Geophysical Research Letters

Supporting Information for

Widespread and Persistent Deposition of Iron Formations for Two Billion Years

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Introduction

Below we expand on the calculations described in the text. We also present Figure S1, overplotted and log-transformed histograms of previous iron formation compilations compared to their preservation-adjusted iron formation accumulations, and Table S1 to show the data used in forming Figures 1-3 in the main text.

Calculations of iron fluxes into and out of the early ocean:

Flux of high-T vent fluids:
Assuming the high-temperature fluid flux was on the high end of today's range, at ~3×10^{13} kg/year, and this water contained 80 mmol/kg of Fe(II) (Kump & Seyfried, 2005), the hydrothermal flux of Fe(II) can be determined as follows:

3×10^{13} kg/yr * 0.080 mol Fe/kg H_2O * 0.0558 kg/mol Fe = 1.34×10^{11} kg Fe/year = 0.134 Gt Fe/yr.

Extending existing rate estimates to whole ocean:
To convert meter-per-Myr accumulation rates to an ocean-wide iron flux, we found a volume by multiplying various assumed million-year thicknesses of IFs (e.g., 180 m, 10 m, and 1 m) by the area of ocean (rounded up to 4×10^{14} m^2 with the likelihood of a larger Archean than present-day oceanic surface area). Then we multiplied by the average density of iron formations (approximated at 3000 kg/m^3 from (Gole & Klein, 1981)) and 0.3 since iron is on average 30% of IFs. Finally, this mass of iron is converted to Gt and divided by time (10^6 yrs).

180 m * (4×10^{14} m^2) * 3000 kg/m^3 * 0.3 / 10^6 yr = 6.5×10^{13} kg/yr = 65 Gt Fe/yr
10 m * (4×10^{14} m^2) * 3000 kg/m^3 * 0.3 / 10^6 yr = 3.6×10^{12} kg/yr = 3.6 Gt Fe/yr

$1 \text{ m} * (4 \text{ x } 10^{14} \text{ m}^2) * 3000 \text{ kg/m}^3 * 0.3 / 10^6 \text{ yr} = 3.6 \times 10^{11} \text{ kg/yr} = 0.36 \text{ Gt Fe/yr}$

Extending average IF thickness to whole ocean:
An alternative way to assess whether ocean-wide deposition is feasible is to examine the thickness of deep ocean (Algoma-type) deposits and extend this over the whole ocean. A review of Algoma-type IF thicknesses in the literature suggested an average thickness of ~25 m: 20-30 m was reported in West Nigeria (Mücke et al., 1996; Mücke, 2005); ~25 m in the Kuhmo, Finland IF (Laajoki, 1975); 10-20 m in the Central Slave Cover Group, Canada (Bleeker et al., 1999); tens of meters in the Ukkolanvaara, Finland IF (Laajoki and Lavikainen, 1977); centimeters to 15 m for the Moodies Group, South Africa (Anhaeusser, 1976); 120 m (Mukhopadhyay et al., 2008) to 220 m (Beukes et al., 2008) for the Southern and Western Iron Ore Group, respectively, in India; tens of meters for the Northern Pilbara IFs, South Africa (Eriksson, 1983); and a few centimeters to several tens of meters (Shimizu et al., 1990) for the Isua Supracrustal Belt, Greenland. The mass of iron formation (IF) was again calculated by multiplying thickness by area by density:

$25 \text{ m} * (4 \times 10^{14} \text{ m}^2) * 3000 \text{ kg/m}^3 = 3 \times 10^{19} \text{ kg} = 3 \times 10^7 \text{ Gt}$

Using the same logic as above, this can be calculated as a Gt of Fe per year rate once an average oceanic crustal age is assumed. There seems little doubt that the Archean mantle was hotter than that today, but at least two views prevail on how heat was lost at that time. Labrosse and Jaupart (Labrosse & Jaupart, 2007) inferred that although heat production has decreased by ~3 times since ~3.5 Ma, the mean age of the lithosphere has changed little. Hence the mean age of Archean oceanic crust would have been approximately 80 Myr, that today. By contrast, McKenzie and Weiss (McKenzie & Weiss, 1975) assumed that heat loss has decreased approximately as heat production has decreased. As the mean age of the lithosphere scales inversely as the square root of heat loss (e.g., Labrosse and Jaupart, 2007), a three-times reduction in heat loss would imply an Archean mean age of oceanic crust of ~50 Ma. To err on the conservative side, we assume an average ocean floor age of 80 Myr. We again multiply by 0.3 to calculate the depositional flux of just iron.

$25 \text{ m} * (4 \text{ x } 10^{14} \text{ m}^2) * 3000 \text{ kg/m}^3 * 0.3 / (80 \times 10^6 \text{ yrs}) = 1.13 \times 10^{11} \text{ kg/yr} = 0.11 \text{ Gt Fe/yr}$

This depositional flux of iron (0.11 Gt Fe/yr) is comparable to the hydrothermal flux calculated above (0.134 Gt Fe/yr), and inputs of iron to the ocean would increase with higher heat fluxes, shallower spreading centers, and continental weathering fluxes (see main text).

To compare with estimates of masses of IFs at different times, this ocean-wide mass was then divided by the areas compiled in Hurley and Rand (Hurley & Rand, 1969) to construct a reference oceanwide IF deposition line to plot on Figure 3. The pre-3.15 Ga interval was assigned areas as described in the main text where we used a simple linear increase [A = Area[3.15-2.7 Ga] * (4000 – age)/(4000 – 3150)].

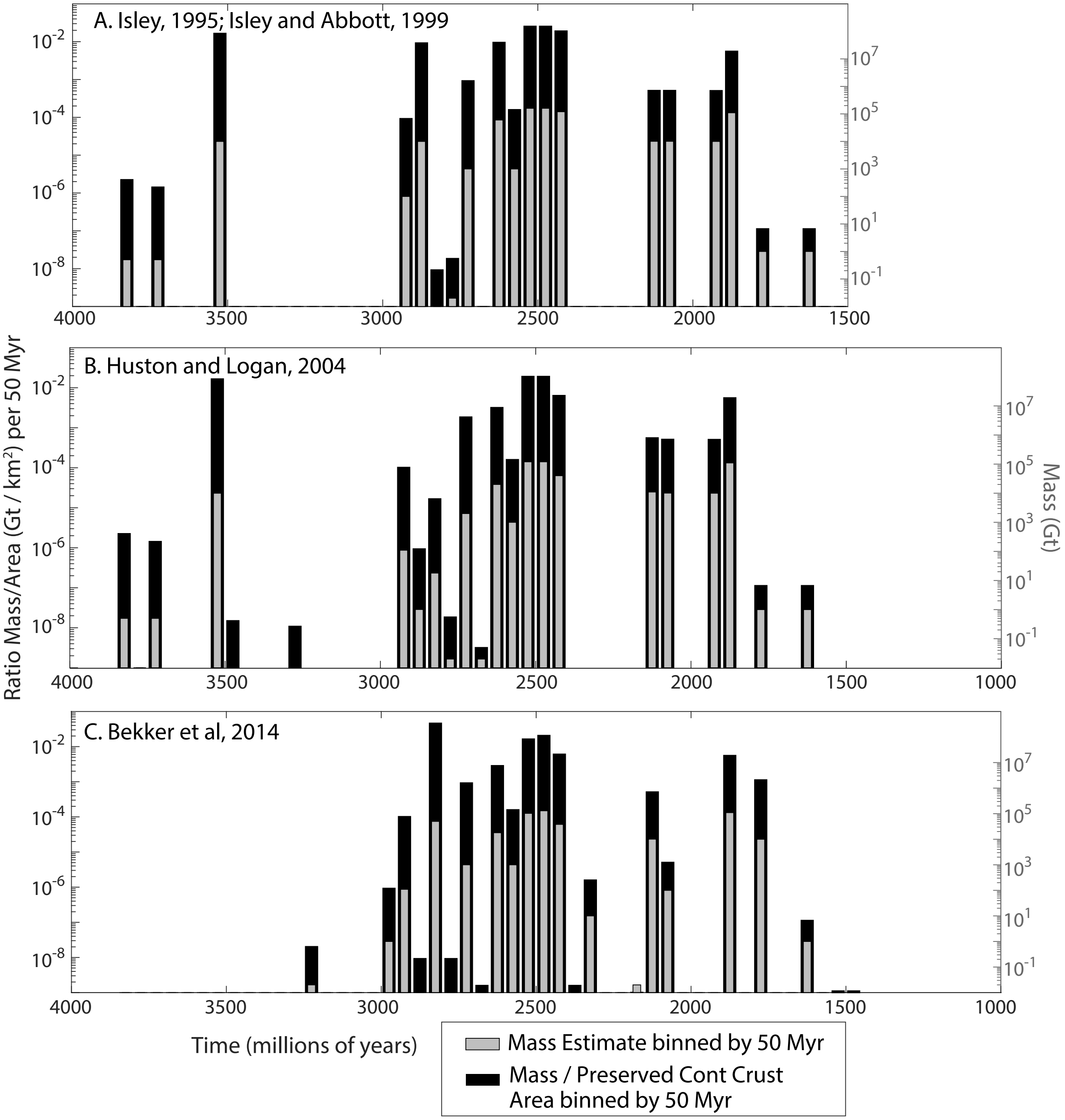

Figure S1: Data in Figure 2 plotted on logarithmic axes. A. From Isley (1995) and Isley and Abbott (1999). Time extends only to 1.5 Ga because that was the interval considered by Isley and Abbott. B. From Huston and Logan (2004). C. From Bekker et al. (2014).

Table S1: Compiled iron formations with age constraints and masses

[1] Iron formations (in blue) excluded from Figure 2 because China and the former USSR were excluded by Hurley and Rand (Hurley & Rand, 1969).

Iron Formation	Age (Ma)	Age Error (Ma)	Mass Bekker (Bekker et al., 2014)	Mass Huston Logan (Huston & Logan, 2004)	Mass Isley (Isley, 1995)	Mass used in Fig 3 (Gt)	Notes and references for Age Constraints
Xiamaling, China[1]	1394	2.9	Small (0.01)			520 [dashed line]	Canfield et al. (2018): lower age constraint 1437 ± 21 Ma, upper constraint 1392.2 ± 1 Ma
Roper Group, Australia	1471	4	Small (0.01)			0.01	Lower age constraint from Jackson et al. (1999) (1492 ± 4 Ma) and upper age constraint from Kendall et al. (2009) (1361 ± 21 Ma)
Mullera Fm (Nicholson), Australia	1500	100	Small (0.01)			0.01	Bekker et al. (2014): unknown/small and c. 1500 Ma;
São José, Brazil	1599	23				0.01	Age from Rosière et al. (2018)
Shoshong, Botswana	1604	33	1	1	1	1	Age from Mapeo et al. (2004)
Chuanlinggou, China[1]	1700	100	Small (0.01)			0.01 [dashed line]	Wan et al. (2003) report < 1800 Ma, Bekker et al. (2014) report 1600-1650 Ma
Alwar, India	1750	50	Small (0.01)			0.01	The Rajasthan and Haryana Formations; Biju-Sekhar et al. (2003) say between 1800-1700 Ma
Wallaroo, Australia	1750	15				0.01	Age from Daly et al. (1998)
Frere, Australia	1753	105	10,000			10,000	Lower age constraints at 1843 ± 10 Ma (Rasmussen & Fletcher, 2002); overlying Bangemall Supergroup constrained to less than 1619 ± 15 Ma by granite age (Nelson, 1998)
Wilgena Hill, Australia	1775	66				600	From Daly et al. (1998): they show > 1723 ± 10 Ma, but younger than 1880 ± 20 Ma, and also estimate 600 Gt
Pike's Peak, Arizona, USA	1778	23	1	1	1	1	Age from Karlstrom et al. (1987): between 1800-1755 Ma

Ashburton, Australia	1795	7				0.01	Age from Wilson et al. (2010)
Serpentina, Brazil	1860	130				0.01	Age from Rosière et al. (2018)
Lake Superior, Canada and USA	1862	14	10,000	10,000	10,000	10,000	All compilations say 10,000 Gt; constrained to between 1878.3 ± 1.3 Ma (Fralick et al. (2002)) and 1850 ± 1 Ma (Cannon et al., 2010)
Sokoman, Canada	1878	1	100,000	100,000	100,000	100,000	Age from Findlay et al. (1995), but given as approximate for the IF.
Bergslagen, Sweden	1885	15		Small (0.01)		42.2	Mass from Allen et al. (1996); age from Oen (1987)
Rochford, South Dakota, USA	1887	7	Small (0.01)			0.01	Age from Frei et al. (2009)
Gibraltar, Canada	1888	6.5	Unknown (0.01)			0.01	Gibraltar Fm constrained between 1882 ± 1 Ma (Hoffman et al., 2011) and 1865 ± 15 Ma (Bowring et al., 1984)
Basile, Canada	1928	11	Unknown (0.01)			0.01	Age from Bowring et al. (1984)
Nabberu, Australia	1929	67		10,000	10,000	10,000	Krapež and Martin (1999): Horseshoe Fm is 1996-1953 Ma, Robinson Range Fm 1905-1862 Ma; we use their average for whole Nabberu Basin
Liaohe, China[1]	1990	60	100			100 [dashed line]	Luo et al. (2004): between 2050 and 1930 Ma
Imataca, Venezuela	2054	10		10,000	10,000	10,000	Rosière et al. (2018) say it has detrital zircons that date until 2061 Ma, and recrystallized at 2018 ± 5 Ma
Estes, South Dakota, USA	2060	40	Small (0.01)			0.01	Bekker et al. (2014) and Frei et al. (2008)
Pääkkö, Finland	2080	45	100	100	100	100	Age from Laajoki (1975); Bekker et al. (2014)
Transamazon, Brazil and Venezuela	2081	75				0.01	From Rosière et al. (2018) and Machado et al. (1996)
Lomagundi, Zimbabwe	2083	48	Small (0.01)			0.01	Constrained to between 2125 ± 6 Ma to 2027 ± 8 Ma by Mapeo et al. (2001)
Ijil, Mauritania	2100	200	100	1,000	100	100 (1,000,000)	Age from Henry (1995): 2100 ± 200 Ma. Launay et

							al. (2018) estimate 1,000,000 Gt, but most is buried.
Nimba Simandou, Liberia	2100	100	10,000	10,000	10,000	10,000	Age estimate between 2200-2000 Ma (Thiéblemont et al., 2004); conservatively constrained to younger than 2615 Ma (Billa et al., 1999) and metamorphism at 2088 ± 5 Ma (Thiéblemont et al., 2004)
Marowijne, Suriname and French Guyana	2134	22				0.01	Rosière et al. (2018)
Schist belts, Nigeria	2150	150	Small (0.01)			0.01	Mücke (2005)
Pastora, Venezuela	2180	80				0.01	Rosière et al. (2018) give 2260–2100 Ma
Barama-Mazaruni, Guyana	2180	80				0.01	Rosière et al. (2018) give 2260–2100 Ma
Glen Township, Minnesota, USA	2197	39	Small (0.01)			0.01	Morey and Southwick (1995) for age 2197 ± 39 Ma
Kursk Magnetic Anomaly (KMA), Russia[1]	2250	Unconstrained ~2600-1900	300,000			[not included]	Age from Kalganov and Kossovkiy (1960)
Vila Nova, Brazil	2260	10				0.01	Rosière et al. (2018) give 2260 Ma
Timeball Hill, South Africa	2316	7	10			10	Age from Hannah et al. (2004);
Caldeirao, Brazil	2382	306	Small (0.01)			0.01	Age constraints from Oliveira et al. (2002)
Krivoy Rog, Ukraine[1]	2390	Unconstrained ~2700-2080	50,000	100,000	100,000	[not included]	Age constraint from Kulik and Korzhnev (1997)
Hotazel, South Africa	2422	5	150			150	Ages from Gumsley et al. (2017), Bau et al. (1999), Fairey et al. (2013)
Boolgeeda, Australia	2445	5	19,000	20,000	60,000	19,000	Trendall et al. (2004) dates Boolgeeda at 2445 ± 5 Ma; Masses inferred from Hamersley Group total given in (Huston & Logan, 2004) and (Isley, 1995)
Weeli Wolli, Australia	2449	3	19,000	20,000	60,000	19,000	Barley et al. (1997) dated Weeli Wolli at 2449 ± 3

							Ma; Masses inferred from Hamersley Group total given in (Huston & Logan, 2004) and (Isley, 1995)
Asbesheuwels Subgroup, South Africa	2460	5	100,000	100,000	100,000	100,000	Transvaal Griquatown, Kuruman, and Penge; Griqutown constrained to 2431 ± 31 Ma (Trendall et al. (1990)); Kuruman constrained to 2465 ± 5 Ma (Pickard, 2003)
Brockman, Australia	2464	5	30,000	20,000	60,000	30,000	Top of Joffre Member of Brockman is 2460 ± 2 from Trendall et al. (2004);, bottom of Dales Gorge Member is 2495 ± 16 Ma also from Trendall et al. (2004); Masses inferred from Hamersley Group total given in (Huston & Logan, 2004) and (Isley, 1995)
Ruker, East Antarctica	2465	15	Un-known (0.01)			0.01	Ruker Series Prince Charles Mountains; age from Bekker et al. (2014)
Cauê, Brazil	2502	83	100,000	100,000	100,000	100,000	Babinski et al. (1995) dated stromatolites overlying BIF to 2419 ± 19 Ma by Pb-Pb; older age constraint at 2584 ± 10 Ma by Hartmann et al. (2006) from detrital zircons in underlying Moeda quartzites
Benchmark, South Dakota, USA	2520	40	Small (0.01)			0.01	Age from Frei et al. (2008)
Mt Sylvia, Australia	2540	31	3,000	20,000	60,000	3,000	Poorer constraints, from bottom of Dales Gorge Member at 2495 ± 16 Ma (Trendall et al., 2004) and underlying Bee Gorge Member 2565 ± 9 Ma (Trendall et al., 2004); Masses inferred from Hamersley Group total given in (Huston & Logan, 2004) and (Isley, 1995)
Hutchison, Australia	2566	20	1,000	1,000	1,000	1,000	Age from Szpunar et al. (2011); really maximum age constraint from detrital zircon but they suggest it is close to depositional age
Chitradurga, India	2611	4	1,000			1,000	Naqvi et al. (1988) gave 2605 ± 18 Ma for granite

							shown above the BIF, and Nutman et al. (1996) gave 2614 ± 8 Ma
Marra Mamba, Australia	2613	16	17,000	20,000	60,000	17,000	2629 ± 5 to 2597 ± 5 Ma: using Trendall et al. (2004) age constraints who cite Arndt et al. (1991) for 2597 ± 5 Ma; Masses inferred from Hamersley Group total given in (Huston & Logan, 2004) and (Isley, 1995)
Sandur, India	2672	16		Small (0.01)		0.01	Age from Nutman et al. (1996)
Beardmore Geraldton, Canada	2691	+3/-2	Small (0.01)	Small (0.01)		0.01	Age from Anglin et al. (1988)
Anshan Liaoning, China[1]	2700	100	10,000	Small (0.01)	Small (0.01)	10,000 [dashed line]	Hou et al. (2007) said around 2700 Ma
Vermillion, Minnesota, USA	2704	11			1,000	1,000	Age from Turek et al. (1982)
Noganyer (Yilgarn), Australia	2706	+200/ -17		1,000	Small (0.01)	1,000	Noganyer Fm 2706 ± 5 Ma from Campbell and Hill 1988 (1988), extremes between 2900 and 2689 ± 7 Ma
Eagle Island, Canada	2708	6					Ages from Fralick and Pufahl (2006); Stott and Corfu (1991)
Abitibi, Canada	2710	17	0	0	0	3.74	Age constraints and estimate in Taner and Chemam (2015)
Bababudan, India	2719	1	1,000	Small (0.01)		1,000	Age constraints of 2720 ± 7 Ma from the bottom and near the top 2718 ± 6 Ma from Trendall et al. (1997)
Nemo, South Dakota, USA	2725	165	Small (0.01)			0.01	Age from Frei et al. (2008)
Hunter Mine, Canada	2728	2		1,000		1,000	Age from Chown et al. (2000)
Manjeri (Belingwe), Zimbabwe	2750	50	Unknown (0.01)	Small (0.01)	Small (0.01)	0.01	Age from Prendergast (2004)
Nova Lima, Brazil	2769	20		Small (0.01)	Small (0.01)	0.01	2792 ± 11 Ma to 2751 ± 9 Ma by Noce et al. (2005) in Rosière et al. (2018)
Carajás / Itacaiúnas Supergroup, Brazil	2805	46	50,000	18	Small (0.01)	50,000	Age from Rosière et al. (2018) and Machado et al. (1991)

Kuhmo, Finland	2820	80		Small (0.01)		0.01	Age from Laajoki (1975)
Ukkolanvaara, Finland	2825	75				0.01	Laajoki and Lavikainen (1977)
Bear Tooth Range, Montana, USA	2850	50		1	1	1	Mueller et al. (1998); Roberts et al. (2002)
Nunavut, Canada	2861	80	Unknown (0.01)	Small (0.01)		0.01	Bleeker et al. (1999); Isachsen and Bowring (1997)
Liberian Shield, Liberia and Sierra Leone	2862	36			10,000	10,000	Age from Rollinson (2016)
Guanhães, Brazil	2867	10				0.01	BIF units in Guanhães Crystalline Complex constrained to 2867 ± 10 Ma from Silva et al. (2002); Rosière et al. (2018)
Fortaleza Minas, Brazil	2918	105				0.01	From Rosière et al. (2018), has lenses of IF, dated by Rb/Sr to 2918 ± 105 Ma by Schrank and Silva (1993)
Tiris, Mauritania	2925	225		Small (0.01)		0.01	Bronner and Chauvel (1979) for date of 3150-2700 Ma
Witwatersrand South Africa	2940	32	10	10	Small (0.01)	10	Smith et al. (2013)
Pongola. Swaziland and South Africa	2940	32	100	100	100	100	Hegner et al. (1994); Smith et al (2013) says correlated to Witwatersrand West Rand Group
Andorinhas, Brazil	2950	50				0.01	Rosière et al. (2018) reported "several Algoma-type BIFs" from 2.9-3.0 Ga
Buhwa Mweza, Zimbabwe	2975	115				0.01	Fedo and Eriksson (1996); Kusky (1998)
Indian Creek, Montana, USA	2990	140	1			1	Mueller et al. (2004) say 2850 < age < 3130 Ma based on detrital zircon populations
Cleaverville, Australia	3020	10				0.01	van Kranendonk et al. (2002)
Woodbrook, Australia	3117	3				0.01	van Kranendonk et al. (2002)
Tozer, Australia	3120	10				0.01	van Kranendonk et al. (2002)
Jack Hills, Australia	3205	96	Small (0.01)			0.01	Rasmussen et al. (2010) constrain BIF to > 3080 ± 20 Ma; Kinny and Nutman (1996) show granitic material underlying IF is 3286 ± 13 Ma

Moodies, South Africa	3218	118	Small (0.01)			0.01	Lower age constraint of 3226 ± 1 Ma from Kamo and Davis (1994); upper age constraint taken from cross-cutting pluton reported at 3100 ± 14 Ma by Zeh et al. (2013)
Nickol River, Australia	3265	6				0.01	van Kranendonk et al. (2002) gave bounds of 3269 ± 2 Ma and 3251 ± 6 Ma
Belozyorsky-Konsky zone, Ukraine[1]	3267	29		1,000	1,000	1,000 [dashed line]	Age from Isley (1995) estimating from James (1983), James and Trendall (1982), and Walker et al. (1983) who constrained age from 3500-3100 Ma
Sargur, India	3298	7		Small (0.01)		0.01	Peucat et al. (1995)
Western Iron Ore Group, India	3376	53				0.01	Western Iron Ore Group in Noamundi-Kiriburi district; age constraints described in Beukes et al. (2008)
Sebakwian, Zimbabwe	3480	33		Small (0.01)		0.01	Horstwood et al. (1999)
Southern Iron Ore Group, India	3507	2		10,000	10,000	10,000	Southern Iron Ore Group in Daitari-Tamka area, recently re-dated by Mukhopadhyay et al. (2008) using conformable lava below
Isua (northern), Greenland	3705	15		0.5	0.5	0.5	Nutman et al. (2009) present zircon ages of a younger, ca. 3700 Ma Isua terrane; collectively the zircons suggest an age of 3705 ± 15 Ma. We divide previous Isua estimates of 1 Gt in 2 for the now-recognized 2 terranes
Isua (southern), Greenland	3810	30		0.5	0.5	0.5	Nutman et al. (1997) present zircon ages from older and younger terrane in the Isua belt that each contain BIFs; the older has detrital zircons as young as 3820 Ma but is cut by tonalite with an age of 3798 ± 4 Ma: therefore we assign an age of 3810 ± 30 Ma

Mass estimates from Bekker et al. (2014), Huston and Logan (2004), and Isley (1995) unless otherwise noted. Age constraints from various sources and referenced in Notes (right column). Blue indicates iron formations excluded from Figure 2 due to the exclusion of China and the former USSR in Hurley and Rand (1969). Formations mentioned by previous compilations but not given a mass estimate were assigned a mass estimate of 0.01 Gt for the purposes of showing the reported presence of these small formations. Also find the raw data in the Deep Blue online repository doi:10.7302/vfer-6744.

References: See the main text for complete citations.