6 pages: AM-14-808; American Mineralogist AugSept 2014

Supplementary Materials – Element Mapping and EPMA

Element mapping of the general distribution of K, Cl, Cu and S was carried out on all samples using a Cameca SX 100 Electron Microprobe at the University of Manchester (UK). X-ray mapping was performed at 15 kV acceleration voltage, 100 nA current, utilizing a 10-20 µm beam size with 20 µm pixel step and dwelling for 20 ms per pixel. The element mapping aided in the identification of djerfisherite, as well as quantifying its overall textural characteristics and spatial distribution throughout the samples.

Prior to quantitative analysis, Cl, Na and K counts were continuously monitored on a djerfisherite grain at 1 count per second, over 300 seconds, using 15 kV acceleration voltage, a 10 nA current and a focused 1 µm spot. Counts were stable over these conditions suggesting that volatilization of these elements did not occur over the selected analytical parameters and durations. For quantitative spot analyses, count times ranged from 60-100 seconds with 1-50 seconds background counts, using a 15 kV acceleration voltage, a 10 nA current and a 1 µm beam size. Various well-characterized standards were analyzed prior to analysis, including: K-feldspar (for K calibration), jadeite (Na), FeS_2 (Fe, S), NaCl (Cl), and native metal (Cu, Ni).

Further quantitative analysis was carried out on all samples using a Cameca SX100 at the Open University (Milton Keynes, UK). Sodium, Mg, Al, Si, Cl, K, Ca, Cr, Mn, Fe, Co, Ni, Cu, Zn, As, and Zr, were measured using a 20 nA current, 20 kV acceleration voltage and 2 µm beam size. Peak count times ranged from 10-45 seconds and background count times from 5-22.5 seconds. Various standards were used, including: Jadeite (Na), forsterite (Mg), K-feldspar (K, Al, Si), sylvite (Cl), pyrite (Fe, S), bustamite (Ca), synthetic Cr_2O_3 (Cr), native metal (Fe, Ni, Cu), willemite (Zn), cobalite (Co, As) and zirconia (Zr). Analyses from both facilities showed good agreement for replicate analyses on the same grains.

Seventeen and 13 analyses were collected on Ilímaussaq and Khibina djerfisherite grains, respectively, and 22, 10 and three analyses were collected for djerfisherite from ALH 77295, SAH 97096 and Peña Blanca Spring, respectively (**Table A1).**

Supplementary Materials- Tables

Table A1. Electron microprobe results for all measured djerfisherite in this study.

Sample	**Fe**	**S**	**K**	**Cu**	**Ni**	**Cl**	**Na**	**Total**
Khibna, Kola (Russia)	43.3	33.2	8.91	13.02	0.10	1.44	0.14	100.1
	43.3	32.7	8.82	13.50	0.10	1.41	0.13	100.0
	43.5	32.4	8.82	12.55	0.08	1.40	0.14	99.0
	43.1	32.4	8.87	12.76	0.10	1.37	0.16	98.8
	43.1	32.4	8.81	12.77	0.08	1.41	0.14	98.8
	43.4	32.3	8.74	12.59	0.09	1.41	0.13	98.6
	42.7	32.5	8.83	12.86	0.12	1.43	0.13	98.6
	42.9	32.2	8.69	13.16	0.12	1.39	0.12	98.6
	42.7	32.5	8.82	12.83	0.13	1.40	0.11	98.6
	42.8	32.3	8.79	12.99	0.08	1.38	0.14	98.4
	43.1	32.0	8.69	12.94	0.10	1.37	0.14	98.4
	43.0	32.2	8.76	12.79	0.12	1.41	0.11	98.4
	40.3	32.2	8.75	14.52	0.01	1.39	0.13	97.3
Average	**42.9**	**32.4**	**8.79**	**13.02**	**0.09**	**1.40**	**0.13**	**98.7**
Standard Deviation	**0.77**	**0.29**	**0.06**	**0.49**	**0.03**	**0.02**	**0.01**	**0.69**
Ilímaussaq (Greenland)	54.8	33.5	8.17	0.13	0.03	1.45	0.08	98.2
	54.7	33.5	8.20	0.16	0.01	1.44	0.05	98.0
	54.7	33.2	8.19	0.10	0.00	1.46	0.08	97.8
	54.2	33.6	8.23	0.24	0.00	1.41	0.07	97.7
	54.1	33.6	8.16	0.20	0.00	1.45	0.04	97.5
	55.0	33.0	7.88	0.15	0.00	1.42	0.08	97.5
	54.0	33.5	8.21	0.13	0.00	1.45	0.13	97.5
	53.9	33.5	8.28	0.16	0.00	1.46	0.10	97.4
	54.7	33.0	7.75	0.17	0.01	1.41	0.08	97.1
	54.5	32.8	7.71	0.17	0.00	1.43	0.13	96.7
	54.4	32.7	7.90	0.16	0.00	1.42	0.07	96.7
	52.9	33.7	8.32	0.17	0.01	1.47	0.06	96.6
	53.2	33.6	8.03	0.15	0.00	1.48	0.05	96.5
	53.9	33.1	7.72	0.17	0.00	1.42	0.22	96.5
	54.0	32.9	7.83	0.15	0.01	1.43	0.07	96.3
	52.8	33.8	7.95	0.18	0.00	1.46	0.08	96.3
	53.8	33.0	7.72	0.16	0.01	1.44	0.10	96.2
Average	**54.1**	**33.3**	**8.0**	**0.2**	**0.0**	**1.4**	**0.1**	**97.1**
Standard Deviation	**0.63**	**0.34**	**0.21**	**0.03**	**0.01**	**0.02**	**0.04**	**0.63**
Peña Blanca Spring	48.2	34.1	9.00	1.61	1.25	1.48	0.08	95.7
	47.4	36.1	9.81	1.42	1.41	1.55	0.05	97.8
	47.8	35.1	9.40	1.52	1.33	1.52	0.06	96.8
Average	**47.8**	**35.1**	**9.4**	**1.5**	**1.3**	**1.5**	**0.1**	**96.8**

Standard Deviation	**0.31**	**0.81**	**0.33**	**0.08**	**0.06**	**0.03**	**0.01**	**0.84**
ALH 77295	53.5	34.4	6.45	1.54	2.20	1.46	0.12	99.7
	53.9	32.6	7.99	2.61	0.98	1.39	0.47	99.9
	52.9	31.5	7.78	2.51	0.97	1.37	0.44	97.5
	52.3	33.1	8.24	2.60	0.79	1.41	0.43	98.8
	52.2	31.9	7.46	2.70	1.03	1.32	0.43	97.1
	52.2	33.2	8.26	2.19	1.12	1.41	0.50	98.8
	52.2	33.6	8.20	2.58	1.05	1.44	0.48	99.5
	52.2	33.2	8.36	2.64	0.76	1.41	0.48	99.0
	52.1	33.4	8.32	2.22	1.11	1.45	0.51	99.1
	52.1	33.1	8.35	2.58	0.81	1.40	0.49	98.8
	52.0	32.8	8.35	2.61	0.87	1.40	0.37	98.5
	51.9	33.8	8.14	2.68	0.97	1.41	0.50	99.4
	51.8	33.0	8.17	2.59	0.79	1.45	0.47	98.3
	51.8	33.3	8.20	2.52	0.72	1.38	0.39	98.2
	51.8	31.9	7.75	2.63	0.70	1.44	0.44	96.6
	51.7	32.9	8.07	2.52	0.99	1.49	0.41	98.0
	51.6	33.3	8.34	2.43	0.85	1.41	0.36	98.3
	51.5	32.6	8.07	2.19	1.10	1.41	0.50	97.4
	51.4	33.7	8.45	2.50	0.82	1.44	0.50	98.8
	51.4	33.5	8.36	2.30	0.82	1.49	0.47	98.3
	51.2	33.5	8.39	2.35	0.77	1.52	0.50	98.2
	51.0	32.5	8.04	2.54	0.82	1.39	0.44	96.7
Average	**52.0**	**33.0**	**8.1**	**2.5**	**1.0**	**1.4**	**0.4**	**98.4**
Standard Deviation	**0.69**	**0.68**	**0.44**	**0.26**	**0.31**	**0.04**	**0.08**	**0.92**
SAH 97096	47.3	34.9	7.95	4.67	1.27	1.51	0.26	97.9
	49.1	34.7	7.74	3.94	1.30	1.47	0.26	98.5
	48.9	34.5	7.88	3.98	1.32	1.49	0.38	98.5
	49.2	34.4	7.79	4.34	1.30	1.49	0.54	99.0
	48.7	34.2	7.91	4.61	1.28	1.48	0.36	98.6
	49.0	34.1	7.82	4.36	1.26	1.44	0.50	98.5
	49.4	34.0	7.64	4.20	1.31	1.45	0.24	98.2
	49.2	33.8	7.79	4.39	1.34	1.45	0.28	98.2
	50.8	33.6	7.68	4.75	1.41	1.42	0.27	99.9
	51.5	33.5	7.24	4.32	1.49	1.44	0.32	99.9
Average	**49.3**	**34.2**	**7.7**	**4.4**	**1.3**	**1.5**	**0.3**	**98.7**
Standard Deviation	**1.14**	**0.46**	**0.20**	**0.27**	**0.07**	**0.03**	**0.10**	**0.68**

Table A2. Calculated djerfisherite structural formula for each sample based on 26 S.

Sample	**Representative structural formulae**
Terrestrial	
Khibina Massif	$(K, Na)_{5.9\text{-}6}$ $(Fe, Cu, Ni)_{23.5\text{-}25}$ S_{26} Cl
Ilímaussaq	$(K, Na)_{5.1\text{-}5.4}$ $(Fe, Cu, Ni)_{24.7\text{-}25.4}$ S_{26} Cl
Extraterrestrial	
ALH 77295	$(K, Na)_{5.4\text{-}5.8}$ $(Fe, Cu, Ni)_{24.6\text{-}26}$ S_{26} $Cl_{1\text{-}1.4}$
SAH 97096	$(K, Na)_{5\text{-}5.8}$ $(Fe, Cu, Ni)_{20.7\text{-}24}$ S_{26} Cl
Peña Blanca Spring	$(K, Na)_{5.7\text{-}6.2}$ $(Fe, Cu, Ni)_{21.9\text{-}22.2}$ S_{26} Cl

Supplementary Material – Figures

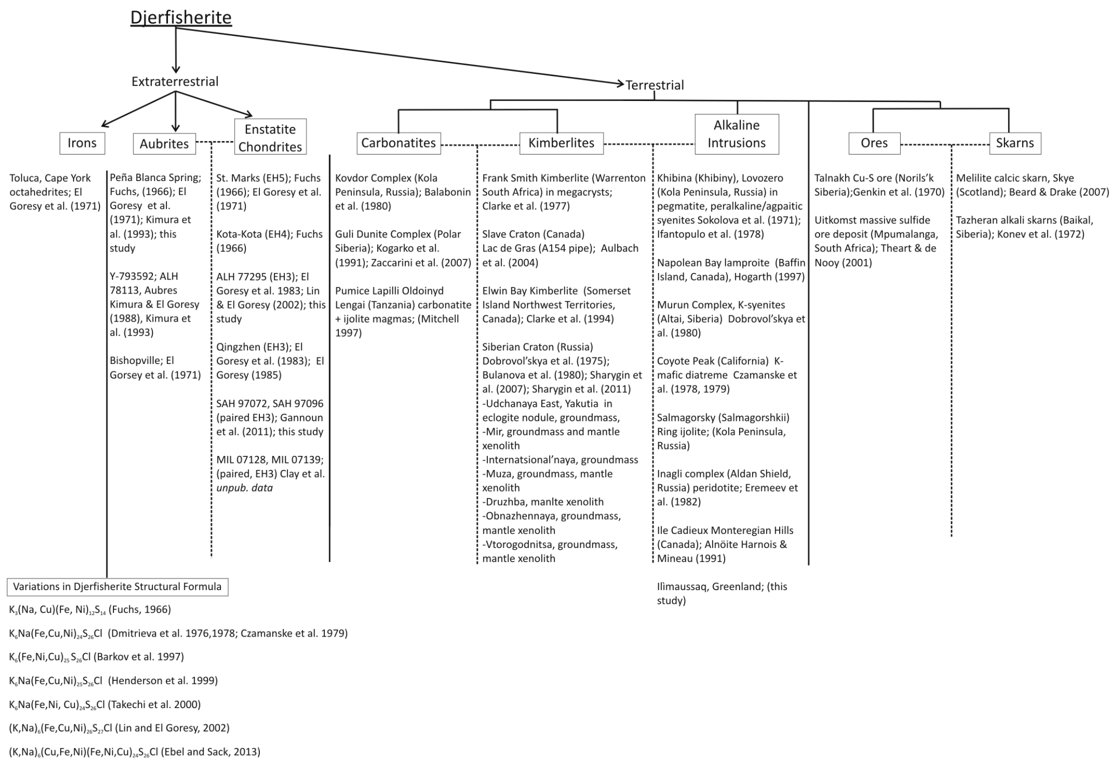

Figure A1

Figure A1 Overview of djerfisherite formed in terrestrial and extraterrestrial environments. In general, the formation of djerfisherite is typically ascribed to metasomatic alteration, such as that occurring during late-stage magmatic activity through the interaction of K-and Cl-rich fluids with alkali-free sulfides (e.g., Guli dunite complex, Zaccarini et al., 2007; Clarke et al., 1977). Occasionally, however, djerfisherite has been suggested to have formed as a primary 'unmixing' phase from magma (Morgan et al., 1985). Whilst terrestrial djerfisherite is suggested to form in fluid-rich areas of extreme metasomatic activity, EH chondrites and aubrites are entirely anhydrous, lacking any evidence of aqueous alteration (Rubin, 1997).

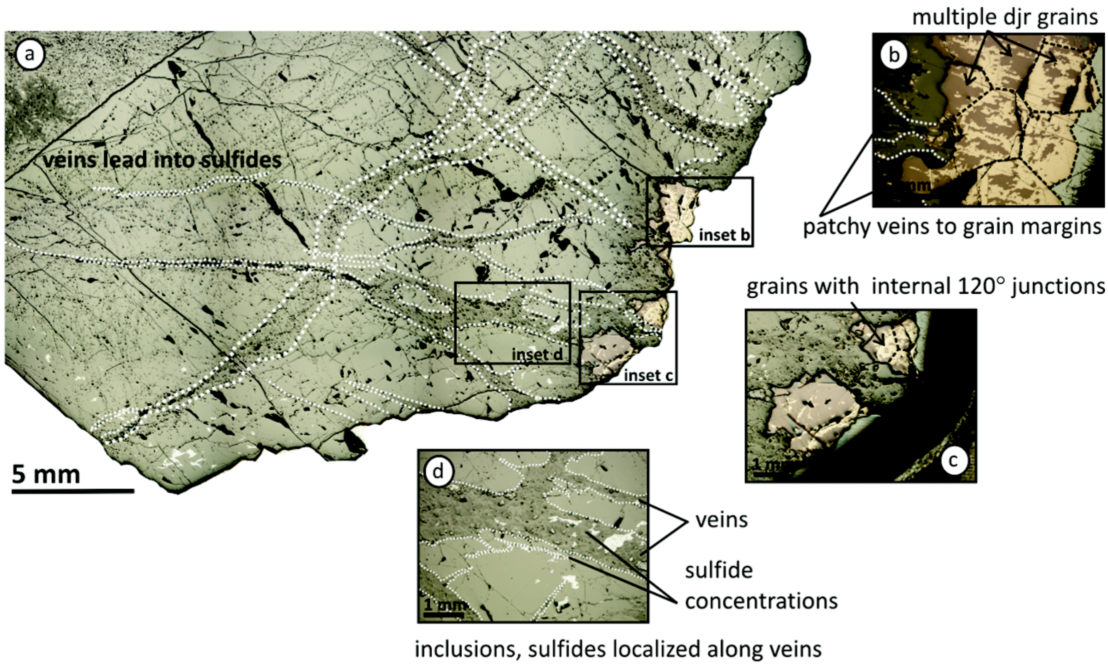

Figure A2

Figure A2 (a) Reflected light photomicrograph map of Khibina, Kola sample section taken at 10x magnification. The distribution of abundant veins is shown by the white dashed lines. Sulfides are concentrated along the veins and djerfisherite grains are concentrated at the terminus of the veins. **(b)** Djerfisherite grain morphology shows polygonal grains with patchy vein network extending outward from the grain margins. **(c)** Large and texturally mature grains with internal 120° triple junction grain boundaries are seen. **(d)** An enlargement of the complex vein network is observed to be punctuated by trails of small sulfide inclusions.