全球现代海底块状硫化物关键金属富集机理及资源前景初探

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附录A

## 本文硫化物数据库参考文献：

Hannington MD, Petersen S, Herzig PM, Jonasson IR (2004) A global database of seafloor hydrothermal systems, including a digital database of geochemical analyses of seafloor polymetallic sulfides. Geological Survey of Canada, Open File 4598, 1 CD-ROM

Anderson M O, Hannington M D, Mcconachy T F, et al. Mineralization and Alteration of a Modern Seafloor Massive Sulfide Deposit Hosted in Mafic Volcaniclastic Rocks[J]. Economic Geology, 2019, 114(5): 857-896.

Bing L , Xuefa S , Sai W , et al. Mafic-hosted seafloor sulfide mineralization at the margin of a non-transform discontinuity on the southern mid-Atlantic ridge[J]. Marine Georesources & Geotechnology, 2018:1-12.

Binns R A. Bikpela: A Large Siliceous Chimney from the PACMANUS Hydrothermal Field, Manus Basin, Papua New Guinea[J]. Economic Geology, 2014, 109(8): 2243-2259.

Bogdanov Y A, Lein A Y, Sagalevich A M, et al. Hydrothermal sulfide deposits of the Lucky Strike vent field, Mid-Atlantic Ridge[J]. Geochemistry International, 2006b, 44(4): 403-418.

Bogdanov, Y.A., Lein, A.Y., Ul’yanov, A.A. et al. Initial stage of the hydrothermal ore accumulation within the field at 9°50′ N on the East Pacific Rise[J]. Oceanology, 2006a, 46, 81–94.

Bogdanov, YA et al. (2005): Hydrothermal ore deposits of the Snake Pit hydrothermal field (Mid-Atlantic Ridge). Translated from Okeanologiya, 2005, 45(4), 574-591, Oceanology, 45(4), 543-561

Bogdanov, YA et al. (2006): Chemical and mineral compositions of hydrothermal sulfide deposits from the Lucky Strike hydrothermal field, Mid-Atlantic Ridge. PANGAEA, https://doi.org/10.1594/PANGAEA.726357

Bogdanov, YA et al. (2006): Hydrothermal Ore Genesis of the Ocean Floor. Nauka Publ. (Moscow): in Russian, 527 pp

Bogdanov, YA et al.Mineralogical-geochemical peculiarities of hydrothermal sulfide ores and fluids in the Rainbow Field associated with serpentinites, Mid-Atlantic Ridge (36°14'N). Translated from: Geologiya Rudnykh Mestorozhdeniy, 2002,44(6), 510-542, Geology of Ore Deposits, 44(6), 444-473

Bogdanov, Yury A; Lein, Alla Yu; Maslennikov, Valery V; Li, Syaoli; Ul'yanov, Alexander A (2008): Mineralogical and geochemical features of sulfide ores from the Broken Spur hydrothermal vent field. Okeanologiya, 2008, 48(5), 734-756, https://doi.org/10.1134/S000143700805007X

Bogdanov, Yury A; Lein, Alla Yu; Sagalevich, Anatoly M, Chemical composition of the hydrothermal deposits of the Menez Gwen vent field (Mid-Atlantic Ridge). Translated from Okeanologiya, 2005, 45(6), 897-905, Oceanology, 45(6), 849-856

Bogdanov, Yury A; Lisitzin, Alexander P; Sagalevich, Anatoly M; Gurvich, Evgeny G (2006): (Table 15) Chemical composition of sulfide deposits from the relict Fir Tree and active Neil hydrothermal mounds, Snake Pit hydrothermal field. PANGAEA, https://doi.org/10.1594/PANGAEA.746196, In supplement to: Bogdanov, YA et al. (2006): Hydrothermal Ore Genesis of the Ocean Floor. Nauka Publ. (Moscow): in Russian, 527 pp

Bogdanov, Yury A; Lisitzin, Alexander P; Sagalevich, Anatoly M; Gurvich, Evgeny G (2006): (Table 70) Chemical composition of low-temperature deposits from the Logachev hydrothermal field. PANGAEA, https://doi.org/10.1594/PANGAEA.746437, In supplement to: Bogdanov, YA et al. (2006): Hydrothermal Ore Genesis of the Ocean Floor. Nauka Publ. (Moscow): in Russian, 527 pp

Bogdanov, Yury A; Lisitzin, Alexander P; Sagalevich, Anatoly M; Gurvich, Evgeny G (2006): (Table 73) Chemical composition of hydrothermal ore manifestations from the Rainbow hydrothermal field. PANGAEA, https://doi.org/10.1594/PANGAEA.746438, In supplement to: Bogdanov, YA et al. (2006): Hydrothermal Ore Genesis of the Ocean Floor. Nauka Publ. (Moscow): in Russian, 527 pp

Bogdanov, Yury A; Lisitzin, Alexander P; Sagalevich, Anatoly M; Gurvich, Evgeny G (2006): (Table 91) Mineral and chemical compositions of hydrothermal deposits from Station AMK21-2231, Central Lau polygon. PANGAEA, https://doi.org/10.1594/PANGAEA.746441, In supplement to: Bogdanov, YA et al. (2006): Hydrothermal Ore Genesis of the Ocean Floor. Nauka Publ. (Moscow): in Russian, 527 pp

Bogdanov, Yury A; Lisitzin, Alexander P; Sagalevich, Anatoly M; Gurvich, Evgeny G (2006): (Table 94) Mineral and chemical compositions of surficial sulfide deposits of a 10 m high hydrothermal mound in the North Lau Basin polygon. PANGAEA, https://doi.org/10.1594/PANGAEA.746467, In supplement to: Bogdanov, YA et al. (2006): Hydrothermal Ore Genesis of the Ocean Floor. Nauka Publ. (Moscow): in Russian, 527 pp

Cherkashov G, Poroshina I, Stepanova T V, et al. Seafloor Massive Sulfides from the Northern Equatorial Mid-Atlantic Ridge: New Discoveries and Perspectives[J]. Marine Georesources & Geotechnology, 2010, 28(3): 222-239.

Cherkashov. G , Bel'tenev. V, Ivanov. V , Lazareva. L, Samovarov. M, Shilo. V , Stepanov. V , Glasb. G. Py & Kuznetso. V,) Two New Hydrothermal Field at the Mid-Atlantic Ridge, Marine Georesources & Geotechnology,2008, 26:4, 308-316, DOI:10.1080/10641190802400708

Craddock PR. Geochemical tracers of processes affecting the formation of seafloor hydrothermal fluids and deposits in theManus back-arc basin[J].2009, Dissertation, Massachusetts Institute of Technology andWoods Hole Oceanographic Institution, Woods Hole

Cruz MIFS (2015) Mineralogy and geochemistry of contrasting hydrothermal systems on the Arctic Mid Ocean Ridge (AMOR): The Jan Mayen and Loki's Castle vent fields. Dissertation, Universidade de Lisboa, pp. 257

De Ronde C E, Hannington M D, Stoffers P, et al. Evolution of a submarine magmatic-hydrothermal system: Brothers volcano, southern Kermadec Arc, New Zealand[J]. Economic Geology, 2005, 100(6): 1097-1133.

De Ronde C E, Walker S L, Ditchburn R G, et al. The Anatomy of a Buried Submarine Hydrothermal System, Clark Volcano, Kermadec Arc, New Zealand[J]. Economic Geology, 2014, 109(8): 2261-2292.

Evans G N, Tivey M K, Seewald J S, et al. Influences of the Tonga Subduction Zone on seafloor massive sulfide deposits along the Eastern Lau Spreading Center and Valu Fa Ridge[J]. Geochimica et Cosmochimica Acta, 2017: 214-246.

Firstova A, Stepanova T V, Sukhanova A, et al. Au and Te Minerals in Seafloor Massive Sulphides from Semyenov-2 Hydrothermal Field, Mid-Atlantic Ridge[J]. Minerals, 2019, 9(5).

Firstova A, Stepanova T, Cherkashov G, et al. Composition and Formation of Gabbro-Peridotite Hosted Seafloor Massive Sulfide Deposits from the Ashadze-1 Hydrothermal Field, Mid-Atlantic Ridge[J]. Minerals, 2016, 6(1).

Fouquet, Y., Cambon, P., Etoubleau, J., Charlou, J.L., OndréAs, H., Barriga, F.J.A.S., Cherkashov, G., Semkova, T., Poroshina, I., Bohn, M., Donval, J.P., Henry, K., Murphy, P. and Rouxel, O. Geodiversity of Hydrothermal Processes Along the Mid‐Atlantic Ridge and Ultramafic‐Hosted Mineralization: a New Type Of Oceanic Cu‐Zn‐Co‐Au Volcanogenic Massive Sulfide Deposit. In Diversity Of Hydrothermal Systems On Slow Spreading Ocean Ridges[J].2010. doi:10.1029/2008GM000746

Glasby G P , Iizasa K , Hannington M , et al. Mineralogy and composition of Kuroko deposits from northeastern Honshu and their possible modern analogues from the Izu-Ogasawara (Bonin) Arc south of Japan: Implications for mode of formation[J]. Ore Geology Reviews, 2008, 34(4):547-560.

Hannah L.J. Grant, Mark D. Hannington, Sven Petersen, Matthias Frische, Sebastian H. Fuchs. Constraints on the behavior of trace elements in the actively-forming TAG deposit, Mid-Atlantic Ridge, based on LA-ICP-MS analyses of pyrite[J]. Chemical Geology, 2018: 45-71.

Hein J R, De Ronde C E, Koski R A, et al. Layered Hydrothermal Barite-Sulfide Mound Field, East Diamante Caldera, Mariana Volcanic Arc[J]. Economic Geology, 2014, 109(8): 2179-2206.

Iizasa K, Asada A, Mizuno K, et al. Native gold and gold-rich sulfide deposits in a submarine basaltic caldera, Higashi-Aogashima hydrothermal field, Izu-Ogasawara frontal arc, Japan[J]. Mineralium Deposita, 2019, 54(1): 117-132.

Ikehata K., Suzuki R., Shimada K., Ishibashi J., Urabe T. (2015) Mineralogical and Geochemical Characteristics of Hydrothermal Minerals Collected from Hydrothermal Vent Fields in the Southern Mariana Spreading Center. In: Ishibashi J., Okino K., Sunamura M. (eds) Subseafloor Biosphere Linked to Hydrothermal Systems. Springer, Tokyo

Kakegawa T , Utsumi M , Marumo K . Geochemistry of Sulfide Chimneys and Basement Pillow Lavas at the Southern Mariana Trough (12.55°N–12.58°N)[J]. Resource Geology, 2008, 58(3):249-266.

Kilias, S., Nomikou, P., Papanikolaou, D. et al. New insights into hydrothermal vent processes in the unique shallow-submarine arc-volcano, Kolumbo (Santorini), Greece[J]. Scientific Reports, 2013, 3.

Kim J , Lee I , Halbach P , et al. Formation of hydrothermal vents in the North Fiji Basin: Sulfur and lead isotope constraints[J]. Chemical Geology, 2006, 233(3-4):0-275.

Kristall B, Kelley D S, Hannington M D, et al. Growth history of a diffusely venting sulfide structure from the Juan de Fuca Ridge: A petrological and geochemical study[J]. Geochemistry Geophysics Geosystems, 2006, 7(7).

Kristall B, Nielsen D, Hannington M D, et al. Chemical microenvironments within sulfide structures from the Mothra Hydrothermal Field: Evidence from high-resolution zoning of trace elements[J]. Chemical Geology, 2011, 290(1): 12-30.

Lein, Alla Yu; Ul'yanov, Alexander A (2008): (Table 2) Chemical composition of samples from the Broken Spur hydrothermal vent field. PANGAEA, https://doi.org/10.1594/PANGAEA.744947, In supplement to: Bogdanov, Yury A; Lein, Alla Yu; Maslennikov, Valery V; Li, Syaoli; Ul'yanov, Alexander A (2008): Mineralogical and geochemical features of sulfide ores from the Broken Spur hydrothermal vent field. Okeanologiya, 48(5), 734-756, https://doi.org/10.1134/S000143700805007X

Lein, AY et al. (2010): Sulfide minerals in the Menez Gwen nonmetallic hydrothermal field (Mid-Atlantic Ridge). Translated from Litologiya i Poleznye Iskopaemye, 2010, 4, 343-362, Lithology and Mineral Resources, 45(4), 305-323, https://doi.org/10.1134/S0024490210040012

Liao S, Tao C, Li H, et al. Bulk geochemistry, sulfur isotope characteristics of the Yuhuang-1 hydrothermal field on the ultraslow-spreading Southwest Indian Ridge[J]. Ore Geology Reviews, 2018: 13-27.

Marques A F A , Barriga F J A S , Scott S D . Sulfide mineralization in an ultramafic-rock hosted seafloor hydrothermal system: From serpentinization to the formation of Cu–Zn–(Co)-rich massive sulfides[J]. Marine Geology, 2007, 245(1-4):20-39.

Melekestseva I Y, Maslennikov V V, Safina N P, et al. Sulfide Breccias from the Semenov-3 Hydrothermal Field, Mid-Atlantic Ridge: Authigenic Mineral Formation and Trace Element Pattern[J]. Minerals, 2018, 8(8).

Melekestseva I Y, Maslennikov V V, Tretyakov G A, et al. Gold- and Silver-Rich Massive Sulfides from the Semenov-2 Hydrothermal Field, 13°31.13′N, Mid-Atlantic Ridge: A Case of Magmatic Contribution?[J]. Economic Geology, 2017, 112(4): 741-773.

Melekestseva I Y, Tretyakov G A, Nimis P, et al. Barite-rich massive sulfides from the Semenov-1 hydrothermal field (Mid-Atlantic Ridge, 13°30.87′ N): Evidence for phase separation and magmatic input[J]. Marine Geology, 2014, 349(349): 37-54.

Nayak B, Halbach P, Pracejus B, et al. Massive sulfides of Mount Jourdanne along the super-slow spreading Southwest Indian Ridge and their genesis[J]. Ore Geology Reviews, 2014: 115-128.

Noguchi T, Shinjo R, Ito M, et al. Barite geochemistry from hydrothermal chimneys of the Okinawa Trough: insight into chimney formation and fluid/sediment interaction[J]. Journal of Mineralogical and Petrological Sciences, 2011, 106(1): 26-35.

Nozaki, Tatsuo, Ishibashi, Jun-Ichiro, Shimada, Kazuhiko,et al. Rapid growth of mineral deposits at artificial seafloor hydrothermal vents[J]. Sci Rep, 6(1):22163.

Paduan J B , Zierenberg R , Clague D A , et al. Discovery of Hydrothermal Vent Fields on Alarcón Rise and in Southern Pescadero Basin, Gulf of California[J]. Geochemistry, Geophysics, Geosystems, 2018.

Paropkari A L , Ray D , Balaram V , et al. Formation of hydrothermal deposits at Kings Triple Junction, northern Lau back-arc basin, SW Pacific: The geochemical perspectives[J]. Journal of Asian Earth Sciences, 2010, 38(3-4):0-130.

Pašava, J., Vymazalová, A. & Petersen, S. PGE fractionation in seafloor hydrothermal systems: examples from mafic- and ultramafic-hosted hydrothermal fields at the slow-spreading Mid-Atlantic Ridge.Miner Deposita, 2007, 42, 423–431. https://doi.org/10.1007/s00126-006-0122-2

Petersen S, Herzig P M, Hannington M D, et al. Submarine Gold Mineralization Near Lihir Island, New Ireland Fore-Arc, Papua New Guinea[J]. Economic Geology, 2002, 97(8): 1795-1813.

Petersen S, Herzig P M, Schwarzschampera U, et al. Hydrothermal precipitates associated with bimodal volcanism in the Central Bransfield Strait, Antarctica[J]. Mineralium Deposita, 2004, 39(3): 358-379.

Petersen S, Monecke T,Westhues A, HanningtonMD, Gemmel JB, Sharpe R, Peters M, Strauss H, Lackschewitz K, Augustin N, Gibson H, Kleeberg R; Drilling Shallow-Water Massive Sulfides at the Palinuro Volcanic Complex, Aeolian Island Arc, Italy[J]. Economic Geology ; 2014, 109 (8): 2129–2158. doi: https://doi.org/10.2113/econgeo.109.8.2129

Ronde D , Massoth, Butterfield, et al. Submarine hydrothermal activity and gold-rich mineralization at Brothers Volcano, Kermadec Arc, New Zealand[J]. Mineralium Deposita, 2011, 46(5-6):541-584.

Rouxel O , Iii W C S , Bach W , et al. Integrated Fe- and S-isotope study of seafloor hydrothermal vents at East Pacific Rise 9–10°N[J]. Chemical Geology, 2008, 252(3-4):0-227.

Snook, B.; Drivenes, K.; Rollinson, G.K.; Aasly, K. Characterisation of Mineralised Material from the Loki’s Castle Hydrothermal Vent on the Mohn’s Ridge[J]. Minerals 2018, 8, 576.

Suzuki R, Ishibashi J, Nakaseama M, et al. Diverse Range of Mineralization Induced by Phase Separation of Hydrothermal Fluid: Case Study of the Yonaguni Knoll IV Hydrothermal Field in the Okinawa Trough Back‐Arc Basin[J]. Resource Geology, 2008, 58(3): 267-288.

Szamałek K., Marcinowska A., Nejbert K. and Speczik S. Sea-floor massive sulphides from the Galápagos Rift Zone – mineralogy, geochem is try and economic importance. Geol. Quart., 2011, 55 (3): 187–202. Warszawa.

Takeshi Kakegawa, Motoo Utsumi and Katsumi Marumo, Geochemistry of Sulfide Chimneys and Basement Pillow Lavas at the Southern Mariana Trough (12.55°N–12.58°N)[J], Resource Geology, 2008, 58, 3, (249-266).

Tao C, Li H, Huang W, et al. Mineralogical and geochemical features of sulfide chimneys from the 49°39′E hydrothermal field on the Southwest Indian Ridge and their geological inferences[J]. Science Bulletin, 2011, 56(26): 2828-2838.

Tao C, Li H, Jin X, et al. Seafloor hydrothermal activity and polymetallic sulfide exploration on the southwest Indian ridge[J]. Science Bulletin, 2014, 59(19): 2266-2276.

Tivey et al., 2009 Geochemistry data from Sulfide samples from the Lau Back-arc Basin acquired during Melville expedition TUIM05MV (2005)

Toffolo L, Nimis P, Tretyakov G A, et al. Seafloor massive sulfides from mid-ocean ridges: Exploring the causes of their geochemical variability with multivariate analysis[J]. Earth-Science Reviews, 2019.

Tuomo Törmänen(Doctoral dissertation, University of Oulu (Finland)). Ore mineralogy, geochemistry, and formation of the sedimenthosted sea floor massive sulfide deposits at Escanaba Trough, NE Pacific, with emphasis on the transport and deposition of gold ,2005

Vesselin Dekov, Tanya Boycheva, Ulf Hålenius, Kjell Billström, George D. Kamenov, Wayne C. Shanks, Jens Stummeyer, Mineralogical and geochemical evidence for hydrothermal activity at the west wall of 12°50′N core complex (Mid-Atlantic ridge): A new ultramafic-hosted seafloor hydrothermal deposit?[J]. Marine Geology, 2011, 288(1-4): 90-102.

Wang H, Li X, Chu F, et al. Mineralogy, geochemistry, and Sr-Pb isotopic geochemistry of hydrothermal massive sulfides from the 15.2°S hydrothermal field, Mid-Atlantic Ridge[J]. Journal of Marine Systems, 2017: 220-227.

Wang Y , Han X , Petersen S , et al. Mineralogy and geochemistry of hydrothermal precipitates from Kairei hydrothermal field, Central Indian Ridge[J]. Marine Geology, 2014, 354:69-80.

Wang, S., Li, H., Zhai, S. et al. Geochemical features of sulfides from the Deyin-1 hydrothermal field at the southern Mid-Atlantic Ridge near 15°S[J]. Ocean Univ. China, 2017,16, 1043–1054. https://doi.org/10.1007/s11802-017-3316-6

Webber A P , Roberts S , Murton B J , et al. Geology, sulfide geochemistry and supercritical venting at the Beebe Hydrothermal Vent Field, Cayman Trough[J]. Geochemistry, Geophysics, Geosystems, 2015, 16(8):2661-2678.

Wu Z , Sun X , Xu H , et al. Occurrences and distribution of “invisible” precious metals in sulfide deposits from the Edmond hydrothermal field, Central Indian Ridge[J]. Ore Geology Reviews, 2016:S0169136816300282.

Ye, J., Shi, X., Yang, Y. et al. The occurrence of gold in hydrothermal sulfide at Southwest Indian Ridge 49.6°E. Acta Oceanol. Sin. 31, 72–82 (2012). https://doi.org/10.1007/s13131-012-0254-4

Yeats C J, Parr J, Binns R A, et al. The SuSu Knolls Hydrothermal Field, Eastern Manus Basin, Papua New Guinea: An Active Submarine High-Sulfidation Copper-Gold System[J]. Economic Geology, 2014, 109(8): 2207-2226.

Zhigang Z, Daigeng C, Xuebo Y, et al. Elemental and isotopic compositions of the hydrothermal sulfide on the East Pacific Rise near 13°N[J]. Science China-earth Sciences, 2010, 53(2): 253-266.

曹红. 西南和中印度洋洋脊热液硫化物的成矿作用研究[D]. 2016.

曾志刚,余少雄,殷学博,王晓媛,张国良,汪小妹,陈代庚.冲绳海槽Jade热液区热液硫化物的元素富集与铀系同位素组成[J].中国科学(D辑:地球科学),2009,39(11):1579-1590.

侯增谦. 西太平洋冲绳海槽烟囱硫化物矿床矿石化学特征与分带型式[J]. 地球学报, 1997, 56(2):2828-2838.

王叶剑. 中印度洋脊Kairei和Edmond热液活动区成矿作用对比研究[D]. 浙江大学, 2012.

杨伟芳. 西南印度洋中脊断桥热液区成矿作用研究[D]. 2017.

叶俊. 西南印度洋超慢速扩张脊49.6oE热液区多金属硫化物成矿作用研究[D]. 2010.

张柏松. 西南印度洋中脊龙旂,断桥热液区成矿作用研究[D]. 2019.