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The Hydrogeochemistry of the Langjiu Geothermal Field in Ali, Tibet

Die Hydrogeochemie des Langjiu Geothermalfeldes in Ali, Tibet

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Content

1. Geological Background and Regional Geothermal Activities

The Langjiu geothermal field is situated in the west section of the Gangdise-Nyingentanglha Yangshan folding zone (it developed between 190 and 70 million years ago), which in the N adjoins the Qiantan-Qamdo folding zone (later Hercynian-to-Indo-China cycle) and, southwards, is next to the Himalayan folding zone. From the viewpoint of plate tectonics, the uplift of the Qinghai-Tibet Plateau resulted from the northward drift of the Southasian subcontinent subducting beneath the Eurasian plate in front of Gangdise Mt. The oceanic crust between them subducted beneath the Eurasian plate as well. This resulted in the melting and/or remelting of continental crusts, which moved upwards and erupted, thus forming the intermediate-acidity central granite and the famous Gangdise andesite zone.

The fractures in this region show many different stages of development. The general trend of structure lines (there are predominantly reserve faults) is in the north-west direction. In parts of this area, they trend toward NWW or almost EW. The regional deep faults with their interwoven nest pattern cut through the crust and are therefore likely to become thermal water reservoirs and passageways for thermal water. The distribution of geothermal fields is controlled by deep fractures. They mainly occur at the intersecting points between them, as it is the case with the Naburu, Suoduo and Baer fields. Along the Mapangyongcuo NWW deep fracture zone there are the Baga and Qupu fields. Another important example, the Langjiu field, is located in the northwest Langjiu River fracture zone (Fig. 1).

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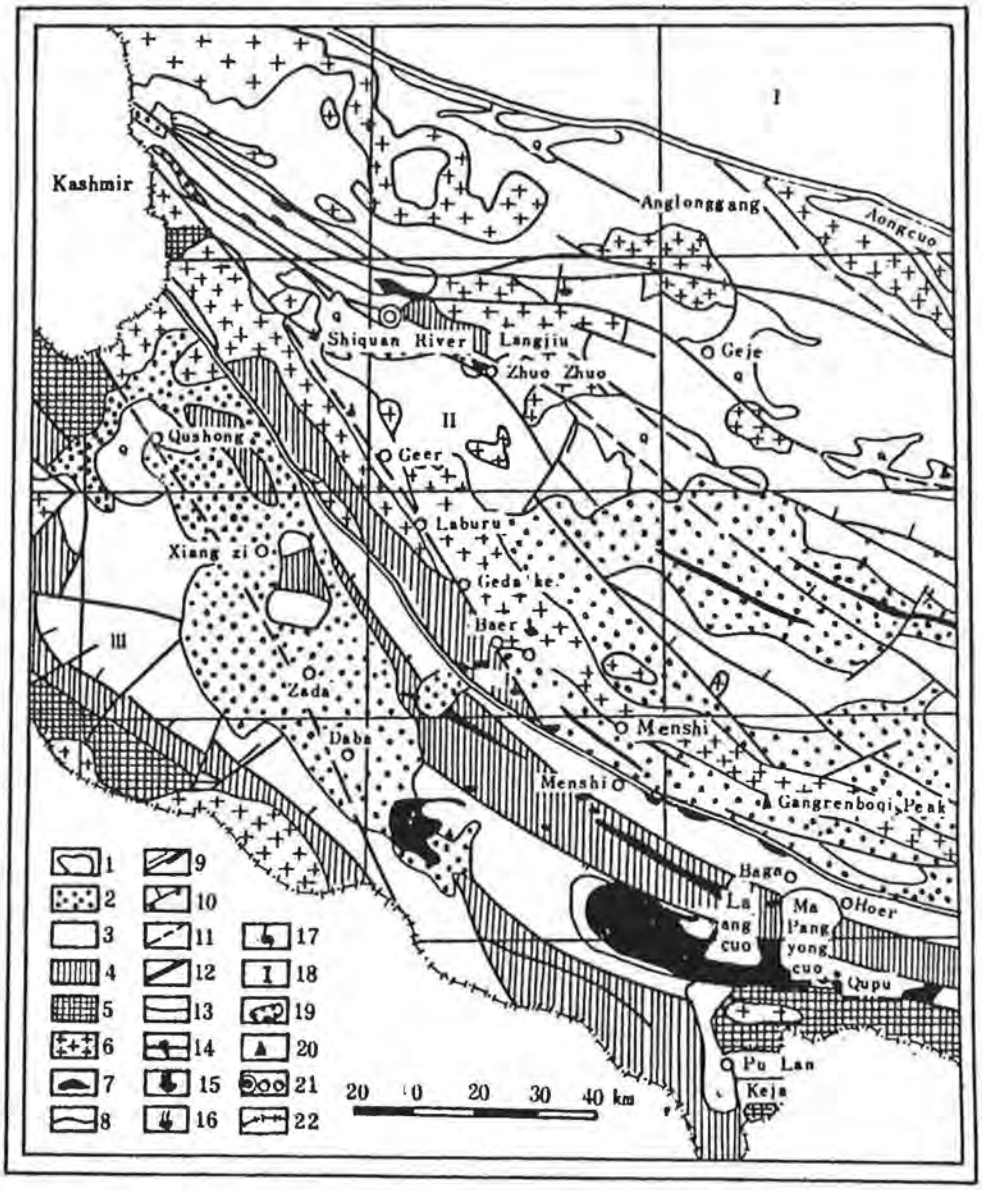


Fig. 1: Schematic structure map of the Shiquan River-Pulan region in Ali, Tibet. 1 – Quaternary system, 2 – Cenozoic Era, 3 - Mesozoic Era, 4 – Paleozoic Era, 5 – Presinian system, 6 – intermediate-acidity magmatite, 7 – ultrabasic rock ophiolite, 8 - geological border line, 9 – transcurrent fault, 10 – reverse fault, 11 – conjectured fault, 12 – deep fault cutting through the crust, 13 – anticlinal axis, 14 – axis of overturned anticline, 15 – hot geothermal field, 16 – mild-temperature spring, 17 – low-temperature spring, 18 – structure-stratum region number: I. Qiantang-Qamdo/later Hercynian-Indo-China folding zone (no charting), II. Gangdise-Nyaigentanglha Yangshan folding zone, III. Himalaya folding zone, 19 – nappe, 20 – mount, 21 – town, 22 – country border line.

2. Characteristics of Chemical Species of Hot Water

The Langjiu thermal water is mainly neutral-to-alkalescent, weakly mineralized chloride water. According to the sample analysis there are eight water types: Cl-HCO_3-Na water acounting for 41.1% of the total; Cl-HCO_3-SO_4-Na, 6.9%; Cl-CO_3-Na, 3.45%; Cl-SO_4-CO_3-Na; HCO_3-Cl-Na; SO_4-Cl-Na etc. The contents of these species are listed in tab. 1.

The K^+ content in hot water ranges between 59.84 and 299.7 mg/l, but it reaches 1142.6 mg/l in the No. 031 pool. From the No. 10 well in the NE to the SE of the field, the K^+ content increases (Fig. 2 and Tab. 1).

Although the F^- content in thermal water generally varies between 7.18 and 50 mg/l, it reaches the much higher value of 146 mg/l in the No. 031 pool. Its trend of distribution in the field is the same as that for K^+ (see fig. 3). Other species such as B, Li^+, As have the same trend as K^+ and F^-. The SiO_2 content ranges from 130 to 190 mg/l, while the average uranium content is 1.48×10^{-5} mg/l.

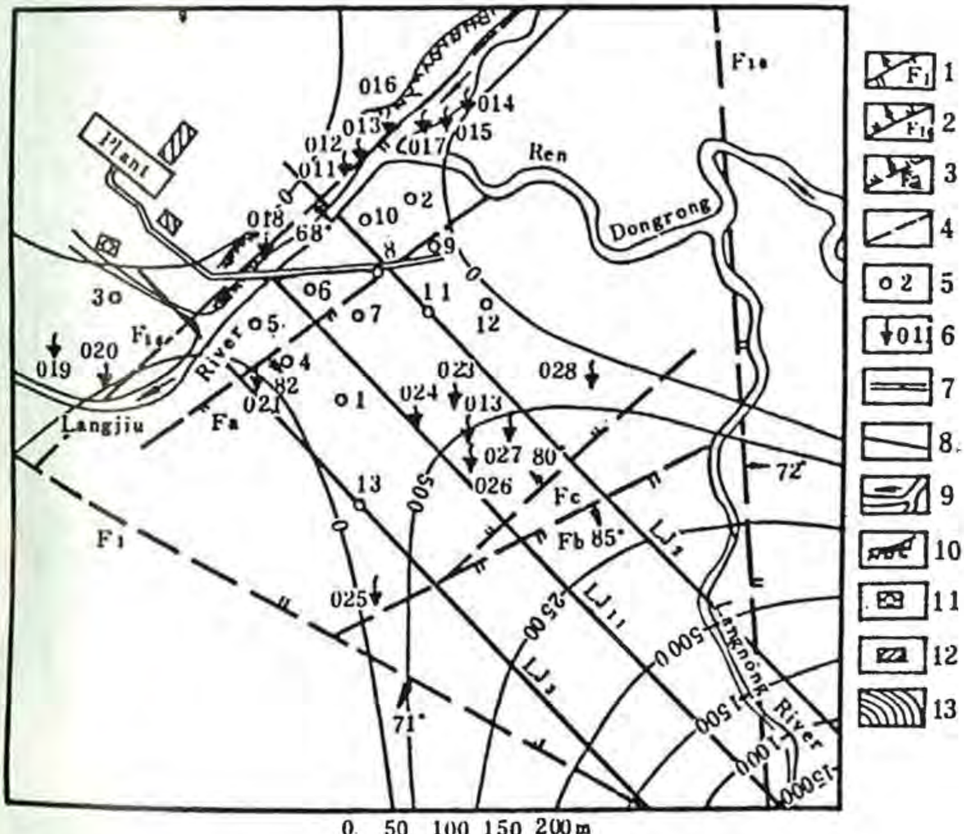


Fig. 2: Cubic trend analysis of K^+ in hot water of the Langjiu geothermal field. 1 – reverse fault and its number, 2 – normal fault and its number, 3 – blind fault and its number, 4 – fault and conjectured fault, 5 – well and its number, 6 – hot spring (pool) and its number, 7 – pipeline, 8 – survey line and its number, 9 – river, 10 – cliff, 11 – power station, 12 – buildings, 13 – isogram.

Tab. 1: Hydrogeochemical data of nature water in Langjiu.

chemical water type	No.	sample no.	min. of deg. (g/l)	pH	major ions (mg/l) cation				major ions (mg/l) anion				other ions (mg/l)							
					K	Na	Ca	Mg	Cl	SO_4	HCO_3	CO_3	F	Li	Rb	Cs	Br	I	Sr	As
$Cl\text{-}HCO_3\text{-}Na$	1	2	2.17	8.30	66.26	588.70	28.92	2.84	384.50	335.87	480.51	75.60	7.80	5.54	0.49	2.54	0.80	0.05	3.79	12.00
	2	4	2.05	8.00	62.34	550.10	33.61	1.90	371.37	309.52	518.97	44.10	8.20	5.87	0.47	2.68	0.70	0.02	3.84	10.00
	3	7	2.04	7.90	62.67	551.00	30.48	1.66	373.55	297.18	611.87	0.00	10.20	5.79	0.42	2.79	0.74	0.04	3.16	5.00
	4	8	2.06	8.15	62.93	552.20	30.48	3.32	382.66	306.23	515.76	50.40	8.20	5.78	0.48	2.64	0.86	0.02	8.93	7.00
	5	12	2.21	8.15	66.95	605.20	34.39	1.66	386.32	332.57	573.41	37.80	8.80	6.04	0.49	3.03	0.76	0.05	3.63	9.00
	6	13	2.02	8.15	63.01	558.60	33.61	1.90	371.73	316.93	480.53	63.00	9.68	5.72	0.43	2.78	0.70	0.06	3.46	8.00
	7	013	2.11	7.90	61.11	570.80	34.39	0.95	379.02	324.34	528.58	44.10	8.80	5.65	0.45	2.89	0.86	0.05	2.86	6.00
	8	014	2.08	8.00	61.44	562.50	32.83	1.90	379.02	321.87	531.62	31.50	8.16	5.71	0.43	3.19	0.88	0.01	2.79	7.00
	9	015	2.13	8.15	60.55	560.80	33.61	3.32	389.95	328.05	579.83	28.35	8.80	5.45	0.42	2.95	1.16	0.02	2.90	7.00
	10	018	2.06	8.20	59.84	543.30	31.26	2.13	379.02	313.64	461.30	81.90	9.00	5.66	0.42	3.20	0.82	0.06	2.67	7.00
	11	021	2.03	8.10	61.89	581.80	34.39	3.08	386.31	315.29	544.60	50.40	9.20	5.82	0.36	3.17	0.96	0.02	3.08	6.00
	12	023	3.45	8.20	110.33	991.90	21.49	2.61	670.57	556.48	788.06	103.95	16.72	10.34	0.86	4.14	2.50	0.13	3.70	17.50
	max.		3.45	8.30	110.33	991.90	34.39	3.32	670.57	556.48	788.06	103.95	16.72	10.34	0.86	4.14	2.50	0.13	8.93	17.50
	min.		2.02	7.90	59.84	543.30	21.49	0.95	371.37	297.18	461.30	0.00	7.80	5.45	0.36	2.54	0.70	0.01	2.67	5.00
	aver.		2.20	8.10	66.61	601.41	31.62	2.27	404.47	338.16	551.25	50.93	9.46	6.11	0.48	3.00	0.98	0.04	3.73	8.46
$Cl\text{-}HCO_3\text{-}SO_4\text{-}Na$	1	9	2.03	8.20	63.02	576.60	27.75	2.13	382.18	348.19	611.68	3.15	8.80	5.95	0.49	2.33	0.10	0.01	4.80	8.00
	2	10	2.10	8.10	62.55	558.90	34.00	1.90	377.20	344.10	557.41	31.50	8.48	5.72	0.48	2.66	0.86	0.05	3.56	4.00
	3	11	2.22	8.15	67.20	605.20	28.92	8.54	377.20	391.02	563.80	34.65	8.20	6.02	0.51	2.89	0.80	0.05	3.35	17.00
	4	011	1.96	7.55	67.28	582.70	31.26	1.42	395.42	393.49	583.04	0.00	9.20	5.81	0.49	3.75	1.10	0.01	3.40	10.00
	5	012	2.55	7.44	71.50	671.40	36.73	1.42	464.66	428.89	717.56	0.00	10.40	6.49	0.52	3.74	0.90	0.01	3.14	10.00
	6	016	1.95	7.90	62.32	565.80	33.22	1.90	371.75	338.75	528.58	37.80	8.16	5.65	0.48	3.18	1.00	0.02	2.79	6.00

chemical water type	No.	sample no.			U	perct. of Ca, Mg distri. coef.						perct. of U-acyl. comp.					ratio			
			SiO_2	HBO_2	mg/l	Ca^{2+}	$CaHCO_3^+$	$CaSO_4^0$	Mg^{2+}	$MgHCO_3^+$	$MgSO_4^0$	UO_2^{2+}	$UO_2(OH)^+$	$UO_2(OH)_2^0$	$UO_2(CO_3)_2^{2-}$	$UO_2(CO_3)_3^{4-}$	Na/K	Mg/Ca	Cl/F	Cl/ (HCO_3+CO_3)
$Cl\text{-}HCO_3\text{-}Na$	1	2	173.21	252.39	25×10^{-3}	75.68	6.78	17.53	72.33	6.49	21.16	2.11×10^{-8}	1.76×10^{-6}	1.56×10^{-5}	10.3	89.6	15.06	0.09	49.23	1.04
	2	4	180.00	211.83	1.06×10^{-3}	76.09	7.41	16.48	72.75	7.12	20.11	1.36×10^{-8}	5.34×10^{-6}	2.69×10^{-5}	18.2	81.7	14.95	0.05	45.30	1.05
	3	7	185.00	212.61	1.25×10^{-3}	75.46	8.69	15.84	72.31	8.36	19.31	1.54×10^{-8}	5.22×10^{-6}	1.86×10^{-5}	19.6	80.3	14.90	0.05	36.62	1.05
	4	8	185.00	214.95	1.25×10^{-3}	76.30	7.39	16.40	73.01	7.10	19.87	4.81×10^{-9}	2.86×10^{-6}	1.80×10^{-5}	13.6	86.3	14.87	0.10	46.66	1.06
	5	12	185.00	246.15	1.35×10^{-3}	75.11	7.96	16.91	71.73	7.64	20.62	3.44×10^{-9}	2.02×10^{-6}	1.27×10^{-5}	11.9	88.0	15.41	0.04	43.90	1.02
	6	13	180.00	215.73	1.06×10^{-3}	76.29	6.82	16.82	72.88	6.59	20.51	5.85×10^{-9}	3.47×10^{-6}	2.19×10^{-5}	14.3	35.6	15.02	0.05	38.40	1.05
	7	013	185.00	222.00	1.25×10^{-3}	75.60	7.46	16.93	72.14	7.16	70.69	2.26×10^{-8}	7.54×10^{-6}	2.67×10^{-5}	21.2	78.7	15.83	0.02	43.07	1.05
	8	014	185.00	215.10	1.26×10^{-3}	75.56	7.52	16.91	72.18	7.22	20.58	1.17×10^{-8}	4.96×10^{-6}	2.22×10^{-5}	17.7	82.2	15.52	0.05	46.44	1.09
	9	015	190.00	220.95	1.25×10^{-3}	74.85	0.13	17.00	71.57	7.79	20.62	3.40×10^{-9}	2.01×10^{-6}	1.27×10^{-5}	12.1	87.8	15.70	0.09	44.31	1.05
	10	018	180.00	217.44	1.25×10^{-3}	76.44	6.65	16.90	73.06	6.38	20.54	4.72×10^{-9}	3.16×10^{-6}	2.22×10^{-5}	13.4	86.5	15.39	0.06	42.11	1.03
	11	021	185.00	221.97	2.5×10^{-3}	75.88	7.69	16.41	72.63	7.38	10.97	5.61×10^{-9}	2.95×10^{-6}	1.65×10^{-5}	14.0	85.9	15.93	0.08	41.99	1.02
	12	023	180.00	371.86	1.06×10^{-3}	69.17	9.78	21.54	85.67	0.02	75.49	7.43×10^{-10}	4.48×10^{-7}	3.02×10^{-6}	5.74	94.2	15.24	0.12	40.10	1.15
	max.		190.00	371.86	2.5×10^{-3}	76.44	9.78	21.54	85.67	8.36	75.49	2.26×10^{-8}	7.54×10^{-6}	2.67×10^{-5}	21.2	94.2	15.93	0.12	49.23	1.15
	min.		173.21	211.83	1.06×10^{-3}	74.85	0.13	15.84	71.57	0.02	10.97	7.43×10^{-10}	4.43×10^{-7}	3.02×10^{-6}	5.74	78.7	14.87	0.02	36.62	1.02
	aver.		182.77	235.25	1.40×10^{-3}	75.19	7.02	17.14	73.52	6.60	28.37	7.75×10^{-9}	3.48×10^{-6}	1.78×10^{-5}	14.34	85.57	15.32	0.07	43.18	1.06
$Cl\text{-}HCO_3\text{-}SO_4\text{-}Na$	1	9	174.63	225.40	8.75×10^{-4}	73.70	8.45	17.84	70.36	8.09	21.53	2.10×10^{-9}	1.39×10^{-6}	9.91×10^{-6}	10.5	89.4	15.51	0.07	43.42	1.06
	2	10	180.00	214.95	8.75×10^{-4}	74.48	7.77	17.23	70.99	7.44	21.56	5.30×10^{-9}	2.30×10^{-6}	1.57×10^{-5}	13.9	86.0	15.14	0.05	44.48	1.04
	3	11	180.00	221.19	1.25×10^{-3}	73.03	7.64	19.31	69.84	7.27	22.87	3.55×10^{-9}	2.07×10^{-6}	1.30×10^{-5}	11.8	88.1	15.27	0.29	46.00	1.02
	4	011	165.00	0.00	2.12×10^{-3}	72.62	7.89	19.47	68.96	7.53	23.50	1.54×10^{-7}	2.28×10^{-5}	3.61×10^{-5}	34.9	65.0	14.68	0.04	42.98	1.16
	5	012	190.00	294.65	1.06×10^{-3}	71.19	9.26	19.53	67.52	8.84	23.63	1.65×10^{-7}	1.85×10^{-5}	2.35×10^{-5}	33.6	66.3	15.92	0.03	44.67	1.11
	6	016	167.02	85.63	1.25×10^{-3}	74.99	7.41	17.58	71.57	7.10	21.37	2.26×10^{-8}	7.56×10^{-6}	2.68×10^{-5}	21.2	78.7	15.39	0.05	45.55	1.05

2.1. Inorganic Complex Compounds

2.1.1. Ca^{2+}, Mg^{2+} Complex Compounds

We calculate the content of Ca^{2+}, Mg^{2+}, $MgHCO_3^+$, $CaHCO_3^+$, $MgSO_4^0$ and $CaSO_4^0$ (see tab. 1 and 2) from the major constituents of natural water (cold and hot water) in Langjiu.

Ca^{2+} and $CaHCO_3^-$ have the same distributive trend but are opposite to the K^+ distribution, as their contents become higher from SE to NW. The distributive trends of Mg^{2+}, $MgHCO_3^+$, $MgSO_4^0$ and $CaSO_4^0$ are almost identical, as similar as K^+ and F^- (Fig. 4 and 5).

2.1.2. Calculation of Uranium-acyl Complex Compounds

In natural water of the Langjiu geothermal field there are several forms of the uranium-acyl complex such as UO_2^{2+}, UO_2OH^+, $UO_2(OH)_2^0$, $UO_2(CO_3)_2^{2-}$ and $UO_2(CO_3)_3^{4-}$.

In hot water, $UO_2(CO_3)_3^{4-}$ is dominant (87.96%); the second most frequent one is $UO_2(CO_3)_2^{2-}$ (16.29%). In cold natural water, the major complex is $UO_2(CO_3)_2^{2-}$ (82.45%), the second most common is $UO_2(CO_3)_3^{4-}$ (17.85%), as shown in tab. 3.

Tab. 2: Ca and Mg Complex Compounds.

ion & ionic pair	mmol/l (range)	mmol/l	percentage (range)	percentage (average)
Ca^{2+}	0.14 – 0.98	0.58	61.78 – 77.05	72.83
$CaHCO_3^+$	0.01 – 0.11	0.06	0.13 – 12.16	7.38
$CaSO_4^0$	0.06 – 0.38	0.15	15.84 – 78.52	21.37
Mg^{2+}	0.02 – 0.24	0.08	50.08 – 85.67	70.07
$MgHCO_3^+$	0.04 – 0.35	0.09	0.02 – 11.29	6.98
$MgSO_4^0$	0.013 – 0.12	0.028	10.97 – 25.49	26.44

Tab. 3 gives the calculation of precipitable conditions of uranium in the Langjiu geothermal field. On the basis of these data, we discuss the relations between solute uranium $UO_2(CO_3)_2^{2-}$ and solid uranium with various oxygen-bearing coefficients $UO_{2(s)}$, $UO_{2.25(s)}$, $UO_{2.67(s)}$ and the uranium-acyl complex. Thus, the pE-pH, pE-mol%

Tab. 3: The list of uranium-acyl complex and redox electronic activity of Langjiu hot water.

No.	sam. no.	U(K) (M)					U(K)×100%		
		UO_2^{2+}	$UO_2(OH)^+$	$UO_2(OH)_2^0$	$UO_2(CO_3)_2^{2-}$	$UO_2(CO_3)_3^{4-}$	UO_2^{2+}	$UO_2(OH)^+$	$UO_2(OH)_2^0$
1	2	2.22 E-19	1.84 E-16	1.64 E-15	1.08 E-09	9.42 E-09	2.11 E-09	1.76 E-06	1.56 E-05
2	3	4.13 E-19	2.41 E-16	1.51 E-15	7.09 E-10	3.74 E-09	9.28 E-09	5.43 E-06	3.41 E-05
3	4	5.64 E-19	2.37 E-16	1.06 E-15	8.11 E-10	3.64 E-09	1.26 E-08	5.34 E-06	2.39 E-05
4	5	3.57 E-19	2.36 E-16	1.67 E-15	7.76 E-10	4.47 E-09	6.81 E-09	4.50 E-06	3.18 E-05
5	6	2.17 E-19	1.43 E-16	1.01 E-15	5.18 E-10	3.15 E-09	5.29 E-09	3.90 E-06	2.76 E-05
6	7	8.12 E-19	2.74 E-16	9.77 E-16	1.03 E-09	4.22 E-09	1.54 E-08	5.22 E-06	1.86 E-05
7	8	2.52 E-19	1.50 E-16	9.49 E-16	7.15 E-10	4.53 E-09	4.81 E-09	2.86 E-06	1.80 E-05
8	9	7.72 E-20	5.14 E-17	3.64 E-16	3.86 E-10	3.28 E-09	2.10 E-09	1.39 E-06	9.91 E-06
9	10	1.95 E-19	1.03 E-16	5.79 E-16	5.11 E-10	3.16 E-09	5.30 E-09	2.80 E-06	1.57 E-05
10	11	1.86 E-19	1.09 E-16	6.85 E-16	6.24 E-10	4.62 E-09	3.55 E-09	2.07 E-06	1.30 E-05
11	12	1.81 E-19	1.06 E-16	6.70 E-16	6.29 E-10	4.62 E-09	3.44 E-07	2.02 E-06	1.27 E-05
12	13	2.60 E-19	1.54 E-16	9.77 E-16	6.40 E-10	3.81 E-09	5.85 E-09	3.47 E-06	2.19 E-05
13	720-011	1.37 E-17	2.03 E-15	3.21 E-15	3.11 E-09	5.79 E-09	1.54 E-07	2.28 E-05	3.61 E-05
14	720-012	7.37 E-18	8.24 E-16	1.00 E-15	1.49 E-09	2.95 E-09	1.65 E-07	1.85 E-05	2.25 E-05
15	720-013	1.18 E-18	3.96 E-16	1.40 E-15	1.11 E-09	4.13 E-09	2.26 E-08	7.54 E-06	2.67 E-05
16	720-014	5.24 E-19	2.21 E-16	9.89 E-16	7.91 E-10	3.66 E-09	1.17 E-08	4.96 E-06	2.22 E-05
17	720-015	1.78 E-19	1.05 E-16	6.67 E-16	6.37 E-10	4.61 E-09	3.40 E-09	2.01 E-06	1.27 E-05
18	720-016	1.19 E-18	3.97 E-16	1.41 E-15	1.11 E-09	4.13 E-09	2.26 E-08	7.56 E-06	2.68 E-05
19	720-017	1.17 E-18	3.90 E-16	1.38 E-15	1.11 E-09	4.14 E-09	2.22 E-08	7.43 E-06	2.68 E-05
20	720-018	2.48 E-19	1.65 E-16	1.17 E-15	7.07 E-10	4.54 E-09	4.72 E-09	5.14 E-06	2.22 E-05
21	720-021	5.89 E-19	3.10 E-16	1.74 E-15	1.47 E-09	9.03 E-09	5.61 E-09	2.95 E-06	1.65 E-05
22	720-023	3.31 E-20	1.97 E-17	1.34 E-16	2.55 E-10	4.19 E-09	7.43 E-10	4.43 E-07	3.02 E-06
23	720-025	4.17 E-20	1.80 E-17	9.51 E-17	2.44 E-10	5.00 E-09	7.94 E-10	3.44 E-07	1.81 E-06
24	720-028	2.06 E-19	1.00 E-16	5.43 E-16	1.49 E-09	2.16 E-08	8.95 E-10	4.33 E-07	2.37 E-06
25	726-01	1.03 E-15	1.23 E-13	1.27 E-13	4.15 E-09	2.97 E-10	2.33 E-05	2.77 E-03	2.86 E-03
26	726-02	3.22 E-14	1.67 E-12	8.04 E-13	9.39 E-08	8.19 E-09	3.15 E-05	1.64 E-03	7.88 E-04
27	726-03	1.60 E-17	9.08 E-15	4.48 E-14	1.54 E-09	5.55 E-10	7.64 E-07	4.32 E-04	2.13 E-03
28	726-04	1.40 E-17	5.95 E-15	2.28 E-14	3.11 E-09	2.14 E-09	2.67 E-07	1.13 E-04	4.35 E-04
29	726-05	3.44 E-16	6.65 E-14	1.13 E-13	4.59 E-09	6.54 E-10	6.56 E-06	1.26 E-03	2.15 E-03
30	726-06	3.23 E-16	1.01 E-13	2.81 E-13	8.76 E-09	1.73 E-09	3.07 E-06	9.69 E-04	2.68 E-03
31	716-01	3.17 E-15	4.16 E-13	4.88 E-13	1.90 E-08	1.94 E-09	1.51 E-05	1.98 E-03	2.32 E-03
32	713-02	2.94 E-16	1.32 E-13	5.19 E-13	1.26 E-08	3.05 E-09	1.87 E-06	8.40 E-04	3.29 E-03
33	713-03	6.58 E-17	3.73 E-10	1.84 E-13	3.69 E-09	1.00 E-09	1.40 E-06	7.93 E-04	3.91 E-03

			pE							Eh (mv)					
$_2^{2-}$	UO_2(CO	)$_3^{4-}$	pE_1	pE_2	pE_3	pE_4	pE_5	pE_6	pE_7	Eh_1	Eh_2	Eh_3	Eh_4	Eh_5	Eh_6
1	8.96 E-	01	-3.74	-3.40	-3.44	-3.20	-3.24	-4.14	-10.10	-255	-204	-207	-192	-195	-248
1	8.40 E-	01	-3.61	-3.27	-3.31	-3.07	-3.11	-4.01	-10.00	-217	-196	-199	-184	-187	-241
1	8.17 E	01	-3.54	-3.20	-3.24	-3.00	-3.04	-3.96	-10.00	-212	-192	-194	-180	-182	-238
1	8.52 E-	01	-3.64	-3.30	-3.34	-3.10	-3.14	-4.03	-9.99	-218	-198	-200	-186	-188	-242
1	8.59 E	01	-3.75	-3.41	-3.45	-3.21	-3.25	-4.18	-10.31	-225	-204	-207	-193	-195	-251
1	8.03 E-	01	-3.46	-3.12	-3.16	-2.92	-2.96	-3.89	-10.04	-207	-187	-189	-175	-177	-233
1	8.63 E-	01	-3.71	-3.37	-3.41	-3.17	-3.21	-4.15	-10.30	-223	-202	-205	-190	-193	-249
1	8.94 E-	01	-3.97	-3.63	-3.67	-3.43	-3.47	-4.48	-10.98	-238	-218	-220	-206	-208	-269
1	8.60 E-	01	-3.77	-3.43	-3.47	-3.23	-3.27	-4.24	-10.58	-226	-206	-208	-194	-196	-255
1	8.81 E-	01	-3.78	-3.44	-3.48	-3.24	-3.28	-4.24	-10.52	-227	-207	-209	-195	-197	-255
1	8.80 E-	01	-3.79	-3.45	-3.49	-3.25	-3.29	-4.25	-10.53	-227	-207	-209	-195	-197	-255
1	8.56 E-	01	-3.71	-3.37	-3.40	-3.17	-3.21	-4.14	-10.29	-222	-202	-204	-190	-192	-248
1	6.50 E-	01	-2.85	-2.51	-2.55	-2.31	-2.35	-3.19	-8.91	-171	-150	-153	-139	-141	-192
1	6.63 E-	01	-2.99	-2.65	-2.69	-2.45	-2.49	-3.42	-9.56	-179	-159	-161	-142	-149	-205
1	7.87 E-	01	-3.38	-3.04	-3.08	-2.84	-2.88	-3.78	-9.80	-203	-182	-185	-170	-173	-227
1	8.22 E-	01	-3.55	-3.21	-3.25	-3.01	-3.05	-3.99	-10.13	-213	-193	-195	-181	-183	-239
1	8.78 E-	01	-3.79	-3.45	-3.49	-3.25	-3.29	-4.25	-10.53	-227	-207	-209	-195	-197	-225
1	7.87 E-	01	-3.38	-3.04	-3.08	-2.84	-2.88	-3.78	-9.80	-203	-182	-185	-170	-173	-227
1	7.88 E-	01	-3.38	-3.04	-3.08	-2.84	-2.88	-3.79	-9.81	-203	-182	-185	-171	-173	-227
1	8.65 E-	01	-3.72	-3.38	-3.42	-3.18	-3.22	-4.14	-10.22	-223	-203	-205	-191	-193	-248
1	8.59 E-	01	-3.53	-3.19	-3.23	-2.99	-3.03	-3.92	-9.86	-212	-191	-194	-180	-182	-235
0	9.42 E-	01	-4.19	-3.85	-3.89	-3.65	-3.69	-4.76	-11.63	-251	-231	-233	-219	-221	-286
0	9.53 E-	01	-4.16	-3.82	-3.86	-3.62	-3.66	-4.77	-11.75	-250	-229	-232	-217	-220	-286
0	9.35 E-	01	-3.78	-3.44	-3.48	-3.24	-3.28	-4.26	-10.61	-227	-206	-209	-195	-197	-255
1	6.68 E-	00	-1.82	-1.48	-1.52	-1.28	-1.32	-1.90	-6.28	-109	- 89	-91	-77	-79	-114
1	8.02 E-	00	-1.10	-0.76	-0.80	-0.56	-0.60	-1.04	-4.76	-66	-45	-48	-34	-36	-62
1	2.64 E-	01	-2.72	-2.39	-2.42	-2.19	-2.22	-2.88	-7.64	-163	-143	-145	-131	-133	-173
1	4.07 E-	01	-2.77	-2.43	-2.47	-2.23	-2.27	-2.98	7.98	-166	-146	-148	-134	-136	-179
1	1.24 E-	01	-2.06	-1.72	-1.76	-1.53	-1.56	-2.15	-6.58	-124	-103	-106	-92	-94	-129
1	1.65 E-	01	-2.08	-1.74	-1.78	-1.54	-1.58	-2.10	-6.20	-125	-104	-107	-92	-95	-126
1	9.25 E-	00	-1.59	-1.25	-1.29	-1.05	-1.09	-1.57	-5.47	-95	-75	-77	-63	-65	-94
1	1.94 E-	01	-2.09	-1.75	-1.79	-1.55	-1.59	-2.07	-5.95	-126	-105	-108	-93	-96	-124
1	2.13 E-	01	-2.42	-2.08	-2.12	-1.88	-1.92	-2.42	-6.72	-145	-125	-127	-113	-115	-148

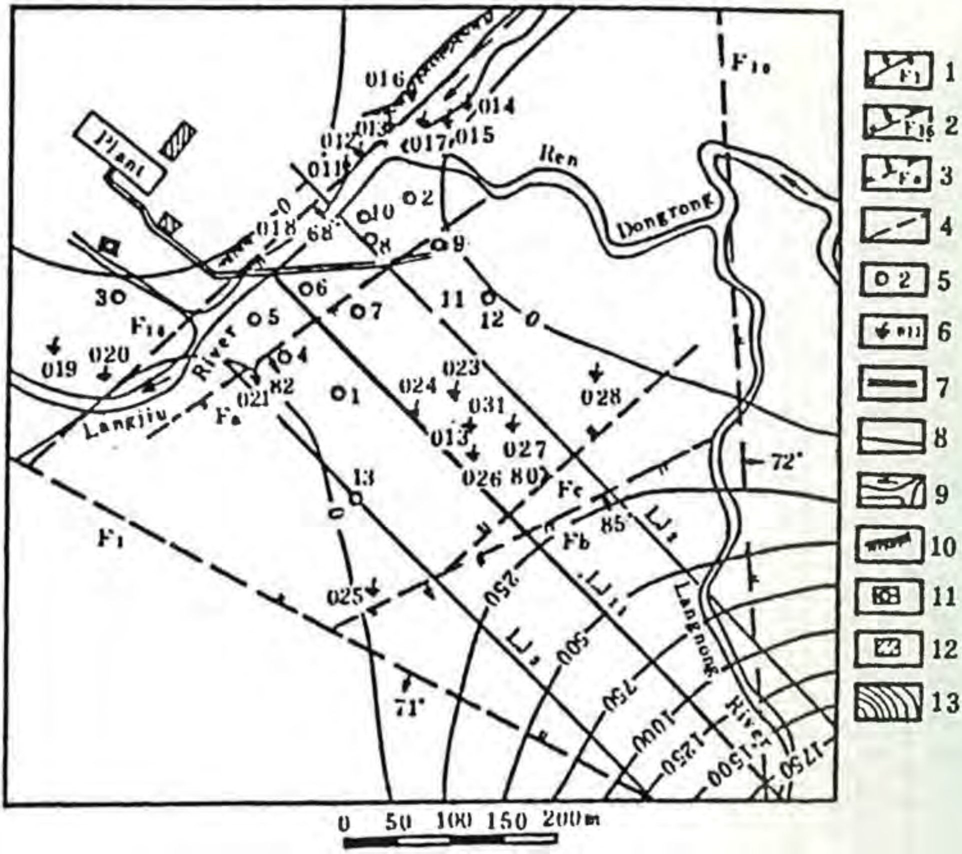
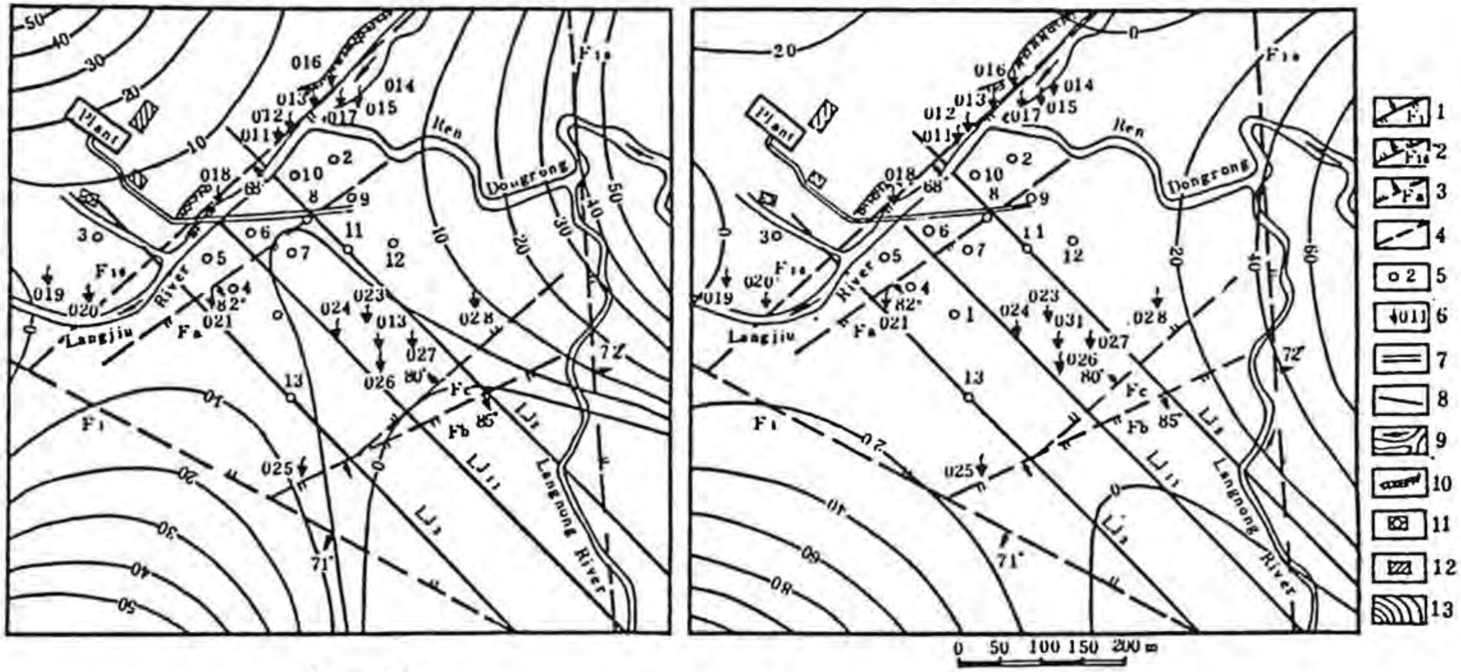


Fig. 3: Cubic trend analysis of F^- in hot water (the same legend as for fig. 2).

plots is electronic activity, pE[3]), of redox from the phase equilibrium of solute uranium and three solid phase uranium with different oxygen-bearing coefficients. The lateral axes are pH vs. mol%.

From Fig. 6 (1) and 6 (2) we can see that the pH value (pE_5, pE_6 and pE_7) increases as the oxygen-bearing coefficient increases, while its unit electronic activity (pE°) value obviously decreases. The uranium precipitation from natural water is also controlled by the pH and the concentration of solute uranium. Furthermore, figures 6 (1) and 6 (2) show the connection between three precipitable zones and the environment of a hot water zone. In other words, zone I has a high pE_5 value, which means that there is more oxidative condition as solute uranium precipitates. The pE_6 of zone II is lower than pE_5 when solute uranium deposits. Cold water is above the lower limit of water stability in the field, hot water is below it. This means that hot water is more reductive. In other words, hot water circles deeper (as shown in fig. 6 and tab. 3).

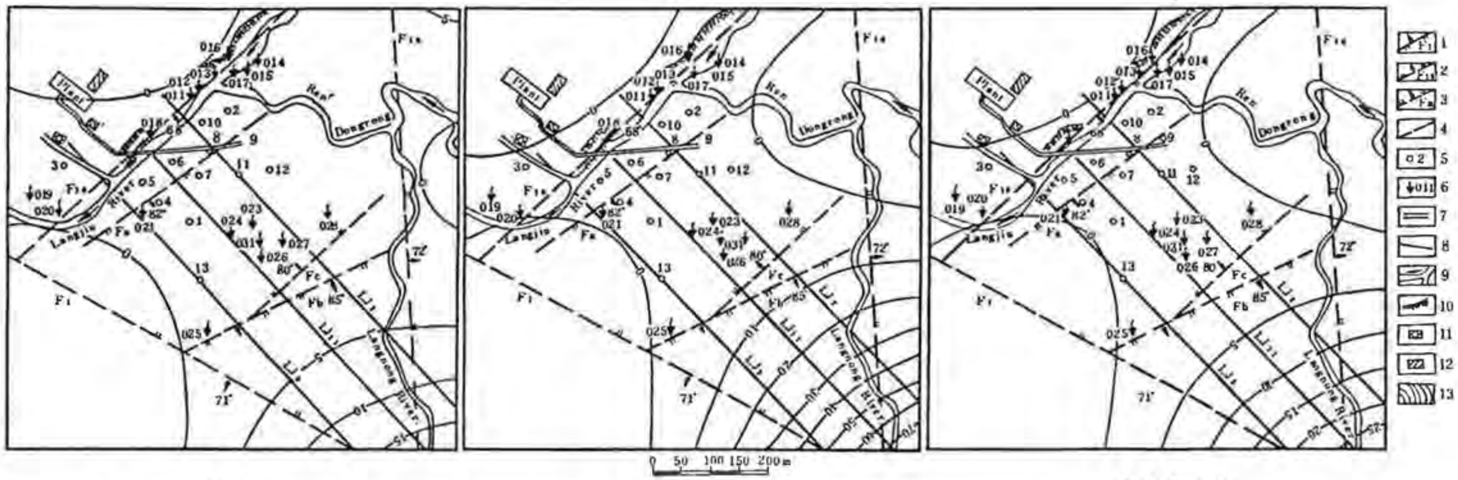
[3]) $pE_5 = -2.82 + 1/2 \lg [UO_2(CO_3)_2^{2-}] - \lg [CO_3^{2-}]$
$pE_6 = -6.27 + 0.67 \lg [UO_2(CO_3)_2^{2-}] - 1.33 \lg [CO_3^{2-}] + 0.33\ pH$
$pE_7 = -25.42 + \lg [UO_2(CO_3)_2^{2-}] - 3 \lg [CO_3^{2-}] + 2\ pH$.



$[Ca]^{2+}$

$[CaHCO_3]^{+}$

Fig. 4: Cubic trend analysis of Ca^{2+} and Ca complex in hot water of Langjiu geothermal field (the same legend as for fig. 2).



[Mg]$^{2+}$ [$MgHCO_3$]$^+$ [$MgSO_4$]^0

Fig. 5: Cubic trend analysis of the Mg^{2+} and Mg complexes in hot water of the Langjiu geothermal field (the same legend as for fig. 2).

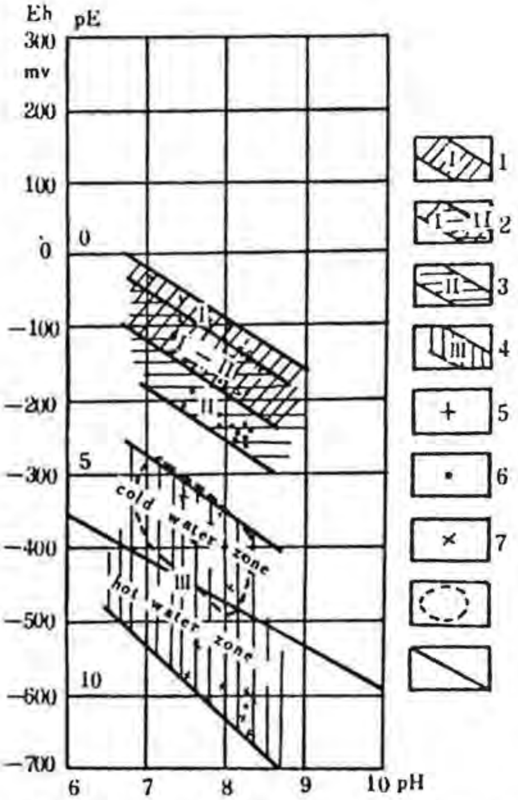


Fig. 6 (1): pE (Eh)-pH plot of Langjiu natural water. 1 – $[UO_2(CO_3)_2]^{2-}_{(solute)}$ and $UO_{2(solid)}$ precipitating zone, 2 – superimposed area of zone I on zone II, 3 - $[UO_2(CO_3)_2]^{2-}_{(solute)}$ and $UO_{2.25(solid)}$ precipitating zone, 4 – $[UO_2(CO_3)_2]^{2-}_{(solute)}$ and $UO_{2.67(solid)}$ precipitating zone, 5 – pE_5, 6 – pE_6, 7 – pE_7, 8 – cold water zone, 9 – lower limit equation of water stability field.

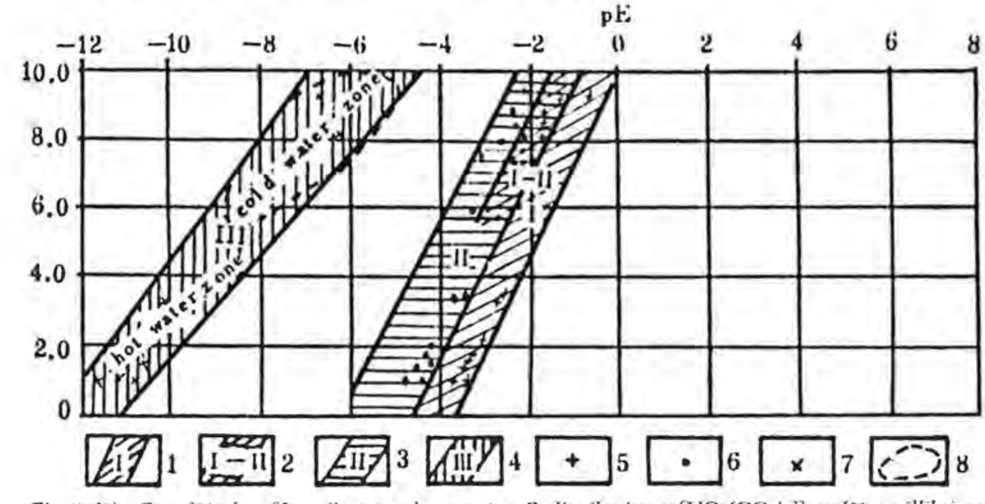


Fig. 6 (2): pE-mol% plot of Langjiu natural water. 1 – pE_5 distribution as $[UO_2(CO_3)_2]^{2-}$ mol% equillibrium with $UO_{2(solid)}$, 2 – superimposed area of I and II, 3 – pE_6 distribution, 4 – pE_7 distribution, 5 – pE_5, 6 – pE_6, 7 – pE_7, 8 – cold water area.

Fig. 7 shows the cubic trend analysis of pE_7, its goodness of fit is 87.94%, and it demonstrates that the electronic activity is more negative when solid phase uranium ($UO_{2.67(s)}$) is deposited from $UO_2(CO_3)_2^{2-}$, i.e. it needs more reductive condition. The most negative data exist around the SE of zone II, similar to the changing trend of thermal mark elements: K^+, F^-, As, HBO_2^-.

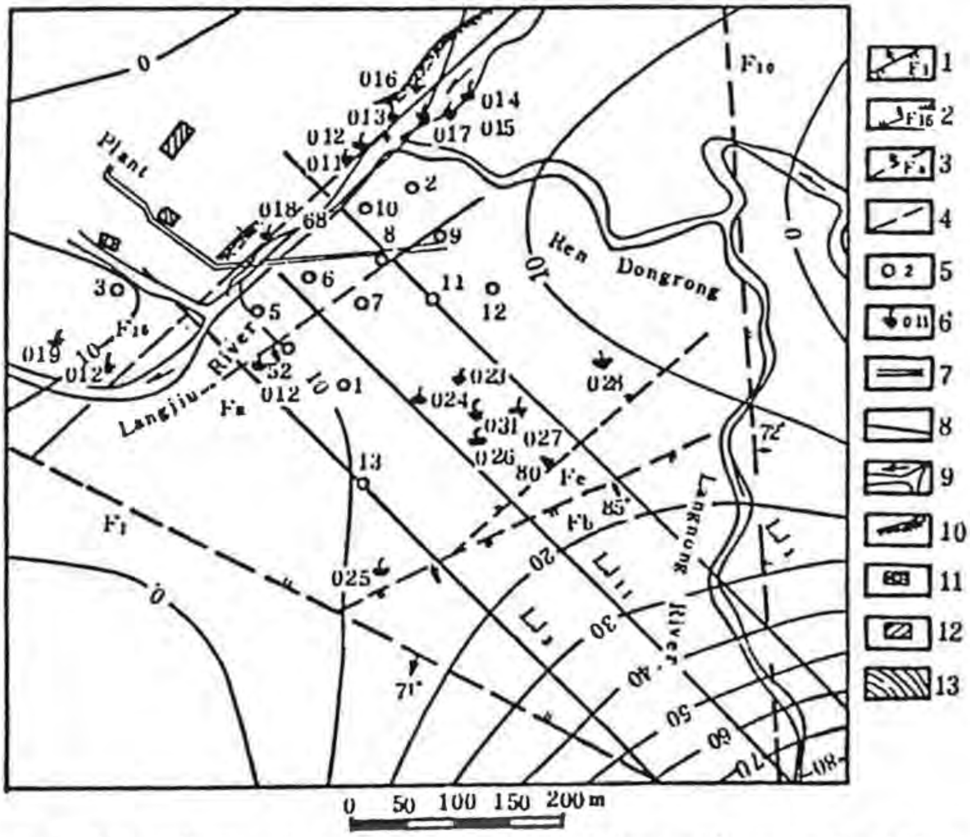


Fig. 7: Cubic trend analysis of redox-electronic activity of Langjiu hot water (the same legend as for fig. 2).

2.2. Stable Isotopes of Hydrogen and Oxygen

The isotopic data of hot water, river and snow water in Langjiu are listed in tab. 4 and shown in fig. 8.

Their δD and δO^{18} values are close to the meteoric water line. The main feature is that snow water is the heaviest, the second heaviest is river water, and hot water is the lightest. This may be caused by elevation (all samples were taken at an elevation of over 4500 m with the elevation gradient being 0.26 x 100 m in Tibet) and the vaporization of river water.

Tab. 4: Hydrogen and Oxygen Isotopes of natural water in Langjiu.

isotope content (%) / nature water	δ D ‰		δ O^{18} ‰		remark
	range	average	range	average	
well hot water	−126.563 – −111.025	−125.570	−15.820 – −13.775	−15.690	13 samples
river water	−109.800 – −94.550	−102.052	−14.658 – −12.385	−13.725	4 samples
snow water	−85.402	−85.402	−11.649	−11.649	1 sample

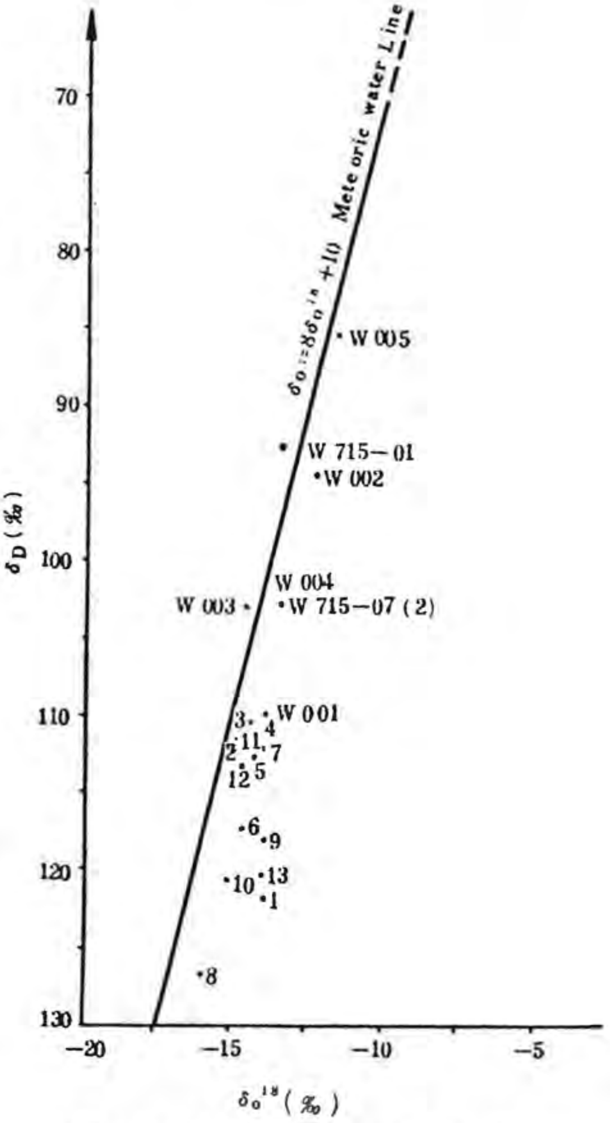


Fig. 8: D-δO[18] plot of natural water in Langjiu.

2.3. Calculation of Geothermometers

SiO_2 Geothermometer

According to the A. M. Truesdell's Conduction Cooling Equation, the calculated temperatures range between 152 and 189° C, the average is 172° C. When using the Adiabatic Cooling Equation, ground temperature is from 147–168° C, the average is 163° C.

Na-K, Na-K-Ca Geothermometer

The temperatures of tab. 5 and 6 are based on the calculations of Fournier and A. H. Truesdell.

If we compare the geothermometers of the Langjiu geothermal system with those of the Yangbajin geothermal system (Tab. 5), we find that the two temperatures are about the same. If the confusion of cold water is considered, the calculated temperature may be lower. The ground temperature should thus be over 200–220° C or more, which represents the temperature of a shallow geothermal reservoir. What we have to investigate is the temperature of the heat source.

Tab. 5: The list of estimated temperatures from the Langjiu geothermal field and the Yangbajin geothermal field.

geothermal field / ground temperature / geo-thermometer	Langjiu		Yangbajing[4])	
	range	average	range	the highest
SiO_2 (A.C.)	152 – 178° C	172° C	155 – 165° C	178° C
Na-K	183 – 201° C	199° C	185 – 215° C	216° C
Na-K-Ca	127 – 244° C	208° C	185 – 225° C	240° C

To sum up the hydrogeochemical features we can say that geothermal water is neutral-to-alkalescent, weakly mineralized, chloride and confused with cold water. Sodium chloride water exists only in the No. 3 and No. 6 wells. Two more wells produce Cl-CO_3-Na and Cl-SO_4-CO_3-Na water with a degree of mineralization of 45.28 g/l. According to the calculation of inorganic complex compounds in the Langjiu geothermal field, Ca^{2+}, $CaHCO_3^+$ and $UO_2(CO_3)_2^{2-}$ in hot water are closely related to cold water, while Mg^{2+}, $MgHCO_3^+$, $MgSO_4^0$, $CaSO_4^0$ and $UO_2(CO_3)_3^{4-}$ are related to hot water. This information is useful to facilitate the exploration and exploitation of geothermal fields as well as to investigate the formation of hot water. According to the stable isotopes of hydrogen and oxygen, the Langjiu geothermal water originates mainly from meteoric water. Attention must be paid, however, to the deep recharge because of the relatively high content of Li^+, Rb, Cs, As and HBO_2 in hot water of the Langjiu field.

[4]) from the Report of the Academy of Sciences of China.

Tab. 6: The list of calculation of ground temperature in the Langjiu geothermal field. 1 – temperature from adiabatic cooling (° C), 2 – temperature from conduction cooling (° C), 3 – from Na-K geothermometer, 4 – from Na-K-Ca geothermometer.

No.	sampling location	chemical water type	SiO_2 cont. (ppm)	T(A.C.) (C°) 1	T(C.C.) (C°) 2	Na mmol/l	K mmol/l	Ca mmol/l	Na-K GM. 3	Na-K-Ca GM. 4
1	2 W	$Cl\text{-}HCO_3\text{-}Na$	173.21	161	170	25.596×10^{-3}	1.699×10^{-3}	0.722×10^{-3}	198	205
2	3 W	Cl-Na	175.00	162	171	25.904×10^{-3}	1.690×10^{-3}	0.800×10^{-3}	196	201
3	4 W	$Cl\text{-}HCO_3\text{-}Na$	180.00	163	173	23.917×10^{-3}	1.599×10^{-3}	0.839×10^{-3}	199	194
4	5 W	$Cl\text{-}SO_4\text{-}Na$	190.00	166	176	25.443×10^{-3}	1.674×10^{-3}	0.371×10^{-3}	197	213
5	6 W	Cl-Na	190.00	166	176	24.909×10^{-3}	1.604×10^{-3}	0.878×10^{-3}	194	205
6	7 W	$Cl\text{-}HCO_3\text{-}Na$	185.00	165	174	23.957×10^{-3}	1.607×10^{-3}	0.761×10^{-3}	199	198
7	8 W	$Cl\text{-}HCO_3\text{-}Na$	185.00	165	174	24.009×10^{-3}	1.614×10^{-3}	0.761×10^{-3}	200	198
8	9 W	$Cl\text{-}HCO_3\text{-}SO_4\text{-}Na$	174.63	162	171	25.070×10^{-3}	1.616×10^{-3}	0.693×10^{-3}	195	203
9	10 W	$Cl\text{-}HCO_3\text{-}SO_4\text{-}Na$	180.00	163	173	24.300×10^{-3}	1.604×10^{-3}	0.849×10^{-3}	197	194
10	11 W	$Cl\text{-}HCO_3\text{-}SO_4\text{-}Na$	180.00	163	173	26.313×10^{-3}	1.723×10^{-3}	0.722×10^{-3}	196	206
11	12 W	$Cl\text{-}HCO_3\text{-}Na$	185.00	165	174	26.313×10^{-3}	1.707×10^{-3}	0.881×10^{-3}	195	199
12	13 W	$Cl\text{-}HCO_3\text{-}Na$	180.00	163	173	24.287×10^{-3}	1.616×10^{-3}	0.839×10^{-3}	198	195
13	(w 720)-011	$Cl\text{-}HCO_3\text{-}SO_4\text{-}Na$	165.00	159	167	25.335×10^{-3}	1.725×10^{-3}	0.780×10^{-3}	201	203
14	(w 720)-012	$Cl\text{-}HCO_3\text{-}SO_4\text{-}Na$	190.00	166	176	29.191×10^{-3}	1.833×10^{-3}	0.917×10^{-3}	191	202
15	(w 720)-013	$Cl\text{-}HCO_3\text{-}Na$	185.00	165	174	24.817×10^{-3}	1.567×10^{-3}	0.858×10^{-3}	192	193
16	(w 720)-014	$Cl\text{-}HCO_3\text{-}Na$	185.00	165	174	24.457×10^{-3}	1.575×10^{-3}	0.819×10^{-3}	194	195
17	(w 720)-015	$Cl\text{-}HCO_3\text{-}Na$	190.00	166	176	24.383×10^{-3}	1.553×10^{-3}	0.839×10^{-3}	193	193
18	(w 720)-016	$Cl\text{-}HCO_3\text{-}SO_4\text{-}Na$	167.02	159	168	24.600×10^{-3}	1.598×10^{-3}	0.829×10^{-3}	195	195
19	(w 720)-017	$Cl\text{-}HCO_3\text{-}SO_4\text{-}Na$	185.00	165	174	24.443×10^{-3}	1.587×10^{-3}	0.858×10^{-3}	195	193
20	(w 720)-018	$Cl\text{-}HCO_3\text{-}Na$	180.00	163	173	23.620×10^{-3}	1.534×10^{-3}	0.780×10^{-3}	195	194
21	(w 720)-019	$Cl\text{-}CO_3\text{-}Na$	185.00	165	174	68.930×10^{-3}	4.419×10^{-3}	0.215×10^{-3}	194	240
22	(w 720)-020	$Cl\text{-}SO_4\text{-}Na$	185.00	165	174	51.513×10^{-3}	3.212×10^{-3}	0.517×10^{-3}	191	222
23	(w 720)-021	$Cl\text{-}HCO_3\text{-}Na$	185.00	165	174	25.296×10^{-3}	1.587×10^{-3}	0.858×10^{-3}	191	193
24	(w 720)-023	$Cl\text{-}HCO_3\text{-}Na$	180.00	163	173	43.126×10^{-3}	2.829×10^{-3}	0.537×10^{-3}	197	221
25	(w 720)-025	$Cl\text{-}SO_4\text{-}Na$	130.00	147	152	59.026×10^{-3}	3.899×10^{-3}	1.287×10^{-3}	198	219
26	(w 720)-026	$Cl\text{-}SO_4\text{-}Na$	145.00	152	159	131.857×10^{-3}	7.666×10^{-3}	0.322×10^{-3}	183	244
27	(w 720)-028	$HCO_3\text{-}Cl\text{-}Na$	180.00	163	173	36.191×10^{-3}	2.305×10^{-3}	1.395×10^{-3}	193	204
28	(w 720)-030	$SO_4\text{-}Cl\text{-}Na$	170.00	160	169	33.674×10^{-3}	1.544×10^{-3}	0.819×10^{-3}	156	190
29	(w 720)-031	$Cl\text{-}SO_4\text{-}CO_3\text{-}Na$	195.00	168	178	642.174×10^{-3}	29.297×10^{-3}	0.147×10^{-3}	156	127

Abstract

This paper is extracted from "The Report of Scientific Investigation in Langjiu Geothermal Field in Ali, Tibet". It shows the characteristics of hydrogeochemistry, chemical constituents of hot water, species of complex compounds, hydrogen and oxygen isotopes and geothermometers in the Langjiu geothermal field. The paper also discusses the distribution of various constituents in the geothermal field and therefore provides geothermal support for its further exploration.

Zusammenfassung

Der Beitrag beschreibt die Charakteristika der Hydrogeochemie, d.h. die Grundelemente der chemischen Zusammensetzung der Thermalwässer, die komplexen Verbindungen, den Gehalt an Wasserstoff- und Sauerstoffisotopen und die Geothermometer des Geothermalfeldes von Langjiu. Auch die räumliche Verteilung der verschiedenen chemischen Typen der Mineralwässer wird diskutiert. Die Untersuchungen stellen einen wesentlichen Beitrag für die erweiterte Nutzung des Langjiu Thermalfeldes dar.