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Short Communications (Research Advances)

Apatite and zircon (U-Th)/He dating of sandstone in the Weibei Uplift, Ordos Basin and its revealed Eocene rapid uplift denudation event

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1. Objective

The Ordos Basin is a large sedimentary basin in central China. It is located in the western part of the North China Craton and contains rich hydrocarbon resources. The Weibei Uplift, a main secondary tectonic unit in the south of the Ordos Basin, is located in the transition zone between an active tectonic zone and a stable block. Its tectonic position is unique and important. Its evolution process is closely related to the tectonic evolution of the rigid block in the northern basin, the Weihe Graben in the south, and even the Qinling orogenic belt. It records the thermodynamic information of the basin-mountain evolution. However, the Weibei Uplift in the southern Ordos Basin has experienced multiple tectonic movements in its geological history. Since the Mesozoic, strong tectonic deformation has occurred, and the tectono-thermal evolution process is complex. Limited by the availability of effective paleo-geothermometers, the previous researches on the tectono-thermal evolution of the Weibei Uplift were relatively scarce. This restricted the geodynamics research of the basin-mountain junction zone of the Weibei Uplift and its surrounding areas from a geothermal perspective. In this study, we collected samples from the Weibei Uplift, southern Ordos Basin, and conducted apatite and zircon (U-Th)/He dating to reveal the low-temperature tectono-thermal events of the Weibei Uplift. This study provides not only geochronological constraints for the study of geodynamics of the basin-mountain junction zone in the southern Ordos Basin, but also scientific basis for geothermal and hydrocarbon exploration in this area.

2. Methods

The samples used in this study were collected from the outcrop section of the Weibei Uplift in the southern Ordos Basin (Fig. 1). The lithology of the samples were purple or gray-green sandstone. Apatite and zircon separation and (U-Th)/He dating were completed at the low-temperature thermochronology laboratory, University of Melbourne. The (U-Th)/He dating of apatite and zircon particles were carried out by ICP-MS (Agilent 7700X). The experimental analysis used BHVO-1 as calibration reference. Each group of samples was calibrated using Mud Tank carbonate apatite and the international rock standard BCR-2. Isoplot 4.15 was used to calculate the weighted mean age of apatite and zircon.

3. Results

This study performed (U-Th)/He dating on 8 apatite samples with 27 single particles (Table 1) and 3 zircon samples with 14 single particles (Table 2).

The apatite (U-Th)/He ages of all the samples range from 47.5 Ma to 31.7 Ma, which are much younger than the ages of the strata they belong to. The strata range from Lower Permian (298.9 Ma) to Lower Cretaceous (100.5 Ma). This indicates that the apatite (U-Th)/He ages of all the samples have been reset, and that the strata of the Weibei Uplift outcrop samples in the southern Ordos Basin experienced a maximum temperature above 70°C. The apatite (U-Th)/He ages are mainly around 40 Ma, revealing that the Weibei Uplift underwent a rapid uplift and denudation event at that time. The Upper Paleozoic and Mesozoic strata cooled rapidly and were uplifted and exposed to the surface during the Eocene. The (U-Th)/He system started to record the ages then.

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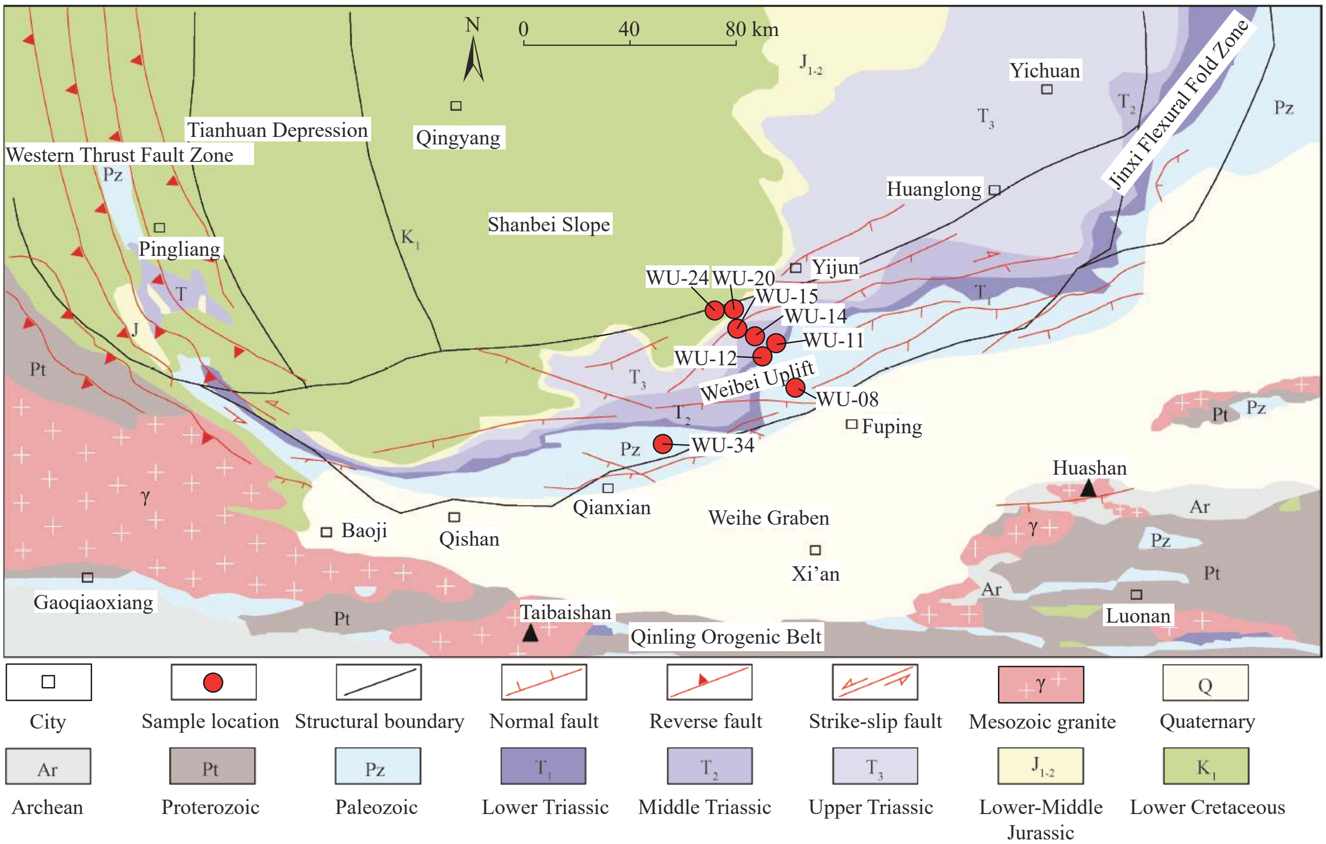

Fig. 1. Geological map of the Weibei Uplift and adjacent area.

The zircon (U-Th)/He ages are close to the Permian age of the strata they were sampled from, indicating that the zircon sample ages have not been completely reset. The results are mixed values of Paleozoic and Precambrian ages. The mixed ages reflect a combination of detrital zircon ages inherited from the source rocks and (U-Th)/He ages reset by thermal events. The zircon (U-Th)/He dating results reflect that the maximum paleotemperature experienced by the samples in this study did not reach the closure temperature (170°C –190°C) of the zircon (U-Th)/He dating system. According to the formula:

$$t\times v=(T_c-T_0)/G$$

where t is the (U-Th)/He age, v is the uplift and denudation rate, T_c is the closure temperature, T_0 is the surface temperature, and G is the geothermal gradient.

The uplift and denudation rate of the Weibei Uplift in the southern basin from Eocene to the present can be calculated by using the ages of outcrop samples. Assuming that the average geothermal gradient of the Weibei Uplift from Eocene to present is 30°C/km, the present average surface temperature is 10°C, and the apatite (U-Th)/He system closure temperature is 70°C. Then, the average amount of denudation of the Weibei Uplift from the Eocene to the present in the southern basin is about 2000 m, and the denudation rate ranges from 42 m/Ma to 63 m/Ma (Table 3). The denudation rates of the samples from the Triassic are higher than those of samples from other strata. This is mainly because the Triassic samples have younger ages.

4. Conclusions

According to the temperature sensitivity of different low-temperature thermochronology methods (apatite (U-Th)/He closure temperature <zircon (U-Th)/He closure temperature), the maximum paleotemperature experienced by the Lower Permian to Lower Cretaceous in the Weibei Uplift is between 70°C –170°C. The apatite (U-Th)/He dating results reveal that the Weibei Uplift underwent a rapid uplift and denudation event (about 42 m/Ma to 63 m/Ma) during the Eocene (about 31.7 Ma to 47.5 Ma), forming the present tectonic pattern of the uplifted southern Ordos Basin.

CRediT authorship contribution statement

Peng Gao wrote the manuscript with support from Sheng-biao Hu. All authors discussed the results and contributed to the final manuscript.

Declaration of competing interest

The authors declare no conflicts of interest.

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Table 1. Apatite (U-Th)/He dating results from the Weibei Uplift.

Sample	Strata	4He gas ncc	Mass /mg	aMean FT	U /×10^{-6}	Th /×10^{-6}	Th /U	b[eU] /×10^{-6}	Age /Ma	Error±1s /Ma	Grain length /mm	Grain half-width /mm	cGrain morphology
WU-08	P_{1s}	5.126	0.01799	0.83	18.2	111.6	6.12	44.4	63.4	3.9	279.4	80.0	0T
		0.874	0.00881	0.80	8.3	54.4	6.55	21.1	48.0	3.0	239.4	74.8	1T
		1.107	0.01483	0.83	17.7	12.9	0.73	20.7	35.3	2.2	223.3	81.3	0T
						Weighted mean age			43.7	3.2			
WU-11	T_{1l}	1.205	0.00481	0.73	34.4	110.8	3.22	60.4	46.1	2.9	185.1	50.8	0T
		0.818	0.00926	0.78	10.7	31.5	2.95	18.1	50.5	3.1	236.5	62.4	0T
		0.227	0.00547	0.75	5.6	38.8	6.92	14.7	30.7	1.9	150.7	60.1	0T
						Weighted mean age			38.5	2.8			
WU-12	P_{1x}	0.294	0.01089	0.80	2.9	13.2	4.56	6.0	45.7	2.8	193.7	74.8	0T
WU-14	T_{2z}	0.630	0.00297	0.71	42.4	28.0	0.66	49.0	34.1	2.1	142.7	45.5	0T
		0.075	0.00258	0.68	4.9	22.1	4.48	10.1	34.6	2.1	114.2	47.4	0T
		0.420	0.00338	0.72	37.1	20.0	37.10	41.8	33.6	2.1	146.9	47.8	0T
						Weighted mean age			34.1	2.1			
WU-15	T_{3y}	0.082	0.00282	0.67	1.6	9.4	5.90	3.8	91.8	5.7	158.8	42.0	0T
		0.072	0.00424	0.71	2.7	17.1	6.44	6.7	29.0	1.8	185.6	47.7	0T
		0.129	0.00740	0.78	5.2	4.7	0.90	6.3	28.5	1.8	180.6	63.9	0T
						Weighted mean age			31.7	2.5			
WU-20	J_{2a}	2.371	0.01333	0.83	26.0	36.9	1.42	34.7	50.1	3.1	284.2	83.8	1T
		0.028	0.00552	0.74	0.2	5.4	22.72	1.5	37.2	2.3	151.6	60.2	0T
		1.182	0.02644	0.85	5.9	21.5	3.67	11.0	38.8	2.4	253.0	102.0	0T
		2.653	0.02137	0.84	11.9	49.9	4.18	23.6	50.8	3.2	276.2	87.7	0T
		1.510	0.00531	0.78	19.8	72.3	3.65	36.8	80.1	5.0	167.1	73.5	1T
						Weighted mean age			42.5	2.7			
WU-24	K_{1h}	2.683	0.00723	0.75	15.8	75.0	4.74	33.4	119.0	7.4	257.1	52.9	0T
		1.628	0.00742	0.77	36.1	52.1	1.44	48.3	47.9	3.0	208.6	59.5	0T
		0.651	0.00659	0.76	11.1	45.0	4.05	21.7	48.5	3.0	161.5	63.7	0T
		0.255	0.00648	0.76	5.8	19.0	3.26	10.3	40.4	2.5	182.5	59.4	0T
						Weighted mean age			45.0	3.2			
WU-34	P_{2s}	3.281	0.00548	0.76	40.6	29.1	0.72	47.4	134.0	8.3	162.2	58.0	0T
		0.298	0.00496	0.74	8.2	34.1	4.16	16.2	40.6	2.5	155.2	56.4	0T
		0.102	0.00276	0.65	0.0	0.4	10.28	0.1	2974.4	184.4	172.7	43.8	2T
		0.359	0.00290	0.69	9.6	52.8	5.48	22.0	66.0	4.1	116.0	49.9	0T
		0.243	0.00247	0.66	0.1	1.6	24.82	0.5	2519.9	156.2	126.3	44.1	0T
						Weighted mean age			47.5	4.3			

Table 2. Zircon (U-Th)/He dating results from the Weibei Uplift.

Sample	Strata	Corrected gas ncc	Mass /mg	aMean FT	U /×10^{-6}	Th /×10^{-6}	Th /U	b[eU] /×10^{-6}	Age /Ma	Error±1s /Ma	Grain length /mm	Grain half-width /mm	cGrain morphology
WU-08	P_{1s}	74.792	0.0108	0.80	223.9	138.1	0.62	256.4	217.2	13.5	309.8	49.5	2T
		15.741	0.0094	0.81	1621.4	260.8	0.16	1682.7	8.2	0.5	259.2	52.5	2T
		42.504	0.0156	0.80	88.2	82.4	0.93	107.6	204.7	12.7	425.9	48.6	2T
		52.849	0.0071	0.75	369.9	305.7	0.83	441.8	137.6	8.5	302.6	39.4	2T
		97.860	0.0076	0.77	139.6	98.9	0.71	162.8	611.8	37.9	279.7	43.5	2T
						Weighted mean age			211.0	18.0			
WU-10	P_{1x}	48.276	0.0028	0.71	418.4	685.1	1.64	579.4	240.1	14.9	144.2	42.9	2T
		55.899	0.0074	0.78	67.8	147.0	2.17	102.4	579.6	35.9	228.7	50.6	2T
		60.258	0.0072	0.79	205.2	181.9	0.89	247.9	271.6	16.8	215.2	52.9	2T
		18.063	0.0045	0.76	108.0	139.3	1.29	140.8	229.7	14.2	167.9	50.8	2T
		163.818	0.0175	0.82	62.3	160.9	2.58	100.1	725.2	45.0	389.9	55.1	2T
						Weighted mean age			245.0	18.0			
WU-34	P_{2s}	12.238	0.0042	0.76	65.5	55.6	0.85	78.5	297.6	18.5	179.8	44.2	2T
		58.319	0.0038	0.74	493.3	152.8	0.31	529.2	231.6	14.4	215.0	35.5	2T
		20.659	0.0044	0.72	294.4	241.1	0.82	351.0	109.8	6.8	129.5	42.6	0T
		74.325	0.0040	0.76	581.8	338.1	0.58	661.3	224.2	13.9	176.8	43.8	2T
						Weighted mean age			244.0	18.0			

Table 3. Denudation rate calculated from reset samples.

Sample	WU-08	WU-10	WU-11	WU14	WU-15	WU-20	WU-24	WU-34
Strata	P_{1s}	P_{1x}	T_{1l}	T_{2z}	T_{3y}	J_{2a}	K_{1h}	P_{2s}
Rate/(m/Ma)	45.8	43.8	51.9	58.7	63.1	47.1	44.4	42.1