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Geochemistry of Manganese Ore Deposits of Mn-hosting Top-10 Countries with A Case Study of Egypt: A Review

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Abstract:

Manganese deposits are very important. Not only in industry but also because of its medical and life applications. Based on geochemistry, the exact Mn-forming process can be known if it's hydrothermal, sedimentary, supergene, and so on.

Globally, these Mn deposits occupy higher ranks in some countries as an economic metal. The top ten countries according to the 2022 Metal Commodity Summaries of the U.S. Geological Survey are South Africa, Gabon, Australia, China, Ukraine, Ghana, India, Côte d'Ivoire, Brazil, and Malaysia.

The main four metallogenetic types of manganese ore deposits across the globe are sedimentary (or volcano-sedimentary); magmatogenic (hydrothermal or contact-metasomatic); meta-morphogenic; and weathering-related deposits.

In these countries, Mn deposits occur as a result of different processes. Such as those that were formed by the hydrothermal action as manganese deposits of *the Oklo Region in Gabon; Northern Guizhou in China; Nishikhal Formation in southern Odisha, India*. Others were formed by supergene processes such as those of *the State of Amapá in Brazil*.

There is an ongoing debate between investigators about the Mn-forming process in some localities of these aforementioned countries such as the Mn deposits of *Kalahari in South Africa; the Mankwadzi region in southern Kibi Winnieba, Ghana*.

Furthermore, the Mn deposits of *the Um Bogma Region, West-central Sinai, and Egypt* as a case study of the present paper also differ in origin between hydrothermal and sedimentary.

In the present paper, the geochemical studies of the manganese deposits of these top ten countries, done by some investigators will be surveyed and discussed.

Keywords: Geochemistry, Manganese, Deposits, Origin, Ore, Egypt

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Introduction

Manganese is ranked 12th as one of the most abundant elements in Earth's crust. It's considered one of the most required metals globally due to its remarkable properties and varied applications in the production of some daily-used things such as steel and batteries. The last updated estimation of manganese reserves declares that there are about 1.5 billion metric tonnes across the globe. The annual production of such an element is about 18.5 million tonnes globally.

The grace of manganese over the industry is great. Because of its remarkable usage in different aspects of the industry. It's widely used as an enhancer for key construction materials, a coloring material for bricks, and animal feed, and a good fertilizer for plants. Additionally, the production of steel and the manufacture of high-capacity batteries depend mainly on such an element. In addition, manganese is used as a cathodic material in zinc-carbon batteries. During the refining processes of crude oil, manganese may be used as an important additive to coat the car's tanks on the way to protect its engine. As aforementioned, manganese can be used as the main component in the preparation of lithium-nickel-manganese-cobalt oxides ($LiNi_xMn_yCo_zO_2$) which are used to fabricate lithium-ion batteries that are widely demanded worldwide.

Manganese, like any other important ore, occurs in many countries all over the world, but it does occur in a remarkably sufficient abundance in certain countries rather than others. According to THE METAL COMMODITY SUMMARIES 2022 REPORT of the U.S. Geological Survey, the top-first country of them is South Africa which holds the largest reserves of manganese, at around 640 million metric tonnes. The most globally famous Kalahari Basin in South Africa country where the Hotazel mine locates, which holds 80% of the whole world's known manganese ore resources. The second of the score is Gabon which locates on the central-western coast of Africa, holding about 3.6 million metric tonnes of manganese. Most of these Gabon's manganese ores are hosted in Moanda town, exactly in the Bangombe plateau. The third producer of manganese is Australia, holding 3.3 million metric tonnes. The fourth producer is China which produces about 1.3 million metric tonnes. China is not only a remarkable producer of manganese, but also a considerable consumer of it in steelmaking. The fifth producer after China successively is Ukraine. The manganese output of this country is about 670,000 metric tonnes. Although it's the fifth country in manganese production, it's considered a major importer of manganese products. The sixth one is Ghana. The manganese output of Ghana weighed 640,000 metric tonnes in 2021, up slightly from the 637,000 metric tonnes it produced in 2020. Most of these manganese deposits are exploited from the Western region of Ghana. the seventh largest producer is India which produced 600,000 metric tonnes in 2021. This amount is less than what was produced in 2020 (632,000 MT). In any way, India uses large amounts of manganese in steel production. The eighth is Cote d'Ivoire which output 500,000 metric tonnes in 2021, a fall from 525,000 metric tonnes of the year prior. The ninth is Brazil which outputs 400,000 metric tonnes in 2021, lower than what it put out in 2020 (494,000 metric tonnes). The tenth is Malaysia. Its output of manganese in 2020 is 360,000 metric tonnes, and there is an increment in the amount produced in the previous year (347,000 metric tonnes).

The processes of manganese extraction and refining are complex. A good number of successive processes eventually reach completely pure manganese suitable for various medical and industrial uses. Many chemical compounds are usually used, one after the other, for these processes. Such as Carbon Monoxide (CO) which plays an important role in the reduction of higher manganese oxides such as MnO2, Mn2O3, and Mn3O4 into manganous oxide (MnO). Then, manganous oxide, as a lower oxide, can be reduced into the pure metal itself by carbon at elevated temperatures. Unfortunately, some complications may occur that impede the completion of a smelting extraction process, due to the presence of some oxides of the impurities existing in the original ore, which combine with this manganous oxide preventing it from reducing into a pure metal. Basic fluxes such as Lime (CaO) can be used to remove these acidic impurities such as Silica (SiO2). However, this aforementioned method may lower the amount of manganese metal in such an ore by producing some unwanted slags tending to dissolve this manganese. It is possible to control such a problem by controlling the smelting temperature itself and the acidity or the basicity of this silica slag so that the silica can be converted to silicon tending to enter the molten metal.

It should be noted that manganese exists in many different varieties like high-carbon "also called the standard", medium-carbon, and low-carbon ferromanganese, in addition to silicomanganese. According to the ASTM (1999) last edition, in the high-carbon variant which can be smelted directly from manganese ores, the manganese grades between 78 and 82 percent, the iron is about 12%–15%, up to 7.5% carbon, up to 1.2% silicon, and very few percentages of P% and S%, which do not exceed the one percent (0.35% and 0.05% respectively). This type of alloy is produced by either a submerged arc furnace or a blast furnace. In the medium-carbon variant, the manganese percentage is about 80%–85%, and equal amounts for C% and Si%, which both equal 1.5% as a maximum percentage, in addition, the P% and S% percentages are both less than 1% (0.30% and 0.02% respectively). In the low-carbon variant, 85%–90% is the average percentage of manganese that exists in such a variant, the Si% is 2%, and the P% and S% percentages equal to 0.2% and 0.02% respectively. These two low- and medium-carbon alloys are produced by either oxygen or silicothermic pneumatic processes. Finally, in the silicomanganese, the Mn% varies from 65% to 68%, the carbon percentage is about 1.5%, the amount of Si existing in such a manganese typical variant is between 18.5%–21%, and the P% and S% percentages are 0.2% and 0.04% respectively as the maximum existence. This alloy is produced by the carbothermic reduction process of manganese ores in a submerged arc furnace. All the aforementioned variants of ferromanganese alloys are free of Nitrogen elements.

The geochemistry of manganese attracted the attention of many investigators from a very early time. Because it's of great importance in the detection of the processes which produce the important economic ore deposits, and the exact origin of them, such as the ore highlighted in the present paper.

This work aims to survey the utmost recent knowledge and the last published articles about the geochemistry of manganese ore deposits across the Mn-hosting top 10 countries, especially in the localities where the manganese deposits occur in economic quantities, on the way to detect the origin of each one of them, by relying on the main outcomes of geochemical analysis done by investigators interested in the geochemistry of such an important metallic deposit in each country of these top ten ones, with a focused overview on the country of Egypt exactly in the Um Bogma Region as a case of study which will be covered geochemically, stratigraphically, and geologically in detail in this paper.

Geochemistry of Mn Ore Deposits of Top-10 Hosting Countries

1. **South Africa:**
   Kalahari in South Africa hosts manganese deposits, and it's considered one of the most important deserts. These deposits were studied by many investigators, by taking samples from different localities of the Mn-bearing region in such a desert, it's noted that these samples contain either manganese oxide or iron oxides, in addition to manganese carbonate which are all characterized by the presence of microbial structures in them (Zhegallo et al, 2000; Shkolnik et al, 2004).
   There is a debate between different authors over the manganese origin of this region. Some of them argue that these manganese deposits were formed during sea-level fluctuations, and then the effect of it appeared upon the manganese oxides (Frankes and Bolton, 1984; Cannon and Force,1983; Force and Cannon, 1988) Others believe that manganese oxides were formed as a result of deep oceanic Mn-rich water (Cannon and Force, 1983).
2. **Gabon:**
   Manganese deposits economically occur in Oklo Mine Region, near the Franceville town of Gabon. Mossman et al (1998) found that; 1) Some samples plucked from such a region have a lower content of some compounds such as Al_2O_3, K_2O, MnO, MgO, Fe_2O_3, TiO_2, CaO, and Na_2O. 2) There is a noticeable increase in the percentages of both Silica and Iron. Such an increase is due to the lack of quartz and the increase in the clay and carbonates in these samples.
   In addition, the samples contain many rare earth elements, as the source of the elements varies from one sample to another, it was found that; 1) There are elements such as U, Ba, Sc, Ga, Sr, V, Zn, and Zr that came from sandstone. 2) Some of the elements are caused by hydrothermal fluids. 3) Elements like Ag, Au, Cr, Ba, Nb, Sn, Pb, and Cd resulted from radioactive decay and nuclear (Menet, C. et al, 1992). Depending on the aforementioned cases, the manganese deposits in Oklo Region are hydrothermal in origin (Bros, 1993).
3. **Australia:**
   The manganese deposits of Australia, especially in Groot Eylandt were studied by many investigators. It's found that these sediments are represented by manganese oxides, which are Supergene in origin. In general, some elements are directly proportional to Mn, such as Sr, where the proportionality constant reaches 0.624. Manganese deposits in this region are divided into four types; 1) Cemented and Uncemented Oolites and Pisolites, which contain the same concentration of minor and major elements, but Cemented Pisolites are rich in K element, while Uncemented ones are rich in some elements such as Al=5% and Si=10%, 2) Concretions which are characterized being rich in elements such as K, 3) Sands and Siliceous ores, predominantly silica, 4) Kaolinitic ores, which contain a large proportion of kaolinite minerals (Bolton et al, 1992).
   These types were also not devoid of trace elements. It was found that Pisolitic ores contain a lower percentage of trace elements than Oolitic ones, but the two types are distinguished by their content of Ni. Concretion ores rich in V. Sands and Siliceous Ores contain a higher percentage of the element V (1200ppm) and also contain trace elements similar to the first type. Kaolinite ores contain Zr (Pracejust, 1989).
4. **China:**
   Manganese deposits in northern Guizhou, southern China are considered to be the most economic spot due to what it contains such an industrially remarkable deposit. Manganese deposits are represented in many minerals differing in the proportions of their presence, such as MgO (4.03 to 5.51 w%), CaO (10.35 to 13.60 w%), MnO (24.01 to 25.2 w%), SiO_2 (5.64 to 11 w%), Al_2O_3 (3.19 to 6.00 w%), Fe_2O_3 (2.14 to 2.39 w%), K_2O (0.06 to 0.08 w%) and Na_2O (0.04 to 0.09 w%). Also, there are some iron deposits associated with these manganese deposits, found in the form of minerals of various shapes such as; 1) Carbonate Minerals (Siderite), 2) Oxides and Sulfides (Marcasite and Pyrite), and 3) Clay Minerals

(Celadonite and Nontronite). In addition, Mn combines with Fe to form many different forms Based on Raman Diagram to Carbonate, Silicate, Sulfides, Oxides, and Hydroxides. From this point of view, the manganese deposits in northern Guizhou are due to hot hydrothermal solutions (Yu et al, 2021).

Another major occurrence of manganese deposits is recorded in Jixian County which is located in the northern part of the north China platform. These deposits were studied by (Fan, D., Yang, P., and Wang, R., 1999). The manganese deposits in this area consist of type B-Mn, including Chambersite output of high salinity, low alkalinity, and high Mn, B, and Mg content, and Rhodochrosite minerals formed as a result of tectonic movements in the middle Proterozoic era. It formed what is known as the Gaoyzhung Formation, which contains several layers of dark-gray dolostone, muddy dolostone, and B-Mn-bearing siliceous shale. It's geochemically composed of Mn, which is divided into; 1) Manganese Carbonate, and 2) Manganese Oxide. Manganese deposits of this region are also rich in some components such as Fe, SiO_2, P, and S (Yao et al, 1995). Based on the foregoing, Jixian manganese deposits are of primary and supergene origin (Fan et al, 1999).

5. **Ukraine:**

Due to the significant impact of its manganese deposits on the world's economy, Nikopol in the south of Ukraine is considered one of the most economic cities which hosts manganese deposits occurred in huge quantities. Hein et al. (1997), Bau et al. (2014), Josso et al. (2017), Garnit et al. (2020), and Dekov et al. (2020) all agreed on the classification of these Nikopol Mn-Fe deposits into three main classes: hydrothermal, diagenetic, and hydrogenetic.

According to the geochemical analysis by different methodologies for the Mn oxides and hydroxides as the most abundant variants of these Nikopol manganese deposits, done by Sasmaz et al. (2020), the major oxides of the Nikopol manganese ores are MnO (40.7 wt.%), Fe_2O_3 (4.1 wt.%), SiO_2 (15.6 wt.%), Al_2O_3 (4.17 wt.%), CaO (7.1 wt.%). And the total rare earth elements "REEs" vary from 60 to 197 ppm, with an average of 108 ppm. The ore-forming rocks of these Nikopol manganese deposits were primarily biogenic or marine chemical deposits, because of positive Ce anomalies (Sasmaz et al, 2020).

The values of Co, Ni, Cu, Sr, As, Cd, and Ba are high. But these of V, Rb, Nb, Hf, U, Th, Pb, and Zn are low (Taylor and Mclennan, 1985). Additionally, there are Ce anomalies that are close to the whole one in comparison to similar environments. And the hydrothermal contributions to seawater (Sasmaz et al, 2020). Depending on the forgoing, these manganese oxide and hydroxide ores formed rapidly within oxic and/or suboxic seawater.

6. **Ghana:**

The most economic manganese deposits of Ghana occurred in the Mankwadzi region which is located in southern Kibi Winnieba. By studying such deposits, it's found that they contain some elements which are less than 61 ppm, such as Cr, U, Th, Pb, Ta, Hf, Ba, Cs, Nb, Rb, Sc. It also contains different percentages of compounds such as SiO_2 (44.4 – 51.4 wt.%), Al_2O_3 (10.75 – 14.45 wt.%), MnO (16.75 – 57.40 wt.%), MgO (1.63 – 3.15 wt.%), Fe_2O_3 (6.92 – 13.75 wt.%), CaO (2.77 – 10.15 wt.%), Na_2O (0.02 – 0.08 wt.%), and K_2O (0.01 – 0.14 wt.%). It's also noted that these deposits contain percentages of Co (24 – 1850 ppm), Ni (844ppm), Zn (55 – 721ppm), and Sr (4.7 – 123.5 ppm), (Ibrahim et al, 2022). Accordingly, these manganese deposits are due to hydrothermal or pyrometasomatic fluid activity of regional metamorphism (Dzigbodi-Adjimah, 2004).

7. **India:**

The major occurrence of manganese deposits in India is recorded in Anmod Region in southern India. These deposits were studied by Sethumadhav et al (2010). It became clear by the aforementioned author's study that this area was formed from manganese deposits of different origins, and therefore it leads to a change in the chemical composition of these deposits.

The first type of manganese deposit that occurred in such as region is Metasedimentary Manganese ore, it consists of medium and large granules resulting from alteration. It is chemically composed of MnO in a higher concentration. Otherwise, the concentration of other compounds such as SiO_2, TiO_2, Al_2O_3, Fe_2O_3, MgO, CaO, Na_2O, K_2O, and P_2O_5 decreases.

Some elements such as Co, Cu, and V elements are negatively proportional to Mn. But Si, Al, K, Ni, and Zn are directly proportional to Mn. The second and third types are Supergene and Ferromanganese deposits. The utmost differences between the two these types depend on the Fe_2O_3 component, and these differences lead to inferring the presence of the goethite mineral. On the other hand, Manganese is inversely proportional to Fe and directly proportional to Sr, Rb, Co, Ni, and K. Additionally, it contains many trace elements such as Ce and La.

Manganese deposits in India are also recorded as a remarkably economic occurrence in Nishikhal Formation, located in southern Odisha, India, by many investigators. By studying many samples plucked from such a region, it's found that there are many types of manganese, outlined as the following; 1) High-grade Manganese ores formed as a result of cavity filling, it contains a lot of minerals such as Romanechite, Pyrolusite, and Cryptomelane. The proportion of manganese is more than 40%. 2)

Ferruginous Manganese ores containing minerals Cryptomelane and Goethite. 3) Siliceous Manganese ores which contain minerals such as Silicate, Quartz, and Orthoclase. 4) Botryoidal ores are in the form of lenses. 5) Friable ores are characterized as a result of manganiferous quartzites. 6) Wad ores are found in the form of lenses and are also formed as a result of a small specific gravity.

Based on the study of these samples, it was found that they contain different percentages of MnO_2, Fe_2O_3, and SiO_2 compounds. Additionally, these samples contain elements such as Cu, Pb, and Ni resulting from high-grade metamorphic terrains (Acharya et al, 1997). The Nishikhal formation is characterized by the dominance of some compounds over others, such as the control of CaO over Mg, and K_2O over Na_2O. It also contains a percentage of Al and Ti (Mookerjee, 1961). K_2O content ranges from 5.01% to 1.22%, with BaO content being lower than K_2O (Frenzel, 1980). Depending on the forgoing, the manganese deposits in Nishikhal are of hydrothermal origin (Choi and Hariya, 1992).

8. **Côte d'Ivoire:**

Côte d'Ivoire has many places of manganese ore deposits occurrence. Such as that occurred at the Lauzoua manganese mine, some 180 km from Abidjan (the economic capital of Côte d'Ivoire). In other words, These Lauzoua manganese deposits are located in the region of Grand Lahou in the south of Côte d'Ivoire. From 1960, manganese deposits in the Lauzoua area were used by a French company, until their exploitation of manganese was stopped in February 1970 (Dago Beugre, 2014).

These manganese deposits of the Lauzoua area were formed as a result of long lateritic weathering processes for protores, and these protores are spessartites and quartzites resulting from the metamorphic recrystallization of the initial deposits of the oxides and the carbonates (Dago Beugre, 2014). According to Beugre's petrographical investigations, the main minerals which are considered to carry the primary mineralization are braunite, spessartite, and rhodochrosite associated with accessory minerals such as rutile, pyrite, pyrophanite, chalcopyrite.

9. **Brazil:**

Manganese deposits in Brazil occurred in many localities. But in the State of Amapá, they do major occurrence, these deposits of the aforementioned locality were studied by some investigators such as; Holtrop (1965), Scarpelli (1973), Rodrigues et al (1986), Gebert (1989), Mclennan (1989), and Costa (1997).

Manganese deposits in such a region are divided into two main types; 1) Manganese Carbonate which is characterized by the proportion of manganese in it reaches 46 – 54 w%, containing many compounds such as CO_2, SiO_2, Fe_2O_3, CaO, MgO, Al_2O_3. It contains a small percentage of rare earth elements, and it's rich in elements such as Ni, Co, Ce, V, and Ba (Chisonga et al, 2012). 2) Metapelite Group which is represented in biotite schist and graphitic schist, containing compounds such as SiO_2 (43 – 79 w%), TiO_2 (0.5 – 1 w%), with depletion of some elements such as K_2O, P_2O_5, Sr (Mclennan, 1989).

Relying on the aforementioned studies' outcomes, the manganese deposits of this region are of supergene origin.

There are many other major occurrences in Brazil such as that of the state of Sao Paulo in southeastern Brazil and Buritirama Province. The firstly mentioned is supergene in origin (Chisonga et al, 2012). And in Buritirama where the manganese deposits were produced by weathering, is also of supergene in origin (Salgado et al, 2019).

10. **Malaysia:**

Manganese ore deposits occur in many localities in Malaysia. Such as Johor, Kelantan, Pahang, and Terengganu. These aforementioned localities are considered economic in their impact. Also, Manganese deposits are associated with volcanic-hosted massive sulfide deposits in the Tasik Chini district which will be discussed in such a paragraph. Geochemically, these associated Fe-Mn deposits are high in Si, Fe, Mn, and base metals such as Cu and Ni. With variable percentages of Al, Zr, and Ti. In addition to high levels of Ba, As, U, and V. Mineralogically, these Fe-Mn-associated layers have some minerals within, such as quartz, magnetite, hematite, barite, and pyrite. In addition to some clastics (Basori et al, 2020). Depending on the forgoing, these Fe-Mn deposits outcropped at the Bukit Botol and Bukit Ketaya were formed in a local submarine environment due to the hydrothermal activity on the seafloor by the remarkable process of mixing of mainly chemical and small detrital components in such an environment (Basori et al, 2020).

Case Study

Manganese ore deposits of Egypt occur in significant commercial quantities in only three places such as Um Bogma Region in west-central Sinai, Gebel Abu Shaar El Qibli in the southern part of the Esh El Mellaha range, and Gebel Elba of Halaib district in the southern part of the Eastern Desert. Economically, the most remarkable and exploitable occurrence of the aforementioned places is in Um Bogma Region. Also, manganese occurs in Abu Ghosun and Ras Banas in the Southern Eastern Desert, but in non-economic small quantities. In this case study, the manganese ore deposits of the Um Bogma Region will be discussed and surveyed in detail.

1. **Geologic Setting:**

   Um Bogma Formation and its enclosed Mn ore deposits which occur within the lower dolomitic part of this formation are both limitedly distributed and restricted only to the Um Bogma Region. In other localities, Um Bogma Formation does not expose. Otherwise, the Abu Thora Formation of the same age exposes. In the southern part of the Um Bogma Region, at Wadi Ferin, Wadi Mokattab, and Gebel Abu Durba, Um Bogma Formation is completely missing and the overlying Abu Thora Formation overlies directly with the Cambrian Naqus Formation (Klitzsch, 1990 and El Barkooky, 1992). Also, in the northern part of Wadi Qena, Eastern Desert, the Abu Thora Formation rests directly on the Cambrian Naqus Formation (Abdallah et al, 1992). At Wadi Araba, along the western side of the Gulf of Suez, the Um Bogma Formation is also missing, while other formations expose, such as the Upper Carboniferous-Permian shallow-marine and continental successions of Rod El Hamal, Abu El Darag, and Eheimar Formations. These aforementioned geological field facts are very remarkably excellent indications, which can reflect the tectonic instability of the Um Bogma Region during the Lower Carboniferous time (El Aref, 1994).

   The basaltic eruptions of the Permo-Triassic age of the Um Bogma Region form sheeted-like bodies over the clastic sediments of the Abu Thora Formation at the Um Bogma Region, and in the direction to the east of the region under study, at Gebel Ghorabi, and towards the south, at Gebel Farsh El Azraq.

   Faults are the most dominant structural elements which widely occurred within the Um Bogma Region and hugely left their prints on the rock units of such a region. These faults cut the Paleozoic rocks in the area under survey with vertical displacement reaching up to 100m, sometimes forming horsts and grabens. These faults can be grouped into three main classes, as the following: a) NNW-SSE trending normal faults (Red Sea trend) where the Permo-Triassic basaltic dykes erupted. b) NW-SE trending faults (Gulf of Suez trend) where the main Wadies of the Um Bogma Region incised, such as the Wadies of Nasib, Baba, Bala, and El Lehian. c) E-W trending faults where the two Wadies of Sahu and Abu Thora incised. The group of faults of the category (b) was responsible for the development of the grabens and horsts of the different Paleozoic stratigraphic units, that existed in the Um Bogma Region. And the group of faults of categories (b) and (c) are both responsible for the uplifting of Gebel Samra-Gebel Nukhul, Wadi Baba-Wadi Sid El Banat, Um Bogma-Wadi Nasib, Gebel Um Reglein, Adedia, and Gebel Ghorabi-Gebel Sarabit El Khadim blocks.

2. **Stratigraphy:**
   a) **Stratigraphy of Um Bogma Region:**

      Barron (1907) subdivided the Paleozoic outcrops of Um Bogma region, in west-central Sinai, Egypt into Lower Sandstone Series, Carboniferous Limestone Series, and Upper Sandstone Series. Kora (1984) subdivided these exposures depending on their field observations, lithological composition, and fossil content into six rock units, starting from the base upward: Sarabit El Khadim, Abu Hamata, Nasib, Adedia, Um Bogma, and Abu Thora Formations. The four first Formations are Cambro-Ordovician in age, but the two last ones are Carboniferous. These six Formations are followed upward by basaltic sill intrusions and lava flows (40m). The Um Bogma (shallow open marine environment) and the Abu Thora (fluviatile to coastal marine environment) Formations represent a different sedimentation phase that occurred in the Carboniferous period. These formations represent the Carboniferous Limestone Series and the Upper Sandstones Series of Barron (1907) respectively. The whole Paleozoic succession overlies unconformably the peneplain surface of the Precambrian basement rocks and underlies unconformably the Permo-Triassic red beds.

   b) **Stratigraphy of Um Bogma Formation:**

      Um Bogma Formation varies in its thickness from 0-10 m in the southeastern and northeastern parts and reaches its maximum thickness of about 30-40 m in the northeastern part between Gebel Nukhul and Wadi Khaboba. The Um Bogma Formation is essentially a pink-grey dolostone sequence. Most of the aforementioned rocks of these dolostone beds are very hard, but the ones that occupy the middle part of this formation are of different marly dolostones and earthly limestone which alternate with other rocks of soft yellowish siltstone in composition. Quartz grains which are in the size of the sand and the silt, with few pebbles, are also recorded within the whole succession, and the southeastern part of the area is considered to be related to the terrigenous facies, which is more typical in this limited area, of the whole region of Um Bogma. In most beds of the Um Bogma succession, veinlets of Mn and Fe are common, but most existed and the high economic ones are confined to the lower member of the Um Bogma Formation. Kora (1994) subdivided the economic Mn-bearing Um Bogma Formation into three lithostratigraphic units including from base to upward: Ras Samra Member, El Qor Member, and Um Shebba Member. The Manganese deposits are recorded in the three members, but the most remarkable economic ones are confined to Ras Samra only.

3. Geochemistry:

The geology and mineralogy of the Mn ore deposits of the Um Bogma Region were studied by some investigators, such as; Mart and Sass 1972, Magaritz and Brenner 1979, Saleeb et al. 1987, Khalil 1988, Saad et al. 1994, and Khalifa 2014. There is a dispute between investigators about the origin of the most economic Mn ore deposits in the Um Bogma Region.

a) Geochemical Studies Outcomes:

There is an inverse relation between Mn and Fe oxides in some of the Mn ore samples plucked from the lower member of the Um Bogma Formation with a suggestion that fractionation between two these Mn and Fe elements took place during their deposition (Saad et al, 1994).

There is an enrichment in some elements such as Pb, Cu, Zn, and Ba. With a depletion of Co, Ni, Be, Mo, Sr, and Sn (Saad et al, 1994).

The main three types of Mn-Fe Ore deposits are 1) Mn-rich Ore, 2) Fe-rich Ore, and 3) Fe-Mn-rich Ore (Khalifa, 2014). This was investigated depending on field observations, MnO and Fe_2O_3 content, and MnO_2/Fe_2O_3 ration.

Bearing in mind, the strong negative correlation between MnO and Fe_2O_3 was noticed in such an ore deposit reflecting that precipitation of these Mn ore deposits occurred under different environmental conditions (Saad et al, 1994 and Khalifa, 2014).

K_2O, Al_2O_3, MgO, Co, Cu, Zn, Sr, and Sn Components were noticed to be negatively correlated with Fe but positively correlated with Mn (Saad et al, 1994). There is a positive correlation between Ba and MnO (r=0.75) and Cu and MnO (r=0.63) reflecting that both Ba and Cu were selectively adsorbed on the manganese oxides (Khalifa, 2014).

b) Origin of Um Bogma Mn Ore Deposits:

There is an ongoing debate between the investigators about the origin of the Um Bogma Mn Ore deposits. Some of them such as Gindy (1961), Nakhla et al. (1963), and Saad et al. (1991) considered these deposits hydrothermal in origin, giving some evidence, such as that these deposits are highly related to the most dominant structural element in such a region, the faults, and such deposits become more concentrated in the points near these faults. The manganite and hausmannite minerals were found associated with these Um Bogma Mn deposits (Hewett, 1972 and Roy, 1981). Additionally, the dolomitic limestone partially disappears whenever these deposits occur with total disappearance in such a region. Finally, Saad et al. (1991) reported the presence of Relict, Core, and Rim Replacement textures within these Mn deposits, in addition to the complete replacement of the *Fusilina* sp. foraminiferal tests by polianite.

Others such as Mart et al. (1972), Magaritz and Brenner (1979), and Kora (1984) gathered on the sedimentary origin of these deposits. The first evidence they introduced is that Um Bogma Mn deposits are occupied within the same stratigraphic horizon and they are older than the faults that existed in the region. The second one is that hematite and goethite minerals were found associated with manganite and pyrolusite ones. Additionally, there is a synchronization between the dolomitization and the mineralogical and chemical reconstitution of these zoned deposits. Finally, there is a narrow transition zone between the Mn ore and the laterally surrounding dolomites. But there is no transition in such mineralization between the Mn ore bodies and the overlying unconformable strata themselves.

Discussion

Geochemistry is an effective methodology for the detection of the major and the trace elements along with knowing the main chemical compounds of ore deposits under investigation (Krauskopf, 1967). There are about 5000 publications focusing on geochemistry, environments, the composition of manganese ores, and more about such an important metal (Kuleshov, 2017).

Although our current days are known as the silicon age, there is a great need for manganese in steel production with no satisfactory substitute for it in our society (Gutzmer et al, 2009). One of the most effective roles of such metal in the human body is to fight the free radicals in the body as a main component in the Superoxide Dismutase SOD antioxidant enzyme (Azadmanesh et al, 2018).

Geochemically, there is a remarkable difference between intrusive igneous rocks and corresponding extrusive ones which have the same percentage of SiO2, in the amount of MnO (Borchert, 1970). Thus, manganese metal is characterized by the negative values of potential ore metal. So, the manganese tends to be strongly concentrated in magmatic residual solutions. Otherwise, the chromium and the titanium both have positive values of the aforementioned factor, so, they tend to be concentrated in the significant early products of fractional crystallization of basaltic magmas.

Many investigators such as N. S. Shatsky, S. Park, S. Roy, I. M. Varentsov, V. P. Rakhmanov, V. N. Kuleshov, and others provided an utmost remarkable knowledge about the basis of classifications of all globally-distributed and known manganese deposits. There are four main genetic types of such deposits: 1) Sedimentary and Volcano-sedimentary, 2) Hydrothermal and Contact-metasomatic, 3) meta-morphogenic by the action of regional and contact metamorphism of the two aforementioned types, and 4) weathering-related crust deposits (Kuleshov, 2011).

Although the main Mn ore deposits types and classes are now well-known and excellently determined, there is a complication in determining the origin of manganese deposits of these top-10 countries spotlighted in the present paper due to the significant differences in investigators' opinions.

The manganese ore deposits of hydrothermal or contact-metasomatic types titled magmatogenic type, with a deep manganese source are very rare and missing economic significance (Kuleshov, 2011). Reversely, Mn ores of sedimentary origin are more abundant and economic than that of hydrothermal origin.

For Egypt, although it's not one of the top-10 Mn-hosting countries highlighted in the present paper, its Um Bogma manganese deposits are important deposits in industries of various classifications, heavy or light, and manganese is also used as a basic element in the Egyptian steel industry. Despite the debate that still exists among investigators about the origin of such deposits, their extraction and exploitation did not stop, and this area is still an important spot for this ore to this day.

Conclusion

Manganese is an essential metal for all aspects of life. It’s widely used in two both small and huge metallurgical industries. In addition, manganese is also an important element in the vital processes of the human body. Hence, we conclude how important it is in everything around us.

Manganese is an ore that occurred throughout almost all of geological history. But the most important manganese ore deposits exploited today for the industry are confined to the early Proterozoic period. Additionally, in this early Proterozoic period, the manganese ore deposits of some of the top-10 countries mentioned in this paper such as South Africa, Gabon, Ghana, Brazil, etc. were formed.

There are some manganese deposits in some of the top-10 Mn-hosting countries mentioned in our paper, the dispute about their origin still exists between investigators, but the matter of extraction and production of such important metallic deposits is still ongoing and non-stop.

Summing up what is reviewed above, the origin of manganese ore deposits of these top-10 Mn-hosting countries can be outlined below:

- Mn deposits of the Kalahari in South Africa are a point of contention among the investigators. Ones consider them to occur during sea-level fluctuations. Others tend to that they were formed as a result of deep oceanic Mn-rich water.
- Mn deposits of the Oklo Mine Region in Gabon are hydrothermal in origin.
- Mn deposits of Groot Eylandt in Australia were found to be represented by manganese oxides, which are Supergene in origin.
- Mn deposits occurred in northern Guizhou in southern China due to hot hydrothermal solutions. And the Mn deposits of the Jixian County in the northern part of the north China platform are of primary and supergene origin.
- Mn deposits of the Nikopol in the south of Ukraine are found to be Mn oxides and hydroxides that were formed rapidly within oxic and/or suboxic seawater.
- Mn deposits in the Mankwadzi region located in southern Kibi Winnieba in Ghana are due to hydrothermal or pyrometasomatic fluid activity of regional metamorphism.
- The Anmod Region in southern India was formed from manganese deposits of different origins. These deposits are Metasedimentary, Supergene, and Ferromanganese. The Nishikhal Formation, in southern Odisha in India, also hosts Mn deposits of hydrothermal origin.

- Mn deposits of the Lauzoua mine in Côte d'Ivoire were formed as a result of long lateritic weathering processes for protores (spessartites and quartzites). Bearing in mind, these protores were formed as a result of the metamorphic recrystallization of the initial deposits of the oxides and the carbonates.
- Mn deposits in the State of Amapá in Brazil are of supergene origin. Other Mn occurrence is also recorded in the same country in the state of Sao Paulo, and It is supergene in origin. In addition to the Buritirama Province where the Mn majorly occurred as a supergene origin.
- Mn deposits in the Tasik Chini district in Malaysia which are associated with the volcanic-hosted massive sulfide deposits, were formed in a local submarine environment due to the hydrothermal activity on the seafloor.

Concludingly, these top-10 Mn-hosting countries have a great impact on the global economy through their manganese deposits. For example, some of them are considered distinguished exporters of such metal in 2022. Such as China ($621M), South Africa ($66.3M), and Gabon ($11.2M). Additionally, the global production of Mn ore is between 10.2 and 11.1 billion U.S.$.

References

[1] Acharya, B. C., Rao, D. S., and Sahoo, R. K. 1997: Mineralogy, chemistry and genesis of Nishikhal manganese ores of South Orissa, India. Mineralium Deposita, Vol. 32, Iss. 1, pp. 79–93.

[2] Azadmanesh, J. and Borgstahl, E. O. 2018: A Review of the Catalytic Mechanism of Human Manganese Superoxide Dismutase. MDPI, Journal of Antioxidants, Vol. 7, Iss. 2.

[3] Beukes, N. J., and Gutzmer, J., 1996: A Volcanic-exhalative Origin for the World's Largest (Kalahari) Manganese Field. A Discussion of the Paper by D. H. Cornell and S. S. Schutte, Min. Deposita, Vol. 31, pp. 242–245.

[4] Bishta, A. Z. 2008: Lithologic discrimination using selective image processing technique of Landsat 7 data, Un Bogma environs, west central Sinai, Egypt. Journal of King Abdul Aziz University, Earth Sciences, Vol. 20, No. 1, pp. 193–213.

[5] Boardman, L. G. 1964: Further Geological Data on the Postmasburg and Kuruman Manganese Ore Deposits, Northern Cape Province. Trans. Geol. Soc. South Africa, Vol. 2, pp. 415–440.

[6] Borchert, H. 1970: On the ore-deposition and geochemistry of manganese. International Journal for Geology, Mineralogy and Geochemistry of Mineral Deposits, Springer, Vol. 5, pp. 300–314.

[7] Bros, R. 1993: Cochimí isotopique (Sn-Nd, Rb-Sr, K-AI, U) des argiles du bassin Prottrozdique de Franceville et des Cacteurs d' Yoklo (Gabon). Ph.D. thesis, Université Louis Paster.

[8] Brusnitsyn, A. I., Starikova, E. V., and Zhukov, I. G. 2000: The Kyzyl-Tash Manganese Deposit (Southern Ural, Russia): A Devonian Prototype of Low Temperature Hydrothermal Buildups in the Modern Ocean. Geol. Miner. Deposits, Vol. 42, No. 3, pp. 231–247.

[9] Cannon, W. F. and Force, E. R. 1983: Potential for High-Grade Shallow-Marine Manganese Deposits in North America, in Unconventional Mineral Deposits. Sranks, W. C. III, New York: Mining Engineers, pp. 175–190.

[10] Chisonga, B. C. et al. 2012: Nature and origin of the protolith succession to the Paleoproterozoic Serra do Navio Manganese deposit, Amapa Province, Brazil. Ore Geology Reviews, Elsevier, Vol. 47, pp. 59–76.

[11] Choi, J., and Hariya, Y. 1992: Geochemistry and depositional environment of MN oxide deposits In the Tokoro Belt, Northeastern Hokkaido, Japan. Economic Geology, Vol. 87, Iss. 5, pp. 1265–1274.

[12] Clarke, C., et al. 2017: A global portrait of the manganese industry: A socioeconomic perspective. Neurotoxicology, Elsevier, Vol. 58, pp.173–179.

[13] Costa, M. L. 1997: Lateralization as major process of ore deposit formation in the Amazon Region. Exploration and Mining Geology, Vol. 6, pp. 79–104.

[14] Dzigbodi-Adjimah, K. 2004: The mineralogy and petrography of the ferruginous manganese rocks at Mankwadzi, Ghana. Journal of African Earth Sciences, Vol. 38, Iss. 3, pp. 293–315.

[15] El Aref, M. M., Abdel Motelib, A. 2001: Geology, facies distribution, and environments of the Carboniferous stratabound Mn deposits of the Um Bogma region, Sinai, Egypt. The second international conference on the geology of the Africa. Vol. 1, pp. 61–77 (Oct. 2001), Assiut, Egypt.

[16] Fan et al. 1999: Early Proterozoic and Cambrian phosphorites. International Geological Correlation Program. Vol. 1, Project 156: Phosphorites.

[17] Fan, D., Yang, P., and Wang, R. 1999: Characteristics and origin of the Middle Proterozoic Dongshuichang chambersite deposit, Jixian, Tianjin, China. Ore Geology Reviews, Elsevier, Vol. 15, pp.15-29.

[18] Force, E. R. and Cannon, W. F. 1988: Depositional Model for Shallow-Marine Manganese Deposits around Black Shale Basins. Econ. Geol., Vol. 83, No. 1, pp. 93–117.

[19] Frankes, L. A. and Bolton, B. R. 1984: Origin of Manganese Giants: Sea Level Change and Anoxic Oxic History. Geology, Vol. 12, No. 1, pp. 83–86.

[20] Frenzel, G. 1980: The manganese ore mineral. Geology and geochemistry of manganese ores. Vol. 2, pp. 25–290.

[21] Gutzmer, J. and Beukes, N. J. 2009: Iron and Manganese Ore Deposits: Mineralogy, Geochemistry, and Economic Geology: A Book Chapter, The Book titled Geology. EOLSS Publishers Co. Ltd., Oxford, United Kingdom.

[22] Hassan M. B., Mohamed Z. K., Ahmed H. A., 2013: Mineralogy, geochemistry and origin of Mn in the high-Mn iron ores, Bahariya Oasis, Egypt. Ore Geology Review, Elsevier, Vol. 53, pp. 63–76.

[23] Hongjun, Z., et al. 2022: Genetic types, geological characteristics, and genetic mechanism of manganese deposits in Africa. Geology in China, Vol. 49, Iss. 1, pp. 81–102.

[24] Jiancheng, X., et al. 2006: Geochemical Characteristics of Sedimentary Manganese Deposit of Guichi, Anhui Province, China. Journal of Rare Earths, Elsevier, Vol. 24, Iss. 3, pp. 374–380.

[25] Kora, M., El Shahat, A., Abu Shabana, M. 1994: Lithostratigraphy of the manganese-bearing Um Bogma Formation, west central Sinai, Egypt. Journal of African Earth Sciences. Elsevier. Vol. 18, No. 2, pp. 151–162.

[26] Krauskopf, K. B. 1967: Introduction to Geochemistry: A Book, 2nd Edition. McGraw-Hill Company, London, Paris, 617 p.

[27] Kuleshov, V. 2017: Isotope Geochemistry: The Origin and Formation of Manganese Rocks and Ores: A Book. Elsevier.

[28] Kuleshov, V. N., 2011: Manganese deposits: Communication 1. Genetic models of manganese ore formation. Lithology and Mineral Resources, Vol. 46, No. 473.

[29] Kwabena Ibrahim, et al. 2022: Petrography and geochemistry of manganiferous rocks in the Mankwadzi, Online library Wiley. (Accessed: October 25, 2022).

[30] Lianjun, Y., Delian, F., Peiji, Y. 1988: Characteristics of manganese ore deposits in China. Ore Geology Review, Elsevier, Vol. 4, Iss. 1–2, pp. 99-113.

[31] Mart, J. and Sass, E. 1972: Geology and origin of the manganese ore of Um Bogma, Sinai. Economic Geology, Vol. 67, pp. 145–155.

[32] McLennan, S. M. 1989: Geochemistry and Mineralogy of Rare Earth Elements: Rare earth elements in sedimentary rocks an influence of provenance and sedimentary processes. Mineralogical Society of America, Vol. 21, pp. 169–200.

[33] Menet, C., Ménager, M., and Petit, J. 1992: Migration of Radioelements Around the New Nuclear Reactors at Oklo: Analogies with a High-Level Waste Repository. Radiochimica Acta, Vol. 58-59, Issue 2, pp. 395–400.

[34] Mineral Commodity Summaries 2022, National Minerals Information Center, U.S. Geological Survey, Reston, VA. Available on https://doi.org/10.3133/mcs2022.

[35] Mookherjee, A. 1961: Distribution of minor elements in the gonditic manganese ore and its geochemical significance. Economic Geology, Vol. 56, Iss. 4, pp. 723–729.

[36] Moreira, C. A., et al. 2015: Geological and geophysical data integration for delimitation of mineralized areas in a supergene manganese deposits in, Geophysics International. No longer published by Elsevier.

[37] Nkele, K., et al. 2022: Challenges, advances and sustainabilities on the removal and recovery of manganese from wastewater: A review. Journal of Cleaner Production, Elsevier, Vol. 377, Iss. 1, 134152.

[38] Ostwald, J. 1992: Mineralogy, paragenesis and genesis of the braunite deposits of the Mary Valley Manganese Belt, Queensland, Australia. Mineralium Deposita, Vol. 27, Iss. 4.

[39] Post, J. E. 1999: Manganese oxide minerals: Crystal structures and economic and environmental significance. PNAS, Vol. 96, Iss. 7, pp. 3447–3454.

[40] Pracejus B., Bolton R. 1992: Geochemistry of supergene manganese oxide deposits, Groote Eylandt, Australia. Society of Economic Geology, Vol. 87, No.5, pp. 1310–1335.

[41] Pracejus, B. 1989: Nature and formation of supergene manganese deposits on Groote Eylandt, Australia. Ph.D. Thesis, University of Adelaide, Dept. of Geology and Geophysics.

[42] Rajagopalan, K., et al. 2022: Examining the Economic and Energy Aspects of Manganese Oxide in Li-Ion Batteries. Materials Circular Economy, Vol. 4, No. 22.

[43] Rodrigues, O. B., Kosuki, R., Filho, A. C. 1986: Distrito Manganesĩfero de Serra do Navio ‹Amapá. Principais Depósitos Minerais do Brasil, Vol. 2, pp. 167–172.

[44] Roy, S. 1981: Mineralogy of the different genetic types of manganese deposits. Academic Press, London.

[45] Roy, S. 1987: Manganese metallogenesis: A Review. Elsevier Science Publisher B. V., Amsterdam–Printed in The Netherland. Ore Geology Reviews, Vol. 4 (1988), pp. 155–170.

[46] Roy, S., 2006: Sedimentary manganese metallogenesis in response to the evolution of the Earth system. Earth Science Reviews, Elsevier, Vol. 77, Iss. 4, pp. 273–305.

[47] Roy, S., 2007: Genetic diversity of manganese deposition in the terrestrial geological record. Geological Society, London, Special Publications, Vol. 119, Iss. 1, pp. 5.

[48] Said, M. S. 2022: Fault control and timing of manganese deposits at Abu Ramad, South Egyptian margin of the Red Sea. International Geology Review, Francis and Tylor Online.

[49] Salem, I. A., Ibrahim, M. E., and Abd El Monsef, M. 2012: Mineralogy, geochemistry, and origin of hydrothermal manganese veins at Wadi Maliek, Southern Eastern Desert, Egypt. Arab J Geosci, Vol. 5, pp.385–406.

[50] Salgado, S. S., et al. 2019: Provenance of the Buritirama Formation reveals the Paleoproterozoic Assembly of the Bacajá and Carajás Blocks (Amazon Craton) and the chrono-correlation of Mn-deposits in the trans-Amazonian/Birimian system of northern Brazil/West Africa. Journal of South American Earth Sciences, Vol. 96, p. 102364.

[51] Sasmaz, A., Zagnitko, V. M., and Sasmaz, B. 2020: Major, Trace and rare earth element (REE) geochemistry of the Oligocene stratiform manganese oxide hydroxide deposits in the Nikopol, Ukraine. Ore Geology Reviews, Vol. 126, p. 103772.

[52] Scarpelli, W. 1968: Precambrian metamorphic rocks of Serra do Navio, Brazil .M.Sc. Thesis, Stanford University.

[53] Scarpelli, W. 1973: The Serra do Navio manganese deposits (Brazil). Paris UNESCO (1973), P. 217–228.

[54] Sethumadhav, M. S., Gunnell, Y., Ahmed, M. M. 2010: Late Archean manganese mineralization and younger supergene manganese ores in the Anmod–Bisgod region, Western Dharwar Craton, southern India: Geological characterization, palaeoenvironmental history, and geomorphological setting. Ore Geology Reviews, Elsevier, Vol. 38, pp. 70–89.

[55] Standard Specification for Ferromanganese, last edition updated in Nov 5, 2019, American Society for Testing and Materials ASTM, DOI: A99-03(2019).

[56] Taylor, S. R., and Mclennan, S. M. 1985: The continental crust: Its composition and evolution. Oxford: Blackwell Scientific Publications.

[57] Woodward W. F., et al. 2016: Manganese mineralogy and diagenesis in the sedimentary rock record. Geochimica et Cosmochimica Acta, Vol. 173, Iss.15, pp. 210–231.

[58] Yao, P., Lin, Z., Du, C., Wang, K., and Song, X. 1995: Records of China's manganese ore deposits.

[59] Yu, W., Polgári, M., Fintor, K., Gyollai, I., Szabó, M., Velledits, F., Liu, Z., and Du, Y. 2021: Contribution of microbial processes to the enrichment of Middle Permian manganese deposits in northern Guizhou, South China. Ore Geology Reviews, Elsevier, Volume 136, Sep. 2021, 104259