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Characteristics and distribution of geothermal-type lithium resources in Southern Tibet

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ABSTRACT

Southern Tibet is one of the main distribution areas of China's high-temperature geothermal belt, with abundant hot water activities. There are about 400 geothermal display areas. According to the results of field sampling and laboratory testing, it is found that the content of Li in the geothermal water in the high-temperature geothermal belts in southern Tibet is up to 34.51mg/l, the relative abundance of geothermal Li is significantly better than the salt lake brine of the three plateaus （the Andean plateau of South America, the western plateau of North America and the Tibetan Plateau of China）, and the ratio of magnesium to lithium is mostly less than 3, which is also significantly better than the salt lake brine. According to the material source of Li in the brine of lithium rich Salt Lake, the material source of Li in the high-temperature geothermal water in the southern Tibet is inferred. It is determined that there are two main material sources of geothermal water Li, which are caused by the leaching of lithium rich rocks by geothermal water and the lithium rich magmatic hydrothermal solution formed in the process of magmatic differentiation. The areas with high Li content in the geothermal water of the high-temperature geothermal zone in southern Tibet are distributed in the Yarlung Zangbo suture zone and its southern region, which has little to do with the distribution of high temperature geothermal zones and is consistent with the distribution range of lithium rich rocks. At the same time, the chemical type of geothermal water in the Yarlung Zangbo suture zone and its southern region is obviously more mature than that in the north. The more developed fault system brings more deep materials to geothermal water, which is also one of the reasons for the formation of lithium rich geothermal water.

1. REGIONAL TECTONIC BACKGROUND

Southern Tibet is one of the main distribution areas of high temperature geothermal zone in China, with rich hot water activities. There are about 400 geothermal display areas, including hot springs, boiling springs and boiling geysers (Wang et al., 2018). The hydrothermal activity in Tibet is the product of the collision orogeny of the Tibetan Plateau. The regional faults control the distribution and scale of hydrothermal activities. The fault system composed of criss cross active structures provides the reservoir space and migration channels for geofluid, thus forming a large number of hydrothermal activity areas. Since the Quaternary, the tectonic activity of the Tibetan Plateau has further developed, showing an abnormally active trend. Hydrothermal activity areas are divided according to the hydrothermal display type, temperature, and the scale and intensity of active structures. The scale of active structures in the study area obviously controls the hydrothermal activity areas, such as the Bangongcuo-Nujiang suture zone, the Yarlung Zangbo suture zone, and the Jiali-Karakoram strike slip fault between them, it is the boundary of obvious hydrothermal activity zoning. With the Bangongcuo-Nujiang suture zone in the north as the boundary, the southward hydrothermal activity is gradually enhanced, and the fault has obvious crust mantle heat exchange. The study area is mainly located in the high-temperature hydrothermal activity area in southern Tibet to the south of the Bangongcuo-Nujiang suture zone and the west of the Jiali-Karakoram fault.

As heat source, partial melting bodies of crustal materials caused by deep tectonic movements in the Tibetan Plateau upwelling in the upper crust along tectonic fissures form local melting bodies. These melting bodies are distributed discontinuously at a depth of about 15~35km, providing heat source for geothermal belt in southern Tibet. Under the background of compression, nearly north-south grabens extending in east-west direction are widely distributed in the Tibetan Plateau, and they are all Quaternary grabens (Cui et al., 2001; Li et al., 2005). Among them, the south-north graben distributed in the south of the Bangongcuo-Nujiang suture zone is the most important distribution area of the high temperature geothermal zone in southern Tibet, which is perpendicular to the east-west suture zone. These graben basins have become structurally weak areas due to the release of stress, which makes it possible for the upwelling of middle-lower crust melt and magmatic materials, and provides a structural channel for them. The Mesozoic Cenozoic sedimentary strata deposited in the grabens, as well as the Mesozoic Cenozoic intrusive rocks and volcanic clastic rocks, have become high-quality geothermal reservoirs due to their loose porosity, good permeability and heat conductivity. Under the joint action of tensile normal faults and bedrock fractures, the fluid in the shallow crust was heated and convection occurred, and finally formed the uplift mountain convection type high temperature geothermal system. For example, Shenzha-Dingjie graben, Naqu-Yadong graben, Riduo-Cuona graben, etc. At the same time, these three grabens are also the areas with the strongest surface geothermal display. According to the density of the hydrothermal display area and the scale of the development of active structures, the hydrothermal activity area can be divided into different zones, and the boundary is basically consistent with the corresponding active structural zones, namely, the Shenzha-Dingjie geothermal zone, the Yadong-Gulu geothermal zone, and the Cuona-Woka geothermal zone. These three hydrothermal geothermal activity zones are also the main development areas of the three near north-south grabens in southern Tibet (Fig.1). The Shenzha-Dingjie geothermal zone (Shenzha-Dingjie graben) extends 200km in NE-SW direction and is about 50 km away from Rikaze in the east. The Yadong-Gulu geothermal zone (Yadong-Yangbajing Graben) extends 590 km from northeast to southwest, which is the most potential area for development. Yangbajing, Yangyi and other geothermal fields are located in this area. The Cuona-Woka geothermal zone (Cuona graben) extends for 250 km in the northeast southwest direction.

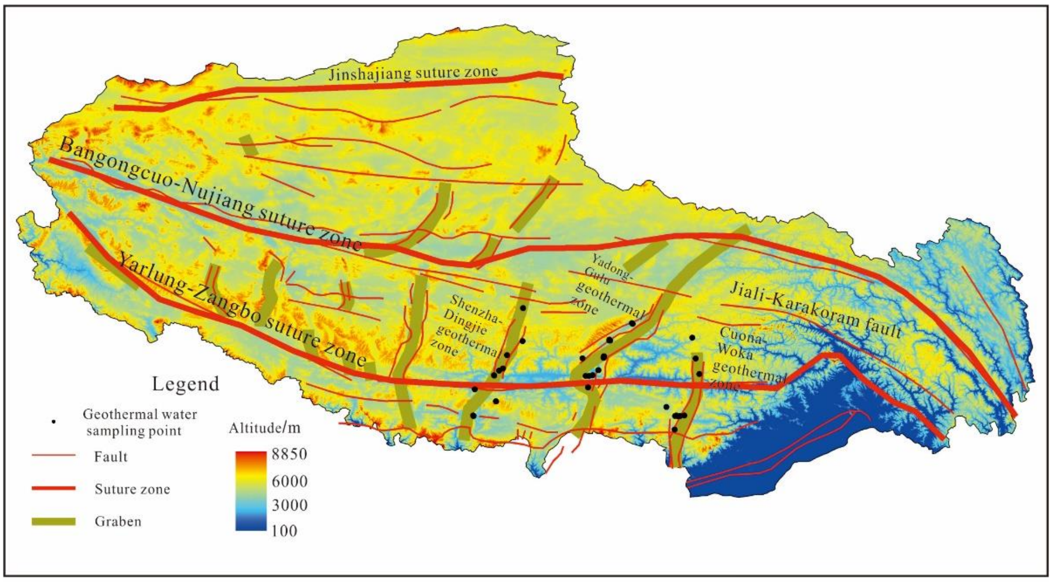

Fig.1 Distribution of main active structures and geothermal water samples in Tibet

2. CHARACTERISTICS OF LITHIUM IN GEOTHERMAL WATER IN SOUTHERN TIBET

In order to carry out research on geothermal water lithium resources in southern Tibet, project team members collected 84 geothermal water samples in 2020 and 2021 for two consecutive years, all of which are hot spring water samples. The distribution of sampling points is shown in Figure 1, which is mainly concentrated in the three high temperature zones in southern Tibet.

The temperature and pH value of water samples were measured by Hach portable dual channel multi parameter water quality analyzer (HQ400). The anion and cation test of water samples was completed in the key laboratory of geothermal resources development and utilization of Sinopec. The anion and cation test instrument is Ion Chromatography (Dionex-500), with a test accuracy of 3% and a detection limit of 0.05mg/L.

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The composition and combination characteristics of ions in geothermal water are the result of water rock interaction, and the main influencing factors in this process include reservoir lithology and mineral composition, lithology and mineral composition of recharge area, reservoir temperature, interaction time (groundwater age), etc. The TDS of geothermal water in Tibet is mostly less than 3g/L, belonging to brackish water. The cations are dominated by Na^+, and the anions Cl^-, HCO_3^-, CO_3^{2-} and SO_4^{2-} are distributed. The hydrochemical types are complex. The geothermal water in the three geothermal zones has no obvious classification and regularity. According to the resource evaluation method of lithium in salt lake brine (Han, 2001; Zheng, 2001; Gao Feng et al., 2011; Yang et al,2019), it is found that the lithium concentration in the mineral composition of geothermal water is obviously lower than that of Salt Lake brine, but the relative abundance of lithium in geothermal water is obviously better than that of Salt lake brine, with the magnesium lithium ratio of less than 10, mostly less than 3, and the magnesium lithium ratio of geothermal water is also significantly better than that of salt lake brine (Fig. 2). A high magnesium lithium ratio will greatly increase the cost of lithium extraction. Generally, Salt Lake brine with a magnesium lithium ratio of less than 10 is divided into low magnesium lithium ratio Salt Lake brine, and its cost is significantly lower than that of Salt Lake brine with a high magnesium lithium ratio (Table 3) (Li et al., 2017; Gao et al., 2011; Liu et al., 2009; Wang, 2001). From the perspective of relative abundance of resources, geothermal lithium in southern Tibet has great potential, and low Mg/Li ratio can also reduce extraction costs.

Table 1 Comparison of geothermal Li and global typical Salt Lake Brine Li resources

Site	Salt Lake /Geothermal field	TDS（g/L）	Li（%）	Li/TDS（relative abundance）	Mg/Li
Western Plateau of Northern America	Clayton Valley	186	0.023	0.001237	1.43
	Great Salt Lake	202	0.004	0.000198	2.5
	Salton Sea	293	0.0266	0.000908	0.16
Andean Plateau of South America	Uyuni	231	0.05	0.002165	8.4
	Atacama	206	0.15	0.007282	6.4

	Homebreto	254	0.062	0.002441	1.4
Tibetan Plateau of China	Bangor Lake	68.5	0.0104	0.104	0.64
	Chagcam Caka	210	0.0426	0.002029	15.96
	Chaerhan Salt Lake	358	0.0124	0.000346	517.34
	Yiliping	327	0.0262	0.000801	92.3
Geothermal water in Southern Tibet	Xietongmen	2.929	0.002384	0.008139	0.5
	Cuomei-Gudui	2.875	0.002394	0.008327	0.01
	Yangyi	3.089	0.003451	0.011172	0.28

Table 2 Classification, extraction technology and cost of Li resources in Salt Lake Brine

Classification of Salt Lakes Brine	Lithium rich and low magnesium lithium ratio carbonate brine	Salt lake brine with medium and low magnesium lithium ratio	Salt Lake Brine with high magnesium lithium ratio				Salt Lake Brine with low lithium and high magnesium lithium ratio
Mg/Li	>0.1	0.1~10	10~100				10~100
Suitable lithium extraction technology	a. Lithium extraction by salt gradient solar pond (salting out method)	b. Step precipitation method	c. Calcination method	d. Extraction method	e. Electrodialysis membrane method	f. Nanofiltration membrane method	g. Adsorption method
Representative Salt Lake	Tibetan Plateau Zabuye Salt Lake	Chile Atacama Salt Lake	Qinghai Xitaijiner Salt Lake	Qinghai Dachaidan Salt Lake	Qinghai Dongtaijiner Salt Lake	Qinghai Xitaijiner Salt Lake	Qinghai Chaerhan Salt Lake
Cost	RMB 20,000 per ton	RMB 20,000 per ton	/	RMB 50,000 per ton	RMB 30,000 per ton	RMB 30,000 per ton	RMB 30,000 per ton

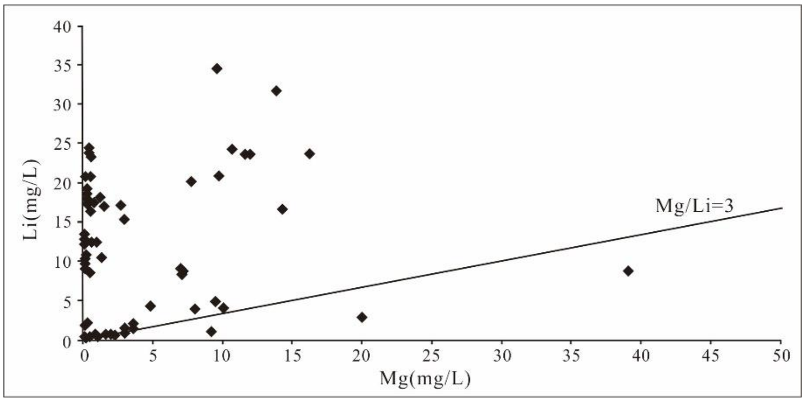

Fig.2 Correlation between Li and Mg in geothermal water in southern Tibet

3. SOURCE OF GEOTHERMAL LITHIUM IN SOUTHERN TIBET

Lithium in geothermal water mainly comes from rocks, which can enter into geothermal water through water rock reaction. From the background value of lithium content in rocks nationwide (Wang et al., 2020), the Tibetan Plateau has a good lithium geochemical background value. The south of Tibet has a high lithium abundance, which is several to ten times higher than that of most rocks compared with all kinds of rocks on the earth (Li et al., 2006; Qinghai Tibet Scientific Research Team of the Chinese Academy of Sciences, 1988). The content of crust derived acid rocks in the Himalayan period is the highest, mainly distributed on both sides of the Yajiang suture zone. The genesis is closely related to volatile minerals brought about by large-scale magmatic activities caused by ocean-continent subduction or continental collision orogeny. Due to the limitation of ionic radius, electric charge and chemical bond, lithium and other rare alkali metal elements are difficult to enter the crystal structure of minerals to form mineral phases. They are typical incompatible elements that are easy to occur in residual melt phases in the late magmatic crystallization. In the process of magmatic differentiation, with the evolution sequence of magma from ultrabasic to acidic, the content of lithium element in the melt gradually increases, and it is most enriched in the acidic magma at the later stage of magmatic differentiation (Zhao, 1997). After crystallization and differentiation, the lithium rich magma forms lithium rich rocks, and a small part enters the groundwater circulation system in the form of magmatic hydrothermal solution.

According to the source of lithium in brine (Liu et al., 2021; Braldy et al., 2013; Li et al., 2021), lithium in geothermal water is one of the important sources of lithium in brine, and most lithium rich geothermal systems are located around the lithium rich Salt Lake brine. Therefore, the source of lithium in geothermal water can be analyzed and determined according to the source of lithium in Salt Lake brine. According to the views of many mathematicians, there are two main sources of lithium in geothermal water. One is that high temperature geothermal water reacts with lithium rich wall rock and leaches the lithium in it (Fig. 3), and the other is lithium rich magmatic hydrothermal solution brought about by magmatic differentiation (Guo et al., 2007; Wang et al. 2019). This magmatic hydrothermal solution can form lithium rich hot spring water on the surface after rising along the fault zone and mixing with groundwater, it can also be directly discharged into surface runoff (Wang et al., 2020).

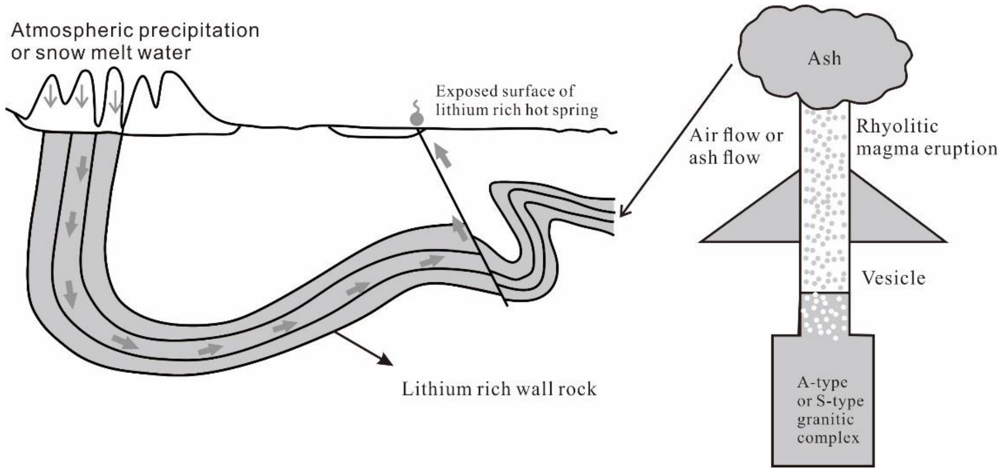

Fig.3 Genetic model of lithium rich geothermal water formed by groundwater leaching（Modified from Hofstra et al., 2013）

4. DISTRIBUTION OF GEOTHERMAL LITHIUM IN SOUTHERN TIBET

The distribution map (Fig. 4a) is drawn by the content of lithium in geothermal water. It can be seen that the distribution characteristics of lithium are bounded by the Yarlung-Zangbo suture zone. The lithium content in geothermal water near the Yarlung-Zangbo suture zone and to the south is high (>10mg/L), while the lithium content in geothermal water in the north is low, the three geothermal zones, Shenzha-Dingjie and Cuona-Woka on both sides of the east and west, have high lithium concentrations in geothermal water in the south of the Yarlung-Zangbo suture zone, which is mainly caused by the uneven distribution of the sampling points in the middle Yadong-Gulu geothermal zone. There is only one sampling point in the south of the Yarlung-Zangbo suture zone, and the sampling point is close to the Yarlung-Zangbo suture zone, and the lithium concentration in the sampling point is reaching 24.34mg/L. However, since there is no data further south, the lithium concentration will be low during interpolation calculation. In fact, according to the current data, it can be inferred that the content of lithium in geothermal water in the region south of the Yarlung-Zangbo suture zone in the Yadong-Gulu geothermal zone is also high.

Based on the hydrochemical characteristics of geothermal water, the distribution law of lithium in geothermal water is analyzed. On the whole, geothermal water can be divided into two categories (Fig. 5). The hydrochemical type of Group A geothermal water is complex and the overall maturity is low. Group B geothermal water is dominated by Na-Cl type with high maturity, which is related to the geothermal water circulation depth and water rock interaction time. Under the same or similar reservoir lithology, the greater the circulation depth, the longer the water rock interaction time, and the more mature the hydrochemical type. In addition, the mixing of shallow cold water will also lead to the change of hydrochemical type, leading to the reduction of maturity. Furthermore, according to the plane distribution map of hydrochemical types, relatively mature Na-Cl geothermal water is mainly distributed in the south of the Yarlung-Zangbo suture zone (Fig.4b), which further proves that the hydrochemical characteristics of geothermal water have little relationship with the distribution of the three geothermal zones, but the Yarlung-Zangbo suture zone is taken as the boundary, and the maturity of geothermal water in the south is higher than that in the north. According to the correlation between TDS of geothermal water and lithium concentration (Fig. 6), the same rule can be seen that TDS of geothermal water is positively correlated with lithium content, which proves that the geothermal water TDS south of the Yarlung-Zangbo suture zone is generally high. The geothermal water near and to the south of the Yarlung-Zangbo suture zone has a higher TDS value and a more mature hydrochemical type. It can be inferred that the deep and shallow fault systems in the region are more developed, and the geothermal water circulation is deeper, which can bring more deep materials to the geothermal system. This is one of the reasons for the high lithium content in the geothermal water near and to the south of the Yarlung-Zangbo suture zone.

In addition, from the perspective of provenance, the distribution of lithium rich rocks in the south of the Yarlung-Zangbo suture zone is also significantly more than that in the south. The Himalayan leucogranite belt has a large area of beryllium-lithium geochemical anomaly (Wang et al., 2020), of which Qiongjiagang and Kuqu regions have the highest lithium element abundance (Qin et al., 2021; Zhao et al., 2021), These two areas are highly coincident with the area south of the Yarlung-Zangbo suture zone in the three geothermal zones. It can be seen that the geothermal water in the south of the Yarlung Zangbo suture zone is closer to the material source, with rich lithium rich rocks and lithium rich magma in the deep, which is the main reason for the high lithium content in the geothermal water in this area.

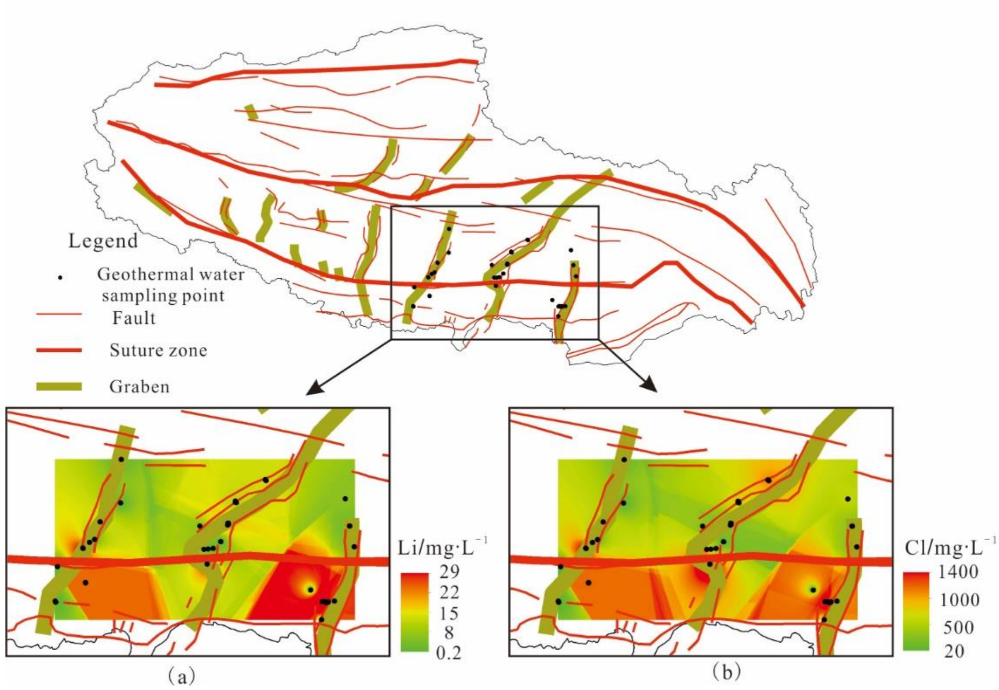

Fig.4 Distribution of Li and Cl contents in geothermal water in southern Tibet

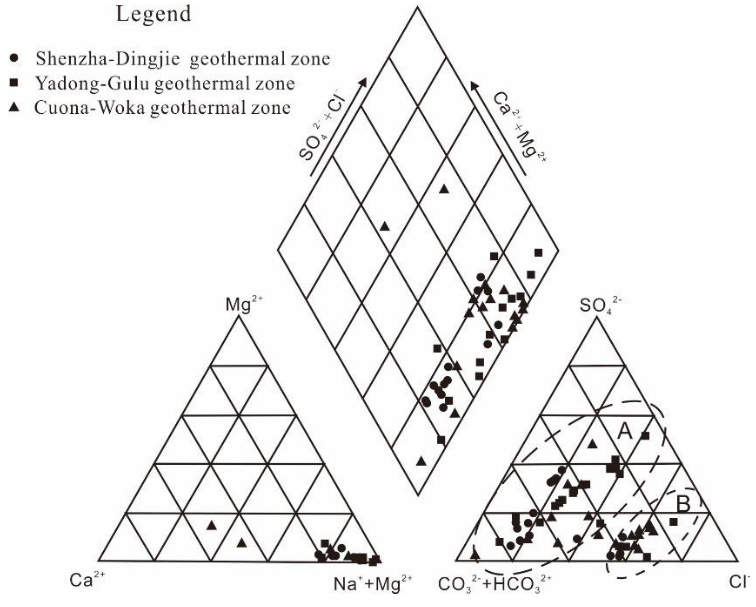

Fig.5 Piper of geothermal water in southern Tibet

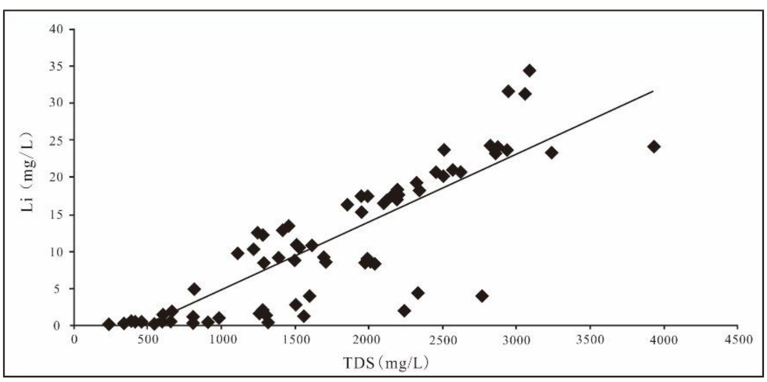

Fig.6 Relationship between Li and TDS contents in geothermal water in southern Tibet

5. CONCLUSION

(1) The geothermal water lithium content in the high temperature geothermal zones of the southern Tibet can reach 34.51mg/L at the highest level. Although the content is far lower than the lithium resources in the typical Salt Lake brines of the three plateaus in the world, the relative abundance of lithium in the geothermal water is obviously better than that in the Salt Lake brines of the three plateaus. At the same time, the magnesium lithium ratio of the geothermal water is less than 10, mostly less than 3, and also significantly better than that in the Salt Lake brines, which will help reduce the extraction cost.

(2) Geothermal lithium is one of the important sources of Salt Lake brines. Geothermal systems are distributed around the world famous lithium rich Salt Lake brines. Therefore, the source of lithium in the geothermal water of the high temperature geothermal zones in southern Tibet can be inferred based on the source of lithium in the lithium rich Salt Lake brines. It is determined that there are two main sources of geothermal lithium: one is that lithium in rocks enters the geothermal water due to the leaching of lithium rich rocks by geothermal water, forming lithium rich geothermal water; Second, the lithium rich magmatic hydrothermal solution formed in the process of magmatic differentiation rose through the fault system into the shallow geothermal water circulation system, forming lithium rich geothermal water.

(3) The areas with high geothermal water lithium content in the high temperature geothermal zones of the southern Tibet are all distributed in the Yarlung-Zangbo suture zone and the areas to the south, which have little relationship with the distribution of the three geothermal zones and are consistent with the distribution range of lithium rich rocks. At the same time, the chemical type of the geothermal water in the Yarlung-Zangbo suture zone and the areas to the south is obviously more mature than that in the north, and the fault system is more developed, Bringing more deep materials to geothermal water is also one of the reasons for the formation of lithium rich geothermal water.

REFERENCES <HEADING 1 STYLE>

Bradly D，Munk L A, Jochens H, et al. 2013. A Preliminary Deposits Model for Lithium Brines. USGS, Openfile-2013~1006.

Cui J W, Li P W, Li L. 2001. Uplift of the Qinghai-Tibet plateau: tectonic geomorphology and lithospheric structure of the Qinghai-Tibet Plateau. Geological Review, 47(2)： 157-163.

Gao F, Zheng M P, Nie Z, et al. 2011. Brine lithium resource in the salt lake and advances in its exploitation. Acta Geoscientica Scinica, 32(4): 486-492.

Guo Q, Wang Y, Liu W. 2007. Major hydrogeochemical processes in the two reservoirs of the Yangbajing geothermal field, Tibet, China[J]. Journal of Volcanology & Geothermal Research, 166(3): 255-268.

Han F Q. 2001. The Geochemistry of Lithium in Salt Lake on Qinghai- Tibetan Plateau. Journal of salt lake research, 9(1): 55-61.

Hofstra A H, Todorov T I, Mercer C N, et al. 2013. Silcate melt inclusion evidence for extreme per-eruptive enrichment and post eruptive deletion of lithium in silicic volcanic rocks of the Western United States: Implications for the origin of lithium rich brines. Economic Geology, 108: 1691~1701.

Liu C L, Yu X C, Yuan X Y, et al. 2021. Characteristics, distribution regularity and formation model of brine-type Li deposits in salt lakes in the world. Acta Geologica Sinica, 95(7): 2009-2029.

Li Q K, Wang J P, Wu C, et al. 2021. Hydrochemistry and Sr-S isotope constraints on the source of lithium in the Nalenggele tiver and its terminal lakes, Qaidam basin. Acta Geologica Sinica, 95(7): 2169-2182.

Liu X L, Zhong H, Tang Z J. 2009. Current status and existing problems of lithium extraction technology from salt lake. Inorganic Chemicals Industry, 41(6): 4-6.

Li Y L, Wang C S, Yi H S, et al. 2005. Current status and existing problems of lithium extraction technology from salt lake. Geological Review, 51(5): 493-501.

Li Z R, Liu G W, Tang F M. 2017. Overview of lithium resources and lithium extraction technology in Qinghai Salt Lake. Resource information and engineering, 32(5)： 94-97.

Li Z Q, Hou Z Q, Nie F Q, et al. 2006. Enrichment of element cesium during modern geothermal action in Tibet, China. Acta Geologica Sinica, 80(9): 1457-1464.

Qin K Z, Zhao J X, He C T, et al. 2021. Discovery of the Qongjiagang giant lithium pegmatite deposit in Himalaya, Tibet, China. Acta Petrologica Sinica, 37(11): 3277~3286.

Research Team of Tibetan Plateau Comprehensive Science. 1988. Tibet Salt Lake. Beijing: Science Press.

Wang C G, Zheng M P, Zhang X F, et al. 2020. Geothermal-type lithium resources in Southern Tibetan Plateau. Science &Technology Review, 38（15）: 24-36.

Wang C G, Zheng M P, Zhang X F, et al. 2019. O, H, and Sr isotope evidence for origin and mixing processes of the Gudui geothermal system, Himalayas, China. Geoscience Frontiers, 11:1175-1187.

Wang F. 2001. Research on Lithium Mineral Resources. Beijing: China University of Geosciences (Beijing).

Wang G L et al. 2018. Geothermal records of China(southwest Volume III). Beijing : Science Press.

Wang X Q, Liu H L, Wang W, et al. 2020. Geochemical Abundance and Spatial Distribution of Lithium in China: Implications for Potential Prospects. Acta Geoscientica Scinica, 41(6)： 797~806.

Yang H P, Liu L, Ding G F. 2019. Present situation and development trend of lithium resources in the world. Conservation and Utilization of Mineral Resources, (5): 26-40.

Zheng M P. 2001. Study Advances in Saline Lake Resources on the Qingha-i Tibet Pleteau. Acta Geoscientica Scinica, 22(2): 97-102.

Zhao J X, He C T, Qin K Z, et al. 2021. Geochronology, source features and the characteristics offractional crystallization in pegmatite at the Qongjiagang giant pegmatite-type lithium deposit, Himalaya, Tibet. Acta Geoscientica Scinica, 37(11): 3325~3347.

Zhao Z H. 1997. Principles of trace element geochemistry. Beijing: Science Press.