99.5

Hanna Basin

No single measured section is available, composite sections including range of measurement uncertainties, from Bowen (1918), Gill et al. (1970), Higgins (2003) and Lillegraven et al. (2004). Some specific age control provided by Higgins (2003) and Lillegraven et al. (2004).

From Bowen (1918)

Formation	Top (m) (range)	Water Depth min (m)	Water Depth max (m)	Age of top (Ma)
Hanna	0	-200	0	55
unconformity	2134			60
Ferris	2134	-50	0	60.5
Medicine Bow	4116	-50	0	65
Lewis	6006	100	500	68
Mesaverde	7012	0	50	72.3
Steele	7835	50	200	80
Niobrara	9055	30	300	85
Carlile	9168	0	100	88
Frontier	9229	0	50	89
Mowry Sh.	9442	30	200	97

From Dobbin et al. (1929)

Formation	Top (m) (range)	Water Depth min (m)	Water Depth max (m)	Age of top (Ma)
Hanna	0	-200	0	55
unconformity	2134			60
Ferris	2134	-50	0	60.5
Medicine Bow	4116	-50	0	65
Lewis	5335–6006	100	500	68
Mesaverde	6341–7012	0	50	72.3
Steele	7165–7836	50	200	80
Niobrara	8384–9360	30	300	85
Carlile	8598–9573	0	100	88
Frontier	8738–9713	0	50	89
Mowry Sh.	8959–9934	30	200	97

From Ferren (1935)

Formation	Top (m) (range)	Water Depth min (m)	Water Depth max (m)	Age of top (Ma)
Hanna	0	-200	0	55
unconformity				60
Ferris	2134	-50	0	60.5
Medicine Bow	3963	-50	0	65
Lewis	5183–5793	100	500	68
Mesaverde	6098–6707	0	50	72.3
Steele	6921–7530	50	200	80
Niobrara	8140–9055	30	300	85
Frontier	8476–9390	0	50	89
Mowry Sh.	8674–9588	30	200	97

From Van Ingen (1978)

Formation	Top (m)	Water Depth min (m)	Water Depth max (m)	Age of top (Ma)
Hanna and Ferris	0	-100	0	55
Medicine Bow	4116	-50	0	65
Lewis	5640	100	500	68
Steele	6646	50	200	80
Niobrara	7378	30	300	85
Frontier	7733	0	50	89
Mowry Sh.	7998	30	200	97
Muddy Ss.	8073	0	50	99.5

From Barlow (1953)

Formation	Top (m)	Water Depth min (m)	Water Depth max (m)	Age of top (Ma)
Fort Union	0	-50	0	61
Medicine Bow	2439	-50	0	65
Lewis	3823	100	500	68
Mesaverde	4405	0	50	72.3
Steele and Niobrara	5211	30	300	80
Frontier	6750	0	50	89
Mowry Sh.	6934	30	200	97
Muddy Ss.	7084	0	50	99.5

From Lillegren et al. (2004)

Formation	Top (m)	Water Depth min (m)	Water Depth max (m)	Age of top (Ma)
Hanna	0	-200	0	55
Ferris	3456	-50	0	60
Medicine Bow	5450	-50	0	65
Fox Hills	7496	0	50	67
Lewis Sh.	7602	100	500	68
Mesa Verde	8646	0	50	72.3
unconformity	8646			73.4
Allen Ridge	8792	-50	0	75
Haystack Mountain	9168	0	50	79
Steele Sh.	9235	50	200	80
Niobrara	10873	30	300	85
Frontier	11248	0	50	89
Thermopolis Sh.	11505			100

North Kaiparowits Plateau

Composite section from Heller et al. (2013) compiled from Eaton (1991), Goldstrand (1992), Nichols (1997) and Roberts et al. (2005a).

Formation	Top (m)	Water Depth min (m)	Water Depth max (m)	Age of top (Ma)
Pine Hollow	0	-200	0	50
unconformity	200			56
Canaan Peak	200	-200	0	63.5
unconformity	300			66
Kaiparowits	300	-200	0	74
Wahweap	1155	0	50	76
Drip Tank	1564	0	50	83
John Henry	1703	0	50	84
Smokey Hollow	1970	0	50	89
Tibbet Canyon	2024	0	50	90
Tropic Shale	2055	0	100	91
Dakota	2255	0	50	95

Piceance Creek Basin

Section 35 of Johnson and Johnson (1991). Paleowater depth for Buck Tongue and Sego Sandstone from Painter et al. (2013). Mancos B age from Kass (1999) and water depth from Kirschbaum (2003).

Formation	Top (m)	Water Depth min (m)	Water Depth max (m)	Age of top (Ma)
Green River	28	-200	0	50
Cow Ridge Mbr. of Green River	643	-200	0	50.3
Fort Union	1038	-100	0	56
Will Fork/Hunter Canyon	1293	-50	0	68
Sego	2450	0	50	75
Buck Tongue of Mancos	2495	50	100	76
Mancos body	2661	50	200	79
lower Mancos B	3085	0	50	81
Frontier/Mowry	3755	0	200	90
Dakota	3870	0	50	100

Powder River Basin—North

Scales Fee 1-H-10 well (API 49-033-20133)

- Ages mostly from Merewether (1996). Water depth of Lewis Shale from Winn et al. (1987), Parkman Sandstone from Hubert et al. (1972), Mowry Shale and Frontier Formation from Kirschbaum and Mercier (2013). Thickness of Lance and Fort Union formations from Ayers (1986) and N. Jones (written comm., 2015).

Formation	Top (m)	Water Depth min (m)	Water Depth max (m)	Age of top (Ma)
Ft Union	0	-200	0	56
Lance	1600	-100	0	65.5
Fox Hills	1800	0	50	67
Lewis Sh.	1818	50	200	68
Teapot Ss	1891	0	50	73
unconformity				74
Parkman Ss.	1994	0	50	76
Steele Sh.	2088	50	200	79
Sussex Ss.	2171	0	50	80
Shannon Ss.	2253	0	50	81
Niobrara	2530	30	300	85
Frontier	2741	0	50	89
Mowry Sh.	2963	30	200	97
Muddy Ss.	3051	0	50	99.5

Powder River Basin—South

Kodner W-59968 32-5 well (API 49-009-22655)

- Ages mostly from Merewether (1996). Water depth of Lewis Shale from Winn et al. (1987), Parkman Sandstone from Hubert et al. (1972), Mowry Shale and Frontier Formation from Kirschbaum and Mercier (2013). Thickness of Lance and Fort Union formations from Ayers (1986) and N. Jones (written comm., 2015).

Formation	Top (m)	Water Depth min (m)	Water Depth max (m)	Age of top (Ma)
Fort Union	0	-200	0	56
Lance	1200	-100	0	65.5
Fox Hills	2100	0	50	67
Lewis Sh.	2141	100	300	68
Teckla Ss. Mbr. of Lewis	2303	0	100	70
Teapot Mbr. of Parkman Ss	2577	0	100	73
unconformity				74
Parkman Ss.	2682	0	50	76
Steele Sh.	2890	50	200	79
Sussex Ss.	3123	0	100	80
Shannon Ss.	3256	0	100	81
Cody	3373	50	200	82
Niobrara	3602	30	300	85
Carlile Mbr. of Cody Sh.	3723	0	100	88
Frontier	3817	0	50	89
Mowry Sh.	4065	30	200	97
Muddy Ss.	4121	0	50	99.5

Raton Basin—Goemmer #2205 well (API 05-055-06101)

Water Depth for Pierre Shale from Flores and Tur (1982)

Formation	Top (m)	Water Depth min (m)	Water Depth max (m)	Age of top (Ma)
Vermejo Coal	0	-30	0	66
Trinidad Ss	96	0	50	67
Pierre	179	50	200	69
Niobrara	941	30	300	84
Fort Hays	1064	30	200	88
Carlile	1072	0	100	88.5
CodeLL	1079	0	100	90
Greenhorn	1130	100	300	91
Graneros	1174	50	200	95

San Juan Basin—Aztec Oil and Gas Trail Canyon No. 1 well

Data from Cather (2004).

Formation	Top (m)	Water Depth min (m)	Water Depth max (m)	Age of top (Ma)
San Juan	0	-200	0	52.5
unconformity	577			56.8
Nacimiento	577	-200	0	61.1
Ojo Alamo	893	-200	0	63.8
unconformity	1021			65
Kirtland/Fruitland	1021	-100	0	70.8
Upper Lewis	1425	50	100	73.8
Mesa Verde	1687	0	50	75.6
Up Mancos	2104	50	200	78.2
unconf	2662			87.6
Lower Mancos	2662	50	200	88.3
lower Mancos	2774	50	200	93
Older units	2823			95

Uinta Basin

Thicknesses from section 14 of Johnson and Johnson (1991). Paleowater depth for Buck Tongue and Sego Sandstone from Painter et al. (2013). Mancos B age from Kass (1999) and water depth from Kirschbaum (2003).

Formation	Top (m)	Water Depth min (m)	Water Depth max (m)	Age of top (Ma)
Green River (part)	0	-200	0	50
Lower Green River	157	-200	0	50.3
Wasatch	1114	-200	0	55.4
unconformity	1114			63
Tuscher-Neslen	1878	-100	0	70.6
Castlegate	1975	-50	0	78
Blackhawk	1999	0	50	80
Mancos	3880	50	100	83.5
Frontier	3916	0	50	89.3
unconformity	3916			93.5
Mowry Sh.	3940	50	100	96

Wind River Basin—Key Spring Unit 1-F14 (API 49-025-21448)

Ages from Finn (2007).

Formation	Top (m)	Water Depth min (m)	Water Depth max (m)	Age of top (Ma)
Waltman	0	-200	0	55.5
Lance	813	-100	0	65.5
Lewis Shale	2316	100	500	69.4
Teapot Ss.	2393	0	50	73
Cody	2733	50	200	79
Niobrara	3665	30	300	84
Carlile	4112	0	100	87
Frontier	4223	0	50	89.3
Frontier-2	4277	0	50	90
Frontier-3	4344	0	50	93
Frontier-4	4400	0	50	95
Mowry Sh.	4496	30	200	97
Muddy Ss.	4605	0	50	99.5

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