Research Advances

Geochemistry of Argillaceous Siliceous Rocks from the North Tianshan Accretionary Complex, Wusu Area, NW China, and its Geological Implications

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Objective

Siliceous rocks can form in different positions in the oceanic plate, for example, the oceanic spreading ridge center, the oceanic basin and the continental margin. The geochemistry of siliceous rocks is very sensitive to the depositional environment, which can thus be used to constrain the tectonic setting of related rocks (Garbán et al., 2017).

The North Tianshan Accretionary Complex (NTAC) forms the northern part of the Chinese Tianshan orogen and marks the final suture between the Yili block and the Junggar terrane by closure of the North Tianshan Ocean (NTO) (Wang et al., 2006; Xiao et al., 2013). There are two lithologic units in the NTAC: the ophiolitic unit and the volcano-sedimentary unit. The ages of the North Tianshan ophiolites have been constrained to be Late Devonian to Carboniferous (Zheng et al., 2019), but the nature of the ophiolites is highly debated. Some researchers regard them as remnants of a 'Red Sea type' oceanic basin or remnants of a long-lived wide ocean, while others suggested that they resulted from subduction of a spreading ridge, or were generated in a forearc setting (Xu et al., 2006; Feng and Zhu, 2018 and references therein). These proposals were mainly based on whole rock geochemistry and isotopes of ophiolitic rocks, studies on the sedimentary rocks being relatively rare.

In this study, we present new whole rock geochemical data for the argillaceous siliceous rocks from the NTAC (Fig. 1a, b), to discuss their depositional environment and provenance, further constraining the nature of the North Tianshan ophiolitic mélange.

Methods

Whole rock geochemical analyses were conducted at the State Key Laboratory of Continental Dynamics, Northwest University. Major elements were determined using the XRF method on a Rigku RIX 2100, trace elements being analyzed using ICP-MS on a PE 6100 DRC. Analytical precision was better than 5% for most major elements, as well as achieving 2% for most trace elements.

Results

A total of 10 samples were analyzed for their whole-rock geochemistry, the results being listed in Table 1. The SiO_2 contents of the argillaceous siliceous rocks were 75.19 to 61.72 wt%, much lower than pure cherts. They had Al_2O_3 = 16.57–10.61 wt%, TiO_2 = 0.15–0.94 wt%, Fe_2O_3(total) = 2.06–7.27 wt% and MnO = 0.01–0.14 wt%. Positive correlations between SiO_2 and Al_2O_3 (or TiO_2), and the low values of MnO/TiO_2 (0.04 to 0.32) reflected significant terrigenous input. In the depositional setting discrimination diagrams, the samples all plotted within the continental margin field (Fig. 1c, d). The Na_2O (1.73 to 6.54 wt%) are mostly higher than K_2O contents (0.06 to 5.76 wt%), with K_2O/Na_2O of 0.01 to 3.33 (mostly <1.0), indicating involvement of the hydrothermal caused by volcanic activity. The $SiO_2/(K_2O + Na_2O)$ (7.34 to 14.88), SiO_2/Al_2O_3 (3.75 to 14.99), Al_2O_3/TiO_2 (18 to 95, mostly 25 to 39), SiO_2/MgO (25 to 114, mostly <70) ratios also suggest that the argillaceous siliceous rocks had an intimate relationship with volcanic activity.

The studied argillaceous siliceous rocks have ∑REE values of 71.21 to 156.04 ppm, with an average of 101.43 ppm. In the NASC normalized REE pattern diagram (Fig. 1e), the samples showed slight depletion in LREE, with $(La/Yb)_N$ values of 0.31 to 0.93, similar to the distribution patterns of hydrothermal-related siliceous rocks. Most of them displayed positive Eu anomalies with δEu = 1.10–1.56, except for three samples with δEu = 0.62–0.91. The δCe values were 0.80 to 1.08, with the $(La/Ce)_N$ values being 0.88 to 0.11. These signatures also indicated

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sedimentation in the basin of a continental marginal sea (Fig. 1f). Furthermore, they had Th/U ratios of 1.59 to 3.65 (average 3.13) and Th/Sc values of 0.18 to 2.28 (average 0.80), indicating the provenance of a magmatic arc, which usually has Th/U ratios of less than 3.0 and Th/Sc ratios from ~1.0 to <0.01.

Conclusions

Geochemical data indicate that the argillaceous siliceous rocks in the NTAC were the result of hydrothermally-related deposition in a continental margin sea, volcanic activity playing an important role in the generation of the siliceous rocks. This is consistent with the fact that the argillaceous siliceous rocks were interbedded with volcanic tuff and turbiditic sandstone. The turbidites in the NTAC displayed unimodal detrital zircon spectra, with few Precambrian zircons, which were thought to be deposited in a convergent basin setting (Wang et al., 2018). Given that previous studies revealed that the North Tianshan ophiolites have supra-subduction zone signatures, we therefore suggest that the volcano-sedimentary rocks and the North Tianshan ophiolites were both formed in a forearc basin.

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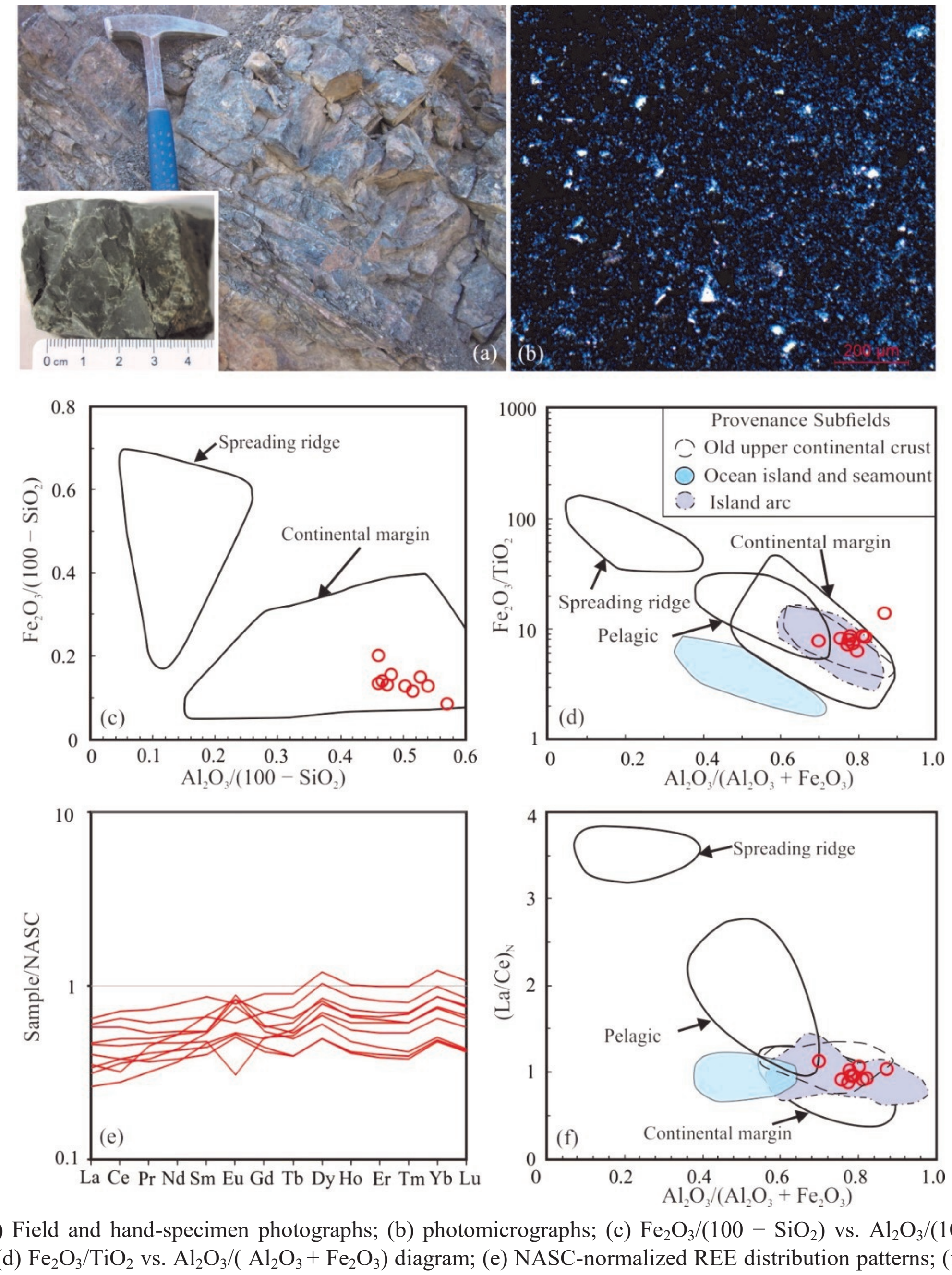

Fig. 1. (a) Field and hand-specimen photographs; (b) photomicrographs; (c) $Fe_2O_3/(100 - SiO_2)$ vs. $Al_2O_3/(100 - SiO_2)$ diagram; (d) Fe_2O_3/TiO_2 vs. $Al_2O_3/(Al_2O_3 + Fe_2O_3)$ diagram; (e) NASC-normalized REE distribution patterns; (f) $(La/Ce)_N$ vs. $Al_2O_3/(Al_2O_3 + Fe_2O_3)$ diagram for the siliceous rocks from the NTAC.

Table 1 Whole rock geochemistry of the argillaceous siliceous rocks from the NTAC

Sample No.	TS17-12	TS17-20	TS17-21	TS17-32	TS17-33	TS17-34	TS17-35	TS17-39	TS17-40	TS17-42
SiO_2	74.44	62.80	72.42	69.84	69.28	61.72	71.72	75.19	73.56	69.75
Al_2O_3	13.78	16.57	11.58	15.06	15.47	16.47	13.36	10.61	12.82	12.81
$^TFe_2O_3$	2.03	4.43	3.40	4.23	3.56	7.08	3.32	3.41	2.79	3.64
MgO	1.11	1.93	0.64	1.07	1.23	2.50	1.20	1.07	1.17	1.49
CaO	0.51	2.46	2.89	0.86	1.41	2.35	1.63	1.36	1.00	1.81
Na_2O	6.45	4.40	4.61	6.13	4.01	4.19	3.71	2.18	4.04	1.69
K_2O	0.06	4.14	0.96	0.53	2.40	1.78	2.56	2.84	2.48	5.62
MnO	0.01	0.09	0.11	0.09	0.07	0.12	0.07	0.09	0.10	0.14
TiO_2	0.14	0.60	0.47	0.49	0.42	0.92	0.53	0.42	0.33	0.46
P_2O_5	0.06	0.20	0.16	0.10	0.09	0.24	0.20	0.11	0.10	0.16
LOI	1.35	2.24	2.61	1.53	1.96	2.52	1.57	2.63	1.49	2.25
Total	99.94	99.86	99.85	99.92	99.89	99.89	99.87	99.90	99.88	99.80
Cr	4.01	23	18.2	10.6	12.8	17.7	11.1	15.4	5.89	18.3
Co	0.74	9.61	7.15	5.22	2.22	13.0	2.33	5.87	4.06	8.64
Ni	1.67	8.50	14.3	7.53	8.47	11.3	6.11	11.5	4.19	15.3
Cu	13.9	31	24	26	17.2	48	33	61	30	52
Zn	35	55	65	82	54	110	46	53	46	58
Ga	13.9	19.7	11.3	17.6	21	17.2	10.8	12.4	14.9	17.0
Rb	1.18	47	11.6	5.84	47	21	31	50	50	172
Sr	128	235	296	104	205	256	322	223	290	209
Zr	76	217	174	224	289	176	146	108	201	178
Nb	6.55	5.85	3.89	5.00	7.68	4.30	4.65	4.66	9.28	7.19
Ba	35	599	815	98	312	144	494	416	413	1166
Hf	3.85	5.05	4.36	5.61	7.44	4.58	3.64	3.50	5.33	4.40
Ta	0.57	0.65	0.31	0.39	0.60	0.50	0.55	1.35	0.75	0.94
Th	7.15	5.27	3.28	1.98	8.69	3.37	4.86	4.90	9.65	7.85
U	2.19	1.68	1.12	1.25	2.71	0.99	1.33	1.45	2.74	2.41
Y	24	18.0	28	26	37	31	15.6	15.3	25	22
La	18.8	19.3	13.0	10.9	27	14.6	16.5	14.0	25	24
Ce	37	41	30	23	60	26	32	31	55	48
Pr	4.75	5.04	3.81	3.24	7.41	4.56	4.17	3.68	6.23	5.47
Nd	17.8	19.9	16.5	14.0	30	20	16.3	14.5	24	21
Sm	3.62	4.09	4.01	3.54	6.54	5.04	3.32	3.04	5.00	4.11
Eu	0.49	1.36	1.23	0.86	1.28	1.34	0.84	0.81	1.00	1.43
Gd	3.22	3.46	3.68	3.17	5.74	4.44	2.82	2.67	4.44	3.79
Tb	0.64	0.61	0.75	0.69	1.12	0.93	0.49	0.48	0.80	0.66
Dy	3.87	3.29	4.69	4.32	6.60	5.63	2.75	2.75	4.48	3.73
Ho	0.82	0.64	0.98	0.92	1.36	1.16	0.55	0.56	0.90	0.74
Er	2.29	1.67	2.66	2.50	3.75	3.05	1.47	1.51	2.38	2.02
Tm	0.39	0.27	0.44	0.43	0.63	0.51	0.24	0.25	0.38	0.34
Yb	2.67	1.78	3.06	3.04	4.32	3.48	1.67	1.73	2.61	2.29
Lu	0.41	0.27	0.47	0.47	0.66	0.53	0.25	0.26	0.40	0.35

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