International Journal of Civil Engineering and Environmental Science. Volume 2, Issue 1, (2014) 1-11
http://www.cayley-nielson.com/ijcees/

Geochemical Characteristics and Ore Deposit Genesis of Copper Polymetallic Ore Deposit

Bo Li
Key Laboratory of Data Storage Systems, Ministry of Education Huazhong University of Science & Technology, 1037 Luoyu Road, Wuhan, China
E-mail: *ielibo@hust.edu.cn*

Abstract

On the basis of the detailed study of the mineral deposits and geochemical anomaly of the ore deposits, the study of the ore deposit geology feature, the ore deposit genesis and the ore-controlling conditions of the Qinghai sola ditch copper polymetallic ore deposit testified it is the type of the sedimentation diagenesis and hydrothermal modification ore deposits. The Qinghai sola ditch copper polymetallic ore deposit underwent two stages which are sedimentation diagenesis and hydrothermal modification. The submarine volcano eruption activities of the Middle Triassic carried a large number of ore-forming materials, it deposited together with the volcanic debris and terrigenous deposit in the relative low-lying area of the offshore platform (under the reductive condition), it forms the initial "source bed" or the lean layer, in the subsequent orogenic process (Indosinian), it was subject to the strong influence of the tectono-magmatic activities, the dehydration of the rock in the strata, Ore-forming elements activation，gathered and formed the rich ore solution, it migrated alonged the strata bedding and the rock fracture, the chemical lively components in the metasomatite was filled in the rock fracture to form ore deposits because of the function of enrichment. So we think the sola ditch copper polymetallic ore deposit should be the sedimentation diagenesis and hydrothermal modification ore-controlling ore deposit. The geological conditions, the ore genesis and geochemical anomaly of this ore deposit all has characteristics. The paper primarily clarified the magmatic activity and the geochemical anomaly which are closely related to the mineralization, discussed the characteristics of the copper polymetallic ore deposit about the mineral source、mineral、element zoning and ore-forming hydrothermal evolution, and gave an analysis of the genesis of the ore deposit.

Keywords: Geochemical Anomaly; Ore Deposit Genesis; Polymetallic Ore Deposit; Hydrotherm Overlying; Mineral Inclusion.

1. Introduction

The Qinghai sola ditch copper polymetallic metallogenic province is located in the northwest of Xinghai of Qinghai province. It is naturally and geographically position in the metallogenic province and lies down in the middle south of the Hubei ELa mountains which is the branch of the Kunlun mountains. It is one of the most important copper polymetallic metallogenic series in China. The reputable mines have prospective to be profitable and it is mainly copper containing mineralization. The area of this mining is 11.98 square kilometers[1]. Through the outdoor geological observation and indoor microscopically research, We have successfully engaged many statistical analysis about the main elements and trace elements of the mineral rocks in this mining area. Main well, according to the test and

ISSN 2333-5416 / Copyright © 2014 CAYLEY NIELSON PRESS, INC.
March, 2014

summarizes of the sulfur isotope, lead isotope and mineral inclusion thermometry, thereby to generalize it's geochemical characteristics, it has theoretical and practical significance to analysis the metallogenic reason of the Qinghai sola ditch copper polymetallic ore deposit.

2. The ore deposit geology characteristics

The Qinghai sola ditch copper polymetallic metallogenic province is located in the northwest of the Xinghai county of the Qinghai province, it is apart from the Xinghai county 80 kilometer, it is apart from the city of Xining 298 kilometer, it is located in the cohesion parts between the east Kunlun geosyncline fold belt and the west Qinling geosyncline fold belt, it also suffers overlying of the north-north west to geologic structure, it forms fracture structure which is more development in this area, together with the volcanic structure formed by volcanic activity, it creates a good tectonic conditions for the migration of the mineral deposits[2]. The submarine volcanism of the Middle Triassic provided submarine volcanism for Middle Triassic mineralization, and the Middle Triassic local lithology changes greatly, it is beneficial to precede selective replacement enrichment and mineralization. The magmatism at the mine is intense, the magma intrusion and the volcanic eruption activity has the feature of more times and multicycle, it creates good conditions for many activities of the hydrothermal, many times migration enrichment of the mineral. Its distribution is strictly controlled by the north north-west to the regional structure; the polymetallic metallogenic belt appears north-north west spread (Figure1).

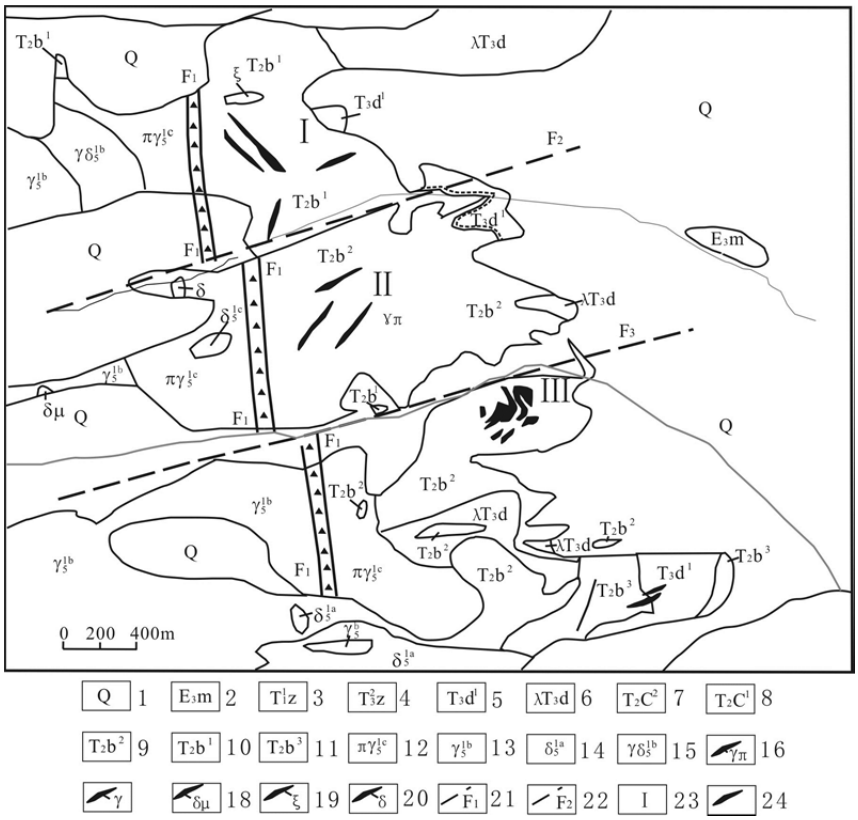

Fig. 1 The geologic scheme of The Qinghai sola ditch metallogenic province

The emergence stratum of the Qinghai sola ditch metallogenic province is Middle Triassic, Upper Triassic, Tertiary system and Quaternary system. The Triassic system as a major part is controlled by

regional faults, it appears NNW direction. The Tertiary system and Quaternary system are mainly located on both sides in the basin, water system and the valleys.

3. The geochemical characteristics of the mining area

Through the statistical analysis of the measuring results which include sedimentary rock major elements characteristics, trace element characteristic and structure characteristics, it uses the R-type factor method to analyse the exploration line surface rock measurement data, it uses the Smirnov test scalping method to analyse the Cu、Pb、Zn、Ag、Sn five elements of the sampling sample, sorting out the soil survey results, Circle the four Cu、Pb、Zn、Ag、Sn combination abnormalities in this survey area. Through the main element analysis and the trace element analysis, according to the test and summarizes of the sulfur isotope, lead isotope and minerals inclusion, it summarizes the geochemical characteristics of this diggings [3].

3.1 The major element characteristics

The sample for chemical analysis quantity of the sedimentary rock in the Mining area is less, but we still learn the sedimentary rock chemical composition characteristics in the Containing ore formation. Comparing with the argillaceous rock in the mining area and the similar rock in the world, it has the characteristics of high content of SiO_2、K_2O、Na_2O,low content of Al_2O_3、CaO,it reflects there are many fragmentary material in the argiloid in this diggings, it's maturity is not high, the chemical ingredients vary of the banded calcium mudstone and the banded not pure silicalite is large, it reflects the material in the ore rock and the surrounding rock is complex, the distribution of the mudstone、calcium、siliceous rocks and the class is very unevenly (Fig 2) [4].

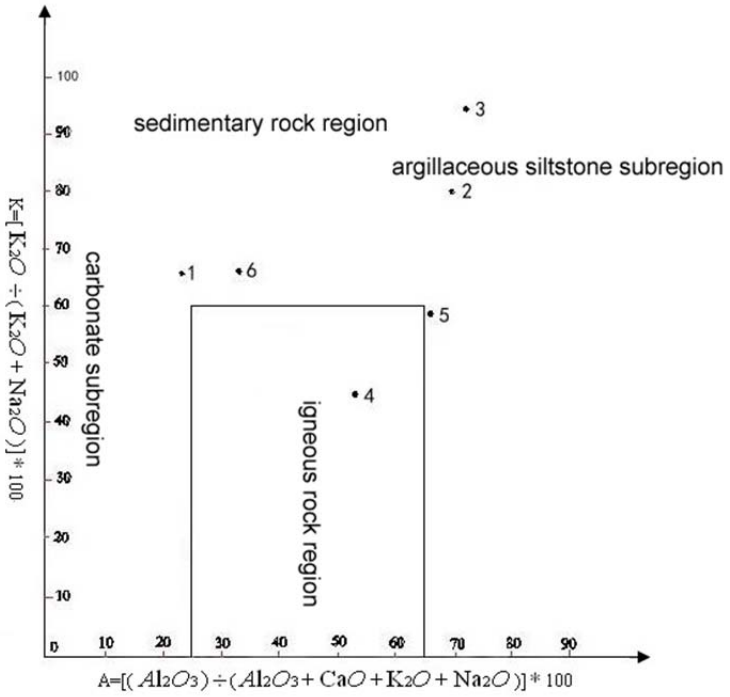

Fig. 2 K-A related graphic (According to Zhou ShiTai 1977 years)

3.2 The characteristics of the trace elements in the stratum and the rock

According to the analysis results of the rock sample collected from exploratory line, we made the statistics and calculation, its result as following Table 1[5].

(1) The Cu、Pb、Zn、Ag（W）element are obvious enrichment, and the distribution is very unevenly, the Cu、Ag、Sn elements are mainly enriched in the change mudstone and the metasandstone, the element Pb、Zn have higher content in the not pure siliceous rocks, the Pb、Zn element have generally high content in the each rock type of the Ⅲ abnormal area.

(2) The Cr、V、Ti element have slightly high content in the change mudstone, and they have highest content in the first lithologic section and the second lithologic section of the slate which is located in the b petrofabric of the middle triassic.

(3) The Ni、Co、Mn、Ba、Sr element have higher content in the individual rock of the individual section. Most content of the rock is relatively low.

(4) The Ga element distribute relatively uniform in all kinds of rock type.

Table 1 The rock geochemical parameter list of the sola ditch metallogenic province

Element	Sample number	Average value (10^{-6})	Deviation	Anomaly threshold (10^{-6})		Concentration zoning (10^{-6})		
				Calculated value	Determined value	External zoning	Mesozone zoning	Inner zoning
Cu	54	36.86	14.12	65.09	70	70-140	140-280	>280
Pb	59	28.22	11.44	51.09	50	50-100	100-200	>200
Zn	54	114.81	25.76	166.32	170	170-340	340-680	>680
Ag	57	0.20	0.075	0.35	0.5	0.5-1.0	1.0-2.0	>2.0
Sn	58	8.41	0.82	10.04	15	15-30	30-60	>60
Co	60	17.08	4.45	25.97	20	20-40	40-80	>80
Mn	59	654.24	208.71	1072	1000	1000-2000	2000-4000	>4000
W					30	30-60	60-120	>120

3.3 The trace element combination characteristic

In order to understand the trace element combination characteristic in the stratum of the sola ditch metallogenic province, it uses the R-type factor method to analyse the exploration line surface rock measurement data(Fig 3) [6].

Element related pedigree chart according to the critical value $\rho = 0.5$ level, can be divided into four groups:

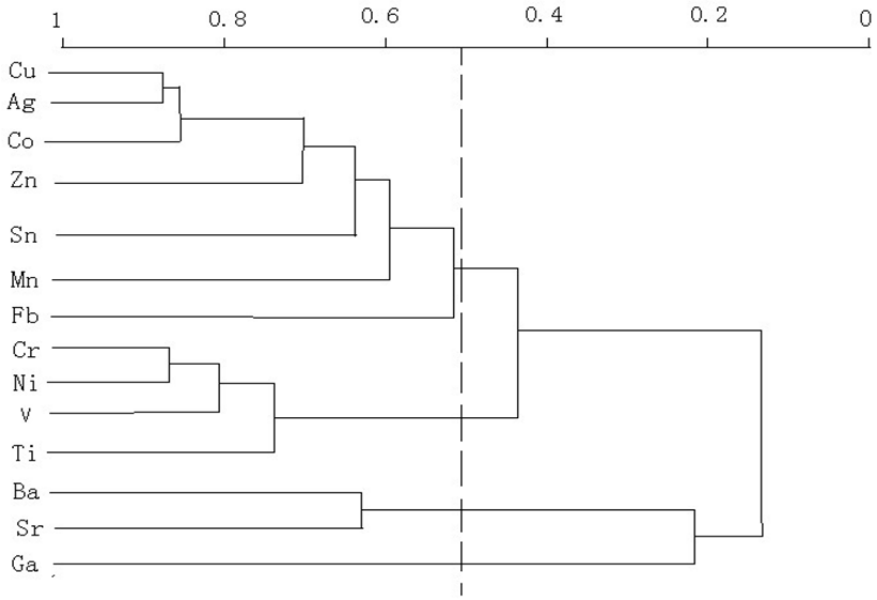

Fig. 3 Element related pedigree chart

The first group is the following seven elements Cu、Ag、Co、Zn、Sn、Mn and Pb, it belongs to F1、F4、F5 three factors in the orthogonal rotating factor, the factor score of the Pb is negative value, the others are positive value, the summation of the facter contribution is 46.70%.It occupies an important position, and it reflects the combination characteristic of the metallogenic element. In this group, the Cu、Pb、Zn、Ag、Sn is related to the Co(Mn), it shows the mineralization is related to the hydrothermal activity.

The second group is the following four elements Cr、V、Ni、Ti. It belongs to F2 factors in the orthogonal rotating factor, the all factor score are positive value, the facter contribution is 22.83%, it stands for sedimentary rock factor, and it has relation with the deposition of the argiloid and the clastic rock class.

The third group is the Ba and the Sr, it belongs to F3 factors in the orthogonal rotating factor, the Ba stands for deposition characteristics of the clastic rocks, and the Sr reflects the deposition characteristics of the carbonate. The Ba and the Sr appears in the same factors at the same time with high load, it suggests that the carbonate rocks and the clastic rocks have a relationship of same growth and decline.

The fourth group is the Ga, it belongs to F5 factors in the orthogonal rotating factor, the factor score of the Pb is negative value, and the factor score of the Ga is positive value, it suggests that the Pb and the Ga has a relationship of same growth and decline. According to the variance of the common factor and the load factor, the Ga appears significantly smaller; it suggests that it is not important.

3.4 Pedogeochemical anomaly

Through the soil measurement results, we found four Cu, Pb, Zn, Ag, Sn combination anomaly in the measuring area (Fig 4, Fig 5).

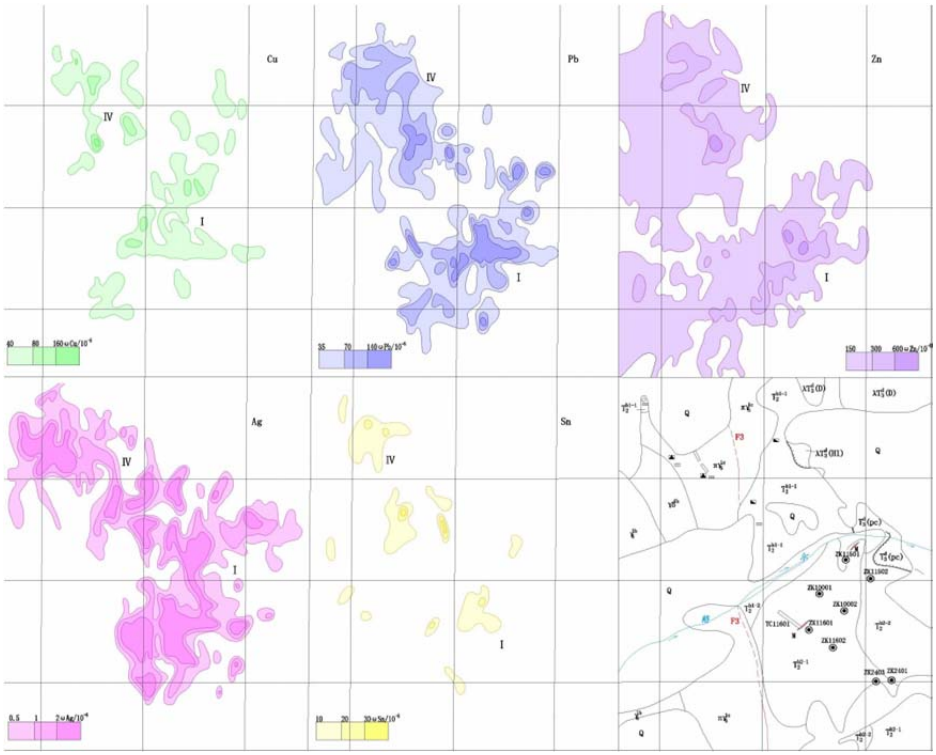

Fig. 4 The Qinghai sola ditch copper polymetallic metallogenic province and the profile chart of the periphery No.Ⅳ, Ⅰpedogeochemical anomaly

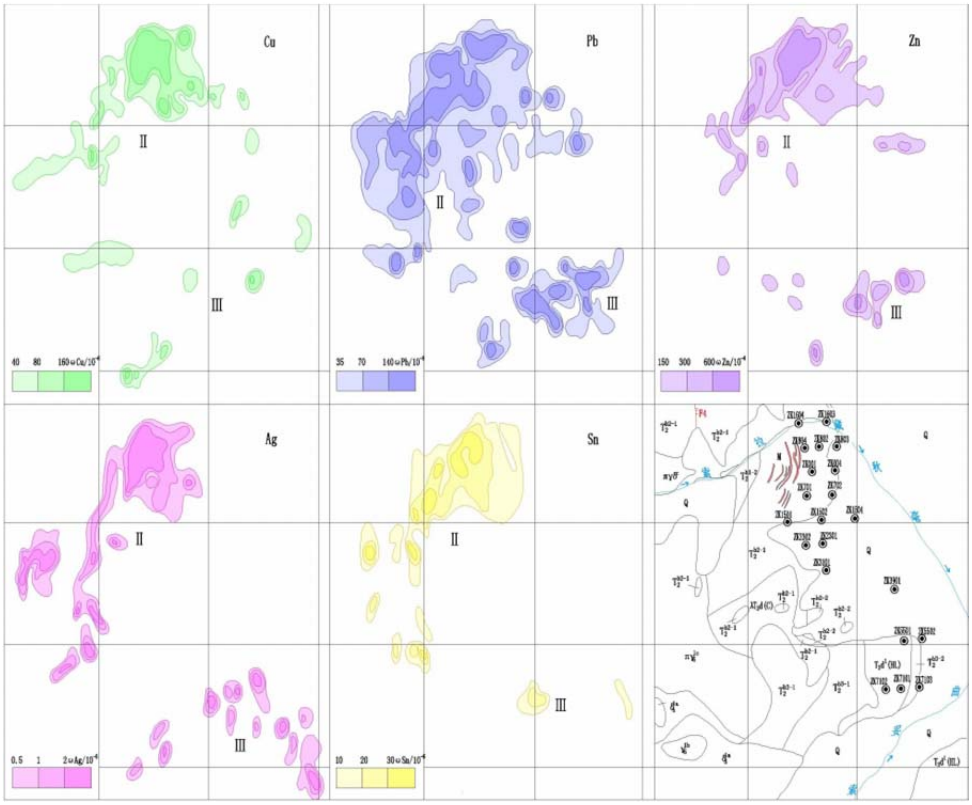

Fig. 5 The Qinghai sola ditch copper polymetallic metallogenic province and the profile chart of the periphery No.Ⅱ、Ⅲpedogeochemical anomaly

The Zn、Cu（Pb）low value anomaly exists in the south part of the measuring area, the area of the Zn is the biggest, above the anomaly ,the highest content of the Zn is 600×10-6，the average is 150—300×10-6，the highest content of the Cu is 100×10-6，the average is 50×10-6;the anomaly of the Pb mainly is high value, the highest content of the Pb is 1000×10-6，of all the anomalies, it mainly exists T3d volcanic and the medium acidic intrusion of the indosinian, the content of the anomaly element is low, it's combination is simple, the abnormal shape is irregular, the continuity is poor [7].

3.5 The thermometric analysis of the mineral inclusion

The temperature measurement results of the mineral inclusion in the diggings (Table 2) reflects the scope of the Ore-forming temperature is 270℃~365℃. As similar as the temperature reflected by the metamorphic facies (low green schist facies), combined with the analysis of the Hydrothermal alteration mineral in the diggings, making the low-to-moderate temperature mineral for the main analysis, the Hydrothermal ore-forming transformation in this diggings belongs to mid-low-temperature environment. The sequence of the mineral formation in the ore roughly are iron pyrite, pyrrhotite, copper pyrites, sphalerite, gelenite and the temperature measurement results is the pyrrhotite is bigger than copper pyrites, sphalerite, it reflects the metallogenic process is a cooling process, the metallogenic matter is reactivating and transporting at a higher temperature, it became enrichment and mineralization with the decrease of temperature [8,9].

Table 2 The measurement results table of the mineral inclusion in the Sola ditch deposit

Model codes	Sampling location	Measurement mineral	Decrepitation temperature
90EsI-31	ZK004 cabinet （surrounding rock）	pyrrhotite	365℃
90EsI-62	ZK002 borehole 187m	pyrrhotite	340℃
90EsI-63	ZK002 borehole 250m	copper pyrites	265℃
90EsI-41	TC003 Western	blende	270℃

4. Ore-forming geological conditions analysis and ore genesis exploration

4.1 Ore-forming geological conditions analysis

The sola ditch copper polymetallic ore deposit has obvious stratabound characteristics; there is certain relation between the metallogenic period and the hydrothermal activation. The enrichment process of the metallogenic material is Long-term and complicated, and it depends on whether it has the geological conditions which is the appropriate metallogenic material enrichment of the geological conditions. It makes a brief mineralization analysis about the stratumat this area、geologic structure、magmatism and hydrothermal transformation.

(1) The mineralization control function of the stratum、lithology [10]

The triassic in this diggings has mineralization material source(Submarine volcanic activity、Terrigenous denudation) and the beneficial sedimentary environment conditions of the mineral deposit enrichment, it causes the initial enrichment of the metallogenic material in the ore formation of this diggings, it has formed “source bed”, it may form ore body in the local area, and the different thin layer of the rock exists marked differences in the respects of the chemical and physical properties in the Ore formation, it provides beneficial condition for the enrichment and the allocation of the metallogenic material in the process of the hydrothermal transformation mineralization.

(2) The ore control function of the structure [11,12]

The structure of the mining area is simpler, the stratum is the uniclinal structure which is totality eastward tilting. The attitude of stratum changes a lot in the trend. The Mining site appeares the axial direction is east to west, the open antiformal form East of plunging, the orebody mainly occurs in the turning parts of the antiform, it has a certain control function to the mineralization. Many fractured zones appears in the mining surface engineering construction, the tectonic breccia most don't be cemented, and in the drilling engineering, it don't exist at the deep part, it could indicate that it's depth is not big, and the scale is small. Judging from the feature that the tectonic breccia is incompetent in the crushed zone, and it should be ruptured at the post-mineralization period, the ore body did not appear destruction effect obviously. The fissures and the jointing in the ore formation are easy to grow, and they mainly were filled with chlorite-epidote-quartz stringer, calcite stringer, fluorite stringer, metal sulfide stringer, it is a major place of the ore fluid activities. From the analysis of the feature of the metal mineral enrichment according to the bedding, the possible interlayer sliding stripping structure of the in the developmental stratum bedding play an important part in the metallogenic activity. At present, it did not found that it exists a large-scale guide ore structure; we could infer that the migration distance of the ore hydrothermal is not too long.

(3) The mineralization function of the magmation [13]

The magmation at this diggings after the late Triassic epoch has strong activity intensity, but the relationship between the magmation and the deposit metallognic is not very obvious, the possibility of the provider of the Metallogenic hydrothermal and to participate in the hydrothermal transformation is small. As a heat source, the magmation has a very important significance to the hot water circulation in the formation strata, and it prompted the activation of the mineral, Mineral migration, enrichment and mineralization, it is one of the important conditions of mineralization.

(4) The mineral concentration function affected by the Hydrothermal transformation [14, 15]

The Hydrothermal alteration activity in the diggings is common, the relation between the mineralization and the alteration is close, and the metallic mineral and the Hydrothermal alteration mineral in the ore body usually appear simultaneously, it has strong alteration, complete Alteration types parts, good mineralization law. The metallic mineral enriches to form band (grain) along with the Stratigraphic principle, and it has relation with the some certain lithology, and it is a key character of the deposit metallogenic at this diggings, and it also indirectly reflects the hydrothermal solution migration, permeate, metasomatism ore-forming along with the bedding. There are some veinlet impregnated ore filled by the mineralization thin (micro) pulse along with the microfissuring, and it appears that the ore filled by the vein structure(amplitude2-5centimeter),it indicates that the hydrothermal activity appears in the metallogenic process. The large-scale fracture structure has not been found in this mining area, therefore the distance of the Thermal fluid migration could not be too long, the dehydration effected by the tectonic magmatic activity, the activation of the ore-forming elements and the formation of the hydrothermal solution perhaps mainly has closed relation. Late hydrothermal transformation activity played an important part in the metallogenic material activation, migration, enrichment formation to form deposit.

4.2 The exploration of the ore genesis

According to the ore deposit geological characteristics and the analysis of the metallogenic geological conditions, it could reach a conclusion that the ore deposit has the following characteristic:

(1) The ore deposit is under certain control of the stratigraphic position, and there is certain relation with the particular lithology. The form of the orebody is simple; most output appearance is stratoid structure or the phacoidal structure. The main mineralizing element of the ore formation has the high background contents, it reflected that the initial enrichment of the ore-forming elements were happened at the sedimentary process, it is the "mineral resources" which is the potential material source at the late hydrothermal ore-forming transformation process.

(2) There are the volcaniclastic rock and the not pure siliceous rock in the ore formation, it reflected that the submarine volcanic activity participate in the formation deposition process, and it provides metallogenic material for the formation of the "mineral resources".

(3) The ore mineral composition is simple, and the ore mineral combination basically consistent at the different types of minerals in the ore body.

(4) The main ore-forming elements has the obvious zoning characteristics in this deposit, it appears that the trend and the tendency along the ore body, the copper mine is the majority in the central regions, the lead and the zinc mine is the majority on the edge of the ore body.

(5) The metasomatic texture has more mature upgrowth, the output state of the metallic mineral is fine vein disseminated, it conforms to the hydrothermal transformation metallogenic characteristics, the ore banding structure reflects the deposition and the lithology have certain control function to the mineralization.

(6) The alteration of the country rock near to ore body is intense, the hydrothermal alteration is primary, and the alteration and mineralization is closely relationship.

(7) The temperature measurement results of the sulfur lead isotope and the mineral inclusion reflected that the deposit has the metallogenic characteristic of the syndepositional structure and the Epigenetic modification.

(8) The surveying results of the drilling primary halo reflected that the anomaly form is simple; it appears that the characteristic of the stratoid, it conforms to the characteristics of stratabound deposits.

(9) The metallogenic age calculated by the lead isotope test results most bring into correspondence with the orogenic period structure and the age interval magmatic activities, it explains orogenic period strong structure, the magmation provides favorable conditions for the activation migration of the metallogenic material and the enrichment in this diggings.

(10) The structural changes make formation generated fracture and local bending; it provides migration pathway and the sediment space for the hydrothermal activity.

According to the above account, the Qinghai sola ditch copper polymetallic metallogenic province got through two stages, the sedimentary rock stage and the hydrothermal transformation stage. A large number of ore-forming materials brought by the submarine volcanic eruption jet activity, they deposited down together with the pyroclastic tephra, terrigenous sand, silt, argillaceous content at the relative low-lying parts of the shallow sea platform, and it forms initial enrichment of the metallogenic material or the lean ore layer; At the subsequent (indo-china period) orogenic processes, it suffered the role of magmatic activity which is a intense structure, the rock dehydration, metallogenic element activation, rich ore fluid formed by the aggregation, it gatheres to form ore deposit along with the stratum bedding, rockburst migration, chemical active components of the Metasomatism rock or filled in the rock fracture. So, we think that the Qinghai sola ditch copper polymetallic metallogenic province should belong to the type of stratabound ore deposit which is the volcanic deposit and the hydrothermal transformation [16-19].

5. Conclusion

With the research of the element geochemical characteristics, mineral deposit geological characteristics, ore genesis and ore-controlling conditions, we can conclud that:

(1) It describes the mineral deposit geological characteristics, make preliminary analysis about the ore genesis, the conclusion indicates that the triassic has the rich source of the ore-forming materials (Submarine volcanic activities, terrigenous denudation) and it has the advantage that it has the beneficial sedimentary environment conditions for the metallogenic matter deposition enrichment, it effected the initial enrichment of the metallogenic material in the ore stratum of the diggings, it forms source bed, and it also forms industrial ore body in the local area.

(2) With the research of the ore deposit geological characteristics and the surrounding rock, we know that the sedimentary rock play an important part in the distinguish of the metallogenic environment, the main ore-forming elements has obvious zoning characteristics in the ore deposit, it appears along the ore body, the copper mine in the central part is a main part, the lead zinc ore in the marginal part is a main part.

(3) The hydrothermal alteration is common in the diggings,the relation between the mineralization and alteration is closely related, the metalliferous mineral and the hydrothermal alteration mineral appears at the same time in the orebody, it has the feature of high alteration level、alteration types is complete、preferable mineralization level，the Hydrothermal transformation at the later period played an important part in the metallogenic process which goes through the process of the Metallogenic material activation、the migration、the redistributed enrichment. Therefore we determine it is the hydrothermal origin, it provides evidence for the reason of the sola ditch copper polymetallic metallogenic province ore genesis theories and the metallogenic process.

(4) The structure of the diggings is relatively simple, it's axially is close to the east and the west, it is an east plunging open antiformal, the ore body occurrence mainly appears at the turning parts of this antiform, it has a certain control function to the mineralization, we have not yet found a large guide ore structure in the diggings, so we know that the migration distance of the ore hot fluid is not very long.

(5) The Mineral package temperature results show that the hydrothermal ore-forming in this area belongs to middle or low temperature environment. The order of the mineral formation in the mineral is iron pyrite, pyrrhotine, towanite, Sphalerite and gelenite, it reflects the metallogenic process is a cooling process, the process of the activation migration of the metallogenic material is in a higher temperature environment, enrichment and mineralization along with the decrease degrees, Combined with other material comprehensive study, we think that the mineralization of this ore deposit got through the process of the sea spray deposition and the hydrothermal superimposed .

References

[1] Abdel-rahman., Abdel-fattah, M., 1990. Petrogenesis of Early-Orogenic Diorites, Tonalites and Post-Orogenic Trondhjemites in the Nubian Shield.Journal of Petrology. 31(6):1285-1312.

[2] Atherton M P., Petferd N., 1993.Cenaration of sedium-rich magmas frome newly underplated basaltie erust. Nature. 362,144～146.

[3] Chi, XG., Li Cai., Jin Wei.,2005.Cenozoic volcanism and lithospheric tectonic evolution in Qiangtang area, northern Qinghai-Tibet Plateau.Science In China (Earth Sciences).48(7).

[4] Cook N. J., Sundblad K., Valkama M.,2011.Indium mineralisation in A-type granites in southeastern Finland: Insights into mineralogy and partitioning between coexisting minerals.Chemical Geology,284,62-73.

[5] Feng, CY., Qi Feng., Zhang, DQ.,2011.China's First Independent Cobalt Deposit and its Metallogenic Mechanism: Evidence from Fluid Inclusions and Isotopic Geochemistry.Acta Geologica Sinica -English edition.85,1403-1418.

[6] Feng, CY., Wang, S., Li, GC., Ma, SC., Li, DS., 2012. Middle to Late Triassic granitoids in the Qimantage area, Qinghai Province, China: Chronology, geochemistry and metallogenic significances. Acta Petrologica Sinica. 28, 665-678.

[7] Fu, YW., Bor-ming Jahn., Simon A. Wilde., Ching-Hua Lo., Tzen-Fu Yui., Qiang Lin., Wen CG., De YS., 2003. Highly fractionated I-type granites in NE China (II): isotopic geochemistry and implications for crustal growth in the Phanerozoic. 67, 191-204.

[8] He, CS., Zhu LP, Wang QC., 2009. The Significance of Crust Structure and Continental Dynamics Inferred from Receiver Functions in West Yunnan.Acta Geologica Sinica -English edition. 83, 1163-1172.

[9] J. L. Smellie., P.Stone.,J. Evans., 1995. Petrogenesis of boninites in the Ordovician Ballantrae Complex ophiolite, southwestern Scotland. Journal of Volcanology and Geothermal Research. 69 (3-4).

[10] L. Beccaluva., P. Di Girolamo, G. Serri., 1991. Petrogenesis and tectonic setting of the Roman Volcanic Province, Italy. Lithos, 26(3-4):191-221.

[11] Li, DW., 2010.Temporal-Spatial Structure of Intraplate Uplift in the Qinghai-Tibet Plateau. Acta Geologica Sinica -English edition.84, 105-134.

[12] Liu, XF., Li CH, Lu QX., 2012. The Genesis Mechanism of the Mantle Fluid Action and Evolution in the Ore-Forming Process: A Case Study of the Laowangzhai Gold Deposit in Yunnan, China.Acta Geologica Sinica -English edition. 86, 608-618.

[13] Marsh, J. S., Bowen, M. P., Rogers, N. W.,Bowen, T. B.,1992. Petrogenesis of Late Archaean Flood-Type Basic Lavas from the Klipriviersberg Group, Ventersdorp Supergroup, South Africa.Journal of Petrology. 33(4), 817-847.

[14] Niu, BG., He ZJ, Song Biao., Ren JS and Xiao LW., 2004. SHRIMP Geochronology of Volcanics of the Zhangjiakou and Yixian Formations, Northern Hebei Province, with a Discussion on the Age of the Xing\'anling Group of the Great Hinggan Mountains and Volcanic Strata of the Southeastern Coastal Area of China. Acta Geologica Sinica-English edition. 78(6).

[15] Parry W. T., Blamey Nigel J. F., 2010. Fault fluid composition from fluid inclusion measurements, Laramide age Uinta thrust fault, Utah. Chemical Geology, 281, 293-304.

[16] Simmons S F., Sawkins F J., Schlutter D J., 1987. Mantle-derived helium in two Peruvian hydrothermal ore deposits.Nature. 329, 429～432.

[17] Wayne T. Jolly., 1987. Lithophile elements in Huronian low-Ti continental tholeiites from Canada, and evolution of the Precambrian mantle.Earth and Planetary Science Letters. 85(4).

[18] Xu, SK., Xia XH., Yuan CJ.,2008. Magnetite-fluorite rock: A new rock type of hot water sedimentation. Acta Geologica Sinica-English edition.82, 906-910

[19] Zhang, ZZ., Gu LX., Wu CZ., Li WQ., Xi AH., Wang Shuo.,2005.Zircon SHRIMP Dating for the Weiya Pluton, Eastern Tianshan: Its Geological Implications.Acta Geologica Sinica-English edition.79,481-490.