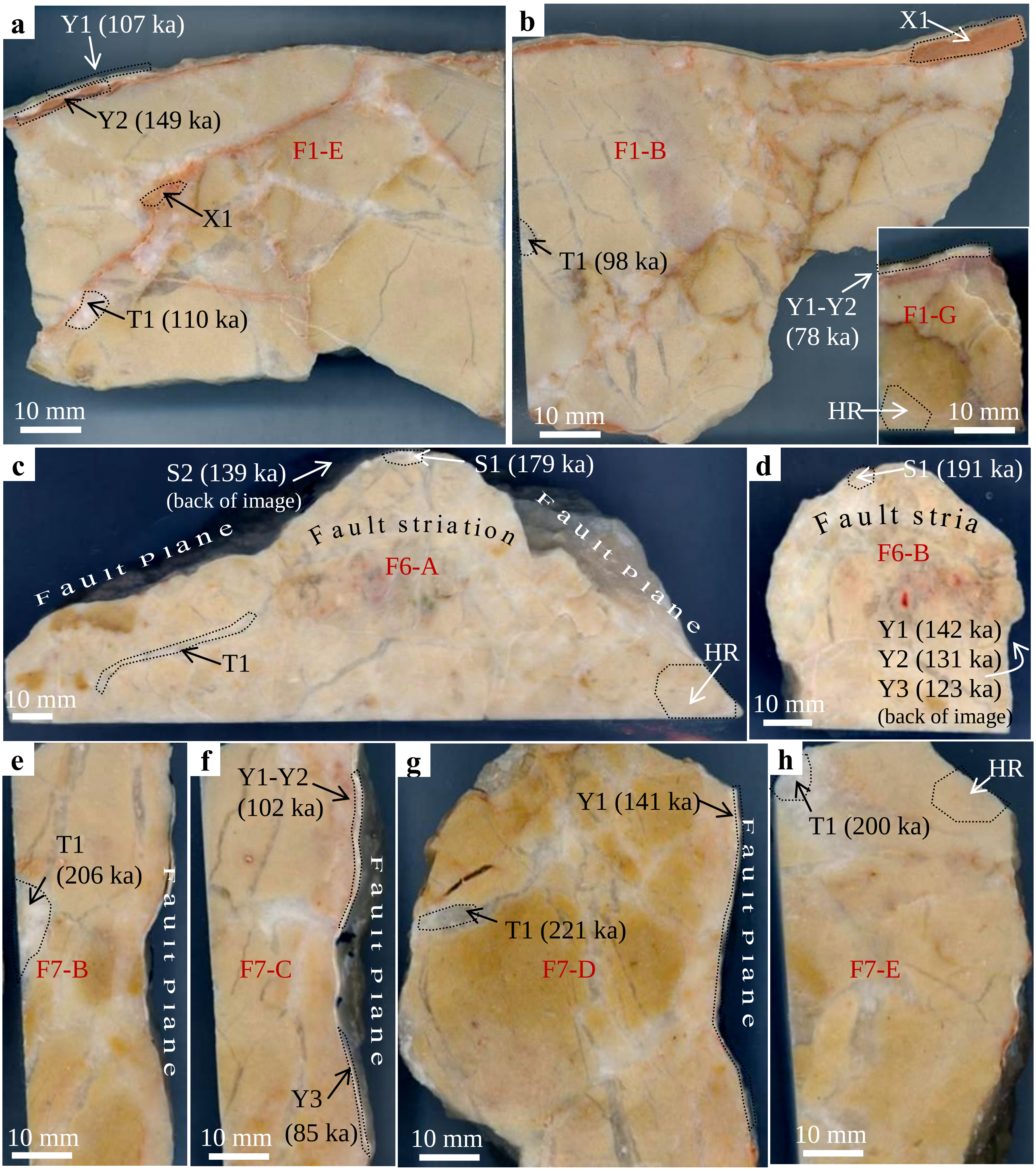

Figure DR1. Sample F-1, 6 and 7 – calcite precipitates and sampling locations. Sample F-1E **(a)**, F-1B and inset of F-1G **(b)**; Sample F-6A **(c)** and F-6B **(d)**; Sample F-7B **(e)**, F-7C **(f)**, F-7D **(g)** and F-7E **(h)**. Locations of the various types of calcite are shown with doted lines and labelled: calcite coating - Y, calcite gouge - X, calcite cement - T, calcite striation - S. Host-rock sample are also shown in b, c, and h (labelled HR). Obtained U-Th ages in ka are also shown (±2σ <5.5, see data repository item #2).

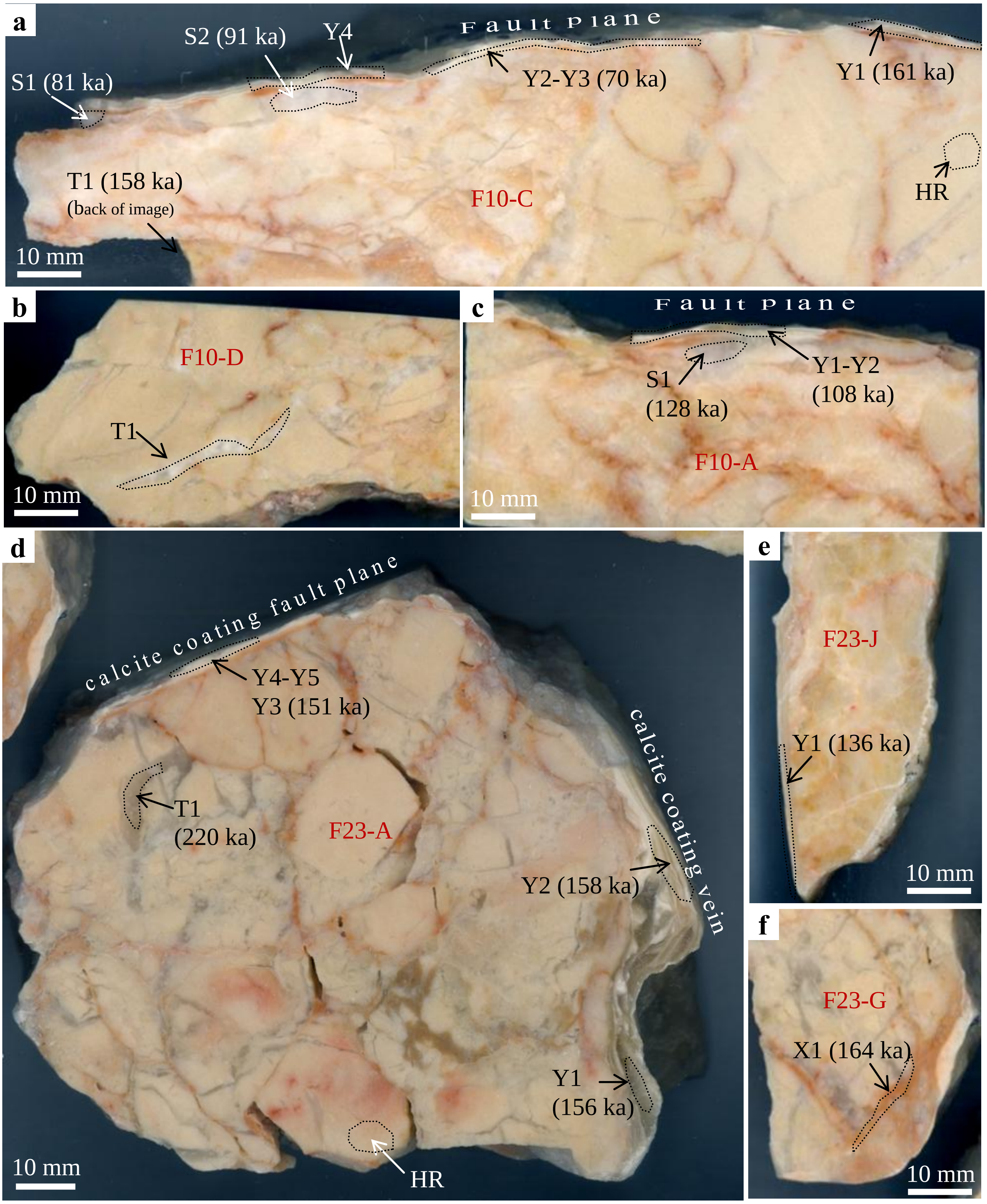

Figure DR2. Sample F10 and F23 – calcite precipitates and sampling locations. Sample F10-C **(a)**, F10-D **(b)**, and F-10A **(c)**; Sample F23-A **(d)**, F23-J **(e)**, and F23-G **(f)**; labelled: calcite coating-Y, calcite gouge-X, calcite cement-T, and calcite striation-S. Host-rock sample is also shown in a (labelled HR).Note the right angle between fault plane and calcite vein. Obtained U-Th ages in ka are also shown (±2σ <1.7, see data repository item #2).

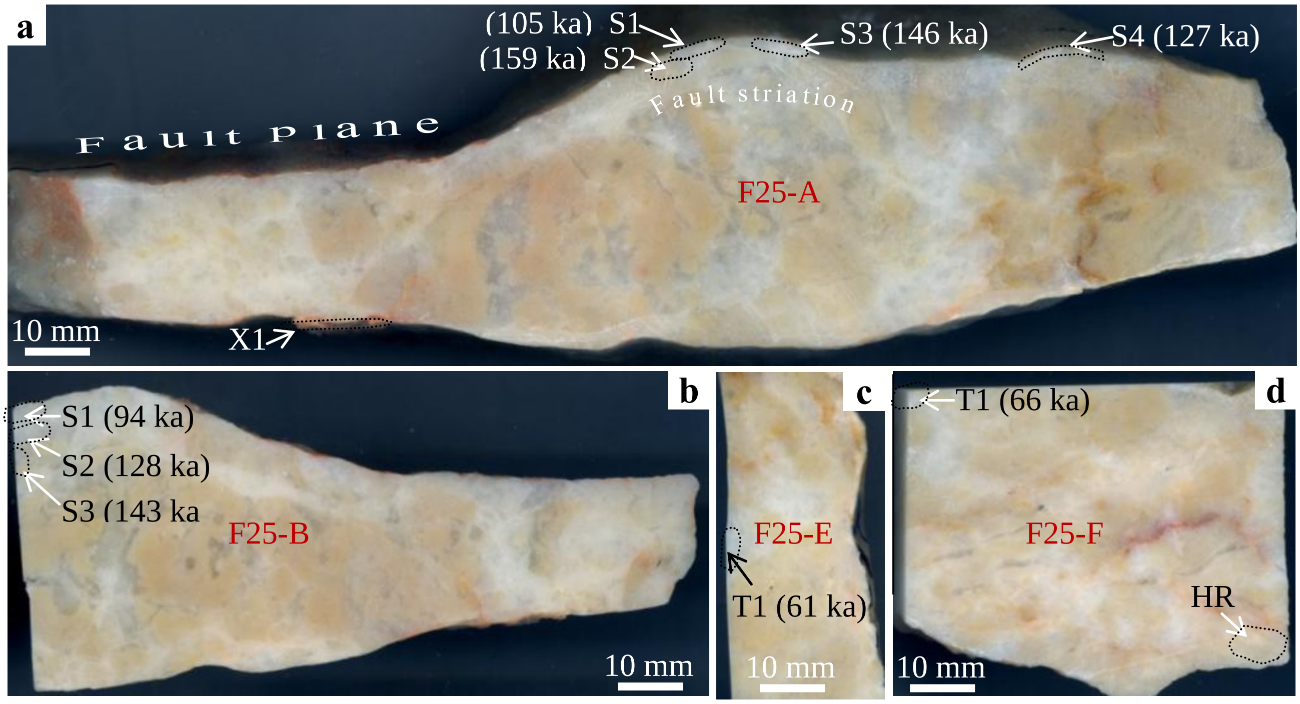

Figure DR3. Sample F25 – calcite precipitates and sampling locations. Sample F25-A **(a)** and F25-B **(b)**. Note the high percentage of recrystallised calcite (glassy to white colours) in these samples; Sample F25-E **(c)**, F25-F **(d)**. Locations of the various types of calcite are shown with doted lines and labelled: calcite gouge-X, calcite cement-T, and calcite striation-S. Host-rock sample is also shown in g (labelled HR). Obtained U-Th ages in ka are also shown (±2σ <1.9, see data repository item #2).

Table DR1.

Sampling[1]							Stable isotopes[2]		Sr isotopes[3]			U-Th geochronology[4]												REY composition (ppb)[5]														
Sample	**Fault**	**Frag.**	**Type**	**#**	**Description**	**Separa-tion**	**δ^{13}C‰ V-PDB**	**δ^{18}O‰ V-SMOW**	**1/Sr (ppm)**	**^{87}Sr/^{86}Sr**	**±2σ**	**Sample (mg)**	**U (ppm)**	**^{232}Th (ppb)**	**(^{230}Th/^{232}Th)**	**(^{230}Th/^{238}U)**	**±2σ**	**(^{234}U/^{238}U)**	**±2σ**	**^{230}Th Age (ka)**	**±2σ**	**Initial ^{234}U/^{238}U**	**±2σ**	**La**	**Ce**	**Pr**	**Nd**	**Sm**	**Eu**	**Gd**	**Dy**	**Y**	**Ho**	**Er**	**Tm**	**Yb**	**Lu**
F1-GHR	F1	G	HR		host rock	powder	-4.0	21.5	0.013	0.707781	0.000024													1579	630	185	764	147	39	210	240	3013	59	176	26	153	24
F1-BT1	F1	B	T	1	breccia cement	chips	-4.9	18.9	0.007	0.707561	0.000010	29.00	0.221	19.27	25	0.7090	0.0036	1.1617	0.0021	**97.7**	1.2	1.2183	0.0037	1523	505	126	488	89	25	141	175	2500	49	167	29	196	32
F1-ET1	F1	E	T	1	breccia cement	chips	-4.4	18.8	0.005	0.707521	0.000010	50.42	0.166	7.842	54	0.8339	0.0027	1.2668	0.0016	**110.18**	0.75	1.3691	0.0029	402	142	44	180	33	9.6	54	56	881	16	51	7.8	47	7.8
F1-BX1	F1	B	X	1	reddish gouge layer	chips	-9.3	25.0	0.053															3727	2902	682	2485	580	148	712	615	5575	135	364	48	255	37
F1-EX1	F1	E	X	1	reddish gouge in vein structure	chips	-8.8	23.9	0.042															5747	4635	1060	4329	944	234	1148	966	8689	214	575	72	390	56
F1-EY1	F1	E	Y	1	coating layer top part	chips	-9.9	25.5	0.074	0.708297	0.000007	183.25	0.137	12.01	32	0.9149	0.0021	1.3983	0.0013	**106.59**	0.82	1.5515	0.0059	55	40	8.6	33	8.3	2.4	10	11	136	2.5	8.6	1.4	8.1	1.4
F1-EY2	F1	E	Y	2	coating layer with reddish gouge	chips	-9.9	25.5	0.076	0.708345	0.000009	100.33	0.280	108.8	**7**	0.8328	0.0018	1.0701	0.0009	**148.78**	4.6	1.1193	0.0068	321	252	60	236	52	13	65	59	583	14	38	5.3	28	4.5
F1-GY1	F1	G	Y	1	coating layer top	powder	-10.1	25.3	0.064			70.35	0.137	9.36	35	0.7821	0.0025	1.4623	0.0020	**78.27**	0.61	1.5877	0.0055	124	80	21	89	18	4.9	24	23	274	5.5	18	2.5	16	2.6
F1-GY2	F1	G	Y	2	coating layer bottem	powder	-10.2	24.8	0.063															110	71	18	80	17	4.4	21	21	258	5.4	16	2.4	15	2.5
F6-AHR	F6	A	HR		host rock	powder	-4.5	21.4	0.008															2225	763	262	1092	204	55	287	288	3601	73	227	35	215	33
F6-AS1	F6	A	S	1	striation top	chips	-5.1	19.2	0.005	0.707529	0.000008	68.12	0.634	16.62	100	0.8653	0.0019	1.0596	0.0012	**178.8**	1.2	1.0995	0.0018	917	300	95	392	75	20	116	136	2022	38	134	22	148	24
F6-AS2	F6	A	S	2	striation top (along fault)	chips	-4.4	18.5	0.004	0.707635	0.000008	33.15	0.328	11.57	68	0.7854	0.0029	1.0747	0.0015	**138.8**	1.2	1.1117	0.0022	894	274	86	338	62	18	104	124	1994	36	126	20	134	22
F6-BS1	F6	B	S	1	striation dilation site	chips	-5.0	19.9	0.007	0.707510	0.000010	152.57	0.826	23.59	87	0.8141	0.0010	0.9871	0.0011	**190.9**	1.1	0.9776	0.0019	2266	783	272	1151	215	56	321	325	4221	85	266	40	240	39
F6-AT1	F6	A	T	1	cement, no age analyses	powder	-4.9	19.5	0.005															387	127	40	162	28	8.2	48	55	895	15	54	8.4	52	8.6
F6-BY1	F6	B	Y	1	vein coating layer bottom	chips	-9.8	25.2	0.076	0.708129	0.000011	86.13	0.275	7.110	102	0.8651	0.0017	1.1596	0.0010	**141.57**	0.66	1.2398	0.0016	138	69	20	85	15	4.5	22	22	251	5.4	16	2.4	13	2.3
F6-BY2	F6	B	Y	2	vein coating layer middle	powder	-9.8	25.2	0.074			86.76	0.209	1.756	323	0.8954	0.0022	1.2385	0.0010	**131.41**	0.65	1.3466	0.0014	42	22	5.7	28	5.1	1.4	6.6	7.4	109	2.0	6.4	0.9	6.1	1.0
F6-BY3	F6	B	Y	3	vein coating layer top	powder	-9.7	25.1	0.072			72.62	0.206	2.835	191	0.8687	0.0020	1.2435	0.0013	**123.29**	0.58	1.3463	0.0017	76	32	9.0	37	7.4	2.2	11	12	186	3.5	11	1.8	11	1.7
F7-EHR	F7	E	HR		host rock	powder	-5.1	20.6	0.013															2335	832	277	1139	219	59	321	330	4152	84	255	38	233	36
F7-BT1	F7	B	T	1	breccia cement	chips	-4.5	19.6	0.005	0.707493	0.000008	142.40	3.02	9.630	815	0.8575	0.0013	1.0084	0.0007	**206.1**	1.0	1.0151	0.0012	1847	667	248	881	199	53	282	282	3424	70	208	30	176	28
F7-DT1	F7	D	T	1	breccia cement	chips	-4.6	18.8	0.006	0.707549	0.000007	38.33	1.66	61.04	70	0.8434	0.0013	0.9765	0.0007	**220.8**	1.5	0.9558	0.0013	1186	382	148	511	127	33	182	177	2204	43	129	18	101	16
F7-ET1	F7	E	T	1	breccia cement	chips	-4.5	19.3	0.004	0.707511	0.000008	46.15	2.17	2.357	2400	0.8598	0.0013	1.0185	0.0007	**200.45**	0.98	1.0326	0.0012	742	231	73	256	55	16	79	92	1360	25	81	13	76	12
F7-CY1	F7	C	Y	1	fault coating layer	powder	-9.9	24.8	0.048	0.708312	0.000008	43.53	0.169	6.96	64	0.8642	0.0028	1.3642	0.0021	**102.40**	0.67	1.4919	0.0035	132	69	19	82	16	4.3	21	23	274	5.8	18	2.8	17	2.6
F7-CY2	F7	C	Y	2	fault coating layer	powder	-10.3	24.0	0.060															93	73	16	67	13	3.3	17	17	207	4.2	13	2.0	12	1.9
F7-CY3	F7	C	Y	3	fault coating layer	powder	-10.2	23.5	0.045			62.17	0.161	3.082	123	0.7787	0.0026	1.3921	0.0018	**84.90**	0.47	1.5011	0.0024	59	38	9.7	41	8.7	2.3	11	11	123	2.6	8.1	1.2	6.8	1.0
F7-DY1	F7	D	Y	1	fault coating layer	powder	-9.9	25.2	0.070	0.708327	0.000008	39.08	0.181	21.33	25	0.9881	0.0028	1.2962	0.0012	**141.4**	1.5	1.4562	0.0063	374	211	58	249	47	13	67	65	730	15	48	6.8	40	6.6
F10-CHR	F10	C	HR		host rock	powder	-4.7	20.2	0.009															1736	570	203	854	156	42	225	235	2949	59	181	27	166	25
F10-AS1	F10	A	S	1	striation dilation site	chips	-4.7	18.9	0.004	0.707518	0.000010	68.03	0.217	5.930	96	0.8611	0.0022	1.2083	0.0013	**128.33**	0.70	1.3016	0.0020	537	143	49	202	33	9.3	55	58	1020	17	55	8.1	51	8.1
F10-AY1	F10	A	Y	1	coating striation AS1	powder	-10.0	25.1	0.066	0.708313	0.000008	52.33	0.150	13.58	32	0.9421	0.0020	1.4233	0.0019	**108.32**	0.87	1.5894	0.0066	128	129	25	100	18	5.8	24	24	271	5.5	17	2.4	14	2.3
F10-AY2	F10	A	Y	2	coating striation AS1	powder	-10.0	25.3	0.068															126	113	23	97	20	5.3	24	22	274	5.6	16	2.5	14	2.7
F10-CS1	F10	C	S	1	striation dilation site top	chips	-4.4	18.7	0.004	0.707525	0.000008	73.15	0.573	4.281	227	0.5585	0.0014	1.0579	0.0011	**81.04**	0.34	1.0730	0.0014	2482	834	320	1367	259	69	378	349	4207	85	252	35	208	33
F10-CS2	F10	C	S	2	striation dilation site bottom	chips	-4.6	18.6	0.003	0.707527	0.000008	111.70	0.108	10.92	25	0.8269	0.0029	1.3908	0.0017	**91.35**	0.90	1.5202	0.0068	1299	419	118	460	77	21	122	135	1960	37	124	19	120	19
F10-CT1	F10	C	T	1	breccia cement	chips	-4.9	20.1	0.007	0.707575	0.000010	34.91	0.503	18.42	70	0.8402	0.0016	1.0794	0.0013	**158.20**	0.91	1.1255	0.0019	1215	337	112	444	75	22	121	145	2058	40	134	21	137	22
F10-CY1	F10	C	Y	1	coating layer with reddish gouge	chips	-9.7	25.0	0.051			93.59	0.419	77.81	14	0.8769	0.0015	1.1010	0.0009	**161.3**	1.9	1.1679	0.0042	1232	807	198	835	165	43	222	202	2166	49	144	20	114	17
F10-CY2	F10	C	Y	2	coating layer	powder	-9.8	25.5	0.065			72.65	0.114	27.84	**9**	0.7532	0.0024	1.4687	0.0017	**70.29**	1.74	1.6126	0.0200	196	254	42	171	38	8.5	39	34	307	7.6	21	3.2	16	2.7
F10-CY3	F10	C	Y	3	coating layer	powder	-9.8	25.5	0.070	0.707679	0.000010													218	207	38	161	35	8.4	39	35	374	8.2	24	3.4	21	3.2
F10-CY4	F10	C	Y	4	coating striation CS2	powder	-9.9	25.4	0.066	0.708368	0.000009													208	170	37	162	32	8.5	40	36	375	8.2	24	3.4	20	3.0
F10-DT1	F10	D	T	1	breccia cement	powder	-4.5	19.1	0.005															524	138	37	135	23	7.0	39	49	772	14	45	7.6	48	8.2
F23-GHR	F23	G	HR		host rock	powder	-5.4	21.4	0.018	0.707742	0.000008													3158	1446	411	1767	337	91	489	470	5834	117	335	46	248	37
F23-AT1	F23	A	T	1	cement in vein structure	chips	-5.8	21.7	0.017	0.707559	0.000010	46.20	4.06	36.14	284	0.8332	0.0017	0.9686	0.0010	**220.3**	1.76	0.9413	0.0021	1588	586	176	762	138	39	217	220	3216	59	179	26	153	24
F23-AY1	F23	A	Y	1	vein coating top	chips	-10.5	23.7	0.034	0.708414	0.000010	64.03	0.345	1.770	548	0.9264	0.0018	1.1833	0.0008	**155.75**	0.70	1.2851	0.0012	11	12	2.0	8.9	2.1	0.5	2.0	2.0	22	0.51	1.3	0.3	1.6	0.06
F23-AY2	F23	A	Y	2	vein coating bottem	chips	-9.6	25.3	0.030	0.708422	0.000010	196.70	0.580	3.530	485	0.9729	0.0009	1.2272	0.0008	**158.03**	0.41	1.3557	0.0011	45	44	8.1	33	6.9	2.1	7.6	7.8	75	1.7	4.6	0.70	4.5	0.54
F23-AY3	F23	A	Y	3	fault coating top	chips	-10.0	25.6	0.055	0.708449	0.000009	165.23	0.398	14.55	75	0.9093	0.0014	1.1771	0.0015	**151.00**	0.75	1.2740	0.0023	613	564	105	437	87	23	112	100	1016	23	65	9.3	52	7.7
F23-AY4	F23	A	Y	4	fault coating bottom	powder	-9.7	25.5	0.036	0.708408	0.000009													196	269	38	163	32	8.6	39	38	401	8.8	25	3.8	20	3.2
F23-AY5	F23	A	Y	5	fault coating bottom	powder	-9.7	25.5	0.029															84	102	16	67	15	4.1	19	19	206	4.2	13	1.9	9.7	1.5
F23-GX1	F23	G	X	1	reddish gouge with striations	chips	-7.1	23.1	0.033	0.707732	0.000010	97.48	0.469	50.95	23	0.8331	0.0013	1.0520	0.0009	**164.3**	1.4	1.0852	0.0018	2788	952	334	1380	243	65	333	327	3548	77	233	34	205	31
F23-JY1	F23	J	Y	1	fault coating	chips	-8.5	25.2	0.033	0.708221	0.000008	173.27	0.249	2.452	303	0.9825	0.0017	1.3241	0.0009	**135.72**	0.49	1.4769	0.0013	77	24	8.6	37	6.5	1.6	8.4	8.1	99	2.0	5.9	1.0	5.9	1.1
F25-AHR	F25	A	HR		host rock	powder	-6.3	20.0	0.007															1372	533	149	618	109	29	154	160	2080	41	133	20	124	19
F25-AS1	F25	A	S	1	striation top part	chips	-4.7	18.7	0.005	0.707513	0.000008	82.58	0.138	10.55	33	0.8181	0.0025	1.2757	0.0017	**104.74**	0.84	1.3785	0.0042	920	365	96	374	68	19	96	104	1392	28	88	13	79	13
F25-AS2	F25	A	S	2	striation middle part	chips	-8.6	21.1	0.027	0.707518	0.000008	162.73	0.418	21.14	49	0.8161	0.0015	1.0508	0.0008	**158.75**	0.94	1.0806	0.0013	422	198	49	186	37	9.8	46	47	591	12	38	6.0	37	5.8
F25-AS3	F25	A	S	3	striation middle part	chips	-7.3	21.1	0.006	0.707534	0.000008	197.05	0.290	16.34	41	0.7673	0.0013	1.0301	0.0007	**145.84**	0.94	1.0462	0.0011	916	379	101	372	73	20	103	114	1453	29	87	13	84	14
F25-AS4	F25	A	S	4	striation top part	powder	-8.9	23.3	0.050	0.707821	0.000020	30.27	0.207	14.63	35	0.8154	0.0039	1.1537	0.0018	**126.7**	1.4	1.2242	0.0032	602	278	75	313	55	16	77	76	938	19	60	8.7	52	8.3
F25-BS1	F25	B	S	1	striation top part	chips	-5.1	19.0	0.004	0.707516	0.000008	171.53	0.105	9.694	27	0.8273	0.0032	1.3703	0.0017	**93.89**	0.89	1.4952	0.0060	575	234	60	235	44	12	64	71	1029	19	60	9.1	54	9.1
F25-BS2	F25	B	S	2	striation middle part	chips	-7.8	21.2	0.018	0.707528	0.000008	182.11	0.210	13.11	39	0.8076	0.0020	1.1407	0.0010	**127.71**	0.85	1.2054	0.0021	473	207	44	171	31	8.6	45	52	682	14	46	7.6	52	9.0
F25-BS3	F25	B	S	3	striation bottom part	chips	-8.5	20.9	0.025	0.707537	0.000008	45.14	0.327	10.92	71	0.7870	0.0029	1.0632	0.0014	**143.0**	1.2	1.0955	0.0021	318	132	31	126	22	6.0	34	37	566	10	35	5.5	37	6.3
F25-ES1	F25	E	S	1	striation away from fault surface	chips	-7.3	20.6	0.031	0.707553	0.000008	85.94	0.060	2.113	70	0.8071	0.0038	1.7985	0.0031	**61.36**	0.45	1.9588	0.0054	164	67	14	53	9.5	2.7	13	17	275	4.9	17	3.1	21	3.6
F25-FS1	F25	F	S	1	striation away from fault surface	chips	-7.8	20.7	0.035	0.707538	0.000008	123.93	0.054	2.041	69	0.8559	0.0044	1.7952	0.0023	**66.39**	0.52	1.9693	0.0052	121	32	8.8	36	6.1	1.7	11	14	284	4.2	16	2.7	17	3.5
F25-GS1	F25	G	S	1	striation away from fault surface	chips	-6.4	20.6	0.012	0.707534	0.000008	69.68	0.155	3.151	124	0.8305	0.0025	1.2875	0.0018	**106.82**	0.62	1.3910	0.0025	266	146	28	111	21	5.7	29	37	521	9.7	33	5.4	35	6.0
F25-AX1	F25	A	X	1	reddish gouge	chips	-8.7	23.5	0.028															3029	2145	482	1770	400	101	480	442	4285	102	284	39	219	34

Combined samples for U-Th age analyses

[1] Samples were cut to small hand-size fragments and polished using diamond disc, cleaned in ultrasonic bath with Milli-Q water, and dried completely prior to separation. Calcite coating layers were sampled using hand-drill tip (0.5 mm) parallel to calcite coating layer. Following the removal of the surrounding host-rock material, 1-5 mm size calcite chips were separated (using hand pliers) from small dilation sites within fault striation structure, calcite gouge veins, and dilation breccia cement. Host-rock samples were also separated from striated fault plane and are used for comparison.

[2] The extraction of CO_2 was performed on a CO_2 extraction line for the host-rock samples (see Swart et al., 1991 for procedure) and using an on-line multi-prep, microanalysis system for all types of calcite precipitate samples. Measurements are calibrated using NBS-18, NBS-19, and BCS carbonate standards. The $\delta^{13}C$ and $\delta^{18}O$ are given in per mil ‰, compared to V-PDB and V-SMOW respectively, with analytical reproducibility better than ±0.1‰ (1σ error).

[3] For the $^{87}Sr/^{86}Sr$ analysis, ~10-20 mg calcite powder for each sub-sample was dissolved by slowly adding 7N nitric acid drop by drop until full digestion. After full digestion, the sample solutions were dried on hotplate and redissolved in 0.2 ml 3.5N HNO_3 prior to chemical separation and purification using ion-exchange micro-columns made of a Sr-Spec resin. The Sr fractions were then loaded onto tantalum filaments with TaF_5 + 0.1M HPO_3 solution. Three loads of NBS-987 standard were run with every 17 samples. Long-term repeated measurement of the NBS-987 standard on this machine yields a mean $^{87}Sr/^{86}Sr$ value of 0.710249 ± 0.000028 (2σ).

[4] U-series dating was carried out by a Nu Plasma multi-collector inductively-coupled plasma mass spectrometer (MC-ICP-MS). Powdered and chipped sub-samples were completely dissolved in concentrated HNO_3 with a mixed ^{229}Th-^{233}U spike. After digestion, U-rich and Th-rich fractions were separated using conventional anion-exchange column chemistry, and then treated with H_2O_2 for the complete removal of residual resin. The U and Th fractions were then mixed and diluted in 3 ml 2% HNO_3. The percentage of U needed for making the mixed solution depends on the amount of U in the sample and range from 100 to 10%. Generally, U concentration of ~10 ppb or less in the final 3-ml solution is targeted, which was calculated based on ICP-MS measurements of U and Th concentrations. The U-Th mixed solution was then injected into the MC-ICP-MS through a DSN-100 desolvation system with an uptake rate of around 0.12 ml per minute. U-Th isotopic ratio measurement was performed on the Nu Plasma MC-ICP-MS following the analytical protocol described by Hellstrom (2003), with minor modification to the detector configuration [e.g. the ^{235}U on IC0 sequence was not used in our protocol, instead we used ^{233}U for IC0/Faraday gain calibration; (Zhou et al., 2011)]. Working sensitivity is about 0.5-0.6 volt per ppb for U and 0.4-0.5 volt per ppb of Th. The time taken to measure each sample was approximately 25 minutes. Once the analysis of each sample was completed, a vigorous 15-minute cleaning procedure was undertaken and all isotopes were monitored and raw counts measured on their respective detectors to ensure no carry-over memories from previous samples. Measurements of samples, standards, and carryover memories were performed automatically using a Cetac ASX-110FR autosampler. A long-term monitoring of the carryover memories over 12 months shows that ^{230}Th memory is consistently less than 0.1 counts per second, which is negligible for most samples. The memories for all other isotopes are also negligible. The $^{230}Th/^{238}U$ and $^{234}U/^{238}U$ activity ratios were calculated using the decay constants of Cheng et al. (2000). The non-radiogenic ^{230}Th correction has a minimal impact on the corrected ^{230}Th ages, as the $^{230}Th/^{232}Th$ activity ratios are commonly higher than 20 in most samples (Richards and Dorale, 2003). U-Th ages were calculated using the Isoplot/Ex 3.0 Program (Ludwig, 2008).

[5] Trace element measurements were performed on a Thermo X-series ICP-MS with conditions as described in Lawrence and Kamber (2006). For trace element analyses, 5–10 mg of carbonate powder was dissolved in 2% nitric acid (diluted to 5000 times) and pre-mixed with internal standards consisting of ^{6}Li, ^{61}Ni, ^{103}Rh, ^{115}In, ^{187}Re, ^{209}Bi and ^{235}U (^{6}Li, ^{61}Ni and ^{235}U are enriched isotopes) for internal correction of mass response drift following the protocol described in Eggins et al. (1997). Raw data were corrected for the low detectable blank, isobaric interferences from oxides and doubly charged species, and then externally corrected for additional drift by repeated measurements of a matrix-matched drift-monitoring solution after the measurement of every 5-7 unknown samples. The raw data were converted into concentrations in ppb using four independent digestions of the USGS reference material W-2 as the calibration standards. Values of W-2 are those reported in Lawrence and Kamber (2006). Experiment detection limit is better than 0.001 ppb within the REY range.

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