Table 1 The relative contents of main minerals in the heavy minerals in the Shishugou Group sandstones, Fukang Sag

Z= Zircon; A= Apatite; R= Rutile;AN= Anatase;   L= Leucoxene; S= Sphene;P= pyrite; B= Barite; T= Tourmaline; E= Epidote; G= Garnet;L= Limonite; I= Ilmenite;C= Chromite;M= Magnetite; TM= Transparent mineral

Sratum	Sample	Depth(m)	Z,%	A,%	R,%	An,%	L,%	S,%	P,%	B,%	T,%	E,%	G,%	L,%	Ilmenite,%	Chromite,%	Magnetite,%	TM,%	ZTR
J3q	D701-1	3901	4.1	0.4	0.7	0.5	1.4	0.0	0.0	0.0	0.0	20.4	1.4	66.6	0.0	0.0	4.5	28.8	16.5
J3q	D701-2	3904.1	0.4	0.4	0.9	0.9	2.2	0.4	0.0	0.0	0.0	16.7	1.8	67.0	0.0	0.4	8.8	23.8	5.6
J3q	D701-3	3905.7	1.4	0.5	0.5	1.8	0.0	4.5	0.0	0.0	0.0	12.6	5.0	54.5	10.4	0.0	9.0	26.1	6.9
J3q	D701-4	3907.2	1.4	0.0	1.4	0.9	2.4	0.5	0.0	2.4	0.0	24.5	0.5	66.0	0.0	0.0	0.0	31.6	8.3
J3q	D6-1	4260.3	2.0	0.3	0.3	0.3	1.0	2.8	0.0	40.7	0.0	27.8	1.5	20.2	0.0	0.8	2.5	35.9	3.0
J3q	D6-2	4257	1.0	0.0	0.1	0.4	0.7	3.9	0.1	0.2	0.0	55.1	2.0	28.9	5.0	1.0	1.7	63.3	1.7
J2t3	D7-1	4138.3	0.1	0.1	0.1	0.1	0.2	0.2	0.0	14.1	0.0	54.5	1.1	28.8	0.9	0.1	0.0	56.1	0.2
J2t3	D7-2	4135.1	0.5	0.0	0.1	0.1	0.2	0.5	0.0	0.0	0.1	35.9	1.1	61.2	0.0	0.0	0.5	38.3	1.5
J2t3	D6-3	4454.7	0.7	0.0	0.7	0.3	1.0	1.0	0.3	6.5	0.3	84.7	3.1	1.0	0.3	0.0	0.0	91.8	1.7
J2t3	D6-4	4453.8	0.2	0.2	0.2	0.4	2.2	7.3	0.0	18.3	0.0	62.9	4.1	0.2	0.0	4.1	0.0	77.5	0.4
J2t3	D101-1	4930	1.0	0.1	0.2	0.4	1.1	0.2	0.0	0.0	0.0	37.3	2.0	54.0	0.0	0.0	3.7	42.3	2.9
J2t3	D101-2	4942	3.5	0.0	1.4	1.2	2.3	1.2	0.0	18.8	0.0	33.2	1.5	33.8	0.0	0.1	2.9	44.3	7.8
J2t3	D101-3	4916	0.3	0.3	3.0	1.5	12.1	0.7	0.0	0.0	0.2	16.9	0.7	47.2	0.0	0.2	16.9	35.8	9.9
J2t3	D101-4	4970	0.1	0.0	0.7	1.5	11.0	0.0	0.0	52.9	0.0	3.0	0.3	28.6	0.0	0.0	1.8	16.7	1.2
J2t3	D101-5	4951	1.5	0.1	0.7	1.5	13.4	0.1	0.0	46.8	0.0	7.1	0.2	25.0	0.0	0.2	3.4	24.6	3.1
J2t2	D11-1	4901.22	0.1	3.5	1.4	0.7	0.7	0.7	71.2	0.0	0.3	12.6	2.8	0.0	0.0	5.9	0.0	22.8	8.1
J2t2	D11-4	4986.3	3.4	1.1	0.7	1.9	1.6	2.7	5.3	0.0	0.1	59.3	9.7	1.8	0.0	12.4	0.0	80.5	5.2
J2t2	D8-1	4425.3	3.5	1.8	0.3	0.2	0.9	2.6	0.0	0.0	1.0	38.1	0.8	33.2	0.0	5.0	12.5	49.3	9.8
J2t2	D8-2	4542.8	0.4	0.4	0.4	0.4	1.8	0.7	0.0	30.2	0.0	61.2	0.7	0.4	0.0	3.6	0.0	65.8	0.7
J2t2	D8-3	4546.4	0.4	0.1	0.6	0.9	1.9	3.3	0.1	1.6	0.2	82.2	1.9	0.2	0.0	6.5	0.0	91.6	1.3
J2t2	D8-4	4547	1.6	0.9	0.5	0.4	1.6	16.4	0.0	0.0	9.3	58.2	4.1	0.2	0.2	5.0	1.8	92.9	11.5

J2t2	D8-5	4548	0.3	0.1	0.1	0.2	0.5	0.8	0.0	76.9	0.0	17.8	0.4	0.1	0.0	1.7	1.0	20.3	0.4
J2t2	D1-1	4961.2	1.1	0.0	0.0	0.0	0.3	1.0	0.0	0.0	0.0	24.3	3.0	65.7	0.0	0.1	4.2	30.0	4.1
J2t2	D1-2	4958.2	2.7	0.5	0.3	0.2	0.4	0.8	0.0	0.0	0.0	18.2	1.0	71.9	0.0	0.0	4.0	24.1	12.4
J2t2	D1-3	4960.1	0.8	0.2	0.1	0.2	0.4	0.5	0.1	0.0	0.0	16.9	0.8	72.5	0.0	0.0	7.6	19.8	4.6
J2t2	D1-4	4960.2	0.3	0.1	0.1	0.1	1.3	0.8	0.0	0.0	0.0	13.8	0.7	81.7	0.0	0.0	1.1	17.2	2.3
J2t2	D3-1	5511.6	5.5	0.0	4.6	5.2	13.3	0.1	0.0	26.7	0.0	14.4	0.9	29.2	0.0	0.0	0.0	44.1	14.3
J2t2	D3-2	5511.3	8.0	0.1	1.1	0.6	1.7	2.5	0.0	5.7	0.0	27.6	3.6	37.7	0.0	2.2	9.2	45.2	17.9
J2t2	D3-3	5512.9	7.4	0.0	0.8	0.9	1.1	0.8	0.0	0.0	0.0	12.1	5.6	58.0	0.0	0.0	13.1	28.8	28.5
J2t2	D3-4	5542.8	0.2	0.1	1.0	0.8	2.0	1.6	0.0	29.8	0.1	30.7	3.9	28.1	0.0	0.0	1.6	40.5	1.9
J2t2	D3-5	5547.6	11.	1.3	1.3	1.3	2.6	2.6	0.0	0.0	0.0	36.8	3.9	23.7	0.0	1.3	13.2	61.8	21.3
J2t2	D101-6	5005	0.1	0.0	3.8	2.3	11.3	0.0	0.0	54.2	0.0	4.4	0.5	21.1	0.0	0.0	2.3	22.4	5.0
J2t2	D101-7	5050	0.2	0.1	0.1	0.1	2.8	0.2	5.7	44.9	0.0	18.1	1.8	19.8	0.0	0.0	6.3	23.3	0.4
J2t2	D101-8	5072	0.2	0.0	1.6	1.6	3.9	0.8	0.0	68.1	0.0	5.1	0.7	11.2	0.9	0.0	6.0	13.8	2.2
J2t1	D7-3	4516.2	0.2	0.1	0.1	0.1	0.8	1.2	13.0	0.0	0.0	78.4	1.9	0.2	0.0	3.7	0.5	82.6	0.3
J2t1	D7-4	4514.8	0.0	0.0	0.0	0.0	0.9	0.4	31.7	41.8	0.0	23.3	0.5	0.0	0.0	1.0	0.3	25.2	0.1
J2t1	D7-5	4517.8	0.4	0.2	0.2	0.4	4.4	2.7	13.1	1.1	0.0	67.4	4.4	0.2	0.0	3.4	2.1	80.2	0.8
J2t1	D1-5	5307.3	2.7	0.1	0.2	3.2	1.2	0.0	90.2	0.0	0.0	0.0	0.6	0.1	0.0	0.6	1.1	8.0	36.0
J2t1	D1-6	5309.5	0.0	0.0	0.0	0.1	0.1	0.0	99.1	0.0	0.0	0.0	0.2	0.0	0.0	0.2	0.3	0.4	16.7
J2t1	D1-7	5299.5	20.	0.3	0.8	0.8	2.2	0.3	59.6	0.0	2.4	0.0	8.4	0.3	0.0	4.3	0.5	35.3	66.4
J2t1	D2-1	4422.85	2.7	1.0	0.6	0.7	0.7	3.8	0.1	0.0	2.0	60.6	18.9	0.1	0.0	7.6	1.3	90.9	5.8
J2t1	D2-2	4423.45	9.5	5.2	3.6	3.9	3.3	5.8	0.0	0.0	0.9	38.9	25.9	0.3	0.0	0.0	2.7	97.0	14.4
J2t1	D2-3	4428.45	13.	3.3	4.1	5.7	6.5	1.6	0.0	0.0	0.1	39.8	22.8	0.6	0.0	0.0	1.7	97.6	18.4
J2t1	D2-4	4428.32	15.	0.7	3.7	3.4	7.1	0.7	0.0	0.0	0.0	56.1	6.6	0.6	0.0	4.4	1.0	94.0	20.7
J2t1	D2-5	4429.15	21.	5.3	5.3	5.3	23.7	0.0	5.3	0.0	0.0	2.6	15.8	0.0	0.0	15.8	0.0	78.9	33.3
J2t1	D2-6	4430.81	8.9	7.5	1.9	1.7	2.5	3.5	0.0	0.0	0.0	44.3	9.1	0.1	0.0	19.8	0.7	79.4	13.7
J2t1	D2-7	4423.5	4.6	1.6	1.8	1.9	2.2	3.4	0.0	0.0	0.2	49.9	15.1	1.8	3.6	12.5	1.4	80.8	8.1
J2t1	D2-8	4428.35	3.5	0.8	0.5	1.0	1.1	4.7	1.4	0.0	0.9	48.2	19.8	0.0	0.0	17.9	0.0	80.6	6.1
	Average(%)		3.5	0.8	1.1	1.2	3.3	1.9	8.3	12.1	0.4	32.4	4.6	23.8	0.4	3.0	3.2	49.2	9.7

Table 2 The contents and ratio of main trace elements in the Shishugou Group mudstone. SSC=Short-term base-level circle

Sample no.	Depth (m)	For	Sequence	V (µg/g)	Cr (µg/g)	Ni µg/g)	Cu µg/g	Rb (µg/g)	Sr (µg/g)	Ba (µg/g)	Ta (µg/g)	Th (µg/g)	U (µg/g)	Cd (µg/g)	Rb/Sr	Sr/Cu	Sr/ Ba	U/Th	V/Cr	V/(V+	V/N i	V/(V+ Cr)
D6-6	3974.8	J3q	SSC6	84.2	59.9	38.4	26.1	163	198	438	1.619	12.3	5.94	0.505	0.65	6.90	0.62	0.26	1.41	0.69	2.19	0.58
D7-4	3974.3	J3q	SSC1	74.7	69.1	39.6	32	170	169	365	0.573	10.7	4.12	0.186	0.74	16.19	0.50	0.30	1.08	0.65	1.89	0.52
D701-6	3907.6	J3q	SSC1	62	66.4	46.2	29.4	132	203	327	0.706	12.8	3.36	0.176	1.14	12.02	0.40	0.23	0.93	0.57	1.34	0.48
D6-8	4257.1	J3q	SSC2	90.2	63.1	33	11.8	142	191	384	0.693	12.1	3.67	0.158	0.72	6.56	0.56	0.14	1.43	0.73	2.73	0.59
D6-10	4260.95	J3q	SSC1	69.8	70.2	37	12.4	170	149	369	0.540	10.6	2.4	0.166	0.71	6.46	0.53	0.25	0.99	0.65	1.89	0.50
D6-12	4454.98	J2t3	SSC8	104	61	30.8	36.9	175	242	434	0.789	13.5	1.89	0.162	1.04	1.38	0.59	0.10	1.70	0.77	3.38	0.63
D3-7	5512.5	J2t2	SSC7	105	246	129	29.4	135	190	359	0.615	11.9	2.96	0.221	0.67	3.71	0.39	0.21	0.43	0.45	0.81	0.30
D8-6	4425.4	J2t2	SSC6	172	66.4	43.5	135	194	186	314	1.127	26.5	2.7	0.242	0.93	3.63	0.34	0.25	2.59	0.80	3.95	0.72
D11-2	4903.2	J2t2	SSC5	124	117	49.3	48.2	120	179	461	0.791	13.5	2.8	0.261	0.44	5.27	0.42	0.20	1.06	0.72	2.52	0.51
D11-3	4989.05	J2t1	SSC4	125	88.1	40.4	39.9	135	145	430	0.518	9.6	2.36	0.242	0.86	6.03	0.39	0.25	1.42	0.76	3.09	0.59
D7-3	4512.1	J2t1	SSC2	90.9	73.1	35.2	39.1	89.9	206	496	0.672	11.8	2.4	0.177	0.86	5.27	0.37	0.46	1.24	0.72	2.58	0.55
		Average		100.2	89.1	47.5	40	147.8	187.1	397.9	0.785	13.2	3.15	0.23	0.8	6.67	0.46	0.24	1.3	0.68	2.4	0.54

Table 3 Raw results (ppm) of rare earth element (REE) concentrations in the Shishugou Group mudstone. North American Shale Composite (NASC) values (Grimet et al.,1984; Harrell, JR.T. L and PE´REZ-HUERTA,A.,2015) were used for normalization of data. SSC=Short-term base-level circle

Sample no.	Depth （m）	Formation	Sequence	La (μg/g)	Ce (μg/)	Pr (μg/g)	Nd (μg/g)	Sm (μg/g)	Eu (μg/g)	Gd (μg/g)	Tb (μg/g)	Dy (μg/g)	Ho (μg/g)	Er (μg/g)	Tm (μg/g)	Yb (μg/)	Lu (μg/)	Total REE(μ	Ce/Ce*	Eu/Eu*	(La$_{sn}$/Yb$_{sn}$)	(Ce/Yb)N
D6-6	3974.8	J3q	SSC6	28.8	790	5.53	20.7	4.45	0.97	7.78	0.84	4.84	1.01	6.64	0.44	2.94	0.45	875.4	3.60	0.17	0.96	12.33
D7-4	3974.3	J3q	SSC1	40.6	65.9	7.19	25.2	5.21	1.07	5.38	0.88	5.24	1.12	3.18	0.46	3.2	0.47	165.1	0.32	0.22	0.93	1.12
D701-6	3907.6	J3q	SSC1	31.4	81.5	7.11	28.2	5.65	1.15	5.76	0.93	5.46	1.14	3.49	0.49	3.34	0.5	176.1	0.22	0.22	1.25	0.94
D6-8	4257.1	J3q	SSC2	44.9	91.5	10.6	37.7	7.24	1.32	6.25	0.96	5.45	1.14	3.32	0.5	3.27	0.49	214.6	0.24	0.22	1.35	1.28
D6-10	4260.95	J3q	SSC1	31.4	60.1	7.02	25.5	5.00	0.97	4.57	0.73	4.36	0.9	2.62	0.38	2.54	0.38	146.5	0.23	0.22	1.22	1.09
D6-12	4454.98	J2t3	SSC8	34.8	71.2	8.38	32.1	6.51	1.39	6.24	0.97	5.74	1.14	3.29	0.47	3.09	0.46	175.8	0.24	0.24	1.11	1.06
D3-7	5512.5	J2t2	SSC7	31.8	1110	7.63	28.8	5.63	1.11	10.07	0.95	5.06	1.05	8.32	0.44	3.00	0.44	1214.3	4.13	0.15	1.04	16.97
D8-6	4425.4	J2t2	SSC6	36	1290	8.36	31.8	6.88	1.26	13.25	1.25	7.05	1.47	10.5	0.62	4.01	0.59	1413.0	4.31	0.14	0.88	14.76
D11-2	4903.2	J2t2	SSC5	35.7	101	8.49	31.1	5.94	1.16	5.78	0.93	5.61	1.19	3.68	0.52	3.50	0.51	205.1	0.34	0.22	1.00	1.32
D11-3	4989.05	J2t1	SSC4	22	45.1	5.47	21.3	4.55	0.93	4.15	0.71	4.21	0.90	2.61	0.39	2.71	0.40	115.4	0.24	0.24	0.80	0.76
D7-3	4512.1	J2t1	SSC2	34	66.6	8.17	31.2	6.47	1.27	5.75	0.91	5.18	1.06	3.00	0.44	2.89	0.43	167.4	0.23	0.23	1.16	1.06
	NASC Values (ppm)			31.1	66.7	7.7	27.4	5.59	1.18	4.9	0.85	4.17	1.02	2.84	0.48	3.06	0.456					
	Average（NASA -normalised）			1.09	5.14	0.99	1.04	1.03	0.97	1.39	1.08	1.27	1.08	1.62	0.98	1.02	1.02	19.72	1.28	0.21	1.06	4.79