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Global research trends on metallogeny in mafic-ultramafic rocks: A bibliometric approach

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Original Research

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Abstract:

A comprehensive assessment and evaluation of metallogeny in mafic-ultramafic rocks, which is essential in determining the novelty value and direction, have not yet been found in past studies. This study aimed to determine the trends and opportunities related to the aforementioned subject using bibliometric methods based on the SCOPUS database, through visualization and analysis using the VOSviewer application; so that we can focus on research that has not been done for the next forward (as the benefit). The results showed a total of 972 publications during the 1969 – 2022 period, with the highest contributing countries being China and Australia, while the Chinese Academy of Sciences is the most productive affiliate. Ore Geology Reviews is the journal with the highest number of publications on this topic. Concurrently, the most productive authors are Santosh M and Mao J. The Earth and planetary sciences, environmental sciences, and engineering dominate the subject areas. Geographically, related research is still focused on China, while gold, zircon, and copper are the metals with the highest focus. In addition, widely used equipment or methods approaches include fluid inclusions, U-Pb zircon dating, and Hf isotopes. Recent trends in research topics include geochemistry, petrogenesis, geochronology, fluid inclusions, and tectonic setting. Low-frequency research topics include ore magmatic systems, reduced intrusion-related, tonalite, palladium, La-ICP-MS, U-Pb dating, lithium, metavolcanic rocks, black shale, hydrocarbons, Rb-Sr geochronology, rare earth elements, Re-Os analysis, Sm-Nd, Sr-Nd-Pb-Hf isotopes, and dunite-peridotite-pyroxenite-gabbro associations.

Keywords: Metallogenic; Bibliometric methods; VOSviewer; Research gap; Geo-research maps

1. Introduction

Human population growth has increased the utilization of various natural resources, including metals and other minerals. Certain metals, minerals, and elements are occasionally declared critical due to necessity, while the reserves and demand are out of balance (Watari et al., 2020). Consequently, the demand for metallic elements, such as lithium, cobalt, gallium, and vanadium, is expected to drastically rise in the next few years (Pohl, 2022).

Metallogeny is an interdisciplinary study in earth science, physics, chemistry, and others. It examines the origin of mineral deposits in space and time, and their impact on regional and global conditions on the earth′s crust, which are studied in geology and geophysics (Pohl, 2022). In this case, the metallogenical study focused on a mafic-ultramafic rock as part of the upper mantle and oceanic crust. Mafic–ultramafic rocks are rocks with a silica content (SiO_2) of $<$ 45 to 52 weight percent (wt.%). The SiO_2 content of ultramafic rock is less than 45 wt.% while the silica content of peridotite rocks is about 41 – 42 wt.% and 40 wt.% of olivine minerals (Le Bas and Streckeisen, 1991). The constituent minerals of ultramafic rocks are olivine, orthopyroxene, clinopyroxene, serpentine, and rarely Ca plagioclase, spinel, or garnet. The ultrabasic rock types include peridotite, dunite, harzburgite, lherzolite, wehrlite, websterite, olivine websterite and serpentinite (Le Bas and Streckeisen, 1991; Ghasempour et al., 2015; Kelemen et al., 2018; Ousta et al., 2024). The serpentinization process

of ultramafic rock is caused by the addition of hot H_2O under temperature conditions of 475 ^{o}C – 500 ^{o}C to 900 ^{o}C (Nicolas, 1989). This process transformed olivine and or pyroxene minerals into serpentines such as antigorite, chrysotile, or lizardite.

The mafic rock includes gabbro, diabase or dolerite and basalt (Zhao, 2021). The main minerals constituting coarse-grain gabbro are augite-type clinopyroxene and calcic plagioclase. Other minerals that can be present in gabbro are enstatite, olivine, quartz, and hornblende. The gabbro is classified into gabbro, norite, norite gabbro, olivine gabbro, anorthosite, and troctolite (Le Bas and Streckeisen, 1991). Diabase rock of fine to medium-grain size commonly present as a dike is composed of the main minerals augite and calcic plagioclase (Best, 2003). The uppermost part of the crust is a basalt rock that forms a melt on the surface of the ocean floor. In mineralogy, basalt rocks are similar to the mineral composition of gabbro rocks distinguished by fine grain size (aphanitic) accompanied by the addition of glass silica because it cooled quickly on the surface of the earth. Basalt rocks are the most abundant rocks on the earth′s surface (Best, 2003).

Numerous publications on metallogeny in mafic-ultramafic rocks have been published in various global scientific journals. However, studies that explicitly assess and evaluate the metallogeny of mafic-ultramafic rocks are not available. A comprehensive picture of previous research is essential and can be an objective consideration in setting research governance policies. It also helps to create opportunities for future studies (Mukherjee et al., 2022).

Research evaluation in a conventional way is almost impossible for large databases. To overcome these limitations, the bibliometric method can be utilized (Yang et al., 2022; Nazari et al., 2023). Bibliometrics is a mathematical and statistical approach to identify, visualize, and analyze publications or literature (Tupan et al., 2018; Bankar and Lihitkar, 2019; Salehpour et al., 2025). This method has been widely recognized and applied in various fields of science (Hu et al., 2022; Li et al., 2022; Moreno et al., 2022).

The primary focus of this study is to determine the research trends on metallogeny in mafic-ultramafic rocks using a bibliometric method based on SCOPUS data. SCOPUS is the world′s largest, most reputable database, and most of its publications undergo a rigorous peer-review process. The study aimed to comprehensively determine the trend of previous research and future research opportunities, including annual trends, countries, affiliations, authors, journals, publications, fields of study, and related topics.

2. Materials and methods

The bibliometric method was utilized in this study to assess and evaluate previous scientific publications Jakah et al. (2021) and Yang et al. (2022) namely metallogeny in mafic-ultramafic rocks, with the SCOPUS database. The bibliometric stages of this study are presented in Fig. 1.

2.1 Data processes

This study used the SCOPUS database based on relevant keywords. The first step was to determine the keywords, which included "metallogeny" OR "metallogenic" OR "metallogenesis" AND "mafic-ultramafic" OR "mafic" OR "ultramafic". Subsequently, the search was conducted by entering the keywords in the search field section of the SCOPUS database. Relevant publications which included information on document type, year, access type, author, journal, and language were selected. The year of publication was set up to 2022 in this study, while the type of access, author, journal, and language were not restricted. The selected data were then extracted into a comma-separated values (CSV) file format.

2.2 Visualizations and analysis

The extracted data in the comma-separated values (CSV) files were then processed and visualized using the latest version of VOSviewer application 1.6.18 (Eck and Waltman, 2022). To obtain comprehensive results, the VOSviewer

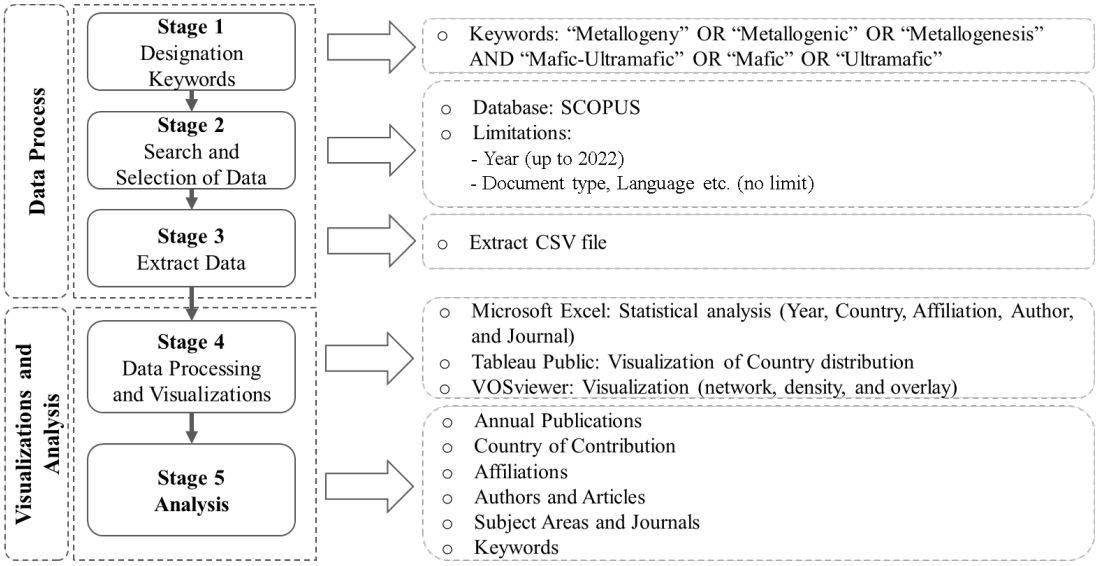

Figure 1. Stages of this study.

visualization was set with threshold options, varying from a minimum of 1 to 5 documents. The results were subsequently descriptively and quantitatively analyzed based on annual progression, country, affiliation, author, journal, publication, areas of study, and keywords.

3. Results and discussion

3.1 The trend of annual publications

A total of 972 publications on metallogeny in mafic-ultramafic rocks from 1969 to 2022 (53 years) were identified. The period division based on the output trend consisted of at least several phases, including 1969 – 2004, 2005 – 2012, and 2013 – 2022 (Fig. 2). From 1969 to 2004, the initial trend of emergence until 1979 showed a flat pattern with an average publication output per year of one document. The fluctuation tended to subsequently rise and continued to increase until 2004, with a total output of 245 documents (25%) with an average of nine documents per year. The increasing trend showed that this field is consistently in demand; even in 2004, there was a very significant increase in the number of publications from the previous year, which reached twice as many.

Furthermore, during the 2005 – 2012 period, the initial output decreased significantly compared to the previous period, then rose again and continued to increase until it equalled the peak of the previous period. The average output of this period reached 24 documents per year. Subsequently, the 2014 – 2022 period was the period with the highest output, with 533 documents and an average output per year of 56.5 documents. For annual output, 2020 was the peak year, with achievements reaching 73 documents or equivalent to 7.5%. In Fig. 2, the blue line represents the publication trend from year to year, with the exponential line coefficient R^2 reaching 0.910. This trend shows that the number of authors enthusiastic about metallogeny in mafic-ultramafic rocks topics was relatively high and continued to increase. In addition to the number of enthusiastic authors on the subject, the increase in publications was also influenced by the development of internet facilities and an increasingly open global network (Badaluddin et al., 2021). The increasing trend shows that this field has broad prospects and opportunities in the future. Meanwhile, the citation rate per document from all years shows a fluctuating trend (see the orange line in Fig. 2). The initial period from 1969 – 1979 to 1983 showed a fluctuating but decreasing trend, then gradually increased until 2010, and decreased until 2022. The year 1995 witnessed the highest citation rate per document, reaching 115 citations. The high number of outputs with a relatively shorter publication period affects the citation rate, therefore relatively recent publications have a low citation rate. Other factors include ease of access to publications (Eysenbach, 2006; Momeni et al., 2021).

3.2 Countries that publish

Authors in 74 countries have published articles on metallogeny in mafic-ultramafic rocks topics. The distribution of contributing countries and the top 15 highest productivity and citation rates per document are shown in Fig. 3.

China was the most productive contributing country, with 508 publications (37.1%). Australia ranked second with 136 documents (9.9%), followed by Canada (109 documents), the United States (85 documents), and Russia (73 documents). Meanwhile, for the citation rate of the top most productive countries, China had the lowest citation rate per document. The highest citation per document was obtained by Hong Kong, which reached 108.7 citations. Interestingly, the top contributing countries in this field were generally dominated by countries with the largest economies, such as China, Australia, Canada, the United Kingdom, Brazil, France, South Africa, Germany, India, Japan, and Spain, which showed that this field correlates with the development and economic strength of a country. The consistency of countries' contributions in publishing scientific publications in the field can be considered in the objectives of the

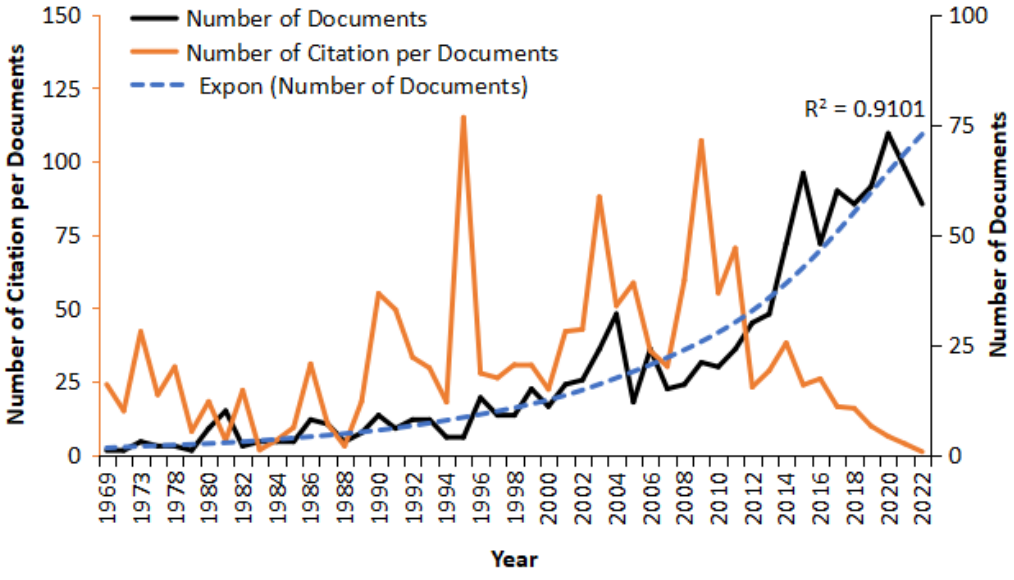

Figure 2. Publication and citation trend 1969-2022.

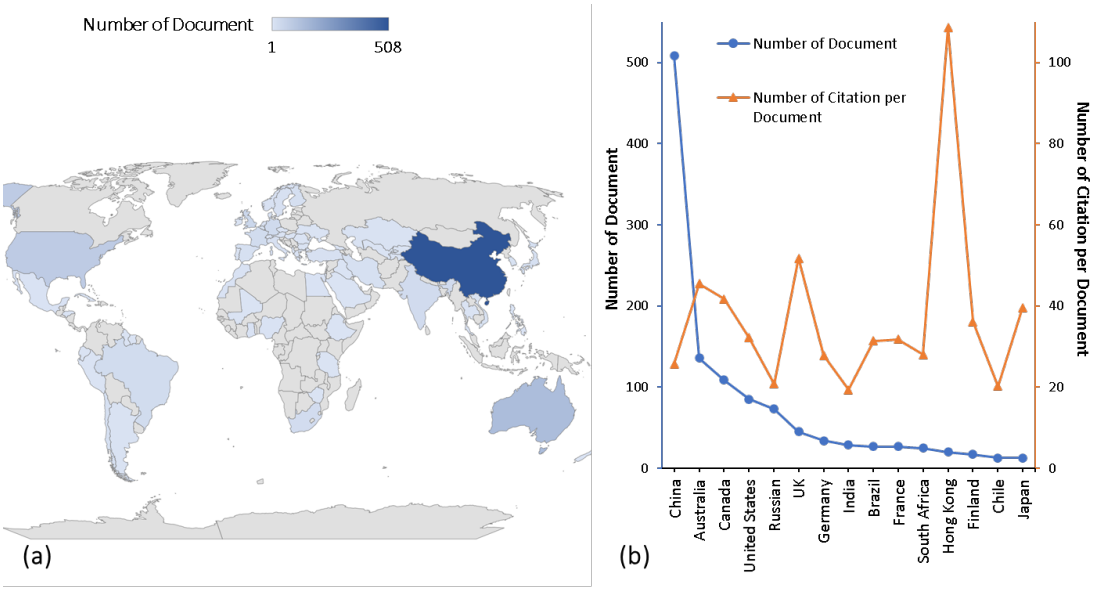

Figure 3. (a) Distribution of contributing countries, and (b) top 15 most productive and citations.

field study plan.

Fig. 4 shows the collaboration network of authors between countries on metallogeny in mafic-ultramafic rocks. The dashes represent a collaboration between countries, while the line's thickness represents collaboration strength (Eck and Waltman, 2010; Shi et al., 2021). Fig. 4 demonstrates that the authors of the contributing countries tend to collaborate and form a global network cluster. Of the 74 contributing countries, 30 were interconnected with an output of at least five publications, with China, Australia, the United States, and France leading this global collaboration. China, with the highest number of publications, had collaborations and tended to form clusters with Russia, Hong Kong, and Vietnam, while the most extensive collaboration cluster was between France with Germany, Finland, Italy, Norway, Belgium, Sweden, Denmark, and Greece. The United States networked with Canada, the UK, Iran, Chile, Switzerland, and Spain. The countries that still need to network include Nigeria, Zimbabwe, Kyrgyzstan, Mali, Saudi Arabia, Ethiopia, Georgia, Ukraine, and Tajikistan.

3.3 Affiliates

A total of 160 contributing affiliations related to metallogeny in mafic-ultramafic rocks (minimum publication limit of 3 documents) were identified. The top 10 affiliations related to metallogeny in mafic-ultramafic rocks topics are shown in Table 1. The affiliation with the highest publication was the Chinese Academy of Sciences with 141 documents. The Chinese Academic of Geological Sciences ranked second with 128 documents, followed by the China University of

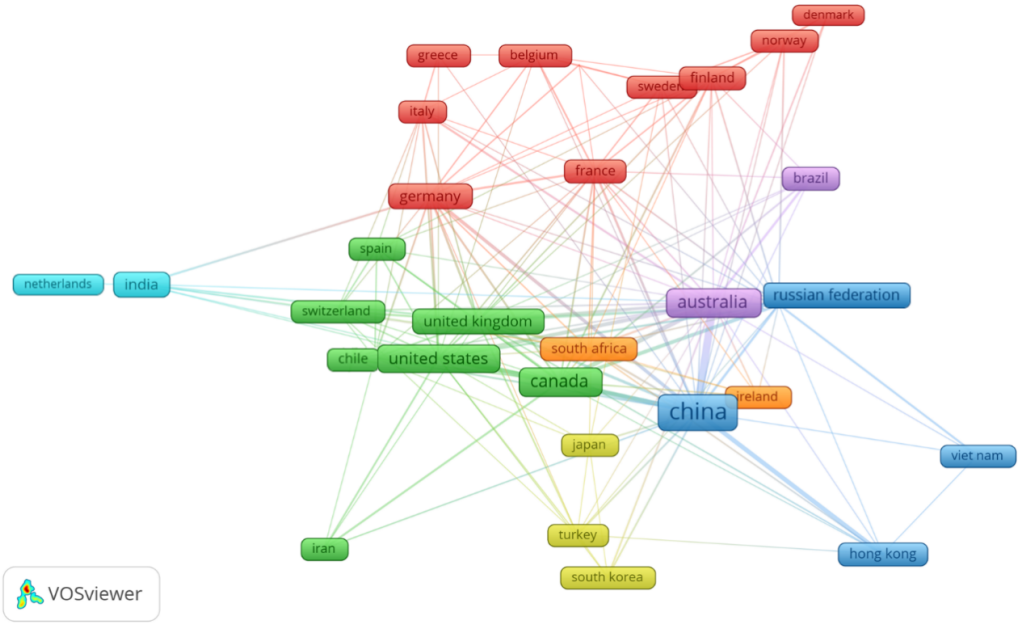

Figure 4. Collaboration on co-authoring between countries.

Table 1. Top 10 most productive affiliates. T.D: total document; T.C: total citation; T.C/T.D: total citation per document.

Rank.	Affiliation	T.D	T.C	T.C/T.D	Country
1	Chinese Academy of Sciences	141	6,280	44.5	China
2	Chinese Academy of Geological Sciences	128	3,296	25.8	China
3	China University of Geosciences, Beijing	89	1,359	15.3	China
4	Institute of Geology, Chinese Academy of Geological Sciences	85	5,009	58.9	China
5	University of Chinese Academy of Sciences	62	1,250	20.2	China
6	China Geological Survey	58	229	3.9	China
7	State Key Lab for Geological Processes and Mineral Resources	57	1,124	19.7	China
8	School of the Earth Sciences and Resources	54	1,397	25.9	China
9	Chinese University of Geosciences	51	1,193	23.4	China
10	Guangzhou Institute of Geochemistry	40	2,471	61.8	China

Geosciences with 89 documents. As for citations per document, the Guangzhou Institute of Geochemistry Chinese Academic of Sciences ranked the highest with 61.8 citations, while China Geological Survey ranked the lowest (3.9 citations).

The ten most productive affiliates in the field of metallogeny in mafic-ultramafic rocks all originated from China. The consistency of these affiliations can be considered for collaborative research in related fields. The high number of contributions from Chinese affiliates indicates that research in this field has received high attention and strong support from the government and researchers. The results showed that China has a vast and strategic interest in this field, given that it has one of the world's vast natural resources.

3.4 Authors and citations of publications

A total of 2,894 contributors of publications related to metallogeny in mafic-ultramafic rocks were identified. The top 10 contributing authors and citation rates can be seen in Table 2.

Santosh M was the most productive author during the study period with 22 publications, followed by Mao J with 20 documents, and Pirajno F with 15 documents. However, for the citation rate of the top 10 authors, Hao Z (China) had the highest citation rate per document with 87.2 citations, while Pirajno F (Australia) ranked second, with 81.5. The lowest citation rate was contributed by Qian B with 10.0 citations. Of the top ten most productive authors, eight authors are from China, and the remaining two are from Australia. The high dominance of contributing authors from China indicates the level of interest and the number of human resources experts in related fields.

A total of 2,894 contributing authors of publications on metallogeny in mafic-ultramafic rocks produced a total publication output of 972 documents published by various reputable journals indexed by SCOPUS. Of the 972 publications, the top 10 most cited publications are presented in Table 3. The publication with the highest citations (933 citations) is the End-Permian to mid-Triassic Termination of the accretionary processes of the southern Altaids: Implications for the geodynamic evolution, Phanerozoic continental growth, and metallogeny of Central Asia (Xiao et al., 2009). Later on, Magmatic to Hydrothermal metal fluxes in convergent and collided margins (Richards, 2011).

3.5 Distribution of studies and journals

The trend of study fields based on subject areas related to metallogeny in mafic-ultramafic rocks until 2022 consisted of 13 fields (Fig. 5). The most dominant field of study was earth and planetary sciences, with a publication output of 953 documents (87.4%), followed by environmental science, with 46 documents (4.2%). Other fields of study included

Table 2. Top 10 most productive authors. T.D: total document; T.C: total citation; T.C/T.D: total citation per document.

Rank.	Authors	Affiliation	T.D	T.C	T.C/T.D	Country
1	Santosh, M.	The University of Adelaide, Department of Earth Sciences	22	789	35.9	Australia
2	Mao, J.	Chinese Academy of Geological Sciences, Beijing	20	911	45.6	China
3	Pirajno, F.	The University of Western Australia, Perth	15	1,222	81.5	Australia
4	Qian, B.	Xi'an Institute of Geology and Mineral Resources, Xi'an	11	110	10.0	China
5	Qin, K. Z.	University of Chinese Academy of Sciences, Beijing	11	571	51.9	China
6	Zhang, Z.	State Key Lab for Geological Processes and Mineral Resources, Beijing	11	434	39.5	China
7	Zhou, M. F.	The University of Hong Kong, Department of Earth Sciences, Pokfulam	11	817	74.3	Hong Kong/ China
8	Hou, Z.	Institute of Geology, Chinese Academy of Geological Sciences, Beijing	9	785	87.2	China
9	Yuan, F.	Hefei University of Technology	9	360	40.0	China
10	Chen, W. T.	Chinese Academy of Sciences, Beijing	8	437	54.6	China

Table 3. Top 10 publications based on citation rate. T.C: total citation.

Rank.	Title	Journal	Year	T.C	Authors
1	End-Permian to mid-Triassic Termination of the accretionary processes of the southern Altaids: Implications for the geodynamic evolution, Phanerozoic continental growth, and metallogeny of Central Asia	International Journal of Earth Sciences	2009	933	Xiao W.J., Huang B.C., Han C.M., Yuan C., Chen H.L., Sun M., Sun S., Li J.L.
2	Magmatic to hydrothermal metal fluxes in convergent and collided margins	Ore Geology Reviews	2011	533	Richards J.P.
3	A review of the geodynamic setting of large-scale Late Mesozoic gold mineralization in the North China Cration: An association with lithospheric thinning	Ore Geology Reviews	2003	438	Yang J.-H., Wu F.-Y., Wilde S.A.
4	The role of komatiitic and picritic magmatism and S-saturation in the formation of ore deposits	Lithos	1995	434	Keays R. R.
5	A review of the Cu-Ni sulphide deposits in the Chinese Tianshan and Altay orogens (Xinjiang Autonomous Region, N W China): Principal characteristics and ore-forming processes	Journal of Asian Earth Sciences	2008	312	Mao J.W., Pirajno F., Zhang Z.H., Chai F.M., Wu H., Chen S.P., Cheng L.S., Yang J.M., Zhang C.Q..
6	Ore-forming fluids associated with granite-hosted gold mineralization at the Sanshandao deposit, Jiaodong gold province, China	Mineralium Deposita	2003	307	Fan H.R., Zhai M.G., Xie Yang J.H.
7	Rb-Sr, Sm-Nd isotopes systematics of pyrite: Implications for the age and genesis of lode gold deposits	Geology	2002	297	Yang J.-H., Zhou X.-H.
8	Metallogenesis of the Tibetan collisional orogen: A review and introduction to the special issue	Ore Geology Reviews	2009	276	Hou Z., Cook N. J.
9	Iron oxide-copper-gold deposits: An Andean view	Mineralium Deposita	2003	276	Sillitoe R.H.
10	Significant achievements and open issues in the study of orogenesis and metallogenesis surrounding the North China continent	Acta Petrologica Sinica	2009	267	Chen Y., Zhai M., Jiang S.

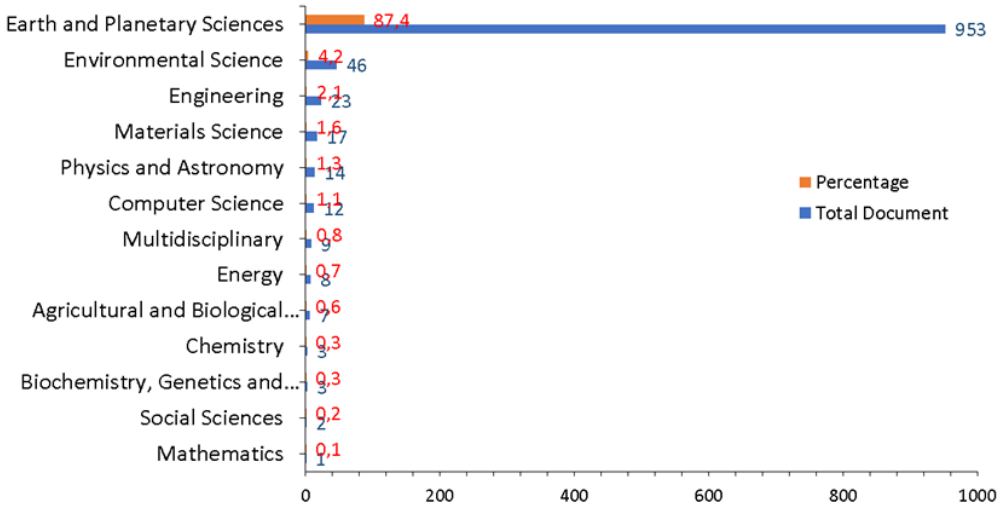

Figure 5. Distribution and percentage of publications areas of the study.

multidisciplinary (0.7%), energy (0.6%), chemistry (0.3%), social sciences (0.2%), and mathematics (0.1%). The contribution and distribution of 13 fields of study are shown in Fig. 5.

The distribution of the subject area documents shows that the related topics are closely related to earth and planetary sciences and environmental science. With science and technology continuing to evolve and become more integrated, this is a very open and exciting opportunity for other fields of science to contribute and provide more advanced and sustainable benefits to metallogeny in mafic-ultramafic rocks topics.

Table 4 shows the 10 most published journals on metallogeny in mafic-ultramafic rocks. Ore Geology Reviews was the most published journal on related research topics, with a complete publication of 154 documents, followed by Economic Geology with 63 documents, and Yanshi Xuebao Acta Petrologica Sinica with 41 documents. Concurrently, for citations per document of the top 10 (Table 4), Mineralium Deposita ranked the highest with a 51.9 score and Economic Geology with a 50.8 score, while Geology in China (6.5), Yanshi Xuebao Acta Petrologica Sinica (5.1), and Northwestern Geology ranked the lowest (4.8). This suggests that publication citation rates have no correlation with the most productive publications.

3.6 Keywords trend

Keywords are terms used to express a particular description or explanation. They are essential because they can describe publications'main topics or content (Wang et al., 2012; Badaluddin et al., 2021). To determine the trend of research topics on metallogeny mafic-ultramafic rocks based on keywords from phase to phase, the phases were divided into 4, from early to recent. The phase is divided into the 1969 – 2004 phase, the 2005 – 2012 phase, and more detail in the recent phase that separated into the 2013 – 2017 and

Table 4. Top 10 most productive journals. T.D: total document; T.C: total citation; T.C/T.D: total citation per document.

Rank.	Journal	T.D	T.C	T.C/T.D
1	Ore Geology Reviews	154	5,704	37.0
2	Economic Geology	63	3,200	50.8
3	Yanshi Xuebao Acta Petrologica Sinica	41	209	5.1
4	Acta Petrologica Sinica	40	1,696	42.4
5	Lithos	38	1,595	42.0
6	Mineralium Deposita	36	1,868	51.9
7	Precambrian Research	32	1,303	40.7
8	Journal of Asian Earth Sciences	26	1,227	47.2
9	Geology In China	19	123	6.5
10	Northwestern Geology	19	91	4.8

2018 – 2022 phases. The first phase, 1969 – 2004, included metallogeny, gold, geochemistry, platinum group minerals, layered intrusions, copper, fluid inclusion, gold deposits, granite, ore deposits, platinum group elements, chromite, early cretaceous, epithermal gold-silver mineralization, hydrothermal alteration, isotopes, nickel, and Paleoproterozoic. The second phase, from 2005 to 2012, included geochemistry, metallogeny, metallogenesis, mafic-ultramafic complex, mineral resources, geochronology, orogenic gold deposit, mantle plume, metal ores, Paleoproterozoic, porphyry copper deposit, Proterozoic, uranium, and Hf isotopes. The 2003 – 2017 phase included geochemistry, metallogeny, geochronology, petrogenesis, metallogenesis, gold, mafic-ultramafic intrusions, fluid inclusions, geochronology, geological characteristics, and zircon U-Pb dating, while the current phase, 2018 – 2022, included geochemistry, petrogenesis, geochronology, metallogeny, fluid inclusions, metallogenesis, gold, tectonic setting, and zircon U-Pb age. The trend of keywords related to metallogeny in mafic-ultramafic rocks can be seen in Table 5.

In the early period, studies on metallogeny in mafic-ultramafic rocks were mainly related to metallogeny, gold, and platinum-group minerals, which subsequently shifted towards the study of geochemistry, metallogenesis, and mafic-ultramafic complex. Along with the development of science and technology, the latest trends are geochemistry,

Table 5. The trend of 20 keywords with the highest frequency. R.K: ranking; F.R frequency.

Period	2018-2022		2013-2017		2005-2012		1969-2004	
Keywords	R.K	F.R	R.K	F.R	R.K	F.R	R.K	F.R
geochemistry	1	28	1	15	1	13	3	6
petrogenesis	2	17	3	9	430	1	39	2
geochronology	3	12	9	6	11	3	24	2
Eastern Tianshan	4	10	65	2	32	2	109	1
South China	5	10	13	6	500	1	-	-
metallogeny	6	9	2	11	2	8	1	11
fluid inclusions	7	8	8	6	211	1	8	3
metallogenesis	8	8	6	8	3	7	-	-
geology	9	7	367	1	-	-	-	-
gold	10	7	5	8	37	2	2	10
Tibet	11	7	4	9	538	1	-	-
Central Asian orogenic belt	12	6	62	2	133	1	-	-
tectonic setting	13	6	18	5	26	3	298	1
East Kunlun	14	5	300	1	187	1	-	-
fractional crystallization	15	5	70	2	213	1	120	1
Iran	16	5	-	-	-	-	-	-
mineralization	17	5	22	4	365	1	31	2
mineralogy	18	5	98	2	-	-	-	-
oxygen fugacity	19	5	103	2	417	1	226	1
zircon u-pb age	20	5	25	4	582	1	-	-

petrogenesis, and fluid inclusions. It shows that research topics related to metallogeny in mafic-ultramafic rocks are closely correlated with geochemistry. The geochemistry approach is fundamental in helping to reveal the chemical composition, compounds, distribution, control, and formation process, including all elements that occur in the periodic table. Element concentrations can range from major or minor ($> 0.1\%$) to trace elements (in units of ppm or ppb) (Trueman, 2005; Sarala, 2015; Demetriades, 2021). Consequently, geochemistry studies will still be essential in advanced research in the coming years.

Keywords or terms that show a significant trend from the beginning of the core issue to the present include petrogenesis, geochronology and fluid inclusions. Petrogenesis is closely related to geological formation processes and the origin of rocks, while geochronology studies the formation history or age dating of earth-forming materials (rocks, minerals, and fossils) and geological events (Eide, 2005; Schmitz et al., 2020; Cuney, 2021; Harmon, 2021). Fluid inclusions are liquids trapped in rock crystals during primary growth from solution or otherwise. Fluid inclusions generally are microscopic ($< 20\ \mu$m). However, the data that can be extracted are fundamental in determining the temperature, pressure, and physicochemical properties at the moment of trapping (Rankin, 2005). Such information helps determine ore provenance, petrogenesis, diagenesis, migration, and other geological processes (Roedder, 2003; Bodnar et al., 2014). In addition to geochemistry, geology studies on petrogenesis, geochronology, fluid inclusions, and mineralogy are predicted to still dominate the research on metallogeny in mafic-ultramafic rocks.

3.7 Network and keywords density

On the basis of the authors'keywords on metallogeny in mafic-ultramafic rocks from 1969 to 2022, a total of 2,609 keywords were identified. Fig. 6 illustrates the network visualization, showing that with the limitation of seven items, six clusters are recognized. Keywords in each cluster have a close relationship and essential role to the core terms (metallogeny, mafic and ultramafic). The lines between items illustrate the relationship between topics in each field; the more lines between items, the closer the relationship between documents. Meanwhile, the thickness represents the frequency of the items. The research issues that have the closest correlation with the main topic, the frequency and percentage as well included geochemistry (62; 2.4%), metallogeny (39; 1.5%), petrogenesis (29; 1.1%), gold (27; 1.0%) and geochronology (23; 0.9%). Geographically, related research was still focused on China (involving Tibet, South China, North China, Xinjiang, and Tianshan), Finland, and Iran. Regarding metal elements topic research, the highest focus was on gold, platinum group, zircon, tungsten, copper, iron, uranium, and nickel. Concurrently, widely used approaches included geochemistry, petrogenesis, geochronology, fluid inclusions, zircon U-Pb dating, and Hf isotopes. Fig. 7 shows the visualization of topic density from 1969 to 2022, in which each item is represented with a colour depending on the density. Dark blue colour indicate topics with high density or frequency, while light colours are topics with relatively low density or frequency (Eck and Waltman, 2010; Jakah et al., 2021). Fig. 7 demonstrates that some topics with high frequency include geochemistry, metallogeny, petrogenesis, gold, geochronology, metallogenesis, fluid inclusions, tectonic setting, zircon U-Pb dating, mineraliza-

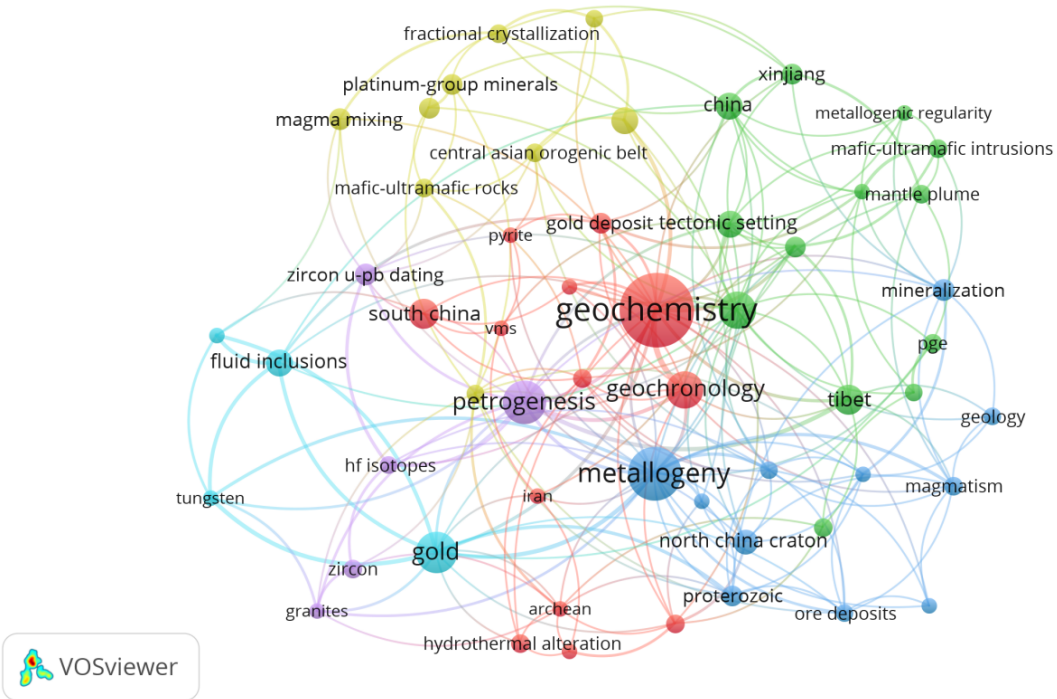

Figure 6. Visualization network of co-occurrences 1969-2022.

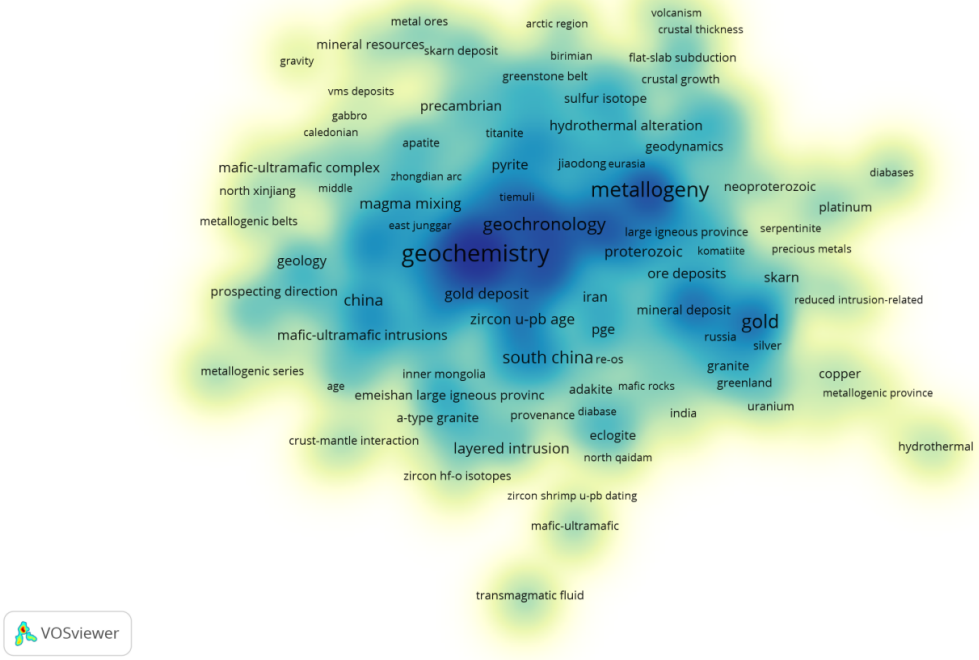

Figure 7. Visualization keyword density of co-occurrences 1969-2022. The dark blue colour depicts high-density, and the light yellow colour represents low density.

tion, magma mixing, Proterozoic, layered intrusions, gold deposits, platinum group minerals, Paleoproterozoic, zircon, magmatism, ore genesis, mantle plume, hydrothermal alteration, fractional crystallization, mafic-ultramafic intrusions, mafic-ultramafic rocks, ore deposits, and geology. Subsequently, some relatively low-frequency topics such as ore magmatic systems, oxidation state, Paleozoic, picrite basalts, precious metals, reduced intrusion-related, tonalite, flat-slab subduction, hydrothermal processes, palladium, economic geology, epithermal gold-silver mineralization, granite-related uranium deposits, La-ICP-MS U-Pb dating, lithium, gabbro, metavolcanic rocks, black shale, hydrocarbons, oil, ore fluids, thermochemical sulfate reduction, Cu-Ni-PGE ores, Rb-Sr geochronology, rare earth elements, Re-Os analysis, Sm-Nd, Sr-Nd-Pb-Hf isotopes, and dunite-peridotite-pyroxenite-gabbro associations.

4. Conclusions

A total of 972 publications related to metallogeny in mafic-ultramafic rocks from 1969 to 2022 have been identified. The most productive countries during the period include China, Australia and Canada, while the most productive affiliation is the Chinese Academy of Sciences. Ore Geology Reviews is the journal that published the most in this field, but the Journal Mineralium Deposita ranks the highest in citation per document. The most productive authors include Santosh M, Mao J, and Pirajno F. Earth and planetary sciences and environmental sciences dominate related studies, followed by environment and engineering. There are a few other fields, such as multidisciplinary, energy, agricultural and biological, chemistry, social sciences, and mathematics. Geographically, related research is still focused on China. Gold, platinum group, zircon, tungsten, copper, iron, uranium, and nickel are the metals with the highest focus, while the widely used equipment or methods involved include geochemistry, petrogenesis, geochronology, fluid inclusions, U-Pb zircon dating, and Hf isotopes. Current research topics with the highest frequency in 2018 to 2022 include geochemistry, petrogenesis, geochronology, fluid inclusions, gold, tectonic setting, fractional crystallization, mineralization, mineralogy, and zircon U-Pb age. Contrary, there are not many research topics until 2022, such as ore magmatic systems, oxidation state, Paleozoic, picrite basalts, precious metals, reduced intrusion-related, tonalite, flat-slab subduction, hydrothermal processes, palladium, and economic geology. Also, epithermal gold-silver mineralization, granite-related uranium deposits, La-ICP-MS U-Pb dating, lithium, gabbro, metavolcanic rocks, black shale, hydrocarbons, oil, ore fluids, thermochemical sulfate reduction, Cu-Ni-PGE ores, Rb-Sr geochronology, rare earth elements, Re-Os analysis, Sm-Nd, Sr-Nd-Pb-Hf isotopes, and dunite-peridotite-pyroxenite-gabbro associations.

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Availability of data and materials
The data that support the findings of this study are available from the corresponding author, upon reasonable request.

Conflict of interests
The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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