Woltz, C.R., et al., 2021, Total organic carbon and the preservation of organic-walled microfossils in Precambrian shale: Geology, v. 49, https://doi.org/10.1130/G48116.1

GSA Supplemental Material

Total organic carbon and the preservation of organic-walled microfossils in Precambrian shale

C.R. Woltz[1] , S.M. Porter[1], H. Agić [1], C.M. Dehler[2], C.K. Junium[3], L.A. Riedman[1], M.S.W. Hodgskiss[4], S. Wörndle[5], G.P. Halverson[6]

[1] *Department of Earth Science, University of California, Santa Barbara, CA 93106, USA*

[2] *Department of Geology, Utah State University, Logan UT 84322, USA*

[3] *Department of Earth and Environmental Sciences, Syracuse University, Syracuse, NY 13244, USA*

[4] *Department of Earth Sciences, University of Cambridge, Cambridge CB2 3EQ, UK*

[5] *Department of Geosciences, John Abbott College, Sainte-Anne-de-Bellevue, Québec, H9X 3L9 Canada*

[6] *Department of Earth and Planetary Sciences, McGill University, Montréal, Quebec, H3A 0E8, Canada*

Sample type and signal averaging

This dataset includes total organic carbon (TOC) values and fossil occurrences that are either reported in the literature or collected as part of the this study. Data from published work are used only when the exact sample names are reported in the publications (see Table S3 for sample names) and organic macerates of each sample have been reexamined for fossil presence or absence. In addition, we find that the source of the data does not influence our findings; TOC and fossil occurrence from this study show the same relationships as TOC and fossil data from published sources.

This dataset is also a combination of field-collected samples and drill core samples. Samples from outcrop, especially in friable textures, are an integration of ~5 to 10 cm of vertical section. Because many samples were collected ~20 years ago, we were not able to design this experiment to take TOC and fossil occurrence from the exact same shale fragment. However, we find little difference in fossil recovery between outcrop and drill core samples. Of samples from outcrop, about 56% are fossiliferous and of the drill core samples, 50% are fossiliferous. Further, the median and variance of the fraction of well-preserved fossils are not significantly different in samples from outcrop and drill core (determined by Mood’s median test and the Fligner-Killeen test of homogeneity of variances).

Total organic carbon measurements

TOC was measured by M.S.W.H, S.W. and G.P.H., at the Stable Isotope Laboratory, McGill University; by C.K.J. at the Paleoclimate/Stable Isotope Clean Chemistry Lab, Syracuse University; and by C.R.W. and C.M.D at the Stable Isotope Laboratory, Utah State University.

McGill University

TOC measurements on samples from the Bylot Supergroup (*n* = 52) were performed in the Stable Isotope Laboratory. Approximately 1 g of shale powder was treated with 6N HCl at room temperature for 48 hours to remove any carbonate minerals. After rinsing with water and drying in an oven at 60°C, the mass of carbonate lost was determined gravimetrically. Total carbon analyses were conducted in triplicate by combustion of ~150 mg of sample powder using an Eltra CS800 carbon/sulphur analyser. Analyses were calibrated using carbon standards from Alpha Resources; measurement precision was usually better than 5%, and values were typically within 10 to 15% of published values. These data were previously published (*n* = 46) in Hodgskiss et al. (2020) or collected as part of this study (*n* = 6) by S.W. and G.P.H.

Syracuse University

TOC measurements for 31 samples from the Blinman-2, SCYW-1A, Wallara-1, and Forest-1 drillcores were performed in Syracuse University's GAPP Laboratory. Decarbonated samples were sealed in tin capsules and analyzed for C and N content using an Elementar Isotope Cube elemental analyzer (EA). EA conditions were as follows: helium purge was set for 45 seconds; oxidation and reduction reactor temperatures were 1100 ˚C and 650 ˚C, respectively; helium carrier gas flow was 230 ml/min; and the O_2 pulse was set for 90 seconds. C and N contents were determined using replicates of NIST-1547 peach leaves (2.98 wt. % N) distributed throughout sample analysis runs and bracketing the quantity of C and N found in the samples. Reproducibility of the C and N content of NIST-1547 peach leaves is 0.5% (relative error) and +/- 0.1 wt. % (2σ).

Utah State University

TOC measurements (*n* = 186) on samples from the Alinya Formation, Aralka Formation, Areyonga Formation, Chuar Group, Greyson Formation, lower Bylot Supergroup, Rae Group, Rocky Cape Group, Roper Group, Togari Group, Uinta Mountain Group, Visingsö Group, and Umbertana Group were performed at Utah State University's Stable Isotope Laboratory. Approximately 5 grams of each sample were powdered and weighed into silver capsules. Inorganic carbon was removed by acid fumigation with 50ml of 57% HCl in a sealed encasement for a minimum of 8 hours. Samples were then dried for 2 hours in a 60° C oven and the silver capsules were wrapped in tin and measured for total C and N on a Costech 4010 elemental analyzer. Samples run in triplicate yield precision of ± 0.06 wt% TOC (2σ).

Randomization test of significance

To assess the statistical significance between TOC and fossil presence, 189 TOC values (representing the number of fossiliferous samples) were selected randomly from the dataset, without replacement, and the median value of the subsample was calculated. Subsampling was repeated 10^6 times and compared to the observed median TOC value of fossiliferous samples (0.32 wt%). The probability of randomly selecting a median TOC value that is less than or equal to the observed median of fossiliferous samples in our dataset (0.32 wt%) is less than 0.004% (Figure S2A). To test if one unit drives this pattern, samples from the Chuar Group, which compose 32% of the dataset, were removed and the randomization analysis repeated on non-Chuar samples only (n = 236, n_{fossil} = 122, median TOC_{fossil} = 0.34 wt%). The probability of randomly obtaining a median TOC value ≤ 0.34 wt%, is less than 0.7% (Figure S2B).

To assess the statistical significance between TOC and fossil preservational quality, the fraction of well-preserved specimens within a sample and TOC values were randomized and the correlation coefficient between TOC and preservational quality was recorded. Figures S3C and S4C show histograms of 10,000 repetitions of this procedure and a mean correlation coefficient around zero (which represents the null hypothesis). The actual correlation coefficients, and their 95% uncertainty by bootstrapping analyses (10,000 subsamples of non-randomized data, with replacement) fall outside of the possible range of random correlations and we reject the null hypothesis. This procedure was conducted for the indices of pitting density and margin quality and because only 39 of 82 total samples had sufficient observations on surface pattern, it was excluded from this analysis.

Relative Water Depth in the Chuar Group

The Chuar Group sediments were deposited in an intracratonic basin and exhibits meter-scale cycles of variegated and organic-rich shales capped by sandstone and dolomite intervals. Relative water depth of Chuar Group was described by Dehler et al. (2001) and is briefly summarized here.

Relative water depth was determined by facies analysis and interpretations of cyclic and non-cyclic intervals in sequence stratigraphic framework. Basal shale facies grade into siltstone and are overlain (either sharply or gradationally) by laminated sandstone, laminated to massive dolomite, stromatolite facies, or pisolite-oolite facies. Some dolomite caps contain vugs, collapse breccias, and mudcracks, which indicate subaerial exposure. These meter-scale cycles suggest shallowing from relatively deeper water environments to shallow subtidal to intertidal environments. There is no evidence for a slope in the basin and the shoreline gradient is estimated to be a very low angle. Non-cyclic intervals, mudrock lacking meter-scale cyclicity, are found throughout the Chuar Group and represent the relatively deepest water environments. Deposition in the Chuar basin was most likely controlled by low- to moderate-amplitude glacioeustatic sea-level change with water depths reaching tens to hundreds of meters.

Iron speciation analysis, Chuar Group, Grand Canyon, USA

Iron speciation of the Chuar Group was published by (Johnston et al., 2010) following the methods of Poulton and Canfield (2005). The redox state of iron is highly oxygen dependent. The ratio of reactive iron to total iron (FeHR/FeT) of a sample can therefore be used as a geochemical proxy for oxygen. Reactive iron pools including iron carbonates, iron oxides, and magnetite are extracted by a series of hydrofluoric, perchloric, and nitric acid digestions (Poulton and Canfield, 2005). Iron present in sulfide minerals was extracted by reaction with chromium (Canfield et al., 1986). Reactive iron (FeHR) is defined by the sum of iron in iron carbonates, iron oxides, magnetite and iron sulfides. Iron in silicate minerals is considered non-reactive in the timespan of early diagenesis and contributes only to the pool of FeT. Empirical measurements of modern sedimentary systems delineate FeHR/FeT ratios >0.38 as anoxic and <0.22 as oxic (Lyons and Severmann, 2006; Poulton and Canfield, 2011; Raiswell and Canfield, 1998). The range in between 0.22 and 0.38 is equivocal because high sedimentation rate (Lyons and Severmann, 2006) and low-grade metamorphism (Slotznick et al., 2018) can lower the amount of reactive iron and lead to false positives for the presence of oxygen.

To reduce potential bias in this redox proxy, iron speciation was compared only in samples from Chuar Group, which contains no evidence of rapid sedimentation events (e.g. no turbidities). Further any FeHR/FeT values in the equivocal range of 0.22 to 0.38 were excluded from this analysis. Thermal maturity in the Chuar Group ranges from immature to late mature corresponding to RockEval Tmax values of ~420 to 490 ˚C (Lillis, 2016). Highest maturity is seen in the Duppa and Carbon Canyon members and when samples from these members are removed, there is no significant change in results; no relationship is observed between preservational quality and the redox state of the bottom waters. In addition, when we compare samples of similar TOC content (from 0.01 wt% to 0.5 wt %), no pattern between preservation and redox state is observed.

Geologic Unit	Drill-core / Outcrop	Location	Coordinates	Age	Age reference	Age Measurement	Taxonomy Reference	TOC Reference	Collected by	Number of Samples
Aralka Formation	Wallara-1	Amadeus Basin, Australia	-24.61528, 132.33973	Surtian – Marinoan interglacial	Kendall et al., 2006; Walter et al., 1995	Re-Os date of 657.2± 5.4 Ma; Unconformably overlies glacial diamictites of the Areyonga Fm	Riedman et al., 2014	C.K. Junium	L.A. Riedman, C. Calver, E. Domack	9
Tapley Hill and Wilyerpa Fms., Umbertana Gp.	SCYW-1A and Blinman-2	Adelaide Rift Complex, Australia	-30.12491, 137.15660 & -31.10221, 138.69231	Sturtian – Marinoan interglacial	Max: Kendall et al., 2006. Min: Grey et al., 2003	Max: Re-Os date of 643.0±2.4 Ma. Min: Marinoan glacial tillite	Riedman et al., 2014	C.K. Junium, C.R. Woltz	L.A. Riedman, C. Calver, E. Domack	17
MacDonaldryggen Member, Elbobreen Formation	Outcrop	Svalbard, Norway	79.89167, 18.48833 & 79.81333, 18.60333	Sturtian–Marinoan interglacial	Hoffman et al.,2012; Halverson et al., 2005; Halverson et al., 2004	stratigraphic relationship to glacial units and $\delta^{13}C$ stratigraphy	Riedman et al., 2014	Kunzman et al., 2015; C.R. Woltz	G.P. Halverson	13
Black River Formation, Togari Group	Forest-1	NW Tasmania, Australia	-40.81518, 145.25523	Sturtian glacial – interglacial	Max: Calver, 1998; Grey et al., 2011 Min: Kendall et al., 2009	Max: Chemo- and Biostratigraphy Min: Re-Os date of 640.7±4.7 Ma	Riedman et al., 2014	C.K. Junium, C.R. Woltz	L.A. Riedman, C. Calver, E. Domack	8
Areyonga Formation	Wallara-1 and BR05DD01	Amadeus Basin, Australia	-24.61528, 132.33973 & -24.45569, 130.38251	Sturtian glacial	Hill et al., 2011 and references therein; Walter et al., 1995	Presence of glaciogenic deposits	Riedman et al., 2014	C.K. Junium	L.A. Riedman, C. Calver, E. Domack	8
Russøya Member, Elbobreen Formation	Outcrop	Svalbard, Norway	79.89367, 18.32833	740 – 719 Ma	Halverson et al., 2017; Hoffman et al., 2012; Halverson et al., 2004	$\delta^{13}C$ correlation with the Islay Anomaly	Riedman et al., 2014	Kunzman et al., 2015	G.P. Halverson	2
Uinta Mountain Group	Outcrop	Uinta Mountains, USA	40.63325, -110.95328	766 ± 4 – 729 ± 0.9 Ma	Max: Dehler et al., 2010 Min: Dehler et al., 2017; Rooney et al., 2017	Max: Detrital zircon of the lower-middle eastern UMG. Min: Correlation with the Kwagunt Fm., Chuar Gp	Nagy and Porter, 2009, Sprinkel and Waanders, 2005	Dehler et al., 2007	C. Brehm, C.M. Dehler	27
Bedgroup 19, Eleonore Bay	Outcrop	Greenland	72.88142, -25.12828	780 –717 Ma	Halverson et al., 2017; Hoffman et al., 2012; Stouge et al., 2011	$\delta^{13}C$ correlation with the Russøya Member, Elbobreen Formation, Svalbard	S.M. Porter, C.R. Woltz	C.R. Woltz	I. Fairschild	1
Chuar Group	Outcrop	Grand Canyon, USA	36.1448, -111.8313	<782 – 729 ± 0.9 Ma	Max: Dehler et al., 2017 Min: Rooney et al., 2017	Max: Detrital zircon of underlying Nankoweap Formation. Min:U-Pb zircon of tuff in Kwagunt Fm	Porter and Riedman, 2016	Dehler et al., 2005; C.R. Woltz	B. Bloeser, A.H. Knoll, S.M. Porter	110
Lossit Limestone	Outcrop	Scotland	55.67281, -6.12644	806 ± 4 – 659.6 Ma	Max: Noble et al., 1996 Min: Halliday et al., 1989; Dempster et al., 2002	Max: U-Pb date. Min: U-Pb date from Tayvallich volcanics	C.R. Woltz	C.R. Woltz	S.M. Porter	1
Alinya Formation	Giles-1	Officer Basin, Australia	-28.43167, 132.38667	811 – 716.5 Ma	Macdonald et al., 2010	Max: correlated with the Bitter Springs carbon isotope anomaly; Min :before the onset of the Strutian Glaciation	Riedman and Porter, 2016	C.K. Junium, C.R. Woltz	L.A. Riedman	13
Svanbergfjellet Formation	Outcrop	Svalbard, Norway	80.15167, 18.33500	811 – 719 Ma	Halverson et al., 2007; Halverson et al., 2005	$\delta^{13}C$ correlation with the Bitter Springs Event	L.A. Riedman	Kunzman et al., 2015	G.P. Halverson	2
Visingsö Group	Outcrop	Sweden	58.05235, 14.47925	886 ± 9 – 729 ± 0.9 Ma	Max: Moczydłowska et al., 2017. Min: Dehler et al., 2017; Rooney et al., 2017	Max: Detrital zircon U-Pb date Min: Correlation with the Kwagunt Fm., Chuar Gp	S.M. Porter	K. Paukert, C.M. Dehler	S.M. Porter	16
Athole Point & Strathcona Sound fms., Bylot Supergroup	Outcrop	Baffin Island, Canada	72.83458, -80.61141 & 73.40868, -83.56321	< 1046 ± 16 Ma	Gibson et al., 2018	Shale Re-Os dates from Arctic Bay and Victor Bay fms	H. Agić and S.M. Porter	G.P. Halverson, M.S.W. Hodgskiss, C.R. Woltz, S. Wörndle	P. Crockford, T. Gibson, G.P. Halverson, M.S.W. Hodgskiss, S. Wörndle	4

Geologic Unit	Drill-core / Outcrop	Location	Coordinates	Age	Age reference	Age Measurement	Taxonomy Reference	TOC Reference	Collected by	Number of Samples
Iqqittuq Formation, Bylot Supergroup	Outcrop	Baffin Island, Canada	72.39133, -80.90756 & 72.40148, -81.04996	1048 ± 12 – 1046 ± 16 Ma	Gibson et al., 2018	Shale Re-Os dates from Arctic Bay and Victor Bay fms	H. Agić and S.M. Porter	G.P. Halverson, M.S.W. Hodgskiss, C.R. Woltz, S. Wörndle	P. Crockford, T. Gibson, G.P. Halverson, M.S.W. Hodgskiss, S. Wörndle	11
Arctic Bay Formation, Bylot Supergroup	Outcrop	Baffin Island, Canada	72.75133, -83.84422 & 72.39250, -81.27633	1048 ± 12 – 1046 ± 16 Ma	Gibson et al., 2018	Shale Re-Os dates from Arctic Bay and Victor Bay fms	H. Agić and S.M. Porter	G.P. Halverson, M.S.W. Hodgskiss, C.R. Woltz	P. Crockford, T. Gibson, G.P. Halverson, M.S.W. Hodgskiss, S. Wörndle	53
Rae Group	Outcrop	NW Territories, Canada	67.6167, -115.7333*	1232 ± 1 – 1013 ± 25 Ma	Rayner and Rainbird 2013	U-Pb detrital zircon	B. Bloeser	C.R. Woltz	H. Wielens	2
Undifferentiated Proterozoic	Atlantic Columbian Carbon Arctic Circle Ontaratue H-34	NW Territories, Canada	66.390, -132.100	1267 ± 2–780 Ma	Correlation: Pugh, 1983; Morrow, 1999; Pyle and Jones, 2009. Date: Le Cheminant and Heaman, 1989; Heaman et al., 1992	Gamma Ray logs and stratigraphic correlation. Max: U/Pb baddeleyite date on underlying volcanics. Min: U/Pb baddeleyite date on diabase sill	C.R. Woltz	C.R. Woltz	B. Bloeser, H. Wielens	4
Rocky Cape Group	Duckbay-1	Tasmania, Australia	-40.83269, 145.17540	1450–1370 Ma	Haplin et al., 2014	Detrital zircon U-Pb date, detrital zircon signatures	Barren	C.R. Woltz	L.A. Riedman	10
Roper Group	Urapunga-3, Urapunga-4	NW Territories, Australia	-14.6578, 133.7550 & -14.7032, 134.2936	1492 ± 4–1361 ± 21 Ma	Max: Jackson et al., 1999 Min: Kendall et al., 2009	Max: U-Pb zircon from volcanic tuff. Min: Re-Os of shale	Javaux and Knoll, 2017	C.R. Woltz	R. Summons	10
Dismal Lakes Group	Outcrop	NW Territories, Canada	66.9402, -119.4256*	1590 ± 4 – 1267 ± 2 Ma	Max: Hamilton and Buchan, 2010. Min: LeCheminant and Heaman, 1989	Max: U-Pb baddeleyite. Min: U-Pb of overlying basalts from Coppermine River Group	B. Bloeser	C.R. Woltz	H. Wielens	4
Greyson Formation	Outcrop	Montana, USA	46.668, -110.884 *	1710 – 1454 ± 9 Ma	Max: Mueller et al., 2016 Min: Evans et al., 2000	Max: Detrital zircon U-Pb. Min: U-Pb date from bentonite	Adam et al., 2017	C.R. Woltz	G.P. Halverson	6
Changcheng Group	Outcrop	Pangjiapu Region, China	40.59569, 118.48745	1731 ± 4 – 1625 ± 6 Ma	Max: Peng et al., 2012 Min: Lu and Li, 1991	Max: U-Pb on baddeleyite Min: zircon U–Pb of trachyte	Heda Agić	C.R. Woltz	S. Awramik	2
Hornby Bay Group	Outcrop	NW Territories, Canada	66.6921, -118.9694 *	1740 +5/-4 – 1590 ± 4 Ma	Max: Irving et al., 2004. Min: Hamilton and Buchan, 2010	Max: U–Pb baddeleyite of trunkated dyke. Min: U-Pb baddeleyite of intruding dyke	B. Bloeser	C.R. Woltz	H. Wielens	3
Undifferentiated Proterozoic	Mobil Colville Hills E-15	NW Territories, Canada	67.07167, -126.30694	1914 – 1000 Ma	Rainbird et al., 1996; Maqueen and Mackenzie, 1973	U-Pb detrital zircon	C.R. Woltz	C.R. Woltz	B. Bloeser	9
Rocknest Formation	Outcrop	NW Territories, Canada	67.2387, -114.4787 *	1960 – 1885 Ma	Bowring and Grotzinger, 1989	U-Pb zircon dates from volcanic tuffs in overlying Recluse Group and underlying Odjick Fm	B. Bloeser	C.R. Woltz	H. Wielens	1

Table S1. Summary of units, location, age, references, and number of samples used in this study. Coordinates marked with an asterisk are approximate.

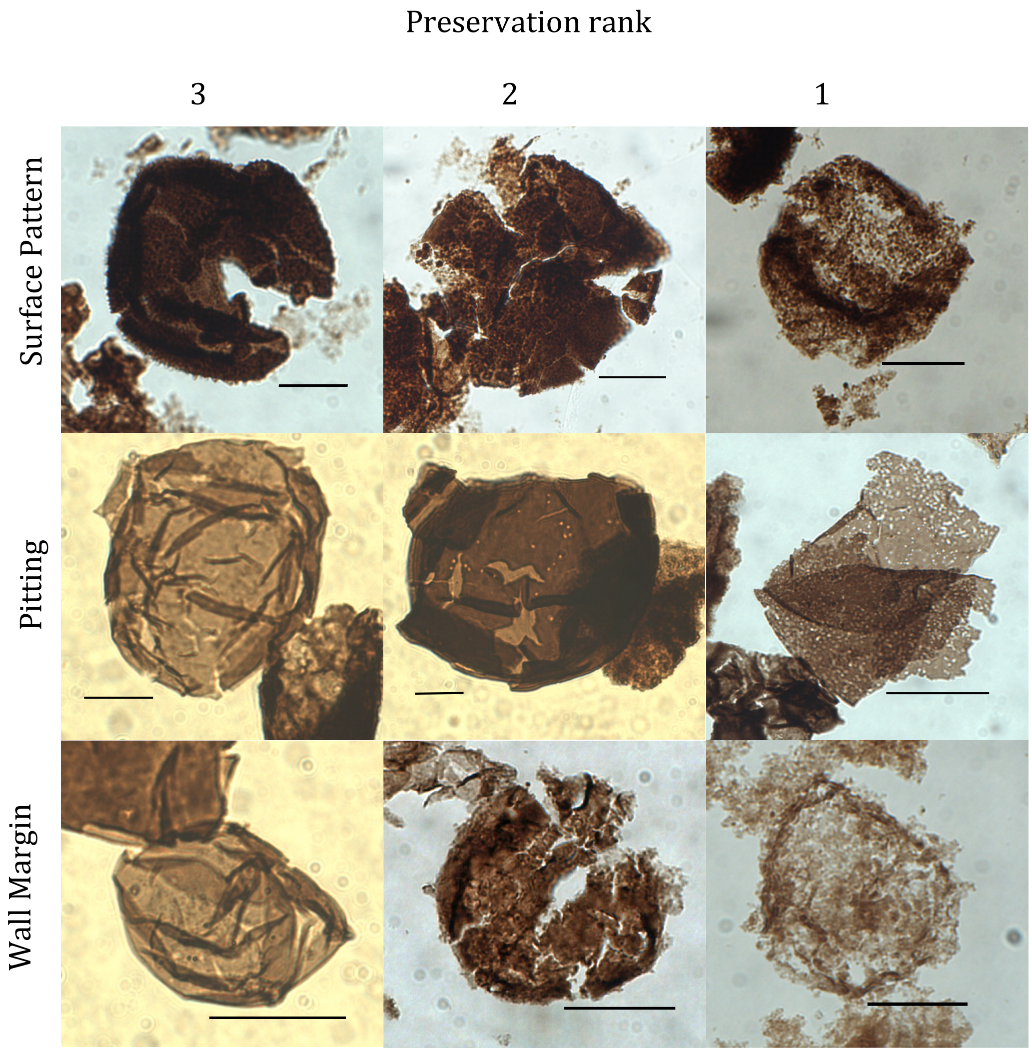

Figure S1: Fossil examples of each rank of preservational quality for three indices that measure the loss of surface pattern, density of pitting on cell/cyst wall, and deterioration of wall margin (See Table S2 for criteria). Preservation rank of 3 corresponds to high preservational quality and a rank of 1 corresponds to poor preservational quality. The top three images that illustrate surface pattern are of *Lanulatisphaera laufeldii* and the middle and bottom rows are *Leiosphaeridia* sp. Scale bar is 15 μm.

Preservation	Rank	Loss of surface pattern	Density of pitting	Deterioration of wall margin
High	**3**	Even distribution of surface pattern (sculpture or ornamentation) allowing for minor imperfections.	Few or no pits and perforations. Wall surface is not damaged (except for minor imperfections).	Cell/cyst margin is intact and exhibits the original fossil shape. No fraying.
Medium	**2**	Uneven distribution of surface pattern – between one third and two thirds of the cell surface still displays original surface pattern.	Random distribution of pitting of wall surface. Fine and irregularly shaped perforations.	Between one third and two thirds of the margin is intact and exhibits original fossil shape. Portions of the margin appear distressed, tattered, and small areas are missing leaving cavities.
Low	**1**	Near loss of surface pattern– less than a third of the cell surface area still displays original surface pattern.	High degree of pitting, randomly distributed and often merged to form larger cavities.	Less than one third of the margin is distinct and exhibits original fossil shape. Most of the margin appears distressed, tattered, and areas are missing leaving large cavities. Margin is heavily frayed.

Table S2: Description of criteria used to rank the preservational quality on a scale of 1 (poorly preserved) to 3 (well-preserved). Note that the loss of surface pattern index only applies to ornamented or sculptured species and does not apply to smooth-walled taxa.

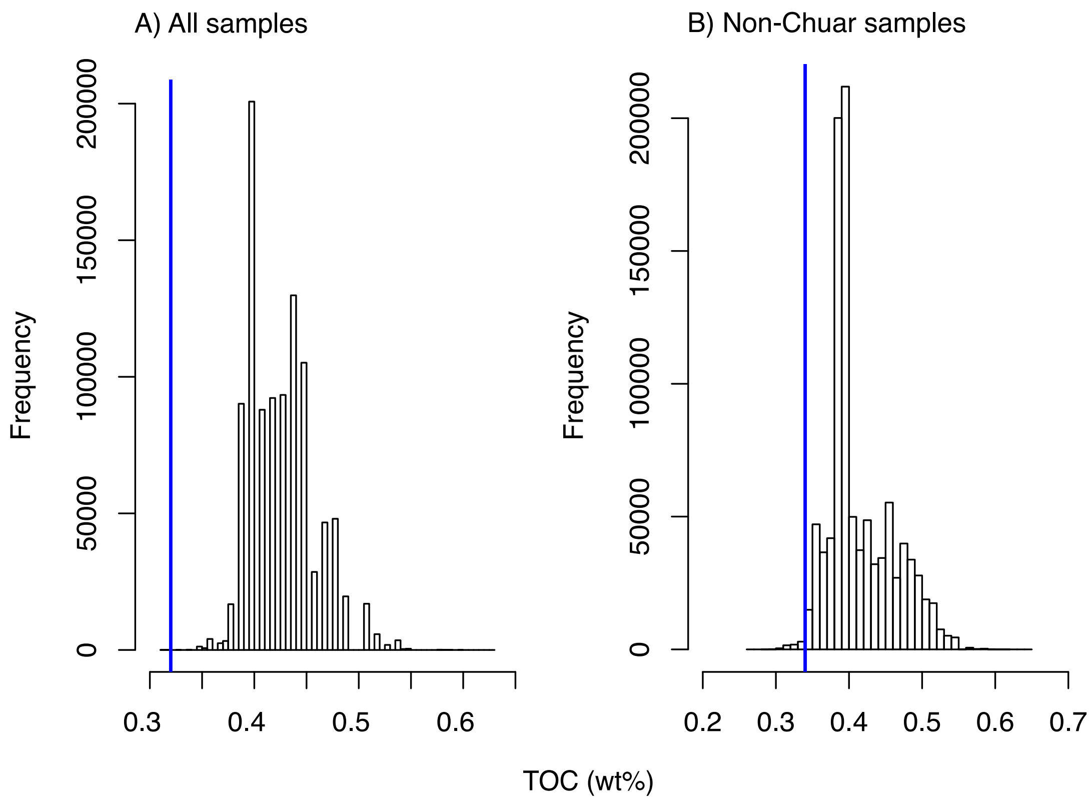

Figure S2: A) Median TOC values from 10^6 subsamples wherein 189 TOC values (of 346 total samples) were randomly selected without replacement. The probability that median TOC of a subsample ≤ 0.32 wt % (blue line) is 0.004%. B) The median TOC of 10^6 subsamples each with 122 randomly selected TOC values excluding all samples from the Chuar Group (of 236 total samples). Probability that median TOC of a subsample ≤ 0.34 wt% (blue line) is 0.7%.

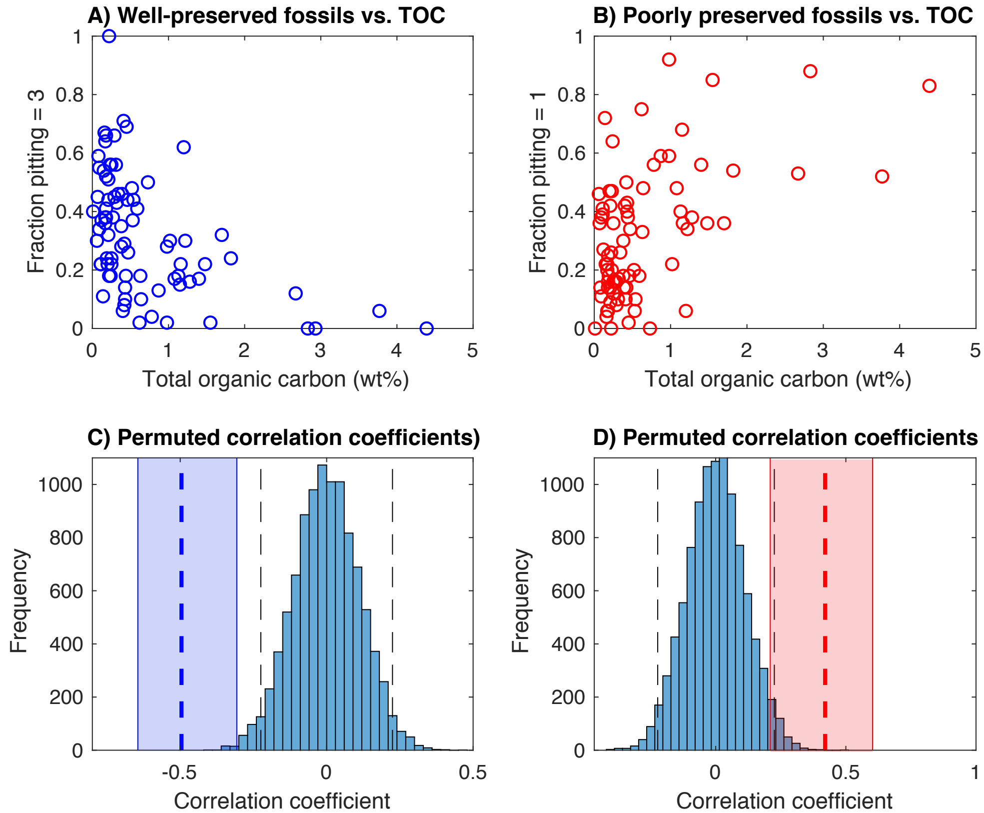

Figure S3. Total organic carbon (wt%) and the fraction of A) well-preserved specimens and B) poorly-preserved specimens within a given sample for degree of pitting index (n = 82 samples). C) Histogram of permuted Spearman's correlation coefficients from 10,000 randomizations of the fraction of well-preserved specimens and TOC. D) Histogram of permuted correlation coefficients from 10,000 randomizations of the fraction of poorly preserved specimens and TOC. The black dashed lines are the 95% confidence intervals of the permuted correlation coefficients. The blue and red dashed lines are the actual correlation coefficient of the fraction of well-preserved specimens and TOC and poorly-preserved specimens and TOC, respectively. The blue and red shaded regions are the uncertainty ($\alpha = 0.05$) around the true correlation coefficients calculated by 10,000 subsamples, with replacement.

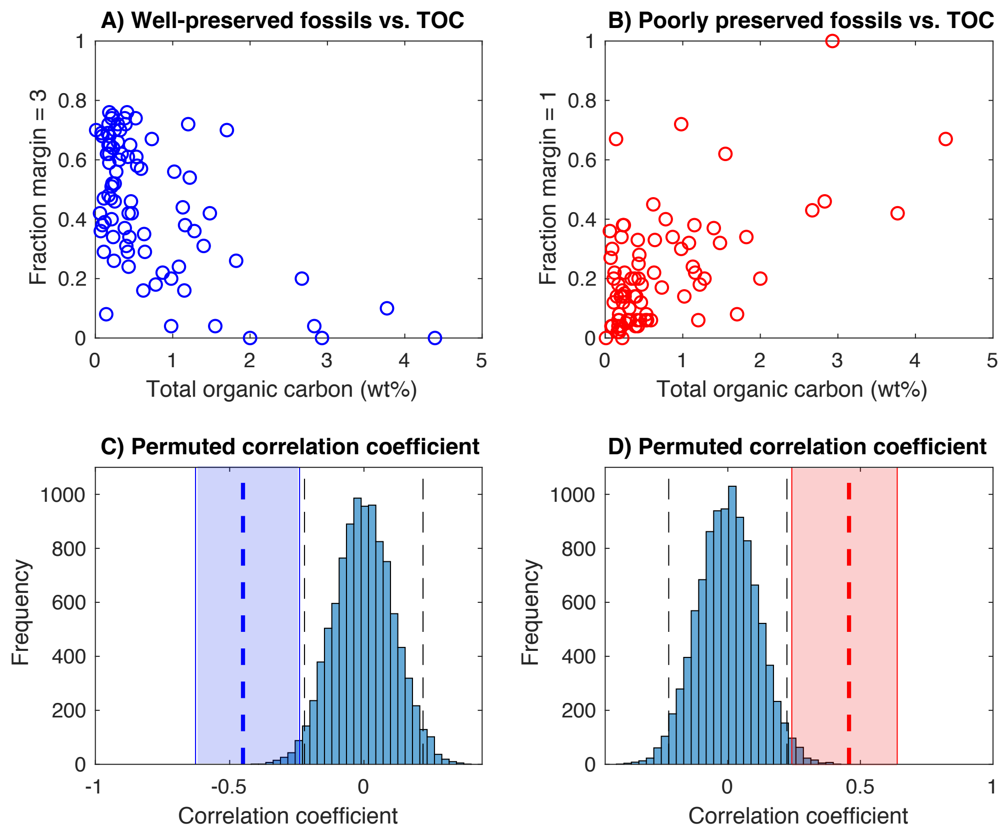

Figure S4. Total organic carbon (wt%) and the fraction of A) well-preserved specimens and B) poorly-preserved specimens within a given sample for the margin quality index (n = 82 samples). C) Histogram of permuted Spearman's correlation coefficients from 10,000 randomizations of the fraction of well-preserved specimens and TOC. D) Histogram of permuted correlation coefficients from 10,000 randomizations of the fraction of poorly preserved specimens and TOC. The black dashed lines are the 95% confidence intervals of the permuted correlation coefficients. The blue and red dashed lines are the actual correlation coefficient of the fraction of well-preserved specimens and TOC and poorly-preserved specimens and TOC. The blue and red shaded regions are the uncertainty (α = 0.05) around the true correlation coefficients calculated by 10,000 subsamples, with replacement.

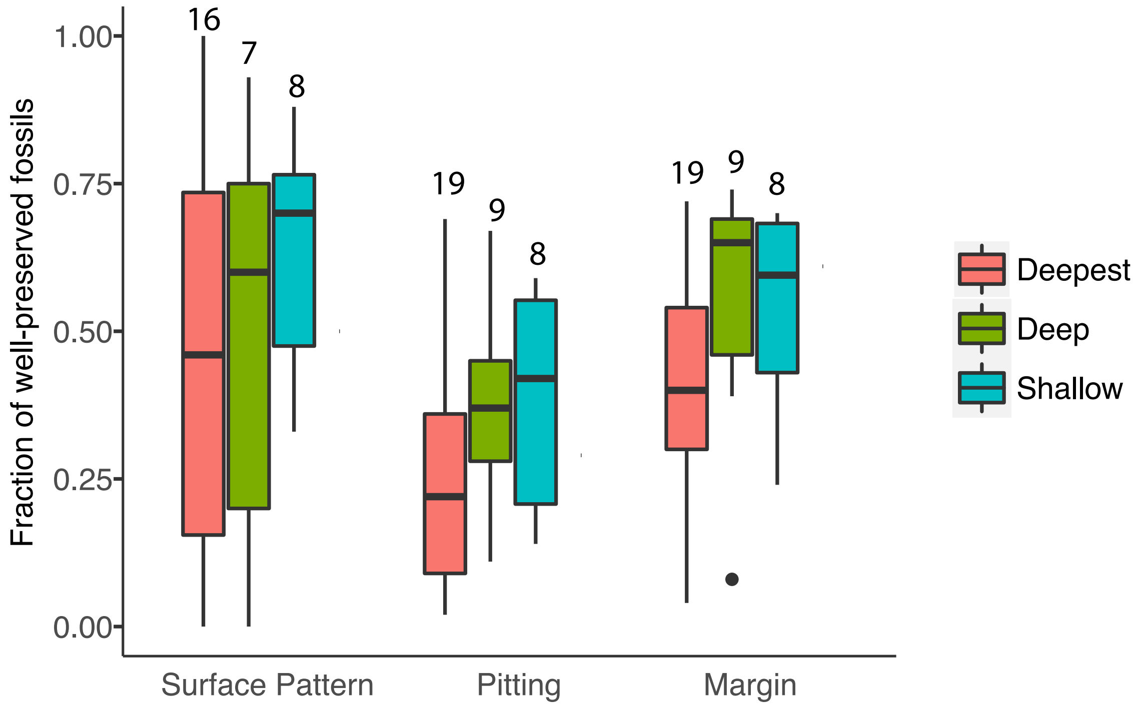

Figure S5. Relative water depths (Dehler et al., 2001) and the fraction of well-preserved specimens within a sample for the indices of surface pattern, degree of pitting, and margin quality from the Chuar Group, Arizona. Horizontal bars are median values, rectangles are interquartile ranges, whiskers extend 150% above and below the quartiles, and black points are outliers. Numbers at the top of each box and whisker are the number of samples in each water depth category.

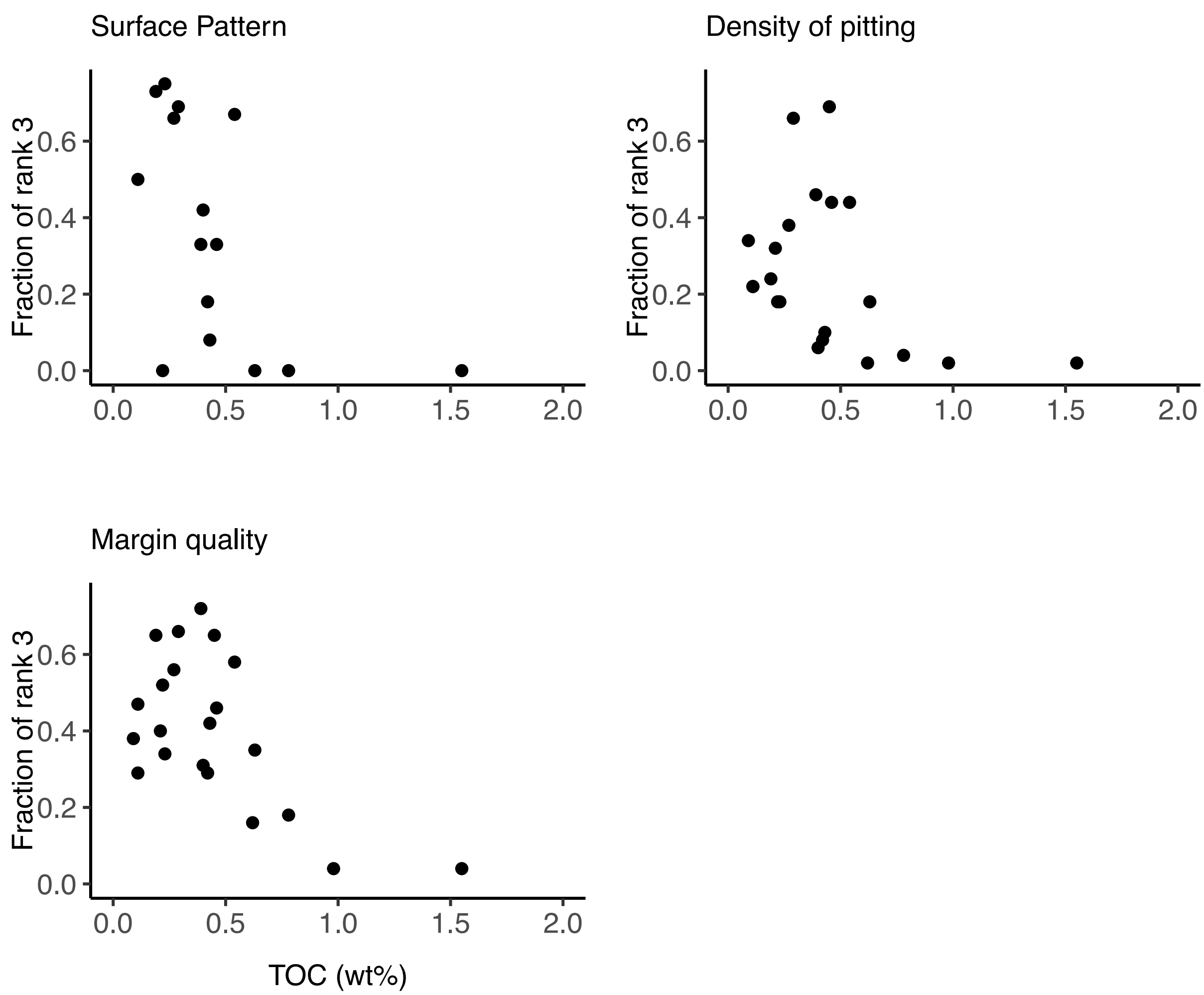

Figure S6. Total organic carbon (wt%) and the fraction of well-preserved specimens within a given sample for the indices of surface pattern, density of pitting, and margin quality from 19 samples from the deepest relative water depth, Chuar Group, Arizona (Dehler et al., 2001).

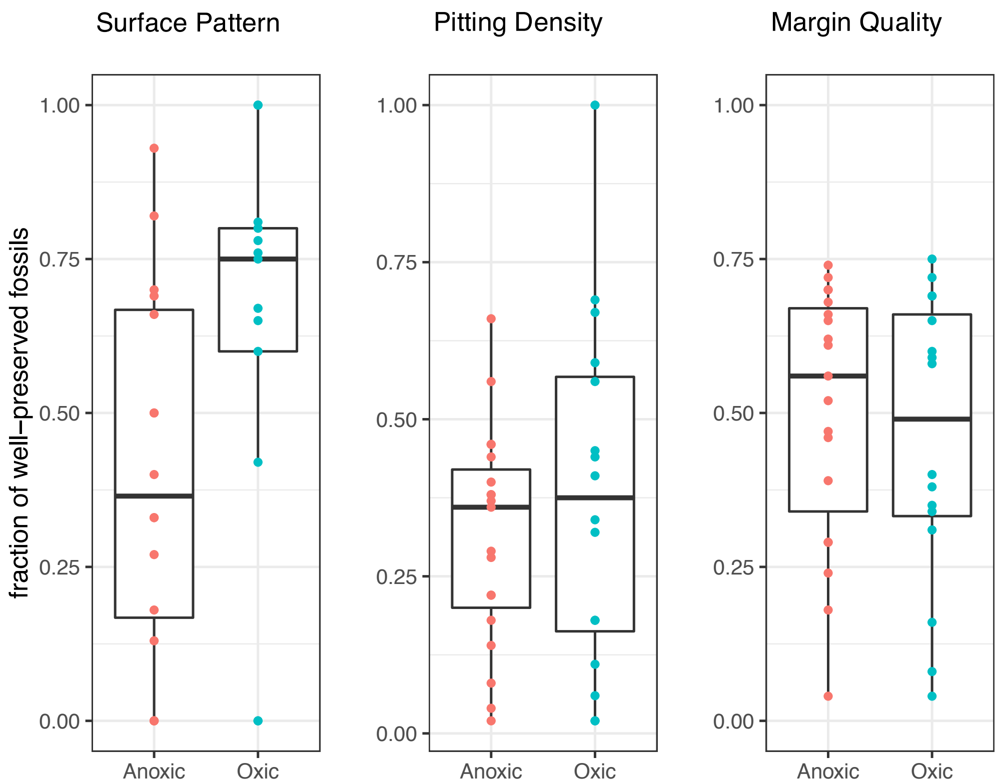

Figure S7. Bottom water redox (Johnston et al., 2010) and preservational quality indices of surface pattern, pitting density, and margin quality for 35 samples from the Chuar Group, Arizona. Redox is measured by the ratio of highly reactive iron species to the total iron within a sample. Individual samples are represented by pink and teal points for anoxic (n = 19) and oxic samples (n = 16), respectively. Horizontal bars are median values, rectangles are interquartile ranges, and whiskers extend 150% above and below quartiles.

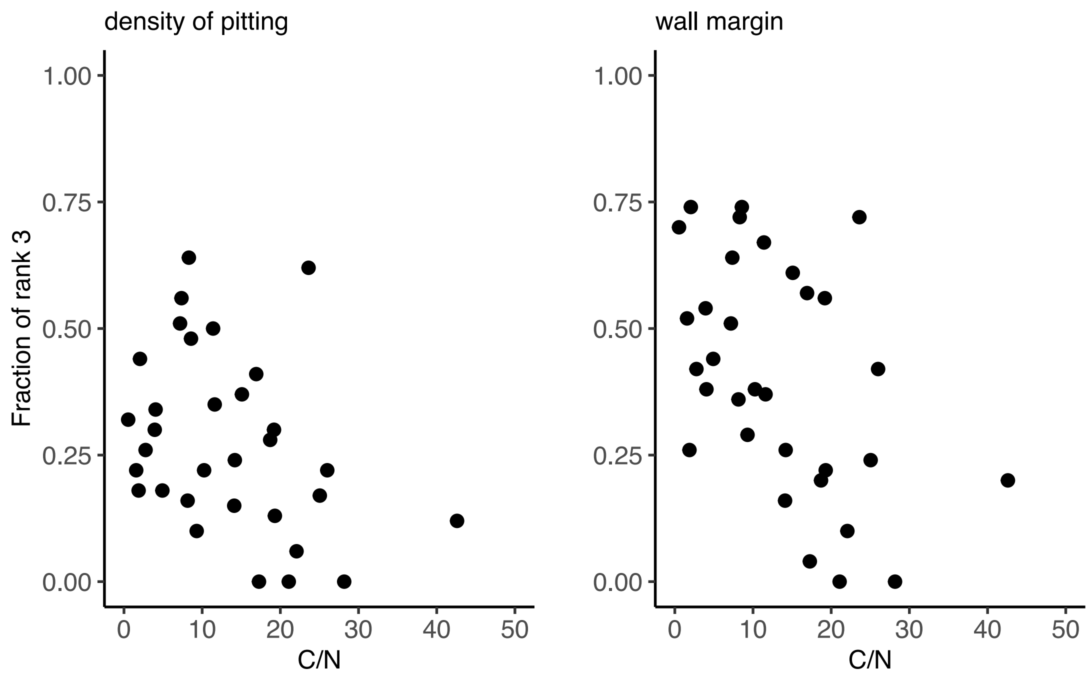

Figure S8. Preservational quality indices of pitting density and margin quality with the ratio of total organic carbon to total nitrogen (C/N) from the Alinya Formation, Australia (*n* = 5); Aralka Formation, Australia (*n* = 6); Bedroup 19, Greenland (*n* = 1); Bylot Supergroup, Canada (*n* = 9), Chuar Group, USA (*n* = 8), Colville-E15, Canada (*n* = 1); and Roper Group, Australia (*n* = 2).

Sample ID	Geologic Unit	Location	Country	TOC (wt%)	C /N	Fossils	taxa count	TOC reference	Fossil reference
Blinman 1499.9	Umberatana Group	Adelaide Rift	Australia	0.39	6.50	N	0	This study	Riedman et al., 2014
Blinman 1505	Umberatana Group	Adelaide Rift	Australia	0.39	6.13	N	0	This study	Riedman et al., 2014
Blinman 1518.2	Umberatana Group	Adelaide Rift	Australia	0.35	5.53	N	0	This study	Riedman et al., 2014
Blinman 1530.2	Umberatana Group	Adelaide Rift	Australia	0.31	5.72	N	0	This study	Riedman et al., 2014
Blinman 1531.9	Umberatana Group	Adelaide Rift	Australia	0.25	4.22	N	0	This study	Riedman et al., 2014
Blinman 1541.6	Umberatana Group	Adelaide Rift	Australia	0.30	5.75	N	0	This study	Riedman et al., 2014
Blinman 1560.2	Umberatana Group	Adelaide Rift	Australia	0.35	7.21	N	0	This study	Riedman et al., 2014
Blinman 1563.7	Umberatana Group	Adelaide Rift	Australia	0.20	5.00	N	0	This study	Riedman et al., 2014
Blinman 1570.6	Umberatana Group	Adelaide Rift	Australia	0.52	8.31	N	0	This study	Riedman et al., 2014
Blinman 1592.4	Umberatana Group	Adelaide Rift	Australia	0.72	13.00	N	0	This study	Riedman et al., 2014
Blinman 1604.1	Umberatana Group	Adelaide Rift	Australia	1.02	17.00	N	0	This study	Riedman et al., 2014
Blinman 1612.3	Umberatana Group	Adelaide Rift	Australia	0.98	13.70	N	0	This study	Riedman et al., 2014
Blinman 1619.2	Umberatana Group	Adelaide Rift	Australia	0.20	5.50	N	0	This study	Riedman et al., 2014
Blinman 1622	Umberatana Group	Adelaide Rift	Australia	0.58	13.10	N	0	This study	Riedman et al., 2014
SCYW-1A 1289.71	Umberatana Group	Adelaide Rift	Australia	0.30	3.40	Y	1	This study	Riedman et al., 2014
SCYW-1A 1314.9	Umberatana Group	Adelaide Rift	Australia	0.39	3.60	Y	2	This study	Riedman et al., 2014
SCYW-1A 1323.9	Umberatana Group	Adelaide Rift	Australia	0.36	4.00	N	0	This study	Riedman et al., 2014
Wallara 1282.4	Aralka Formation	Amadeus Basin	Australia	0.55	6.76	Y	2	This study	Riedman et al., 2014
Wallara 1284.4	Aralka Formation	Amadeus Basin	Australia	0.64	9.30	Y	1	This study	Riedman et al., 2014
Wallara 1286.4	Aralka Formation	Amadeus Basin	Australia	0.73	11.40	Y	1	This study	Riedman et al., 2014
Wallara 1294.5	Aralka Formation	Amadeus Basin	Australia	0.89	12.80	N	0	This study	Riedman et al., 2014
Wallara 1298.5	Aralka Formation	Amadeus Basin	Australia	1.15	14.10	Y	1	This study	Riedman et al., 2014
Wallara 1300.4	Aralka Formation	Amadeus Basin	Australia	0.98	18.70	Y	2	This study	Riedman et al., 2014
Wallara 1301.9	Aralka Formation	Amadeus Basin	Australia	0.87	19.30	Y	2	This study	Riedman et al., 2014
Wallara 1304.3	Aralka Formation	Amadeus Basin	Australia	2.67	42.60	Y	2	This study	Riedman et al., 2014
Wallara 1306.2	Aralka Formation	Amadeus Basin	Australia	0.31	9.70	Y	1	This study	Riedman et al., 2014
BR 489.4	Areyonga Formation	Amadeus Basin	Australia	0.12	2.24	Y	2	This study	Riedman et al., 2014
BR 493.6	Areyonga Formation	Amadeus Basin	Australia	0.09	1.90	Y	1	This study	Riedman et al., 2014
BR 517.16	Areyonga Formation	Amadeus Basin	Australia	0.23	4.70	Y	3	This study	Riedman et al., 2014
BR 532.25	Areyonga Formation	Amadeus Basin	Australia	0.11	3.03	Y	2	This study	Riedman et al., 2014
Wallara 1354.9	Areyonga Formation	Amadeus Basin	Australia	0.14	7.30	Y	4	This study	Riedman et al., 2014
Wallara 1367	Areyonga Formation	Amadeus Basin	Australia	0.12	6.50	Y	2	This study	Riedman et al., 2014
Wallara 1376.8	Areyonga Formation	Amadeus Basin	Australia	0.06	2.60	N	0	This study	Riedman et al., 2014
Wallara 1411.2	Areyonga Formation	Amadeus Basin	Australia	0.09	3.58	Y	2	This study	Riedman et al., 2014
U3 28.00	Roper Group	McArthur Basin	Australia	2.93	21.08	Y	1	This study	This study
U4 122.80	Roper Group	McArthur Basin	Australia	1.83	19.48	Y	1	This study	This study
U4 133.05	Roper Group	McArthur Basin	Australia	6.23	40.70	N	0	This study	This study
U4 137.76	Roper Group	McArthur Basin	Australia	7.25	42.13	N	0	This study	This study
U4 145.00	Roper Group	McArthur Basin	Australia	4.39	28.17	Y	1	This study	This study
U4 187.70	Roper Group	McArthur Basin	Australia	4.16	27.01	N	0	This study	This study
U4 197.80	Roper Group	McArthur Basin	Australia	3.00	25.85	N	0	This study	This study
U4 90.93	Roper Group	McArthur Basin	Australia	1.53	17.33	Y	1	This study	This study
U4 93.12	Roper Group	McArthur Basin	Australia	1.19	12.83	Y	1	This study	This study
U4 97.97	Roper Group	McArthur Basin	Australia	0.20	3.70	Y		This study	This study
Forrest-1 850.9	Togari Group	NW Tasmania	Australia	0.40	10.70	N	0	This study	Riedman et al., 2014
Forrest-1 880.75	Togari Group	NW Tasmania	Australia	0.25	5.60	Y	1	This study	Riedman et al., 2014
Forrest-1 886.3	Togari Group	NW Tasmania	Australia	0.59		Y	1	This study	Riedman et al., 2014
Forrest-1 902.3	Togari Group	NW Tasmania	Australia	0.63	7.00	Y	1	This study	Riedman et al., 2014
Forrest-1 907.1	Togari Group	NW Tasmania	Australia	0.81		N	0	This study	Riedman et al., 2014
Forrest-1 914.9	Togari Group	NW Tasmania	Australia	1.45	38.90	N	0	This study	Riedman et al., 2014
Forrest-1 933.3	Togari Group	NW Tasmania	Australia	2.48		N	0	This study	Riedman et al., 2014
Forrest-1 939.9	Togari Group	NW Tasmania	Australia	1.84		N	0	This study	Riedman et al., 2014
Giles 1237.74	Alinya Formation	Officer Basin	Australia	0.11	4.28	Y	5	This study	Riedman and Porter, 2016
Giles 1242.72	Alinya Formation	Officer Basin	Australia	0.21	7.17	Y	6	This study	Riedman and Porter, 2016
Giles 1244	Alinya Formation	Officer Basin	Australia	2.00	166.33	Y	2	This study	Riedman and Porter, 2016
Giles 1244.17	Alinya Formation	Officer Basin	Australia	0.23	9.83	Y	8	This study	Riedman and Porter, 2016
Giles 1248.91	Alinya Formation	Officer Basin	Australia	0.12	7.69	Y	5	This study	Riedman and Porter, 2016
Giles 1255.45	Alinya Formation	Officer Basin	Australia	1.02	19.19	Y	9	This study	Riedman and Porter, 2016
Giles 1256.4	Alinya Formation	Officer Basin	Australia	0.13	6.89	N	0	This study	Riedman and Porter, 2016
Giles 1257.73	Alinya Formation	Officer Basin	Australia	0.05	2.60	Y	4	This study	Riedman and Porter, 2016
Giles 1265.2	Alinya Formation	Officer Basin	Australia	0.09	2.68	N	0	This study	Riedman and Porter, 2016
Giles 1265.46	Alinya Formation	Officer Basin	Australia	1.20	23.61	Y	16	This study	Riedman and Porter, 2016
Giles 1265.57	Alinya Formation	Officer Basin	Australia	0.53	15.09	Y	21	This study	Riedman and Porter, 2016
Giles 1265.71	Alinya Formation	Officer Basin	Australia	0.17	8.30	Y	11	This study	Riedman and Porter, 2016
Giles 1266.3	Alinya Formation	Officer Basin	Australia	0.09	2.57	Y	8	This study	Riedman and Porter, 2016
DB 217.2	Rocky Cape Group	Tasmania	Australia	0.34	5.10	N	0	This study	This study
DB 274.3	Rocky Cape Group	Tasmania	Australia	0.85	14.42	N	0	This study	This study
DB 313.4	Rocky Cape Group	Tasmania	Australia	1.03	13.89	N	0	This study	This study
DB 341	Rocky Cape Group	Tasmania	Australia	1.10	20.33	N	0	This study	This study
DB 357	Rocky Cape Group	Tasmania	Australia	0.78	12.44	N	0	This study	This study
DB 360	Rocky Cape Group	Tasmania	Australia	0.68	40.12	N	0	This study	This study
DB 391	Rocky Cape Group	Tasmania	Australia	0.31	10.89	Y	1	This study	This study
DB 424	Rocky Cape Group	Tasmania	Australia	0.44	9.46	N	0	This study	This study

DB 462	Rocky Cape Group	Tasmania	Australia	0.51	31.88	N	0	This study	This study
DB 489	Rocky Cape Group	Tasmania	Australia	0.08	7.18	N	0	This study	This study
MB1401- 107.6	Arctic Bay Fm, Bylot Supergroup	Baffin Island	Canada	1.22	3.94	Y	22	Hodgskiss et al., 2020	This study
MB1401- 113.7	Arctic Bay Fm, Bylot Supergroup	Baffin Island	Canada	1.13	4.91	Y	28	Hodgskiss et al., 2020	This study
MB1401- 132	Arctic Bay Fm, Bylot Supergroup	Baffin Island	Canada	0.85	3.40	Y	19	Hodgskiss et al., 2020	This study
MB1401- 140	Arctic Bay Fm, Bylot Supergroup	Baffin Island	Canada	0.32	1.14	Y	13	Hodgskiss et al., 2020	This study
MB1401- 150	Arctic Bay Fm, Bylot Supergroup	Baffin Island	Canada	0.48	1.60	Y	17	Hodgskiss et al., 2020	This study
MB1401- 160	Arctic Bay Fm, Bylot Supergroup	Baffin Island	Canada	0.36	1.38	Y	23	Hodgskiss et al., 2020	This study
MB1401- 167.2	Arctic Bay Fm, Bylot Supergroup	Baffin Island	Canada	0.54	2.45	Y	24	Hodgskiss et al., 2020	This study
MB1401- 441.5	Arctic Bay Fm, Bylot Supergroup	Baffin Island	Canada	0.25	1.56	Y	18	Hodgskiss et al., 2020	This study
MB1401- 465.5	Arctic Bay Fm, Bylot Supergroup	Baffin Island	Canada	0.47	2.76	Y	32	Hodgskiss et al., 2020	This study
MB1401- 6.4	Arctic Bay Fm, Bylot Supergroup	Baffin Island	Canada	1.62	9.53	Y	11	Hodgskiss et al., 2020	This study
MB1401- 85	Arctic Bay Fm, Bylot Supergroup	Baffin Island	Canada	0.74	2.85	Y	11	Hodgskiss et al., 2020	This study
MB1401- 91	Arctic Bay Fm, Bylot Supergroup	Baffin Island	Canada	1.08	2.70	Y	10	Hodgskiss et al., 2020	This study
PWC 1405 347.0	Arctic Bay Fm, Bylot Supergroup	Baffin Island	Canada	0.21	2.05	Y	1	This study	This study
PWC-1405 632	Arctic Bay Fm, Bylot Supergroup	Baffin Island	Canada	1.70	0.54	Y	1	This study	This study
T1413 244	Arctic Bay Fm, Bylot Supergroup	Baffin Island	Canada	1.22	16.09	Y		This study	This study
T1413 304.2	Arctic Bay Fm, Bylot Supergroup	Baffin Island	Canada	0.67	12.66	Y		This study	This study
T1413 104	Arctic Bay Fm, Bylot Supergroup	Baffin Island	Canada	0.49	8.36	Y		This study	This study
T1413 96.4	Arctic Bay Fm, Bylot Supergroup	Baffin Island	Canada	0.24	1.87	Y		This study	This study
T1413- 105.7	Arctic Bay Fm, Bylot Supergroup	Baffin Island	Canada	1.04	6.50	N	0	Hodgskiss et al., 2020	This study
T1413- 112.3	Arctic Bay Fm, Bylot Supergroup	Baffin Island	Canada	1.51	6.57	N	0	Hodgskiss et al., 2020	This study
T1413- 126.5	Arctic Bay Fm, Bylot Supergroup	Baffin Island	Canada	10.54	27.74	N	0	Hodgskiss et al., 2020	This study
T1413- 129.7	Arctic Bay Fm, Bylot Supergroup	Baffin Island	Canada	7.53	23.53	N	0	Hodgskiss et al., 2020	This study
T1413- 134.7	Arctic Bay Fm, Bylot Supergroup	Baffin Island	Canada	5.94	20.48	N	0	Hodgskiss et al., 2020	This study
T1413- 140	Arctic Bay Fm, Bylot Supergroup	Baffin Island	Canada	3.83	18.24	N	0	Hodgskiss et al., 2020	This study
T1413- 149.4	Arctic Bay Fm, Bylot Supergroup	Baffin Island	Canada	9.72	21.60	N	0	Hodgskiss et al., 2020	This study
T1413- 154.7	Arctic Bay Fm, Bylot Supergroup	Baffin Island	Canada	2.41	12.05	N	0	Hodgskiss et al., 2020	This study
T1413- 158.9	Arctic Bay Fm, Bylot Supergroup	Baffin Island	Canada	5.04	26.53	N	0	Hodgskiss et al., 2020	This study
T1413- 16.3	Arctic Bay Fm, Bylot Supergroup	Baffin Island	Canada	0.23	2.56	N	0	Hodgskiss et al., 2020	This study
T1413- 163.2	Arctic Bay Fm, Bylot Supergroup	Baffin Island	Canada	4.94	19.76	N	0	Hodgskiss et al., 2020	This study
T1413- 166.4	Arctic Bay Fm, Bylot Supergroup	Baffin Island	Canada	5.17	22.48	N	0	Hodgskiss et al., 2020	This study
T1413- 192.5	Arctic Bay Fm, Bylot Supergroup	Baffin Island	Canada	3.12		N	0	Hodgskiss et al., 2020	This study
T1413- 196.9	Arctic Bay Fm, Bylot Supergroup	Baffin Island	Canada	1.63	9.06	N	0	Hodgskiss et al., 2020	This study
T1413- 204.5	Arctic Bay Fm, Bylot Supergroup	Baffin Island	Canada	3.27	14.86	N	0	Hodgskiss et al., 2020	This study
T1413- 213	Arctic Bay Fm, Bylot Supergroup	Baffin Island	Canada	3.49	11.63	N	0	Hodgskiss et al., 2020	This study
T1413- 226.5	Arctic Bay Fm, Bylot Supergroup	Baffin Island	Canada	2.93	15.42	N	0	Hodgskiss et al., 2020	This study
T1413- 245	Arctic Bay Fm, Bylot Supergroup	Baffin Island	Canada	2.92	19.47	N	0	Hodgskiss et al., 2020	This study
T1413- 25.6	Arctic Bay Fm, Bylot Supergroup	Baffin Island	Canada	0.58	19.33	N	0	Hodgskiss et al., 2020	This study
T1413- 259.6	Arctic Bay Fm, Bylot Supergroup	Baffin Island	Canada	3.23	17.00	N	0	Hodgskiss et al., 2020	This study
T1413- 268.6	Arctic Bay Fm, Bylot Supergroup	Baffin Island	Canada	2.12	21.20	N	0	Hodgskiss et al., 2020	This study
T1413- 275	Arctic Bay Fm, Bylot Supergroup	Baffin Island	Canada	1.33	9.50	N	0	Hodgskiss et al., 2020	This study
T1413- 282.2	Arctic Bay Fm, Bylot Supergroup	Baffin Island	Canada	2.48	13.78	N	0	Hodgskiss et al., 2020	This study
T1413- 298.7	Arctic Bay Fm, Bylot Supergroup	Baffin Island	Canada	1.23	15.38	N	0	Hodgskiss et al., 2020	This study
T1413- 306.9	Arctic Bay Fm, Bylot Supergroup	Baffin Island	Canada	0.54	18.00	N	0	Hodgskiss et al., 2020	This study
T1413- 310.3	Arctic Bay Fm, Bylot Supergroup	Baffin Island	Canada	1.51	30.20	N	0	Hodgskiss et al., 2020	This study
T1413- 325.2	Arctic Bay Fm, Bylot Supergroup	Baffin Island	Canada	2.01	50.25	N	0	Hodgskiss et al., 2020	This study
T1413- 327	Arctic Bay Fm, Bylot Supergroup	Baffin Island	Canada	1.48	26.00	Y		This study	This study
T1413- 328.4	Arctic Bay Fm, Bylot Supergroup	Baffin Island	Canada	0.73	14.60	N	0	Hodgskiss et al., 2020	This study
T1413- 333.9	Arctic Bay Fm, Bylot Supergroup	Baffin Island	Canada	0.60		N	0	Hodgskiss et al., 2020	This study
T1413- 342.6	Arctic Bay Fm, Bylot Supergroup	Baffin Island	Canada	2.08		N	0	Hodgskiss et al., 2020	This study
T1413- 347	Arctic Bay Fm, Bylot Supergroup	Baffin Island	Canada	0.51	51.00	N	0	Hodgskiss et al., 2020	This study
T1413- 67.2	Arctic Bay Fm, Bylot Supergroup	Baffin Island	Canada	7.11	29.63	N	0	Hodgskiss et al., 2020	This study
T1413- 76.4	Arctic Bay Fm, Bylot Supergroup	Baffin Island	Canada	3.97	17.26	N	0	Hodgskiss et al., 2020	This study
T1413- 94.9	Arctic Bay Fm, Bylot Supergroup	Baffin Island	Canada	0.20	1.00	Y		Hodgskiss et al., 2020	This study
R1609 192.1	Athole Point Fm, Bylot Supergroup	Baffin Island	Canada	0.45	13.55	N	0	This study	This study
R1609 207A	Athole Point Fm, Bylot Supergroup	Baffin Island	Canada	0.17	5.28	N	0	This study	This study
SW1604- 145.1	Iqqittuq Fm, Bylot Supergroup	Baffin Island	Canada	0.25		Y	18	This study	This study
SW1604- 146.7	Iqqittuq Fm, Bylot Supergroup	Baffin Island	Canada	0.07		Y	3	This study	This study
SW1604- 149.6	Iqqittuq Fm, Bylot Supergroup	Baffin Island	Canada	0.07		Y	5	This study	This study
SW1604- 152.1	Iqqittuq Fm, Bylot Supergroup	Baffin Island	Canada	0.06		Y	5	This study	This study
SW1604- 16	Iqqittuq Fm, Bylot Supergroup	Baffin Island	Canada	0.23		Y	15	This study	This study
SW1604- 176.4	Iqqittuq Fm, Bylot Supergroup	Baffin Island	Canada	0.41		Y	20	This study	This study
SW1604- 181.0	Iqqittuq Fm, Bylot Supergroup	Baffin Island	Canada	0.33	8.35	Y	28	This study	This study
SW1604-221.6	Iqqittuq Fm, Bylot Supergroup	Baffin Island	Canada	0.39	7.40	Y	20	This study	This study
T1412 139.0	Iqqittuq Fm, Bylot Supergroup	Baffin Island	Canada	0.35	9.43	Y		This study	This study
T1412 153.7	Iqqittuq Fm, Bylot Supergroup	Baffin Island	Canada	0.30	5.96	Y		This study	This study
T1412 194.3	Iqqittuq Fm, Bylot Supergroup	Baffin Island	Canada	0.52	8.57	Y	6	This study	This study
G1608	Strathcona Sound, Bylot Supergroup	Baffin Island	Canada	0.17	8.24	N	0	This study	This study
T1606 56	Strathcona Sound, Bylot Supergroup	Baffin Island	Canada	0.07	6.18	Y		This study	This study
ONT H-34 10006	Undifferentiated Proterozoic	NW Territories	Canada	0.10	1.98	N	0	This study	This study
ONT H-34 10007	Undifferentiated Proterozoic	NW Territories	Canada	0.04	1.75	N	0	This study	This study
ONT H-34 10013	Undifferentiated Proterozoic	NW Territories	Canada	0.09	5.29	N	0	This study	This study
ONT H-34 9490	Undifferentiated Proterozoic	NW Territories	Canada	0.10	5.26	N	0	This study	This study
BV 26	Dismal Lake Formation	NW Territories	Canada	1.46	29.14	N	0	This study	This study

BW 31	Dismal Lake Formation	NW Territories	Canada	2.14	35.02	N	0	This study	This study
BX 35	Dismal Lake Formation	NW Territories	Canada	0.55	18.97	Y		This study	This study
BY 39	Dismal Lake Formation	NW Territories	Canada	0.38	17.05	Y		This study	This study
BZ 46	Hornby Bay Formation	NW Territories	Canada	0.29	19.33	Y		This study	This study
CA 52	Hornby Bay Formation	NW Territories	Canada	0.29	14.30	Y		This study	This study
CE 65	Hornby Bay Formation	NW Territories	Canada	0.60		N	0	This study	This study
BS 12	Rae Group	NW Territories	Canada	0.20	3.15	Y		This study	This study
BT 15	Rae Group	NW Territories	Canada	0.08	2.39	N	0	This study	This study
CC55	Rocknest Formation	NW Territories	Canada	0.70		N	0	This study	This study
Col E-15 4531	Undifferentiated Proterozoic	NW Territories	Canada	0.12	3.97	N	0	This study	This study
Col E-15 5035	Undifferentiated Proterozoic	NW Territories	Canada	0.08	3.80	N	0	This study	This study
Col E-15 5115	Undifferentiated Proterozoic	NW Territories	Canada	0.38	11.61	Y	2	This study	This study
Col E-15 5180	Undifferentiated Proterozoic	NW Territories	Canada	0.32	16.20	Y		This study	This study
Col E-15 5236	Undifferentiated Proterozoic	NW Territories	Canada	0.28	11.67	Y		This study	This study
Col E-15 5422	Undifferentiated Proterozoic	NW Territories	Canada	0.28	13.10	Y		This study	This study
Col E-15 5587	Undifferentiated Proterozoic	NW Territories	Canada	0.36	22.31	Y		This study	This study
Col E-15 5901	Undifferentiated Proterozoic	NW Territories	Canada	0.12	5.90	Y		This study	This study
Col E-15 5996	Undifferentiated Proterozoic	NW Territories	Canada	0.18	17.90	N	0	This study	This study
CH05pv 1	Chuanlinggou Fm, Changcheng Group	Kuancheng	China	0.23	10.59	Y		This study	This study
CH05pv 4	Chuanlinggou Fm, Changcheng Group	Kuancheng	China	0.55	19.64	Y		This study	This study
Greenland Gp 19	Bedgroup 19, Andrée Land	Ella Ø	Greenland	1.28	8.14	Y	1	This study	This study
G407.233 TS	MacDonalddryggen Mbr, Polarisbreen Fm	Nordaustlanded	Norway	0.24		N	0	Kunzmann et al. 2015	Riedman et al., 2014
G407.278 TS	MacDonalddryggen Mbr, Polarisbreen Fm	Nordaustlanded	Norway	0.19		N	0	Kunzmann et al. 2015	Riedman et al., 2014
G435 56	MacDonalddryggen Mbr, Polarisbreen Fm	Nordaustlanded	Norway	0.38	7.07	Y	2	This study	Riedman et al., 2014
G435 66	MacDonalddryggen Mbr, Polarisbreen Fm	Nordaustlanded	Norway	0.51	0.13	N	0	This study	Riedman et al., 2014
G435 79.5	MacDonalddryggen Mbr, Polarisbreen Fm	Nordaustlanded	Norway	0.47	9.40	N	0	This study	Riedman et al., 2014
G435.25 TS	MacDonalddryggen Mbr, Polarisbreen Fm	Nordaustlanded	Norway	0.24		N	0	Kunzmann et al. 2015	Riedman et al., 2014
G435.45 A	MacDonalddryggen Mbr, Polarisbreen Fm	Nordaustlanded	Norway	0.83		N	0	Kunzmann et al. 2015	Riedman et al., 2014
G435.76	MacDonalddryggen Mbr, Polarisbreen Fm	Nordaustlanded	Norway	0.68		N	0	Kunzmann et al. 2015	Riedman et al., 2014
MacG 22-4-0.5	MacDonalddryggen Mbr, Polarisbreen Fm	Nordaustlanded	Norway	0.313	7.83	N	0	This study	Riedman et al., 2014
MacG 22-4-10.2	MacDonalddryggen Mbr, Polarisbreen Fm	Nordaustlanded	Norway	0.396	9.21	N	0	This study	Riedman et al., 2014
MacG 22-4-15.2	MacDonalddryggen Mbr, Polarisbreen Fm	Nordaustlanded	Norway	0.183	10.76	N	0	This study	Riedman et al., 2014
MacG 22-4-28	MacDonalddryggen Mbr, Polarisbreen Fm	Nordaustlanded	Norway	0.25	4.81	N	0	This study	Riedman et al., 2014
MacG 22-4-3	MacDonalddryggen Mbr, Polarisbreen Fm	Nordaustlanded	Norway	0.29	9.77	N	0	This study	Riedman et al., 2014
G406.0	Russoya Mbr, Polarisbreen Fm	Nordaustlanded	Norway	0.40	13.62	Y	2	This study	Riedman et al., 2014
G406.35	Russoya Mbr, Polarisbreen Fm	Nordaustlanded	Norway	1.69		Y	2	Kunzmann et al. 2015	Riedman et al., 2014
G471.6.1	Svanbergfjellet Formation	Nordaustlanded	Norway	0.35		Y	4	Kunzmann et al. 2015	Riedman et al., 2014
G471.8.3	Svanbergfjellet Formation	Nordaustlanded	Norway	0.30		Y	5	Kunzmann et al. 2015	Riedman et al., 2014
Islay-1	Lossit Formation	Islay	Scotland	0.16	2.14	N	0	This study	This study
BN12	Visingso Group	Lake Vättern	Sweden	0.76		Y	1	This study	This study
BN2.8	Visingso Group	Lake Vättern	Sweden	0.80		Y	1	This study	This study
BN22.5	Visingso Group	Lake Vättern	Sweden	0.58		Y	1	This study	This study
BN30	Visingso Group	Lake Vättern	Sweden	0.39		N	0	This study	This study
BN30.8	Visingso Group	Lake Vättern	Sweden	0.60		Y	2	This study	This study
BN34.85	Visingso Group	Lake Vättern	Sweden	1.23		Y	2	This study	This study
BN4.6	Visingso Group	Lake Vättern	Sweden	0.28		Y	1	This study	This study
BN46.4	Visingso Group	Lake Vättern	Sweden	0.85		Y	2	This study	This study
BN52.2	Visingso Group	Lake Vättern	Sweden	0.35		N	0	This study	This study
BN58.5	Visingso Group	Lake Vättern	Sweden	0.96		N	0	This study	This study
BN68.5	Visingso Group	Lake Vättern	Sweden	0.54		Y	1	This study	This study
BN73.2	Visingso Group	Lake Vättern	Sweden	0.12		N	0	This study	This study
BN79.5	Visingso Group	Lake Vättern	Sweden	0.69		Y	1	This study	This study
BN88.5	Visingso Group	Lake Vättern	Sweden	0.91		N	0	This study	This study
Neg10	Visingso Group	Lake Vättern	Sweden	0.49		N	0	This study	This study
Neg3	Visingso Group	Lake Vättern	Sweden	0.44		Y	2	This study	This study
SP12-53-1	Galeros Fm., Chuar Group	Grand Canyon	USA	0.09	0.68	Y	1	This study	Porter and Riedman, 2016
SP12-53-12	Galeros Fm., Chuar Group	Grand Canyon	USA	1.40	18.36	Y	1	This study	Porter and Riedman, 2016
SP12-53-15	Galeros Fm., Chuar Group	Grand Canyon	USA	3.81	26.92	N	0	This study	Porter and Riedman, 2016
SP12-53-17	Galeros Fm., Chuar Group	Grand Canyon	USA	0.09	4.04	Y	3	This study	Porter and Riedman, 2016
SP12-53-3	Galeros Fm., Chuar Group	Grand Canyon	USA	1.40		Y	3	This study	Porter and Riedman, 2016
SP12-53-4	Galeros Fm., Chuar Group	Grand Canyon	USA	1.20		N	0	This study	Porter and Riedman, 2016
SP12-53-7	Galeros Fm., Chuar Group	Grand Canyon	USA	0.14		Y	1	This study	Porter and Riedman, 2016
SP12-63-15	Galeros Fm., Chuar Group	Grand Canyon	USA	0.48		N	0	Dehler et al., 2005	Porter and Riedman, 2016
SP12-63-22	Galeros Fm., Chuar Group	Grand Canyon	USA	0.22		Y	1	Dehler et al., 2005	Porter and Riedman, 2016
SP12-63-23	Galeros Fm., Chuar Group	Grand Canyon	USA	0.20		Y	1	Dehler et al., 2005	Porter and Riedman, 2016
SP12-63-24	Galeros Fm., Chuar Group	Grand Canyon	USA	1.40		Y	1	Dehler et al., 2005	Porter and Riedman, 2016
SP12-63-28	Galeros Fm., Chuar Group	Grand Canyon	USA	0.18		Y	4	Dehler et al., 2005	Porter and Riedman, 2016
SP12-63-29	Galeros Fm., Chuar Group	Grand Canyon	USA	0.09		Y	1	Dehler et al., 2005	Porter and Riedman, 2016
SP12-63-3	Galeros Fm., Chuar Group	Grand Canyon	USA	0.46		Y	1	This study	Porter and Riedman, 2016
SP12-63-30	Galeros Fm., Chuar Group	Grand Canyon	USA	0.45		Y	9	Dehler et al., 2005	Porter and Riedman, 2016
SP12-63-31	Galeros Fm., Chuar Group	Grand Canyon	USA	0.01		Y	1	Dehler et al., 2001	This study
SP12-63-33	Galeros Fm., Chuar Group	Grand Canyon	USA	0.42		Y	4	Dehler et al., 2005	This study
SP12-63-35	Galeros Fm., Chuar Group	Grand Canyon	USA	0.63		Y	2	Dehler et al., 2005	Porter and Riedman, 2016
SP12-63-4	Galeros Fm., Chuar Group	Grand Canyon	USA	0.62		Y	1	Dehler et al., 2005	Porter and Riedman, 2016
SP12-63-8	Galeros Fm., Chuar Group	Grand Canyon	USA	0.54		Y	6	This study	Porter and Riedman, 2016

SP12-69-1	Galeros Fm., Chuar Group	Grand Canyon	USA	0.41		N	0	Dehler et al., 2005	Porter and Riedman, 2016
SP12-69-12	Galeros Fm., Chuar Group	Grand Canyon	USA	0.22		Y	4	Dehler et al., 2005	This study
SP12-69-13	Galeros Fm., Chuar Group	Grand Canyon	USA	0.29		Y	9	Dehler et al., 2005	This study
SP12-69-14	Galeros Fm., Chuar Group	Grand Canyon	USA	0.43		Y	3	Dehler et al., 2005	Porter and Riedman, 2016
SP12-69-15	Galeros Fm., Chuar Group	Grand Canyon	USA	0.39		Y	4	Dehler et al., 2005	This study
SP12-69-16	Galeros Fm., Chuar Group	Grand Canyon	USA	0.27		Y	11	Dehler et al., 2005	Porter and Riedman, 2016
SP12-69-17	Galeros Fm., Chuar Group	Grand Canyon	USA	0.31		Y	10	Dehler et al., 2005	This study
SP12-69-3	Galeros Fm., Chuar Group	Grand Canyon	USA	0.45		N	0	This study	Porter and Riedman, 2016
SP12-69-7	Galeros Fm., Chuar Group	Grand Canyon	USA	0.34		Y	9	Dehler et al., 2005	Porter and Riedman, 2016
SP12-69-8	Galeros Fm., Chuar Group	Grand Canyon	USA	0.25		Y	7	Dehler et al., 2005	Porter and Riedman, 2016
SP14-63-10	Galeros Fm., Chuar Group	Grand Canyon	USA	0.29		Y		Dehler et al., 2005	This study
SP14-63-11	Galeros Fm., Chuar Group	Grand Canyon	USA	0.18		Y	14	Dehler et al., 2005	Porter and Riedman, 2016
SP14-63-12	Galeros Fm., Chuar Group	Grand Canyon	USA	0.08		Y	8	Dehler et al., 2005	Porter and Riedman, 2016
SP14-63-14	Galeros Fm., Chuar Group	Grand Canyon	USA	0.16		Y	13	Dehler et al., 2005	Porter and Riedman, 2016
SP14-63-15	Galeros Fm., Chuar Group	Grand Canyon	USA	0.19		Y	3	Dehler et al., 2005	Porter and Riedman, 2016
SP14-63-17	Galeros Fm., Chuar Group	Grand Canyon	USA	0.42		Y	12	Dehler et al., 2005	Porter and Riedman, 2016
SP14-63-19	Galeros Fm., Chuar Group	Grand Canyon	USA	0.23		Y	5	Dehler et al., 2005	Porter and Riedman, 2016
SP14-63-21	Galeros Fm., Chuar Group	Grand Canyon	USA	0.38		Y	5	Dehler et al., 2005	This study
SP14-63-23	Galeros Fm., Chuar Group	Grand Canyon	USA	0.32		Y	3	Dehler et al., 2005	Porter and Riedman, 2016
SP14-63-24	Galeros Fm., Chuar Group	Grand Canyon	USA	0.12		Y	5	This study	Porter and Riedman, 2016
SP14-63-25	Galeros Fm., Chuar Group	Grand Canyon	USA	0.07	0.99	Y	1	This study	Porter and Riedman, 2016
SP14-63-27	Galeros Fm., Chuar Group	Grand Canyon	USA	0.09		N	0	This study	Porter and Riedman, 2016
SP14-63-28	Galeros Fm., Chuar Group	Grand Canyon	USA	1.38	18.89	Y	3	This study	Porter and Riedman, 2016
SP14-63-29	Galeros Fm., Chuar Group	Grand Canyon	USA	0.11		Y	5	This study	Porter and Riedman, 2016
SP14-63-5	Galeros Fm., Chuar Group	Grand Canyon	USA	2.34		N	0	This study	Porter and Riedman, 2016
SP14-63-8	Galeros Fm., Chuar Group	Grand Canyon	USA	0.25		Y	3	Dehler et al., 2005	Porter and Riedman, 2016
SP17-56-1	Galeros Fm., Chuar Group	Grand Canyon	USA	0.04	3.15	N	0	This study	This study
SP17-56-5	Galeros Fm., Chuar Group	Grand Canyon	USA	1.87	103.61	N	0	This study	This study
SP17-56-9	Galeros Fm., Chuar Group	Grand Canyon	USA	1.15	71.94	N	0	This study	This study
TW17-63-J14	Galeros Fm., Chuar Group	Grand Canyon	USA	0.03	1.75	N	0	This study	This study
TW17-63-J15	Galeros Fm., Chuar Group	Grand Canyon	USA	0.14	5.64	Y	4	This study	This study
TW17-63-J17	Galeros Fm., Chuar Group	Grand Canyon	USA	0.13	8.33	N	0	This study	This study
TW17-63-J2	Galeros Fm., Chuar Group	Grand Canyon	USA	2.20	168.85	N	0	This study	This study
TW17-63-J3	Galeros Fm., Chuar Group	Grand Canyon	USA	0.04	1.23	N	0	This study	This study
TW17-63-J4	Galeros Fm., Chuar Group	Grand Canyon	USA	0.15	4.61	Y	6	This study	This study
TW17-63-J5	Galeros Fm., Chuar Group	Grand Canyon	USA	0.06	1.44	Y	1	This study	This study
TW17-63-J7	Galeros Fm., Chuar Group	Grand Canyon	USA	0.31	10.52	Y	3	This study	This study
TW17-63-J9	Galeros Fm., Chuar Group	Grand Canyon	USA	0.59	16.91	Y	6	This study	This study
TW17-63-T1	Galeros Fm., Chuar Group	Grand Canyon	USA	1.08	25.05	Y	4	This study	This study
TW17-63-T10	Galeros Fm., Chuar Group	Grand Canyon	USA	0.35	15.39	N	0	This study	This study
TW17-63-T14	Galeros Fm., Chuar Group	Grand Canyon	USA	0.17	7.59	Y	5	This study	This study
TW17-63-T17	Galeros Fm., Chuar Group	Grand Canyon	USA	0.03	1.03	N	0	This study	This study
TW17-63-T20	Galeros Fm., Chuar Group	Grand Canyon	USA	0.15	3.82	Y	7	This study	This study
TW17-63-T23	Galeros Fm., Chuar Group	Grand Canyon	USA	0.23	7.35	Y	3	This study	This study
TW17-63-T25	Galeros Fm., Chuar Group	Grand Canyon	USA	0.19	6.26	Y	6	This study	This study
TW17-63-T3	Galeros Fm., Chuar Group	Grand Canyon	USA	1.01	18.72	N	0	This study	This study
TW17-63-T6	Galeros Fm., Chuar Group	Grand Canyon	USA	0.48	16.10	N	0	This study	This study
TW17-63-T7	Galeros Fm., Chuar Group	Grand Canyon	USA	0.54	16.72	N	0	This study	This study
AK10-53-13E	Kwagunt Fm., Chuar Group	Grand Canyon	USA	1.94	9.17	N	0	This study	Porter and Riedman, 2016
AK10-53-15	Kwagunt Fm., Chuar Group	Grand Canyon	USA	0.72		N	0	Dehler et al., 2005	Porter and Riedman, 2016
AK10-60-20	Kwagunt Fm., Chuar Group	Grand Canyon	USA	0.40		N	0	Dehler et al., 2005	Porter and Riedman, 2016
AK10-60-21	Kwagunt Fm., Chuar Group	Grand Canyon	USA	3.42		N	0	Dehler et al., 2005	Porter and Riedman, 2016
AK10-60-22	Kwagunt Fm., Chuar Group	Grand Canyon	USA	0.89		N	0	Dehler et al., 2005	Porter and Riedman, 2016
AK10-60-23	Kwagunt Fm., Chuar Group	Grand Canyon	USA	2.12		N	0	Dehler et al., 2005	Porter and Riedman, 2016
AK10-60-24	Kwagunt Fm., Chuar Group	Grand Canyon	USA	1.56		Y	1	Dehler et al., 2005	Porter and Riedman, 2016
AK10-60-26	Kwagunt Fm., Chuar Group	Grand Canyon	USA	2.58		N	0	Dehler et al., 2005	Porter and Riedman, 2016
AK10-60-28	Kwagunt Fm., Chuar Group	Grand Canyon	USA	1.20		N	0	Dehler et al., 2005	Porter and Riedman, 2016
AK10-60-3	Kwagunt Fm., Chuar Group	Grand Canyon	USA	0.11		Y	1	Dehler et al., 2005	Porter and Riedman, 2016
AK10-60-31	Kwagunt Fm., Chuar Group	Grand Canyon	USA	3.76		N	0	Dehler et al., 2005	Porter and Riedman, 2016
AK10-60-32	Kwagunt Fm., Chuar Group	Grand Canyon	USA	1.42		N	0	Dehler et al., 2005	Porter and Riedman, 2016
AK10-60-34	Kwagunt Fm., Chuar Group	Grand Canyon	USA	1.69		N	0	Dehler et al., 2005	Porter and Riedman, 2016
AK10-60-7	Kwagunt Fm., Chuar Group	Grand Canyon	USA	0.40		Y	5	Dehler et al., 2005	Porter and Riedman, 2016
AWA 245	Kwagunt Fm., Chuar Group	Grand Canyon	USA	1.82	14.18	Y	1	This study	This study
AWA 247	Kwagunt Fm., Chuar Group	Grand Canyon	USA	1.16	10.25	Y	3	This study	This study
AWA 265.5	Kwagunt Fm., Chuar Group	Grand Canyon	USA	3.77	22.07	Y	1	This study	This study
AWA265ch	Kwagunt Fm., Chuar Group	Grand Canyon	USA	3.31	27.81	N	0	This study	This study
Chuar Shale 2	Kwagunt Fm., Chuar Group	Grand Canyon	USA	1.54	10.83	Y	1	This study	This study
Chuar Shale 3	Kwagunt Fm., Chuar Group	Grand Canyon	USA	3.00	17.77	Y	1	This study	This study
SP12-56-10	Kwagunt Fm., Chuar Group	Grand Canyon	USA	1.14		N	0	Dehler et al., 2005	Porter and Riedman, 2016
SP12-56-11	Kwagunt Fm., Chuar Group	Grand Canyon	USA	2.77		N	0	Dehler et al., 2005	Porter and Riedman, 2016
SP12-56-14	Kwagunt Fm., Chuar Group	Grand Canyon	USA	4.57		N	0	Dehler et al., 2005	Porter and Riedman, 2016
SP12-56-18	Kwagunt Fm., Chuar Group	Grand Canyon	USA	1.14		N	0	Dehler et al., 2005	Porter and Riedman, 2016
SP12-56-19	Kwagunt Fm., Chuar Group	Grand Canyon	USA	1.14		N	0	Dehler et al., 2005	Porter and Riedman, 2016
SP14-53-10	Kwagunt Fm., Chuar Group	Grand Canyon	USA	0.17		Y	4	Dehler et al., 2005	Porter and Riedman, 2016
SP14-53-11	Kwagunt Fm., Chuar Group	Grand Canyon	USA	0.21		Y	2	Dehler et al., 2005	Porter and Riedman, 2016

SP14-53-14	Kwagunt Fm., Chuar Group	Grand Canyon	USA	0.98		Y	2	Dehler et al., 2005	Porter and Riedman, 2016
SP14-53-19	Kwagunt Fm., Chuar Group	Grand Canyon	USA	0.78		Y	3	This study	Porter and Riedman, 2016
SP14-53-20	Kwagunt Fm., Chuar Group	Grand Canyon	USA	1.55		Y	2	This study	Porter and Riedman, 2016
SP14-53-21	Kwagunt Fm., Chuar Group	Grand Canyon	USA	1.00		N	0	Dehler et al., 2005	Porter and Riedman, 2016
SP14-53-22	Kwagunt Fm., Chuar Group	Grand Canyon	USA	1.61		N	0	Dehler et al., 2005	Porter and Riedman, 2016
SP14-53-4	Kwagunt Fm., Chuar Group	Grand Canyon	USA	0.44		Y	1	This study	Porter and Riedman, 2016
SP14-53-6	Kwagunt Fm., Chuar Group	Grand Canyon	USA	0.37		Y	2	This study	Porter and Riedman, 2016
SP14-53-7	Kwagunt Fm., Chuar Group	Grand Canyon	USA	0.11		Y	2	Dehler et al., 2005	Porter and Riedman, 2016
SP14-53-9	Kwagunt Fm., Chuar Group	Grand Canyon	USA	0.43		Y	6	Dehler et al., 2005	Porter and Riedman, 2016
TW17-56-W-1.3BA	Kwagunt Fm., Chuar Group	Grand Canyon	USA	1.89	10.43	N	0	This study	This study
TW17-56-W-19.2 BA	Kwagunt Fm., Chuar Group	Grand Canyon	USA	2.75	12.77	N	0	This study	This study
TW17-56-W-3.6 BA	Kwagunt Fm., Chuar Group	Grand Canyon	USA	2.57	14.06	N	0	This study	This study
TW17-56-W-32BD	Kwagunt Fm., Chuar Group	Grand Canyon	USA	1.71	12.69	N	0	This study	This study
TW17-56-W-48BD	Kwagunt Fm., Chuar Group	Grand Canyon	USA	0.90	5.61	N	0	This study	This study
Wal 31	Kwagunt Fm., Chuar Group	Grand Canyon	USA	2.83	17.27	Y	2	This study	This study
G1724 Greyson	Greyson Formation	Montana	USA	0.12	4.68	N	0	This study	This study
Greyson 1	Greyson Formation	Montana	USA	0.09	1.96	N	0	This study	This study
Greyson 2	Greyson Formation	Montana	USA	0.08	1.44	N	0	This study	This study
Greyson 3	Greyson Formation	Montana	USA	0.08	1.56	N	0	This study	This study
Greyson 4	Greyson Formation	Montana	USA	0.08	1.46	N	0	This study	This study
Greyson 5	Greyson Formation	Montana	USA	0.08	1.42	N	0	This study	This study
JE73101-1	Uinta Mountain Group	Utah	USA	0.15		Y	2	Sprinkel & Waanders, 2005	Sprinkel & Waanders, 2005
LP10-03-01-1	Uinta Mountain Group	Utah	USA	0.11		Y	2	Sprinkel & Waanders, 2005	Nagy and Porter, 2005
LP10-03-01-2	Uinta Mountain Group	Utah	USA	0.10		Y	5	Sprinkel & Waanders, 2005	Sprinkel & Waanders, 2005
RP01A-50	Uinta Mountain Group	Utah	USA	0.17		Y	2	Dehler et al., 2007	Nagy and Porter, 2005
RP01A-63	Uinta Mountain Group	Utah	USA	0.15		Y	2	Dehler et al., 2007	Nagy and Porter, 2005
RP01A-68	Uinta Mountain Group	Utah	USA	0.66		Y	2	Dehler et al., 2007	Nagy and Porter, 2005
RP01A-70	Uinta Mountain Group	Utah	USA	0.16		Y	2	Dehler et al., 2007	Nagy and Porter, 2005
RP01A-85	Uinta Mountain Group	Utah	USA	3.70		N	0	Dehler et al., 2007	Nagy and Porter, 2005
RP03B-01	Uinta Mountain Group	Utah	USA	0.07		N	0	Dehler et al., 2007	Nagy and Porter, 2005
RP03B-24	Uinta Mountain Group	Utah	USA	0.19		N	0	Dehler et al., 2007	Nagy and Porter, 2005
RP03B-25	Uinta Mountain Group	Utah	USA	0.18		Y	1	Dehler et al., 2007	Nagy and Porter, 2005
TW16-MH 19.6	Uinta Mountain Group	Utah	USA	0.06	1.33	N	0	This study	This study
TW16-MH-1.2	Uinta Mountain Group	Utah	USA	0.15	2.88	Y	6	This study	This study
TW16-MH-13.7	Uinta Mountain Group	Utah	USA	0.13	3.54	Y	7	This study	This study
TW16-MH-16.3	Uinta Mountain Group	Utah	USA	0.29	4.72	Y	6	This study	This study
TW16-MH-21.3	Uinta Mountain Group	Utah	USA	0.23	4.09	Y	6	This study	This study
TW16-MH-29.5	Uinta Mountain Group	Utah	USA	0.11	3.93	Y	4	This study	This study
TW16-MH-3	Uinta Mountain Group	Utah	USA	0.07	1.71	Y	2	This study	This study
TW16-MH-7	Uinta Mountain Group	Utah	USA	0.25	5.06	Y	4	This study	This study
TW17-LP15	Uinta Mountain Group	Utah	USA	0.10	7.36	Y		This study	This study
TW17-LP3	Uinta Mountain Group	Utah	USA	0.09	3.54	Y	2	This study	This study
TW17-LP5	Uinta Mountain Group	Utah	USA	0.12	4.64	Y	4	This study	This study
TW17-LP9	Uinta Mountain Group	Utah	USA	0.12	5.08	Y		This study	This study
USFS WWI	Uinta Mountain Group	Utah	USA	0.23		Y	3	Sprinkel & Waanders, 2005	Sprinkel & Waanders, 2005
WR 15.3	Uinta Mountain Group	Utah	USA	0.40	3.28	Y		This study	This study
WR10-01-01-3	Uinta Mountain Group	Utah	USA	0.64		Y	3	Sprinkel & Waanders, 2005	Sprinkel & Waanders, 2005
WR10-01-01-5	Uinta Mountain Group	Utah	USA	1.60		Y	3	Sprinkel & Waanders, 2005	Sprinkel & Waanders, 2005

Table S3: Sample identification, location, TOC (wt%), C/N (total organic carbon/total nitrogen), fossil data and references for 346 shale samples.

	Surface pattern				Pitting density				Margin quality				
Sample ID	Fraction of 3	2	1	number of specimens	Fraction of 3	2	1	number of specimens	Fraction of 3	2	1	number of specimens	TOC
AK10-60-3B					0.22	0.37	0.41	50	0.47	0.41	0.12	50	0.11
AK10-60-7	0.42	0.42	0.16	19	0.06	0.52	0.42	50	0.31	0.55	0.14	50	0.40
AWA 245					0.24	0.22	0.54	50	0.26	0.40	0.34	50	1.82
AWA 247	0.20	0.00	0.80	5	0.22	0.42	0.36	50	0.38	0.40	0.22	50	1.16
AWA 265.5	0.00	1.00	0.00	1	0.06	0.42	0.52	31	0.10	0.48	0.42	31	3.77
Colville E-15 5115					0.35	0.35	0.30	46	0.37	0.43	0.20	46	0.38
Giles 1242.72					0.51	0.40	0.09	35	0.51	0.34	0.14	35	0.21
Giles 1244.0					0.20	0.80	0.00	4	0.00	0.80	0.20	4	2.00
Giles 1255.45	0.00	0.00	1.00	1	0.30	0.48	0.22	50	0.56	0.30	0.14	50	1.02
Giles 1265.46	0.00	0.00	1.00	1	0.62	0.32	0.06	50	0.72	0.22	0.06	50	1.20
Giles 1265.57	0.57	0.43	0.00	7	0.37	0.57	0.06	50	0.61	0.31	0.08	50	0.53
Giles 1265.71					0.64	0.30	0.06	50	0.72	0.22	0.06	50	0.17
Greenland 19					0.16	0.46	0.38	50	0.36	0.44	0.20	50	1.28
MB 1401 107.6	0.50	0.50	0.00	2	0.30	0.36	0.34	50	0.54	0.28	0.18	50	1.22
MB 1401 113.7					0.18	0.42	0.40	50	0.44	0.32	0.24	50	1.13
MB 1401 465.5	0.60	0.40	0.00	5	0.26	0.40	0.34	50	0.42	0.40	0.18	50	0.47
MB 1401 441.5					0.22	0.42	0.36	50	0.52	0.26	0.22	50	0.25
PWC 1405 347	1.00	0.00	0.00	2	0.44	0.42	0.14	50	0.74	0.22	0.04	50	0.21
PWC 1405 632	1.00	0.00	0.00	1	0.32	0.32	0.36	50	0.70	0.22	0.08	50	1.70
RP01A-50					0.38	0.42	0.20	50	0.48	0.34	0.18	50	0.17
RP01A-63					0.54	0.24	0.22	50	0.62	0.24	0.14	50	0.15
RP03B-25	1.00	0.00	0.00	1	0.52	0.32	0.16	50	0.62	0.30	0.08	50	0.18
SP12-53-17	1.00	0.00	0.00	4	0.34	0.28	0.38	50	0.38	0.32	0.30	50	0.09
SP12-53-3	0.33	0.33	0.33	3	0.17	0.27	0.56	50	0.31	0.31	0.37	50	1.40
SP12-53-7					0.11	0.17	0.72	36	0.08	0.25	0.67	36	0.14
SP12-63-22					1.00	0.00	0.00	4	0.75	0.25	0.00	4	0.22
SP12-63-23	0.50	0.50	0.00	8	0.22	0.31	0.47	50	0.47	0.39	0.14	50	0.20
SP12-63-28	0.70	0.22	0.07	27	0.38	0.38	0.25	50	0.68	0.24	0.08	50	0.18
SP12-63-29	0.88	0.12	0.00	41	0.55	0.34	0.11	50	0.68	0.28	0.04	50	0.09
SP12-63-3	0.33	0.33	0.33	6	0.44	0.38	0.18	50	0.46	0.42	0.12	50	0.46
SP12-63-30	0.81	0.16	0.03	31	0.69	0.29	0.02	50	0.65	0.29	0.06	50	0.45
SP12-63-31					0.40	0.60	0.00	10	0.70	0.30	0.00	10	0.01
SP12-63-33	0.18	0.18	0.64	11	0.08	0.42	0.50	50	0.29	0.39	0.33	50	0.42
SP12-63-35	0.00	1.00	0.00	1	0.18	0.49	0.33	40	0.35	0.43	0.22	40	0.63
SP12-63-4	1.00	0.00	0.00	1	0.02	0.23	0.75	50	0.16	0.39	0.45	50	0.62
SP12-63-8	0.67	0.33	0.00	21	0.44	0.46	0.10	50	0.58	0.36	0.06	50	0.54
SP12-69-12	0.00	0.60	0.40	5	0.18	0.56	0.26	50	0.52	0.32	0.16	50	0.22
SP12-69-13	0.69	0.28	0.03	36	0.66	0.26	0.08	50	0.66	0.28	0.06	50	0.29
SP12-69-14	0.40	0.60	0.00	5	0.14	0.43	0.43	50	0.24	0.51	0.25	50	0.43
SP12-69-15	0.33	0.67	0.00	6	0.46	0.40	0.14	50	0.72	0.24	0.04	50	0.39
SP12-69-16	0.66	0.27	0.07	41	0.38	0.47	0.16	100	0.56	0.39	0.05	100	0.27
SP12-69-17	0.76	0.16	0.08	25	0.56	0.34	0.10	50	0.60	0.30	0.10	50	0.31
SP12-69-7	0.27	0.45	0.27	11	0.46	0.28	0.26	50	0.62	0.18	0.20	50	0.34
SP12-69-8	0.82	0.18	0.00	11	0.56	0.32	0.12	50	0.70	0.16	0.14	50	0.25
SP14-53-10	0.93	0.07	0.00	14	0.36	0.42	0.22	50	0.65	0.31	0.04	50	0.17
SP14-53-11					0.32	0.26	0.42	50	0.40	0.26	0.34	50	0.21
SP14-53-14					0.02	0.06	0.92	50	0.04	0.24	0.72	50	0.98
SP14-53-19	0.00	0.43	0.57	7	0.04	0.40	0.56	50	0.18	0.42	0.40	50	0.78
SP14-53-20	0.00	0.50	0.50	6	0.02	0.13	0.85	52	0.04	0.35	0.62	52	1.55
SP14-53-7	0.50	0.25	0.25	4	0.22	0.39	0.39	50	0.29	0.51	0.20	50	0.11
SP14-53-9	0.08	0.33	0.58	12	0.10	0.50	0.40	50	0.42	0.38	0.20	50	0.43
SP14-63-10	0.60	0.40	0.00	5	0.45	0.39	0.16	50	0.72	0.22	0.06	50	0.29
SP14-63-11	0.65	0.35	0.00	20	0.41	0.45	0.14	50	0.59	0.35	0.06	50	0.18
SP14-63-12	0.78	0.16	0.06	32	0.59	0.27	0.14	50	0.69	0.27	0.04	50	0.08
SP14-63-14	0.80	0.15	0.05	20	0.67	0.29	0.04	50	0.69	0.30	0.02	50	0.16
SP14-63-15	0.73	0.18	0.09	22	0.24	0.59	0.18	70	0.65	0.32	0.03	70	0.19
SP14-63-17	0.50	0.38	0.13	16	0.29	0.55	0.14	50	0.61	0.35	0.04	50	0.42
SP14-63-19	0.75	0.08	0.17	12	0.18	0.36	0.47	47	0.34	0.28	0.38	47	0.23
SP14-63-21	0.00	0.43	0.57	7	0.28	0.54	0.18	50	0.74	0.12	0.14	50	0.38
SP14-63-23	0.75	0.25	0.00	12	0.43	0.40	0.17	50	0.70	0.24	0.06	50	0.32
SP14-63-24	0.13	0.63	0.25	8	0.37	0.35	0.27	50	0.39	0.39	0.22	50	0.12
SP14-63-8 .					0.24	0.60	0.16	26	0.46	0.38	0.15	26	0.25
SW 1604 152.1					0.30	0.24	0.46	50	0.42	0.22	0.36	50	0.06
SW 1605 63.3	1.00	0.00	0.00	6	0.66	0.28	0.06	50	0.76	0.22	0.02	50	0.18
SW1604- 149.6					0.45	0.18	0.36	13	0.36	0.36	0.27	13	0.07
SW1604- 176.4	0.90	0.00	0.10	10	0.71	0.19	0.10	51	0.76	0.18	0.06	51	0.41
T 1413 327	0.00	1.00	0.00	1	0.22	0.42	0.36	50	0.42	0.26	0.32	50	1.48
T 1413 96.4	1.00	0.00	0.00	1	0.18	0.18	0.64	50	0.26	0.36	0.38	50	0.24
T 1412 194.3	0.57	0.29	0.14	7	0.48	0.32	0.20	50	0.74	0.20	0.06	50	0.52
TW17-63-J9	0.67	0.33	0.00	21	0.41	0.41	0.18	50	0.57	0.37	0.06	50	0.59
TW17-63-T1	0.75	0.25	0.00	8	0.17	0.35	0.48	50	0.24	0.44	0.32	50	1.08
TW17-63-T23	0.78	0.22	0.00	18	0.56	0.24	0.20	50	0.64	0.24	0.12	50	0.23
U3 28.00					0.00	0.00	1.00	2	0.00	0.00	1.00	2	2.93
U4 145.00					0.00	0.17	0.83	6	0.00	0.33	0.67	6	4.39
VG neg 3					0.18	0.44	0.38	50	0.34	0.38	0.28	50	0.44
Wal 31					0.00	0.12	0.88	26	0.04	0.50	0.46	26	2.83
Wallara-1 1284.4					0.10	0.43	0.48	21	0.29	0.37	0.33	21	0.64
Wallara-1 1286.4					0.50	0.50	0.00	6	0.67	0.17	0.17	6	0.73
Wallara-1 1298.5					0.15	0.18	0.68	34	0.16	0.46	0.38	34	1.15
Wallara-1 1300.4					0.28	0.14	0.59	29	0.20	0.50	0.30	29	0.98
Wallara-1 1301.9					0.13	0.28	0.59	32	0.22	0.44	0.34	32	0.87
Wallara-1 1304.3 A	1.00	0.00	0.00	1	0.12	0.35	0.53	50	0.20	0.37	0.43	50	2.67

Table S4: Fractions of well-preserved to poorly preserved fossils and number of fossils observed (see methods for more information).

Sources Cited

Adam, Z. R., Skidmore, M. L., Mogk, D. W., and Butterfield, N. J., 2017, A Laurentian record of the earliest fossil eukaryotes: Geology, v. 45, no. 5, p. 387-390.

Bowring, S. A., and Grotzinger, J. P., 1989, Implications of new U-Pb dating and stratigraphic correlations for current tectonic models for Wopmay orogen and Thelon tectonic zone: A74.

Calver, C. R., 1998, Isotope stratigraphy of the Neoproterozoic Togari Group, Tasmania: Australian Journal of Earth Sciences, v. 45, no. 6, p. 865-874.

Canfield, D. E., Raiswell, R., Westrich, J. T., Reaves, C. M., and Berner, R. A., 1986, The use of chromium reduction in the analysis of reduced inorganic sulfur in sediments and shales: Chemical geology, v. 54, no. 1-2, p. 149-155.

Dehler, C., Gehrels, G., Porter, S., Heizler, M., Karlstrom, K., Cox, G., Crossey, L., and Timmons, M., 2016, Synthesis of the 780–740 Ma Chuar, Uinta Mountain, and Pahrump (ChUMP) groups, western USA: Implications for Laurentia-wide cratonic marine basins: Geological Society of America Bulletin, v. 129, no. 5-6, p. 607-624.

Dehler, C. M., Elrick, M., Bloch, J. D., Crossey, L. J., Karlstrom, K. E., and Des Marais, D. J., 2005, High-resolution $\delta^{13}C$ stratigraphy of the Chuar Group (ca. 770–742 Ma), Grand Canyon: Implications for mid-Neoproterozoic climate change: Geological Society of America Bulletin, v. 117, no. 1-2, p. 32-45.

Dehler, C. M., Elrick, M., Karlstrom, K. E., Smith, G. A., Crossey, L. J., and Timmons, J. M., 2001, Neoproterozoic Chuar Group (~ 800–742Ma), Grand Canyon: a record of cyclic marine deposition during global cooling and supercontinent rifting: Sedimentary Geology, v. 141, p. 465-499.

Dehler, C. M., Fanning, C. M., Link, P. K., Kingsbury, E. M., and Rybczynski, D., 2010, Maximum depositional age and provenance of the Uinta Mountain Group and Big Cottonwood Formation, northern Utah: Paleogeography of rifting western Laurentia: Geological Society of America Bulletin, v. 122, no. 9-10, p. 1686-1699.

Dehler, C. M., Porter, S. M., De Grey, L. D., Sprinkel, D. A., and Brehm, A., 2007, The Neoproterozoic Uinta Mountain Group revisited; a synthesis of recent work on the Red Pine Shale and related undivided clastic strata, northeastern Utah, U. S. A: Special Publication - Society for Sedimentary Geology, v. 86, p. 151-166.

Dempster, T. J., Rogers, G., Tanner, P. W. G., Bluck, B. J., Muir, R. J., Redwood, S. D., Ireland, T. R., and Paterson, B. A., 2002, Timing of deposition, orogenesis and glaciation within the Dalradian rocks of Scotland: constraints from U–Pb zircon ages: Journal of the Geological Society, v. 159, no. 1, p. 83-94.

Evans, K. V., Aleinikoff, J. N., Obradovich, J. D., and Fanning, C. M., 2000, SHRIMP U-Pb geochronology of volcanic rocks, Belt Supergroup, western Montana: evidence for rapid deposition of sedimentary strata: Canadian Journal of Earth Sciences, v. 37, no. 9, p. 1287-1300.

Gibson, T. M., Shih, P. M., Cumming, V. M., Fischer, W. W., Crockford, P. W., Hodgskiss, M. S. W., Wörndle, S., Creaser, R. A., Rainbird, R. H., and Skulski, T. M., 2018, Precise age of Bangiomorpha pubescens dates the origin of eukaryotic photosynthesis: Geology, v. 46, no. 2, p. 135-138.

Grey, K., Hill, A. C., and Calver, C., 2011, Biostratigraphy and stratigraphic subdivision of Cryogenian successions of Australia in a global context: Geological Society, London, Memoirs, v. 36, no. 1, p. 113.
Grey, K., Walter, M. R., and Calver, C. R., 2003, Neoproterozoic biotic diversification: Snowball Earth or aftermath of the Acraman impact?: Geology, v. 31, no. 5, p. 459-462.
Halliday, A. N., Graham, C. M., Aftalion, M., and Dymoke, P., 1989, Short paper: the depositional age of the Dalradian Supergroup: U-Pb and Sm-Nd isotopic studies of the Tayvallich Volcanics, Scotland: Journal of the Geological Society, v. 146, no. 1, p. 3-6.
Halpin, J. A., Jensen, T., McGoldrick, P., Meffre, S., Berry, R. F., Everard, J. L., Calver, C. R., Thompson, J., Goemann, K., and Whittaker, J. M., 2014, Authigenic monazite and detrital zircon dating from the Proterozoic Rocky Cape Group, Tasmania: Links to the Belt-Purcell Supergroup, North America: Precambrian Research, v. 250, p. 50-67.
Halverson, G. P., Dudás, F. Ö., Maloof, A. C., and Bowring, S. A., 2007, Evolution of the 87Sr/86Sr composition of Neoproterozoic seawater: Palaeogeography, Palaeoclimatology, Palaeoecology, v. 256, no. 3-4, p. 103-129.
Halverson, G. P., Hoffman, P. F., Schrag, D. P., Maloof, A. C., and Rice, A. H. N., 2005, Toward a Neoproterozoic composite carbon-isotope record: GSA Bulletin, v. 117, no. 9-10, p. 1181-1207.
Halverson, G. P., Kunzmann, M., Strauss, J. V., and Maloof, A. C., 2017, The Tonian-Cryogenian transition in Northeastern Svalbard: Precambrian Research.
Halverson, G. P., Maloof, A. C., and Hoffman, P. F., 2004, The Marinoan glaciation (Neoproterozoic) in northeast Svalbard: Basin Research, v. 16, no. 3, p. 297-324.
Hamilton, M. A., and Buchan, K. L., 2010, U–Pb geochronology of the Western Channel Diabase, northwestern Laurentia: implications for a large 1.59 Ga magmatic province, Laurentia's APWP and paleocontinental reconstructions of Laurentia, Baltica and Gawler craton of southern Australia: Precambrian Research, v. 183, no. 3, p. 463-473.
Heaman, L. M., LeCheminant, A. N., and Rainbird, R. H., 1992, Nature and timing of Franklin igneous events, Canada: implications for a Late Proterozoic mantle plume and the break-up of Laurentia: Earth and Planetary Science Letters, v. 109, no. 1-2, p. 117-131.
Hill, A. C., Haines, P. W., and Grey, K., 2011, Neoproterozoic glacial deposits of central Australia: Geological Society, London, Memoirs, v. 36, no. 1, p. 677-691.
Hodgskiss, M. S. W., Sansjofre, P., Kunzmann, M., Sperling, E.A., Cole, D.B., Crockford, P.W., Gibson, T.M., Halverson, G.P., 2020, A high-TOC shale in a low productivity world: the late Mesoproterozoic Arctic Bay Formation, Nunavut: Earth and Planetary Science Letters, v. 544.
Hoffman, P. F., Halverson, G. P., Domack, E. W., Maloof, A. C., Swanson-Hysell, N. L., and Cox, G. M., 2012, Cryogenian glaciations on the southern tropical paleomargin of Laurentia (NE Svalbard and East Greenland), and a primary origin for the upper Russøya (Islay) carbon isotope excursion: Precambrian Research, v. 206, p. 137-158.
Irving, E., Baker, J., Hamilton, M., and Wynne, P. J., 2004, Early Proterozoic geomagnetic field in western Laurentia: implications for paleolatitudes, local rotations and stratigraphy: Precambrian Research, v. 129, no. 3-4, p. 251-270.
Jackson, M. J., Sweet, I. P., Page, R. W., and Bradshaw, B. E., 1999, The South Nicholson and Roper Groups: evidence for the early Mesoproterozoic Roper Superbasin. In ‘Integrated basin analysis of the Isa Superbasin using seismic, well-log, and geopotential data: an evaluation of the economic potential of the northern Lawn Hill

Platform in Bradshaw B.E., and Scott D.L., eds: Australian Geological Survey v. 1999/019, p. 36–45.
Javaux, E. J., and Knoll, A. H., 2017, Micropaleontology of the lower Mesoproterozoic Roper Group, Australia, and implications for early eukaryotic evolution: Journal of Paleontology, v. 91, no. 2, p. 199-229.
Johnston, D. T., Poulton, S. W., Dehler, C., Porter, S., Husson, J., Canfield, D. E., and Knoll, A. H., 2010, An emerging picture of Neoproterozoic ocean chemistry: Insights from the Chuar Group, Grand Canyon, USA: Earth and Planetary Science Letters, v. 290, no. 1–2, p. 64-73.
Kendall, B., Creaser, R. A., Calver, C. R., Raub, T. D., and Evans, D. A. D., 2009a, Correlation of Sturtian diamictite successions in southern Australia and northwestern Tasmania by Re–Os black shale geochronology and the ambiguity of "Sturtian"-type diamictite–cap carbonate pairs as chronostratigraphic marker horizons: Precambrian Research, v. 172, no. 3-4, p. 301-310.
Kendall, B., Creaser, R. A., Gordon, G. W., and Anbar, A. D., 2009b, Re–Os and Mo isotope systematics of black shales from the Middle Proterozoic Velkerri and Wollogorang formations, McArthur Basin, northern Australia: Geochimica et Cosmochimica Acta, v. 73, no. 9, p. 2534-2558.
Kendall, B., Creaser, R. A., and Selby, D., 2006, Re-Os geochronology of postglacial black shales in Australia: Constraints on the timing of "Sturtian" glaciation: Geology, v. 34, no. 9, p. 729-732.
Kunzmann, M., Halverson, G. P., Scott, C., Minarik, W. G., and Wing, B. A., 2015, Geochemistry of Neoproterozoic black shales from Svalbard: Implications for oceanic redox conditions spanning Cryogenian glaciations: Chemical Geology, v. 417, p. 383-393.
LeCheminant, A. N., and Heaman, L. M., 1989, Mackenzie igneous events, Canada: Middle Proterozoic hotspot magmatism associated with ocean opening: Earth and Planetary Science Letters, v. 96, no. 1-2, p. 38-48.
Lillis, P. G., 2016, The Chuar petroleum system, Arizona and Utah: Hydrocarbon Source Rocks in Unconventional Plays, Rocky Mountain Region: Denver, Colorado, Rocky Mountain Association of Geologists, p. 79-137.
Lu, S. N., and Li, H. M., 1991, Single-grain zircon U–Pb age of volcanics in the Dahongyu Formation of the Changcheng Group: Bull. Chin. Inst. Geol. Sci, v. 22, p. 137-146.
Lyons, T. W., and Severmann, S., 2006, A critical look at iron paleoredox proxies: New insights from modern euxinic marine basins: Geochimica et Cosmochimica Acta, v. 70, no. 23, p. 5698-5722.
Macdonald, F. A., Schmitz, M. D., Crowley, J. L., Roots, C. F., Jones, D. S., Maloof, A. C., Strauss, J. V., Cohen, P. A., Johnston, D. T., and Schrag, D. P., 2010, Calibrating the cryogenian: Science, v. 327, no. 5970, p. 1241-1243.
Macqueen, R. W., and MacKenzie, W. S., 1973, Lower Paleozoic and Proterozoic stratigraphy, Mobil Colville Hills E- 15 well and environs, Interior Platform, District of Mackenzie: Geological Survey of Canada, no. 73-1, p. 183 - 188.
Moczydłowska, M., Pease, V., Willman, S., Wickström, L., and Agić, H., 2017, A Tonian age for the Visingsö Group in Sweden constrained by detrital zircon dating and biochronology: Implications for evolutionary events: Geological Magazine, v. 155, no. 5, p. 1175-1189.

Morrow, D. W., 1999, Lower Paleozoic stratigraphy of northern Yukon Territory and northwestern District of Mackenzie: Geological Survey of Canada, Bulletin, v. 538, no. 202.
Mueller, P., Mogk, D., Wooden, J., and Spake, D., 2016, U-Pb ages of zircons from the Lower Belt Supergroup and proximal crystalline basement: Implications for the early evolution of the Belt Basin: Geological Society of America Special Papers, v. 522, p. SPE522-511.
Nagy, R. M., Porter, S. M., Dehler, C. M., and Shen, Y., 2009, Biotic turnover driven by eutrophication before the Sturtian low-latitude glaciation: Nature Geosci, v. 2, no. 6, p. 415-418.
Noble, S. R., Hyslop, E. K., and Highton, A. J., 1996, High-precision U–Pb monazite geochronology of the c. 806 Ma Grampian Shear Zone and the implications for the evolution of the Central Highlands of Scotland: Journal of the Geological Society, v. 153, no. 4, p. 511-514.
Pehrsson, S. J., and Buchan, K. L., 1999, Borden dykes of Baffin Island, Northwest Territories: a Franklin U-Pb baddeleyite age and a paleomagnetic reinterpretation: Canadian Journal of Earth Sciences, v. 36, no. 1, p. 65-73.
Peng, P., Liu, F., Zhai, M., and Guo, J., 2012, Age of the Miyun dyke swarm: constraints on the maximum depositional age of the Changcheng System: Chinese Science Bulletin, v. 57, no. 1, p. 105-110.
Porter, S. M., and Riedman, L. A., 2016, Systematics of organic-walled microfossils from the ca. 780–740 Ma Chuar Group, Grand Canyon, Arizona: Journal of Paleontology, v. 90, no. 5, p. 815-853.
Poulton, S. W., and Canfield, D. E., 2005, Development of a sequential extraction procedure for iron: implications for iron partitioning in continentally derived particulates: Chemical geology, v. 214, no. 3-4, p. 209-221.
Poulton, S. W., and Canfield, D. E., 2011, Ferruginous conditions: a dominant feature of the ocean through Earth's history: Elements, v. 7, no. 2, p. 107-112.
Pugh, D. C., 1983, Pre-Mesozoic Geology in the subsurface of Peel River Map Area, Yukon Territory and District of Mackenzie: Geological Survey of Canada, v. Memoir 401, no. 59.
Pyle, L. J., and Jones, A. L., 2009, Regional Geoscience Studies and Petroleum Potential, Peel Plateau adn Plain, Northwest Territories and Yukon: Project Volume: Yukon Geological Survey, v. YGS Open file 2009-25, p. 1- 549.
Rainbird, R. H., Villeneuve, M. E., Cook, D. G., and MacLean, B. C., 1996, Detrital zircon ages from two wells in the Northwest Territories: Implications for the correlation and provenance of Proterozoic subsurface data: Geological Survey of Canada Current Research 1996-B, p. 29-38.
Raiswell, R., and Canfield, D. E., 1998, Sources of iron for pyrite formation in marine sediments: American Journal of Science, v. 298, no. 3, p. 219-245.
Rayner, N. M., and Rainbird, R. H., 2013, U–Pb geochronology of the Shaler Supergroup, Victoria Island, northwest Canada: 2009–2013: Geological Survey of Canada, Open File, v. 7419, no. 62, p. 10-4095.
Riedman, L. A., and Porter, S., 2016, Organic-walled microfossils of the mid-Neoproterozoic Alinya Formation, Officer Basin, Australia: Journal of Paleontology, v. 90, no. 5, p. 854-887.

Riedman, L. A., Porter, S. M., Halverson, G. P., Hurtgen, M. T., and Junium, C. K., 2014, Organic-walled microfossil assemblages from glacial and interglacial Neoproterozoic units of Australia and Svalbard: Geology, v. 42, no. 11, p. 1011-1014.
Rooney, A. D., Jacqueline Austermann, Emily F. Smith, Yang Li, David Selby, Carol M. Dehler, Mark D. Schmitz, Karl E. Karlstrom, and Francis A. Macdonald, 2017, Coupled Re-Os and U-Pb geochronology of the Tonian Chuar Group, Grand Canyon: GSA Bulletin, v. 130, no. 7-8, p. 1085-1098.
Slotznick, S. P., Eiler, J. M., and Fischer, W. W., 2018, The effects of metamorphism on iron mineralogy and the iron speciation redox proxy: Geochimica et Cosmochimica Acta, v. 224, p. 96-115.
Sprinkel, D. A., and Waanders, G., 2005, Stratigraphy, organic microfossils, and thermal maturation of the Neoproterozoic Uinta Mountain Group in the eastern Uinta Mountains, northeastern Utah.
Stouge, S., Christiansen, J. L., Harper, D. A. T., Houmark-Nielsen, M., Kristiansen, K., Macniocaill, C., and Buchardt-Westergård, B., 2011, Neoproterozoic (Cryogenian–Ediacaran) deposits in East and North-East Greenland, *in* Arnaud, E., Halverson, G. P., and Shields-Zhou, G., eds., The Geological Record of Neoproterozoic Glaciations, Geological Society of London.
Walter, M. R., Veevers, J. J., Calver, C. R., and Grey, K., 1995, Neoproterozoic stratigraphy of the Centralian Superbasin, Australia: Precambrian Research, v. 73, no. 1, p. 173-195.