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Iron Ores of Sri Lanka: Are They Related to the Snowball Earth?

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Abstract

Sri Lanka is a country rich in various types of mineral resources. Following new discussions, Sri Lankan scientists have begun to investigate and explore the iron ore deposits in Sri Lanka. The iron ore deposits in Sri Lanka could be categorized into several groups. Attention has been paid to iron ore deposits in Seruwila Panirendawa and Buttala. Iron ore deposits in the world belong to Precambrian iron formation and iron ore stones which are Phanerzoic in age. This paper is an attempt to fill the existing chronological gap for Seruwila and other Sri Lankan iron ore deposits. Most likely, the deposition time period and the rock types of the deposits suggest a possible link to the Snowball Earth, proposed by Paul Holfman in 1998, a geologist at Harvard. The Supergene type iron ores in the southwest region of the island could have formed by late diagenesis, but as the majority of iron first originate in the form of ferrous as iron, at least some of the Supergene type ores could have come from the same plutonic activities as Seruwila and Buttala..

Keywords: iron ore deposits, Snowball Earth, iron formation, iron ore stones, Sri Lanka

Introduction

Iron ore deposits of Sri Lanka can be categorized under three major groups (Fig. 1)

1. Hydrated iron oxides of limonite (feO(OH).nH2O) and goethite [(Fe3+O(OH)], that occur in the Southwest sector with prominent deposits at Dela, Noragolla, Balangoda and Rakwana,
2. Magnetite [Fe3004] deposits of Panirendawa east of Chilaw in the Northwest and Buttala east of Wellawaya in the Southeast, and
3. Copper [Cu] - magnetite deposit of Seruwila, south of Trincomalee in the Northeast.

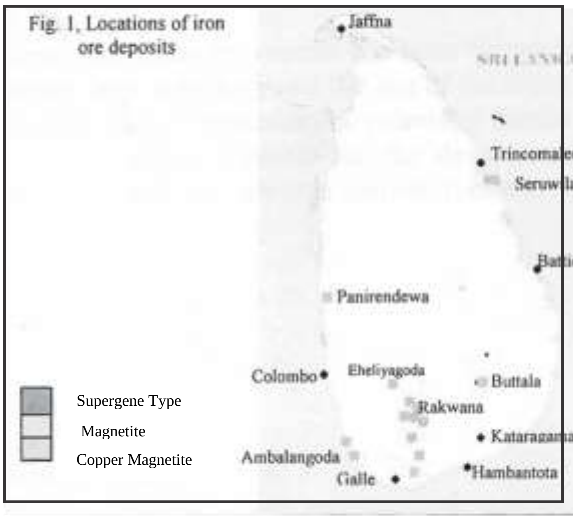


Fig. 1. Locations of iron ore deposits

Of these, Seruwila and Panirendawa had been studied in detail. There are two reports on Seruwila, one of which is an unpublished technical report based on a preliminary investigation, by D.E. de S. Jayawardena and S. Padmasiri in 1977 and the other is an essay compiled by Jayawardena in 1982 (see reference). The 1977 report is descriptive, but the 1982 essay is analytical and explains the tectonic setting and estimates the geological timeline of the deposit.

Their effort to obtain the age of the deposit is hampered by the lack of specific radiometric dating of iron ores and the poor understanding of the Seruwila area in relation to the rest of the island. The first situation is unfortunate because, the calculation of the age of iron by radiometric method, compared to most of the other rock types, is fairly straightforward (but expensive). The second is tolerable as no convincing geological model had been developed by 1982 based on the theory of Plate Tectonics. Even though there was a new model proposed in 1980 by C.B. Dissanayake and Tissa Munasinghe based on geo chronological data compiled by A.R. Crawford and R.L. Oliver in 1969, it does not even appear in the reference list of Jayawrdena's 1982 paper. Instead, Jayawardena's reference list suggests that he relied on Sri Lanka for his geological information, mainly on P.G. Cooray's 1966 book named An Introduction to the Geology of Ceylon which does not mention even the Continental Drift hypothesis of Alfred Wagener. However, the lack of good chronological data cannot be tolerated in 2012, especially considering the fact that, there was a geo-chronological study done as a part of a comprehensive geological research conducted by a German-Sri Lankan project, which began in 1985 and concluded in 1991. Its results were published as a technical report captioned THE CRYSTALINE CRUST OF SRI LANKA.

This paper is an attempt to fill in the existing chronological gap for Seruwila and possibly other Sri Lankan iron ore deposits, by proposing a most likely deposition period, using the rock types and their interrelationship, and invoking a possible link to the Snowball Earth theory proposed by Paul Hoffman, a geologist at Harvard, in 1998 (see reference).

At the outset I wish to emphasize the following:

1. The term Charnockites used here refers only to un-metamorphosed or metamorphosed hypersthene bearing rocks of plutonic origin (associated with oceanic ridges, island arcs or the cores of regional mountain ranges) with compositional variations from gabbro to granite.

2. The author does not contribute to the current notion that the "Kataragama Complex" is a thrust from the “Highland Complex" (Vithanage, 1959) on two basic geological principles:
   a). Joining of two plates by lateral movements, as proposed by Wilbert Kehelpannala (Kehelpannala, 2003 and 2007), does not and cannot produce thrust to move across the fault,
   b). Not a single structural evidence for thrust movement has been shown so far. The similarity of chemistry, mineralogy, petrology and the age of the rocks does not imply similarity in birthplace; the principles of metamorphic petrology dictate that, it is the P, T and t conditions that are responsible for the development of metamorphic facies at any given time and/or place (see section Tectonic setting below for detail).

Discussion

Iron ore

Iron ore deposits in the world are broadly divided into:

1. Precambrian Iron Formations and,
2. Iron Stones which are Phanerozoic in age.

The Precambrian Iron Formations are assigned to two separate time periods. The first period covers about 1.5 billion years, starting from ca 3.3 to 1.8 Ga and the second had a short duration of deposition from ca 900 - 600 Ma. The Precambrian iron formations are, again divided into two subgroups. The deposits older than 2.6 Ga are named Algoma type, and the rest is named Lake Superior type. Generally, both types are called Banded Iron Formations or BIF, but it is the Algoma type that shows banding more commonly. The Algoma type is very fine grained and covers a total area over 50,000 km^2. The Lake Superior type is more widespread and more granular than banded. Because of their granular nature, they are referred to as Granular Iron Formations (GIF). The BIF and the GIF are believed to be deposited in two different types of marine environments; since BIF contain a band of chert, pillow basalts and turbidites, they are thought to have been deposited in deep ocean basins while the granular nature suggests that the GIF were deposited in more disturbed shallow marine environments of continental platforms (Blatt et. al, 2006).

The Phanerozoic iron deposits are known as Iron Stone deposits and are not as widespread as the two types. Their sedimentary structures and types clearly show that they were deposited near the shore in shallow water environments. In Sri Lanka, this type of iron stones is found on top of the Miocene limestone along most of the Northwest shoreline and its mechanism of formation has been proposed by P.G. Cooray (2003) with a certain degree of doubt.

One very important phenomenon with iron formations (BIF and GIF) is that they ceased forming, almost abruptly, by 1.8 Ga and showed up again after about 900 Ma and lasted for around 300 million years to disappear again of ca 600 Ma. There is an easy explanation for the first disappearance of ca 1.8 Ga.: it could be linked to the building up of free oxygen in the atmosphere. But the second short blip of deposition demands a mechanism that blocks ocean water from mixing with free oxygen in the atmosphere. Paul Hoffman's theory of the Snowball Earth provides this mechanism (Hoffman et al., 1998).

The theory of the Snowball Earth

Even though the theory now goes by Paul Hoffman's name, the term was first introduced to science by physicist J. L. Kirschvink from Caltech in 1992 (Kirschvink, 1992). However, the idea of global ice and glaciation has a much longer history, dating to the late 1940s (Walker, 2003). Brian Harland from the University of Cambridge who did field research near Greenland first discovered rock evidence for glaciation in the tropics (Harland, 1963). Harland's ideas did not get much attention for two reasons. One was that some geologists tried to explain Harland's rock evidence for glaciation in the tropics as turbidites. The other was that during late 1950s and 1960s, the theory of Plate Tectonics received all the attention. Later, Kirschvink made several contributions to the idea, after he reviewed a paper about evidence for tropical glaciation from Australia. He introduced paleo-magnetism as a tool for verification and correlated the possible global ice with the late Algoma iron ore deposits, as well as the sudden expansion of bio-mass known as the Cambrian Explosion (Gould, 1990). Both Harland and Kirschvink did not make any attempt to bring their ideas to the wider scientific community; it was Hoffman who publicized the theory (Hoffman, 1998).

There is another interesting twist to the story of the Snowball Earth which apparently had no effect on Harland or Kirschvink. During early 1960s, two physicists (Michail Buddyko from Russia and William Sellers from Tucson, Arizona, USA) working on the stability of the Arctic ice based on a computer model, came to the conclusion that a runaway global ice cover could theoretically be possible if the albedo effect is strong enough to keep the Earth from warming by the green-house effect. Since they could not see how the Earth could recover from such a global ice cover and did not have any geological evidence for such an event, they concluded that it never occurred. The irony was that neither Harland nor the two physicists knew each other’s work.

Iron ores of Sri Lanka

According to descriptions in published research reports, Seruwila deposits undoubtedly fit with the GIF (Jayawardena, 1982), but there is controversy related to the Panirendewa deposits. The technical report (Kumarapeli, 1962) says that they are BIF. Cooray also confirms that opinion (Cooray, 1966).

Since both deposits are in the Wanni and the Vijayan complexes and since the rocks in both regions are supposed to be younger than 2 Ga (de Maesschalck et al., 1990; Hölzl et al., 1991), it is reasonable to assign both deposits to the GIF type. But the important question is: Which time periods do they belong to? Do they belong to the Snowball Earth period or to the one that ended by 1.8 Ga? This paper argues that the Seruwila deposits (probably others as well) belong to the Snowball Earth period.

There is only one proposed time of deposition available so far for iron ore deposits in Sri Lanka. S. Jayawardena (1982) who studied the Seruwila deposits postulates that they are contemporary to the dolerite dike that cuts through the deposits and runs almost parallel to the shoreline toward Batticaloa. This proposal cannot be accepted for two reasons:

1. According to the best estimates (GSMB, 1991) the maximum age of the dyke is 130 Ma, and
2. By the time the intrusion began, Sri Lanka was not an island, but was in the middle of the Gondwana super continent.

The intrusion of the dyke and the formation of the island are related to contemporary events. For the same reason, the age of the Seruwila deposits (probably most of them) can be pushed back to a date prior to the Gondwana assembly because the rocks in the island could have "seen" an ocean only prior to the assembly and after the breakup from Gondwana, but not while it remained a part of the continent. Since rocks in Sri Lanka last underwent high grade metamorphism ca 610 - 550 Ma ago (GSMB 1991), it is very realistic to put the lowest age of the deposits near the same period assuming that this portion of the Gondwana assembly coincided with the metamorphic event. Note that this lower limit correlates with the lower limit of the Snowball event very well. Assuming the above timing (lower limit) is correct, the following scenario is proposed for how and when the Seruwila iron ores were deposited.

The tectonic setting

The Vijayan complex is a portion of subducting land mass (an Active Margin). It was bordered by an Aleutian or Japanese type, but perhaps smaller, oceanic island arch (Kröner et al., 2003). Iron ore deposited around these islands while they were still covered with ice. During the completion of the subduction, the island arch abducted along the ocean line that had already vanished. The charnockites (charnockite proper, according to our definition) on the Eastern border of Highland range, including Buttala and Kataragama are the remnants of this island arch. These rocks got metamorphosed when the subducting plate overrode the already abducted island arc. Later, erosion supported by the stretching during the breakup of the Gondwana, exposed these rocks. This scenario explains not only the Seruwila deposits and associated rocks, but also the ones at Buttala and Balangoda. This scenario also makes the thrust hypothesis (Vithanage, 1959) and the lateral contact hypothesis (Kehelpannala, 2003 and 2007) that have been used to explain the similarities between the highland rocks and the Kataragama and Buttala rocks invalid.

However, is there geological evidence to support this hypothesis? The answer, I believe, is positive. Jayawardena described the following rocks and mineral types that are found in association with the Seruwila iron ore: charnockites, anorthosite (coarse grained), granite and granitic gneiss, hornblende biotite gneiss, limestones, anhydrite and scapolite. The charnockite vary in composition from gabbroic to granitic.

Limestone contains serpentined veins and scapolite sometimes cuts through iron ore. The limestone is probably coarse-grained marble and contains olivine (fayalite). From this description we can build a somewhat logical sequence of rock formation at this location. The hornblende gneiss could have been the first-generation rocks. The next in the sequence should be the limestones, suggesting the first sequence undergoing a marine transgression (probably following a rift; limestones also suggest a tropical ocean).

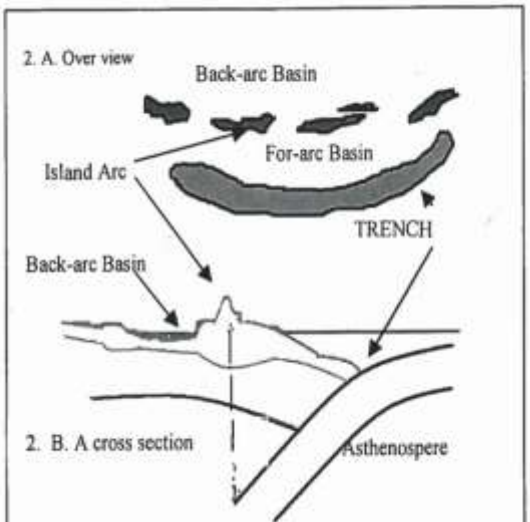


Fig. 2 A Subduction Complex (simplified). The source of iron is believed to be the under water volcanism at the ridge (not shown) and the plutonic activity associated with the island arc.

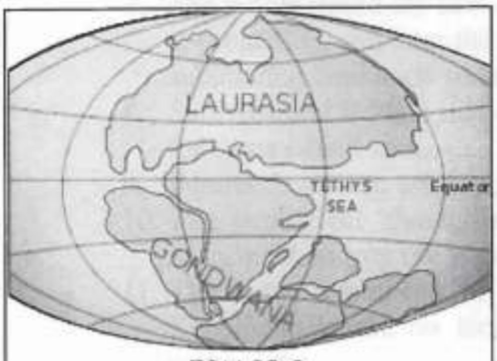
It is possible that the limestone was re-metamorphosed with the charnockites when the obducted island arc was overridden by the approaching land mass, but there is no sufficient evidence at this juncture to confirm or deny the idea. Next in the sequence of events could be the ice cap and the deposition of iron.

The theory of the Snowball Earth is accepted tentatively until a better explanation is found to explain the mechanism of deposition of iron on the sea floor. We know that ferrous iron cannot get distributed in the ocean water if free oxygen is available because free oxygen oxidizes them immediately. An ice cap would effectively act as a barrier preventing the mixing of free oxygen with ocean water. Immediately after the deposition of iron, charnockite intrusion must have occurred, because scapolite (a secondary mineral formed from feldspar) cuts through the iron ore, suggesting that the cracks were already there or were produced by the charnockite intrusions (the explanation for the presence of Scapolite given by Jayawardena is much more accurate, and therefore one must wonder why some good analyses were ignored in the 1991 study) (Prame, 1991). Formation of marble by contact metamorphism also could be associated with the charnockite intrusion. Inclusion of serpentinite in the limestones can be explained by the same igneous activity because serpentinite is a byproduct of the reaction that occurs when hot olivine rich rocks come in contact with ocean water. Since anorthosite has been found in many layered intrusions (Hess, 1960), the presence of anorthosite can be explained with the intrusion of charnockite. The ice cap (if we accept the theory) should have waned prior to the obduction of the island arch, because Jayawardena recognized two stages of oxidation in the iron. I agree with the two stages of oxidization but disagree with their explanation for the presence of two stages. He tried to explain the two stages by the fluorine content in iron, i.e., by relating the increase of the content of fluorine to the increase of the amount of iron in the ore. But the decrease in the content of iron and the content of fluorine can be attributed to the increase of H2O due to addition of melt water. It is possible that the waning ice cap reduced the deposition of iron by allowing free oxygen to mix with ocean water, and, at the same time, the addition of more H2O from melting water reduced the ratio of fluorine content of the ocean water.

The decrease of the fluorine content and the decrease of iron content can be easily explained this way. Based on the time sequence described above, it can be predicted that a similar rock pattern could be found at Buttala as well, since it is almost certain that this rock unit belonged to the same island arc (similar to the Kataragama rocks).

It is important to note here that the hydrated iron oxide deposits in the category one (see introduction above) cannot be explained using the same process because they are formed by secondary diagenesis. Weathering of iron rich rocks could transform reduced iron to hydrated iron oxides such as limonite and geothite.

Once formed by weathering, they could be transported and deposited in sedimentary basins away from the original sites. Therefore, it is admittedly difficult be conclusive about the origin of iron ores in the Southwest region (Eheliyagoda, Kahawatte, Dela, Noragolla, Kalawana, Deniyaya, Akuressa, Ambalangoda and Kosgoda), in the absence of dates of origin and the events of each diagenesis. It is worth noting that the S-W region hosts numerous charnockite plutons and is presently the wettest part of the island. Therefore, the possibility of at least some of the iron ores in this region originating in a reducing environment cannot be ruled out. In any case, this argument cannot be applied to the other two because magnetite is formed in anoxic environments only.



TRIASSIC
Fig. 3 200 million years ago
Pangea Supercontinent with Laurasia (Laurentia+Asia) and Gondwana joined together
Source: USGS website

It is an established fact that the land mass which margined the island arc was at a high latitude in the Southern hemisphere during the time of final collision. Sri Lanka has moved 3,000 km North with the Indo Australian plate during the last 65 Ma. See Fig. 3 for the geography of continents 550 Ma ago and the beginning of the Gondwana break up in the Triassic (Stanley, 1999). This suggests that it moved to the Southern position from the tropics and that iron deposition took place during this journey.

The deposition of iron should have terminated ca (Fig. 3) 200 million years ago 610 Ma ago, because almost all the geo chronological data conform that a high-grade metamorphism initiated around that period, meaning at the beginning of the convergent collision event.

The abduction of the island arc must have occurred slightly prior to the main collision event. If the argument proposed above can be accepted, the age bracket of 1 - 2 Ga (de Maesschalck et al., 1990 and Liew et al., 1991) of the Vijayan rocks (Wanni rocks as well), cannot be sustained any longer, because the age of the charnockites falls below 900 Ma. On evidence based on zircon analysis, other studies have found that their ages, including the crustal residence ages, do not exceed more than 1.7 Ga (Hölzl et al., 1991 and Kröner et al., 2003). Kröner had even proposed that hornblende and granitic gneisses of WC and VC could have been formed during Grenville orogeny, 1 - 1.3 Ga ago. All these age data strongly indicates that the iron ore deposits in Sri Lanka are younger than 1.8 Ga, and therefore, could not have come from the first Algoma iron ore deposition. Therefore, iron ores at Seruwila, Buttala and Balangoda could be linked only to the Snowball Earth theory. The same argument applies to Panirendawa, in terms of the upper and the lower age limits, and therefore Panirendawa iron ore deposition could be linked to the same Snowball Earth event, with one important difference in the geological setting. According to Kumarapeli, almost all the basement rocks on which iron ore is deposited are calc gneiss. No traces of any igneous rocks had been described (Kumarapeli, 1964). This suggests that Panirendawa belonged to a Continental Platform of a Passive Margin, possibly of the same age.

Conclusion

1. The iron ore deposits cannot be older than 1.75 Ga.
2. Their lower age limit must be 610 Ma or a little less.
3. For this reason, they could be placed in the period of the Snowball Earth.
4. The ice cap created a reducing environment for ferrous iron to move freely in oceanic water.
5. Iron was deposited at an Active margin where island arc type plutonic activity was occurring.
6. This land mass first originated in or near the tropic and moved South to high latitudes under an ice cap, while iron was depositing on the floor.
7. The whole island arc first abducted as the subducting land mass was approaching, and later the whole abducted unit metamorphosed as the subducting land mass rode over it.
8. Seruwila and Buttala iron ore deposits are linked as they both belonged to the same island arch.
9. Panirendawa iron ore deposits also belong to the same period.
10. The geological characteristics suggest that Panirendawa was a passive margin when iron ore was deposited.
11. The thrust hypothesis of Vithanage and the lateral contact hypothesis of Kehelpannala are no longer needed to explain Kataragama and Buttala rocks.
12. The Supergene type iron ores in the Southwest region (see category 1 in the introduction) of the island could have formed by late diagenesis, but as the majority of iron first originate in the form of ferrous as iron, at least some of the Supergene type ores could have come from the same plutonic activities as Seruwila and Buttala.

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