AN ANCIENT IRON CARGO IN THE INDIAN OCEAN: THE GODAVAYA SHIPWRECK

A Thesis

by

ARIANNA MICHELLE DIMUCCI

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Chair of Committee,	Deborah Carlson
Committee Members,	Donny Hamilton
	Robert Warden
Head of Department,	Cynthia Werner

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ABSTRACT

The Godavaya shipwreck, located off Sri Lanka's southern coast at a depth of approximately 33 m (110 ft), is one of the oldest shipwrecks yet discovered in the Indian Ocean. Dated to between the second century B.C.E and the first century C.E., its excavation and study is vitally important to augmenting our current understanding of maritime trade and ancient seafaring activities in this region of the world. As such, the Godavaya shipwreck represents a unique opportunity to examine existing scholarship concerning Indian Ocean trade. The focus of this thesis is the examination of the site's iron concretion pile – made up of corroded iron bar or strap-shaped ingots – via XRF and SEM analysis to potentially help answer questions about these materials and ultimately the shipwreck itself. The historical background of iron in the region will be examined, particularly its production in Sri Lanka and its appearance at terrestrial sites, in order to contextualize the material carried onboard the Godavaya shipwreck. To that extent, this work will incorporate ancient sources that discuss Sri Lanka and its maritime trade, focusing not only on well-known Greek works like the *Periplus of the Erythraean Sea* but also on less frequently considered Chinese texts like the *Han Shu* and *The Sea Route from Guangzhou to Countries in the Indian Ocean* – manuscripts that underscore the island's connection to the far East. Lastly, a discussion of the degradation of iron in a marine environment and a proposed conservation treatment plan of the metal cargo are within the scope of this research.

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INTRODUCTION

THE HISTORICAL CONTEXT OF THE GODAVAYA SHIPWRECK

Located off Sri Lanka's southern coast, the Godavaya shipwreck and its cargo represent a remarkable opportunity for those interested in early Indian Ocean trade. The shipwreck, which dates to between the second century B.C.E and the first century C.E., is the oldest found to date in the Indian Ocean. While little analysis of the wreck site and the cargo has yet been done, the shipwreck's potential to inform scholars about this region of the world should not be understated. The vessel's iron concretion pile – made up of corroded iron bar or strap-shaped ingots – forms the focus of this thesis. The production of iron in Sri Lanka and the island's involvement in maritime trade as a linchpin between the East and West, from China to the Red Sea and the Mediterranean, are both necessary to contextualize the Godavaya material. Literary sources, particularly the writings of Greek and Roman scholars and geographers, Chinese exploratory texts and sailing directions, Tamil literature, and the island's own chronicles and inscriptional evidence are all pertinent to an understanding of the island and its role in maritime trade in antiquity. Sri Lanka, or Taprobanê as the island was known to the Greeks and Romans, served a pivotal role in facilitating commercial networks of the ancient world. Understanding that role means examining not only the shipwreck but also the nearby ancient port of Godavaya in Sri Lanka's Ruhuna kingdom.

MAJOR SITES OF THE EARLY HISTORIC PERIOD

Sri Lanka's early cultural history is divided into Mesolithic (1800 B.C.E.), Iron Age (900-600 B.C.E.), and Early Historic (600 B.C.E.-300 C.E.) periods by Siran U. Deraniyagala, who served as

Assistant Commissioner of Sri Lanka's Archaeological Survey Department between 1968 and 1988.[1] The island's Early Historic period corresponds to when the Godavaya ship was sailing and as such is focused on here. This period is well-represented by a number of archaeological sites in Sri Lanka, particularly at Anuradhapura, in the island's north where excavations have found some of the earliest examples of ancient iron working, and at Tissamaharama, in the south (Fig. 1.1).

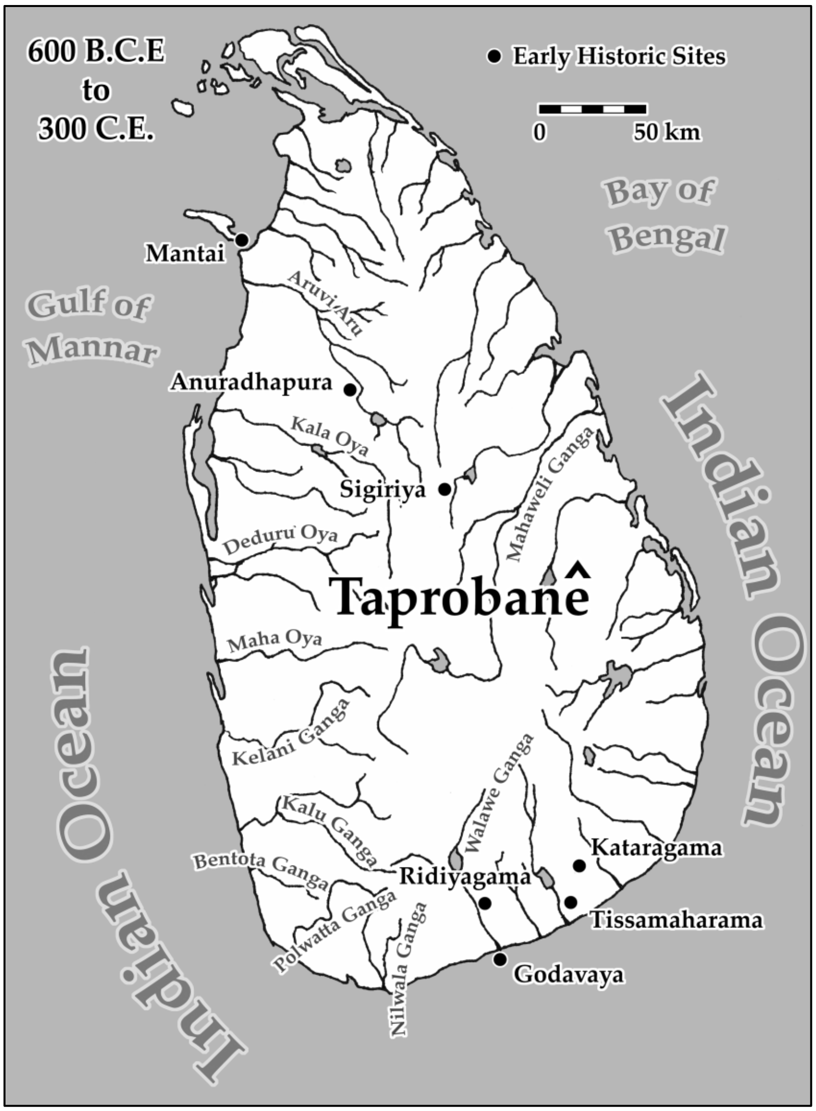

Fig.1.1 Early historic sites in Sri Lanka.

[1] Deraniyagala 1992.

Excavations at Tissamaharama, begun in 1992 as part of a collaborative project between the Archaeological Department of Sri Lanka and the Commission for General and Comparative Archaeology (KAVA) of the German Institute of Archaeology, have revealed the remnants of metal working in an area designated 'Tissa 1' and referred to as the 'Workmen's Quarter.'[2] Two well-preserved battery furnaces and the remains of a third, likely utilized to work bronze, have been found alongside evidence of iron and gold working.[3] Ceramics chronologically associated with the Early Historic period, including Black-and-Red Ware, Fine Red Ware, and so-called Rouletted Ware, in addition to imported pottery such as Roman amphorae and Islamic glazed ware, have also been found.[4] Excavation along the western edge of the ancient citadel, designated as 'Tissa 2' or the 'Court's Garden,' has revealed two clay seal impressions, or sealings, on which a bull is depicted. Excavations at Tissamaharama have also revealed a number of Lakshmi plaques – copper-alloy goddess plaques thought to date to the first century C.E. – as well as South Indian punch-marked coins, Roman coins, and imitations of Roman coins.[5]

TERRESTRIAL EXCAVATIONS AT GODAVAYA

Near Tissamaharama is Godavaya, a small fishing village and the possible 'south-facing harbor' mentioned by Pliny in his description of Taprobanê.[6] Situated between Ambalantota and Hambantota near the mouth of the Walawe Ganga (river), Godavaya was the focus of collaborative archaeological work between the Department of Archaeology of Sri Lanka and the German Archaeological Institute (DAI) in the 1990s. Excavations at Godavaya's ancient stūpa, or Buddhist temple, associated small monastic complex, outlying residential community, and nearby sea port have shed some light on the

[2] Weisshaar et al. 2001.
[3] Weisshaar et al. 2001, 12-13, 24.
[4] Weisshaar et al. 2001, 12-13, 15; Tomber 2008, 147.
[5] Walburg 2001.
[6] Plin. *HN* 6.24.

region's commercial activities.[7] An inscription near Godavaya's ancient stūpa refers to the presence of a southern port or emporium and illustrates the role the harbor may have played.[8] The inscription, translated by Senarat Paranavitana in 1970 and reexamined in the 1990s by Harry Falk, identifies King Gajabahu I (113/14-135/36 C.E.) by name and mentions the collection of customs duties at the port.[9] Excavation of the area unearthed a number of finds which further demonstrate that Godavaya was an ancient trading port or emporium. These include two well-preserved clay sealings on which a lion is depicted; these are similar to the motif found on coins struck by King Mahasena, who ruled in Ruhuna in the fourth century C.E.[10] These sealings may have been used for merchandise, as described in Kautilya's *Arthasastra*, an ancient Indian treatise written in Sanskrit and dated to the fourth century B.C.E. Kautilya, who served as a key adviser to the Indian king Chandragupta Maurya (c. 317- 293 B.C.E.), wrote the *Arthasastra* to teach a king to govern. The fourth century B.C.E. treatise specified that commodities be weighed and measured before being sold, and that all imports and exports, including foreign merchandise, needed a seal.[11] Merchandise found without a seal or with a counterfeit seal was subject to penalties.[12] Precious metals, such as gold, needed two seals, one from the manufacturer and one from a superintendent.[13] Comparable sealings have been found at Tissamaharama – these have a bull, with a pronounced hump on its back – and clay and lead sealings are well represented throughout the Mediterranean world.[14] Although the exact function of these clay artifacts cannot be known for sure, they were presumably used as some kind of "proof of identity, receipt, or other form of control."[15]

[7] Kessler 1998; Roth 1998; Bopearachchi et al. 2013.
[8] Bopearachchi 1997; Roth 1998; Bopearachchi et al. 2013.
[9] Paranavitana (1970) translates the word 'patana' as 'port;' Falk (2001) proposes a revised translation and interprets 'patana' to mean 'emporium' or 'market place.'
[10] Roth (1998, 8-9) specifies that the sealings, found in 1995, originated from trench 5, layer 2.
[11] Shamasastry 1967, 156-158.
[12] Shamasastry 1967, 155.
[13] Shamasastry 1967, 120; Roth 1998, 9.
[14] Roth 1998,11.
[15] Müller 2001, 249.

Excavations of the Godavaya area have additionally unearthed local, Near Eastern, and Roman ceramics, as well as an early Chinese celadon ware fragment, dated to the period of the "Three Kingdoms" (Wei/Shu/Wu, 220-280 C.E.).[16] The olive-green, thick-bodied fragment, likely part of a large transport or storage vessel, constitutes the earliest archaeological evidence for early Chinese-Sri Lankan contact.[17] Further evidence identifying Godavaya as an ancient harbor includes the discovery of several thousand Roman and Indo-Roman coins, 6 km to the north and 8 km to the west of Godavaya's monastic complex.[18] Such finds, close to the sea port at Godavaya, support the likelihood that this was an active commercial center.[19]

Additional excavation in 1997 included the opening of a 4 m test pit on the beach in Godavaya bay.[20] This revealed four monolithic pillars, which may have formed part of a footbridge or other structure designed to assist with the loading and unloading of ships. The pillars found at Godavaya have been compared to a stone bridge north of Jetavana, Anuradhapura.[21] While ancient port facilities in this part of the world had not been discovered or investigated previously, the monolithic pillars unearthed at Godavaya are intriguing, although little can be determined conclusively at this point in time.[22]

Upriver from Godavaya are a number of ancient settlement sites, including Ridiyagama, where more than 20 furnace structures have been excavated, and monastic sites such as the complex at Ramba – which served as an important religious and academic center between the 10th and 12th centuries – and at Mahanavulu Pura. Finished iron ingots may have been transported downriver from Ridiyagama, to the estuary of the Walawe Ganga (river) and exported from Godavaya.[23] The shipwreck's location

[16] Kessler 1998, 33.
[17] Kessler 1998, 33; Roth et al. 2001.
[18] Kessler 1998, 14.
[19] Roth 1998, 9.
[20] Kessler (1998, 22-24) notes that these had similar dimensions and were all weathered at a certain height, leading to the conclusion that they had been used in the same pier-structure.
[21] Kessler 1998, 28; 31.
[22] Kessler 1998, 31.
[23] Solangaarachchi 2011; Bopearachchi et al. 2013.

near the river's estuary is especially relevant as excavation work completed by the Sri Lankan Department of Archaeology and the French Archaeological Mission indicates that large ships in ancient times were anchored close to river mouths, enabling commodities to be brought to inland markets via such waterways.[24]

ICONOGRAPHIC EVIDENCE FOR SHIPS FROM THE EARLY HISTORIC PERIOD

Depictions of sailing vessels have been found at a number of Early Historic coastal sites extending from Tissamaharama, in southern Sri Lanka, to Kalinga and Tampralipti in eastern India. The engraved depiction of a ship found in a cave at Duvegala in India's Polonnaruva District and dated to the second or first century B.C.E. is one such example. A rouletted ware sherd from Alagankulam, on the southeast coast of India, with an incomplete graffito initially thought to represent a 'Roman boat' and later identified as an incomplete representation of a three-masted ship, is another.[25] Clay sealings which feature ships have been recorded at Chandraketugarh, in India, as well.[26] Similar depictions have also been found on Satavahana bilingual coins, Indian coins dating to the early centuries following the Mauryan dynasty. These feature a bilingual inscription on one side in Prakrit, a language derived from a vernacular form of Sanskrit and spoken throughout India, and in Tamil, spoken throughout South India, on the other. [27] In Sri Lanka, at Tissamaharama, a potsherd decorated with the rough outline of a sailing ship with a single mast has been found.[28] Scratched lines form a triangular sail and a line at the stern hints at a single rudder. Elsewhere, at Anuradhapura, the scratched depiction of a ship with a single mast, rigging and twin steering oars has been found on another potsherd.[29] On the Indian subcontinent, representations of ships have been found on Buddhist

[24] Bopearachchi 1997; Bopearachchi et al. 2013.
[25] Ray (2003, 62-63) references Casson's (1997) writings and Tchernia's (1998) identification.
[26] Guy 1999.
[27] Weisshaar et al. 2001, 16; Ray 2003.
[28] Weisshaar et al. 2001, 16.
[29] Coningham and Allchin 1992, 164.

monuments and on coins and sealings dating from the second century B.C.E. to the seventh century C.E. and may reflect Buddhist involvement or support of trading activities.[30]

THE GODAVAYA SHIPWRECK

The ancient shipwreck at Godavaya, Sri Lanka, has been excavated since 2012 as part of a collaborative project funded by the National Endowment for the Humanities and organized by a joint team of American, Sri Lanka, Turkish, and French divers, archaeologists, and scholars. The shipwreck has been tentatively dated between the second century B.C.E and the first century C.E. based upon ceramic material scattered around the wreck and later corroborated by radiocarbon dating.[31] Found over a decade ago, the Godavaya shipwreck is located off of Sri Lanka's south eastern coast at a depth of approximately 33 m (110 ft) (Fig. 1.2).

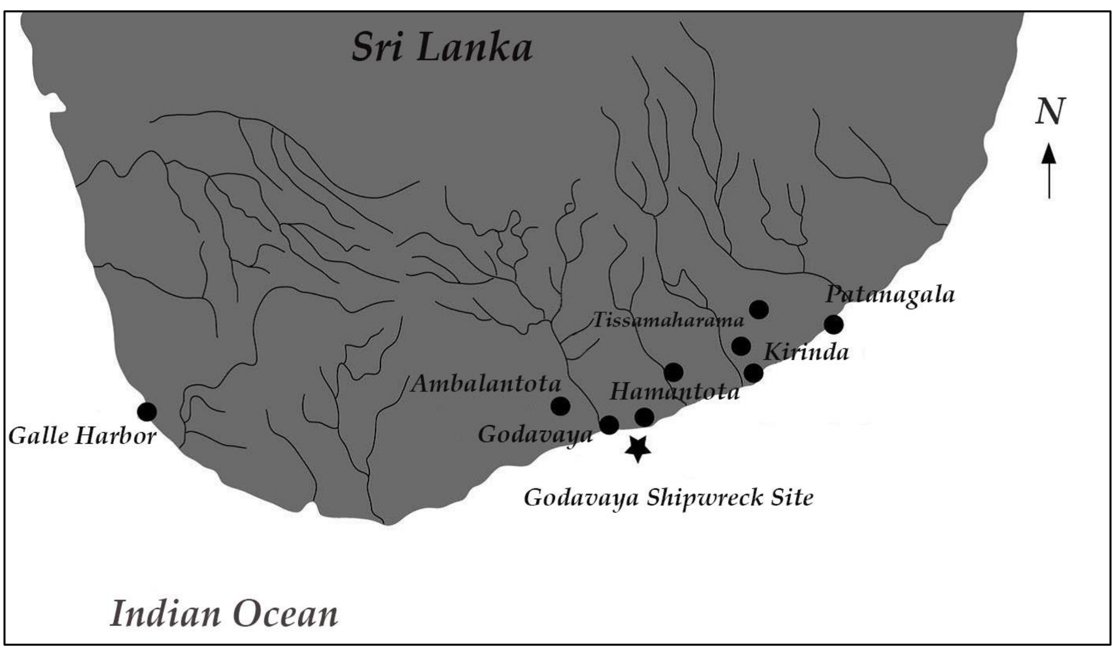

Fig. 1.2 Location of the Godavaya shipwreck, after Muthucumarana et al. 2014.

[30] Ray 1994; 2003.
[31] Carlson 2011.

It was first brought to the attention of officials from the Department of Archaeology in 2003 after local fishermen B.G. Preminda and Sunil Ratnaweerapatabandige found a small stone quern while diving for conch shells.[32] Five years later, divers from the Department of Archaeology (DOA) and the Maritime Archaeology Unit (MAU) of the Central Cultural Fund (CCF) conducted a brief exploration of the area, creating a preliminary site plan of the wreckage and raising several artifacts, including ceramic bowls and a hemispherical blue glass ingot with a diameter of about 20 cm. In 2010, Institute of Nautical Archaeology (INA) archaeologists Deborah Carlson and Sheila Matthews were joined in Sri Lanka by Sanjyot Mehendale, an archaeologist at the University of California at Berkeley, and by Osmund Bopearachchi of the Centre National de la Recherche Scientifique (CNRS) in Paris to conduct an exploratory investigation of the site. Wood samples were collected for radiocarbon analysis during this preliminary survey and again in 2011.[33] The first full-scale excavation season of the Godavaya shipwreck was launched in winter 2012-2013 with a longer field season conducted in 2014 – the rough plan below (Fig. 1.3) provides a basic overview of the shipwreck site. Fieldwork has revealed that, along with a variety of ceramics, stone querns, and grinding stones, the ship was transporting a cargo of raw materials including glass ingots and iron ingots.[34] The pottery recovered from the wreck – large storage jars and carinated cooking vessels with rounded bases and inward sloping sides – has been primarily identified as Black-and-Red ware, a type found ubiquitously throughout India and Sri Lanka.[35] Hemispherical or bun-shaped glass ingots, raised in the first season and thought to have originated in South India, substantiate the existence of a regional maritime network between the two countries that dates back to the Early Historic period.[36] Such a network is well-attested in the literary and archaeological records.

[32] Carlson 2011; Carlson and Trethewey 2013.
[33] Trethewey 2012.
[34] Carlson and Trethewey 2013; Muthucumarana et al. 2014.
[35] Begley 1967; Bopearachchi 1997; Schenk 2001; Muthucumarana et al. 2014.
[36] Muthucumarana et al. 2014.

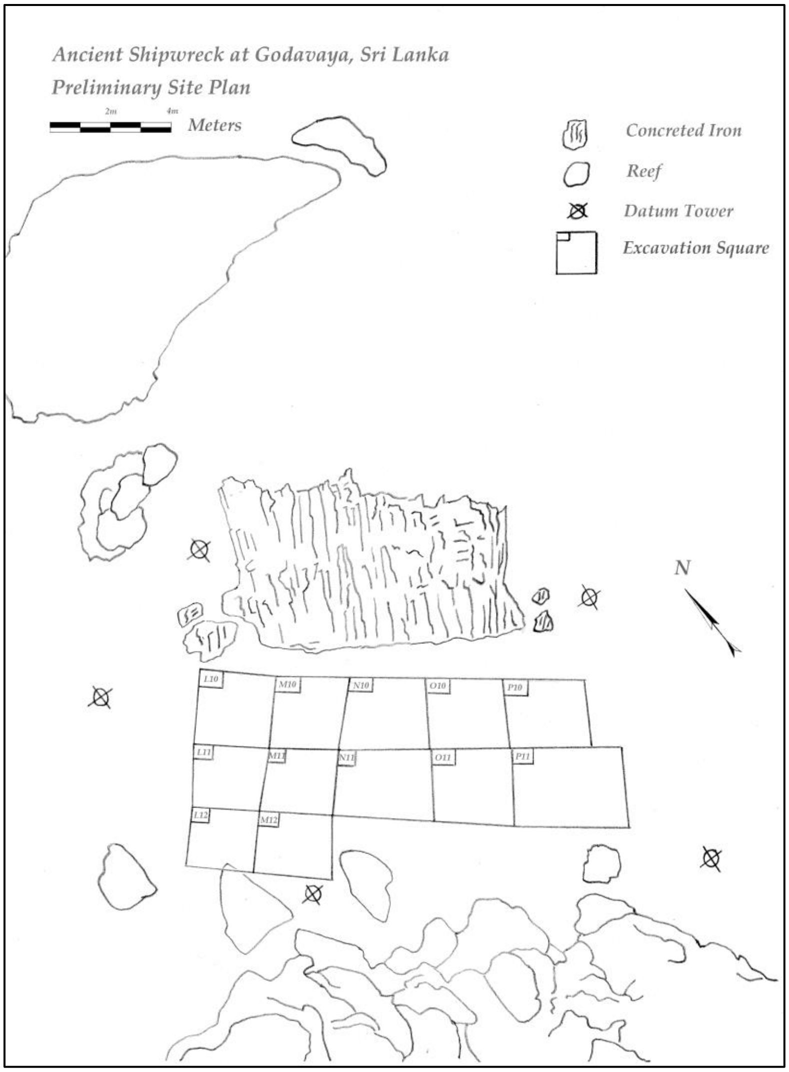

Fig 1.3 Preliminary site plan of the Godavaya shipwreck.

Grinding stones and four-legged querns similar to those that made up the cargo of the Godavaya shipwreck, (Fig. 1.4), have been found elsewhere in Sri Lanka as well as at a variety of Early Historic sites in India. Near Godavaya and on display at the site museum at the Yatala monastery, is another quern dated to 250-100 B.C.E. based on a short Brahmi inscription carved on its surface.[37] The site museum at the Ramba monastic complex, located upriver from Godavaya, has a similar quern on

[37] Somadeva 2006,187.

display.[38] At Kaundinyapura, an Early Historic site in central India, eight mullers, or grinding stones, were found along with the fragments of several four-legged querns.[39] Excavation at Satanikota, occupied sporadically from the Paleolithic to the Medieval period, revealed two sandstone querns with concave grinding surfaces and three sandstone grinding stones.[40] Excavations in Nasik, an ancient town in western India situated on the banks of the Godāvarī river, revealed the remains of 16 four-legged querns, albeit only one was intact.[41] These had a flat or concave surface and were referred to by authors Sankalia and Deo as "saddle querns." Three of the 16 had Buddhist symbols. At Bhokardan, a site on the ancient trade route from Ujjainī to Pratiṣṭhāna, 18 four-legged querns, three of which were intact, and nine saddle querns were found.[42]

Fig. 1.4 Four-legged quern recovered from the Godavaya shipwreck site during the 2012-2013 season, ©2013 Susannah H. Snowden/www.OmniaPhoto.com, for INA .

[38] Muthucumarana et al. 2014.
[39] Dikshit 1968, 130; Smith 2001.
[40] Ghosh 1986, 153-4.
[41] Sankalia and Deo 1955.
[42] Deo 1974.

Elsewhere in India the remains of stone querns and grinding stones have been found at Nevasa (1st century B.C.E.)[43], Bahal (3rd century B.C.E.)[44], Nagarjunakonda (1st century B.C.E.)[45], Atter (3rd century B.C.E.)[46], Nagal (3rd century B.C.E.)[47], Kundanpur (1st century C.E.)[48], Noh (1st century B.C.E.)[49], and Paithan (3rd century B.C.E. to the 1st century C.E.).[50] A stone quern, identified as a basalt 'stool,' has also been found at Bet Dwarka.[51]

The iron cargo from the Godavaya shipwreck is made up of corroded iron bar or strap-shaped ingots (Fig. 1.6). These have been briefly examined by scanning electron microscopy (SEM-EDS). SEM analysis has revealed the presence of iron oxide, sulfur trioxide, silicon dioxide, aluminum oxide, magnesium oxide, potassium oxide, and calcium oxide.[52] Additional SEM analysis has been done, as well as x-ray fluorescence (XRF), in an attempt to determine the major and trace element composition of the shipwreck's corroded iron cargo and provide a more complete understanding of the material that was being transported. Recent analyses revealed a significant amount of iron and traces of manganese, copper, and zinc. The results and their implications will be discussed further in the following chapters.

[43] Ghosh 1989.
[44] Ghosh 1989.
[45] Ghosh 1989.
[46] Ghosh 1989.
[47] Ghosh 1989.
[48] Ghosh 1989.
[49] Ghosh 1989.
[50] Ghosh 1989.
[51] Rao 2001, 135.
[52] Chandraratne et al. (2012, 482-483) reveal that 77.54% of the iron sample is iron oxide, 16.48% is sulfur trioxide, and 7.06% is silicon dioxide. Aluminum oxide, magnesium oxide, potassium oxide, and calcium oxide appear in trace amounts.

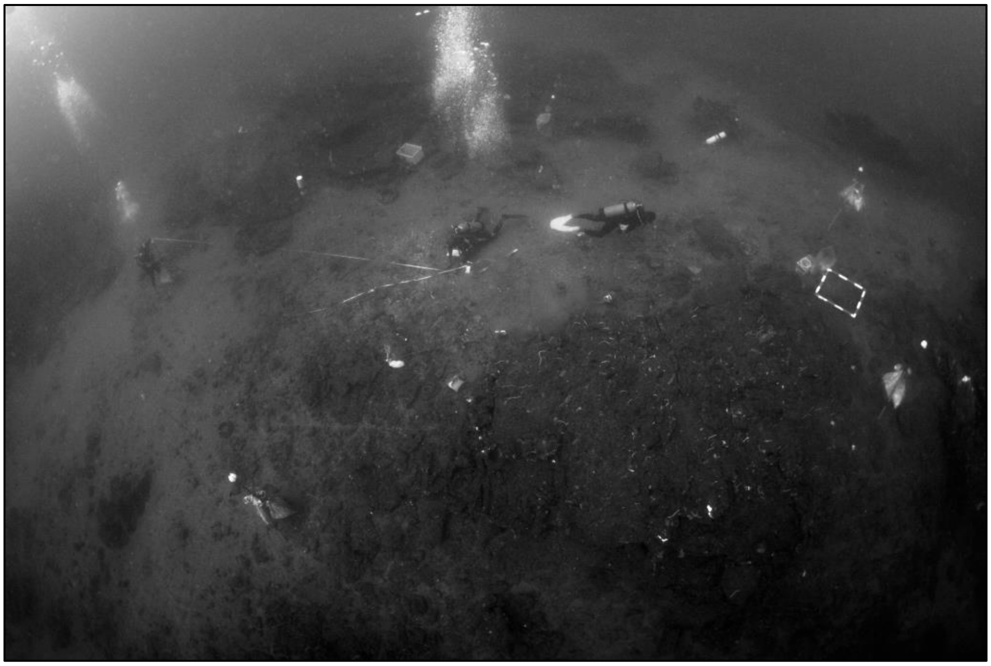

Fig. 1.5 Site overview, ©2014 Susannah H. Snowden/www.OmniaPhoto.com, for INA .

Fig 1.6 Divers examining the iron concretion pile

IMPLICATIONS

Sri Lanka's Godavaya shipwreck is without parallel. Its excavation, in the words of Osmund Bopearachchi, "may revolutionize our knowledge of the history of maritime trade in South Asia, particularly between India and Sri Lanka."[53] Indian Ocean shipwrecks date from the ninth century – on Belitung Island of Indonesia – to the 20th century.[54] While considerable work has been done in Sri Lanka, notably in Galle harbor with the Dutch East India Company (VOC) shipwreck *Avondster*,[55] such projects are not aptly poised to contribute to our knowledge of early trade in the region; the Godavaya shipwreck is. As the earliest shipwreck so far discovered in the Indian Ocean, a detailed investigation of the ancient vessel and its cargo is invaluable to an understanding of the region's early historic commerce and trade (Fig. 1.5). While literary and archaeological evidence provide numerous examples of general commercial activity between the Indian Ocean and the Mediterranean, there exists far less evidence for the exchange of iron in the region. The shipwreck's metal cargo (Fig. 1.6), which represents one of the most promising examples of the direct exchange of iron, raises a number of interesting questions concerning iron production and exchange. This thesis, with its focus on the Godavaya shipwreck and the concreted iron cargo carried on board, functions as a starting point from which to examine the scholarship concerning maritime trade in this area of the world. The following chapters aim to contextualize the material onboard by discussing the island's commodities, the production of iron in Sri Lanka, the island's ancient trade with India, and its wider role as a linchpin in the trade between the East and West. Non-destructive analytical techniques, including x-ray fluorescence (XRF) and scanning electron microscopy (SEM), augment existing research that has been done on the metal cargo and enhance what little is known about the antiquity of iron production in this region.

[53] Bopearachchi et al. 2013, 393.
[54] Flecker (2001) discusses the Belitung wreck, a ninth century C.E. Arab or Indian shipwreck excavated in 1998 and 1999 off the Indonesian island of Belitung and its cargo of Chinese ceramics, in more detail.
[55] Parthesius et al. 2005.

CHAPTER II

COMMODITIES, MERCHANTS, AND TRADE ROUTES: MARITIME TRADE IN THE INDIAN OCEAN

Pliny (c. 23-79 C.E.), in describing ancient Sri Lanka, or Taprobanê as the island was known to the Greeks and Romans, complained that despite its remoteness, the island was beset with vices:

> But not even Taprobane, though consigned by nature outside the world, lacks our vices: there too gold and silver have commercial value, marble is considered similar to tortoiseshell, and pearls and gems have high prestige. Their entire mass of luxury is greater than ours.[56]

Located at the midpoint of major sea routes linking China and Southeast Asia with the Middle East and the Mediterranean, Sri Lanka served as an important "transit trading place," or linchpin between the East and West.[57] Gems, pearls, muslins, ivory, and tortoise-shell, along with rice, ginger, honey, beryl, amethyst, gold, silver, and other metals – mentioned by Ptolemy (c. 90-168 C.E.) – constituted quite a few of the island's luxury commodities that reached the Mediterranean.[58]

The discovery of an ancient shipwreck off Sri Lanka's southern coast and its cargo of iron ingots, which forms the focus of this thesis, prompt a discussion of the region's various exchange networks. The Godavaya shipwreck, dated to between the second century B.C.E. and the first century C.E.,

[56] Plin. *HN* 6.89.
[57] Solangaarachchi 2011, 99.
[58] Weerakkody (1997, 4) draws from Strabo, Pliny, Ptolemy, and the anonymous writer of the *Periplus Maris Erythraei* in listing Sri Lankan commodities; McLaughlin (2010) references Strabo in writing that ivory, tortoise shell and other wares were brought from Sri Lanka north to the Indian markets where they would have been sent westward to the Mediterranean world.

merits attention for a number of reasons: 1) it is likely the oldest sunken cargo in the Indian Ocean, 2) it provides direct evidence for Indian Ocean trade and 3) it represents one of the most promising opportunities to study the iron trade in this region.[59] One of the best resources available to us to examine such a shipwreck is the well-known work, the *Periplus Maris Erythraei*, a text thought to have been written by an un-named Greco-Egyptian merchant between the first and third centuries C.E.[60] Less frequently considered Chinese texts like the *Hou Han-Shou*, written between the second century B.C.E. and the second century C.E., and *The Sea Route from Guangzhou to Countries in the Indian Ocean*, a late Tang Dynasty document written in the eighth century, which underscore the island's connection to the East, are equally relevant to a discussion of regional commerce.

SOURCES FOR INDIAN OCEAN TRADE

Evidence for Indian Ocean trade is well-represented in Greek and Roman literature especially in the above-mentioned text, the *Periplus Maris Erythraei*, which is considered the "most detailed and comprehensive surviving account of Roman involvement in the Eastern commerce."[61] Written by an un-named, Greco-Egyptian merchant between the first and third centuries C.E., the text was likely intended as a guide for other merchants and subsequently contains a considerable amount of first-hand knowledge of the trade, including information on the routes and various ports in Arabia, Africa, and India. It contains distances between locations, principal anchorage points, and lists of merchandise, making it an invaluable resource for any ancient merchant determined to undertake a commercial expedition to the Indian Ocean.[62] The author's first-hand knowledge of the region is particularly underscored by certain details in the text: for instance, he orients East Africa's coastline towards the west, which Ptolemy neglects to do in his *Geography*, and knows, too, that the Indian

[59] Carlson and Trethewey 2013.
[60] Pirenne (1961) argues in support of a third century C.E. date for the *Periplus*; whereas Robin (1997, 43) supports a first century C.E. date; Tomber (2014, 883), reviewing 2012 Topoi 11 proceedings of a conference dedicated to the *Periplus*, writes that the 'current consensus' is that the text was written in the first century C.E.
[61] McLaughlin 2010, 7; 42.
[62] Robin 1997, 42; Young 2001, 5-6.

coastline below the Indus region curves towards the south.[63] It is apparent that the un-named author of the *Periplus* had direct experience of the world about which he wrote. His mention of the trees in Egypt, the Egyptian name for the month of July (Epeiph), and his use of the first-person in describing part of the route between Egypt and India, particularly his 'setting a course' and 'putting on more speed' during the journey all attest to this.[64]

Where ancient Sri Lanka is concerned, the *Periplus* is less detailed. The author indicates in the text where the island was, i.e. beyond India, and calls it Palaisimundu or Taprobanê; he also writes that its northern parts were civilized and states that the island produced pearls, transparent gems, cotton garments, and tortoise shell.[65] He additionally exaggerates the size of the island and writes that it projected west into the ocean, orienting it east-west as opposed to north-south.[66] He is not the only ancient author to do so. Onesicritus of Astypalaea (c. 360-290 B.C.E.) a Greek commander in Alexander's fleet whose writings were preserved by Strabo (c. 64/63 B.C.E.-24 C.E.) and by Pliny (c. 23-79 C.E.) commented on the island's size and its distance from India.[67] Strabo quoted Onesicritus as having written that Taprobanê was 5000 stadia in size and 20 days' voyage from the mainland, though whether this journey was from the Indus delta or from the southern end of India is unclear.[68] Pliny quoted Onesicritus as having written that Taprobanê was for a long time considered to be another world.[69] A fragment from the Greek writer Megasthenes (c. 350-290 B.C.E.), preserved by Pliny, described Taprobanê as richer in gold and pearls than India.[70] Eratosthenes of Cyrene (c. 275-194 B.C.E.), an Alexandrian scholar whose writings were also preserved by Strabo, wrote that Taprobanê was seven days' journey south of India and measured, length-wise, about 8000 stadia in

[63] Robin 1997, 46.
[64] Casson 1989.
[65] *Periplus* 61.
[66] *Periplus* 61.
[67] Strab. 15.1.5.; Plin. *HN* 6.82-83.
[68] Strab. 15.1.5.
[69] Plin. *HN* 6.82-83.
[70] Plin. *HN* 6.82-83.

the direction of Ethiopia.[71] Pliny credits Eratosthenes with different measurements: the island supposedly measured 7000 stadia in length and 5000 in breadth and had no cities but 700 villages.[72] Again, the island was thought to run east-west towards Africa and its size was overestimated.[73] Hipparchus of Bithynia (c. 190-126 B.C.E.), whose writings were preserved in the work of the Roman geographer Pomponius Mela, commented that Taprobanê was either a very big island or the first part of another world.[74] Strabo commented that Taprobanê, which he places in front of India, was no smaller than Britain.[75] The size of both Britain and Taprobanê were exaggerated and both came to be thought of as possessing parallel characteristics. As the "ends of the known world" they provided symmetry, with the northern part of Britain turned eastward to hug the coast of the European mainland and the southern part of Taprobanê extended westwards towards the eastern shore of Africa.[76] Strabo, placing Taprobanê in the real world, pinpoints the island opposite the 'Cinnamon-bearing Land,' i.e. Somalia.[77] Finally, Ptolemy (c. 90-168 C.E.), though similarly misinformed about Taprobanê's size, was much more accurate concerning its shape and its north-south orientation.[78]

According to Pliny, the Mediterranean world had known of the island's existence since the time of Alexander the Great, but direct contact with the island did not begin until the reign of Claudius (41-54 C.E.).[79] Young adds that there appears to have been limited or indirect contact between the Roman Empire and Sri Lanka, especially prior to the fourth century.[80] Indeed, the *Periplus* implies that the strait between India and Sri Lanka was the furthest point normally reached by western vessels trading with India, due in part to the fact that Mediterranean vessels may have been too large to easily

[71] Strab. 2.1.15.
[72] Plin. *HN* 11.81.
[73] Weerakkody 1997, 37.
[74] Weerakkody 1997, 40.
[75] Strab. 2.1.15.
[76] Weerakkody 1997, 46.
[77] Strab. 2.1.15.
[78] Ptol. 7.4.1.
[79] Young 2001, 32.
[80] Young 2001, 33.

negotiate the shallow straits between India and Sri Lanka.[81] Weerakkody contends that circumnavigating the island would have been "uninviting due to the hidden crops of rock that…lay to the southeast of the island."[82]

Such Greek and Roman sources reveal that Sri Lanka was known to the Mediterranean world, partly as a distant island south of India and partly as a far-away 'other' – a producer of exotic goods whose inhabitants lived long lives. What sources like the *Periplus Maris Erythraei* make clear is that voyages across the Indian Ocean were part of established trading routes that involved both Mediterranean and Indian craft, potentially even the vessel recently discovered off Sri Lanka's southern coast, the Godavaya shipwreck.

Prosperous commercial activity along India's western coastline between the first century B.C.E. and the second century C.E. is well-attested to by non-western sources particularly in Tamil poetry written in the centuries following the height of commerce between Rome and India. In the Tamil poem *Maduraikanch*, for example, written between the first and second centuries C.E.,

> Large ships on which high flags on mast-tops wave
> Spread out their sails and cleave the rolling waves,
> Tossed by the winds of the great dark, treble sea
> On which rest clouds. They come to the sound of drums
> To the port, their trade successful, with the gold
> That much increases people's wealth.[83]

[81] Young, 2001, 31.
[82] Weerakkody 1997, 10.
[83] Chelliah 1962.

The Tamil poem *Pattinapalai*, written before the third century C.E., describes the port city of Kaveripattinam and the travel of goods between the port and the country's hinterland:

> So goods flow in from sea to land,
>
> And also flow from land to sea.
>
> Unmeasured are the abundant wares
>
> Here brought and piled.[84]

Another poem denotes that merchants arrived at 'flood time.'[85] Foreigners, or *Yavanas*, were primarily traders, but Tamil poetry also attests to their presence as craftsmen and bodyguards.[86] *Yavanas* are mentioned drinking and wandering along the streets at night; all of which provide interesting evidence of their presence in the early centuries of the Christian era.[87]

INDIAN OCEAN TRADE: MERCHANTS AND ROUTES

Before the arrival of the Romans, the Ptolemies of Egypt had begun to exploit trade with both India and Arabia through the construction of ports along the Red Sea coast. Although such trade was well established by the end of the Hellenistic period (323 B.C.E.-31 B.C.E), Strabo indicated that the volume of the commerce was nowhere near as large as it was after Rome's annexation of Egypt (31/27 B.C.E.):

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[84] Chelliah 1962.
[85] Ray (1988) writes that the word *Yavana* is derived from the Persian word for Ionian Greeks, *Yauna*, and applies to any group of people coming either from West Asia or the eastern Mediterranean, though it is most commonly thought to refer to those from the Roman East.
[86] Chelliah (1962, 179) translates the poem *Nedunalvadai* (120-123), in which a lamp is credited as having been made by Yavanas.
[87] Ray 1988, 314.

> When Gallus was prefect of Egypt, having accompanied him and ascended to Syene and the borders of Ethiopia, we found that even 120 ships were sailing from Myos Hormos to India, but under the Ptolemaic kings only a very few dared to sail and to trade in Indian goods.[88]

Sailing routes across the Red Sea and Indian Ocean have received a substantial amount of scholarly attention. The *Periplus of the Erythraean Sea* indicates that such routes were dictated by the monsoons, with merchants utilizing the southwest monsoon winds for outbound voyages and the northeast monsoons for return voyages.[89] During the summer months the monsoon winds blow violently from the southwest, suspending most sailing activity from May through September along the west coast of India and the south Arabian coast; the northeast monsoon dominates between November and April.[90] Sailors making the journey to India left from Myos Hormos and Berenike in July sailing down the Red Sea to the Arabian port of Mouza or to the port of Okêlis before following the coast along the southern Arabian shore as far as Kanê. From there they either sailed to India's northwest coast, to the ports of Barbarikon and Barygaza, or to the southern part of the Indian sub-continent, and the ports of Muziris and Nelkynda (Fig. 2.1).[91]

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[88] Strab. 2.5.12.
[89] Sidebotham (1996b, 288) writes that monsoons were first discovered by Mediterranean peoples in Ptolemaic times, probably towards the end of the second century B.C.E.
[90] Ray 2003, 20.
[91] Casson 1991, 8.

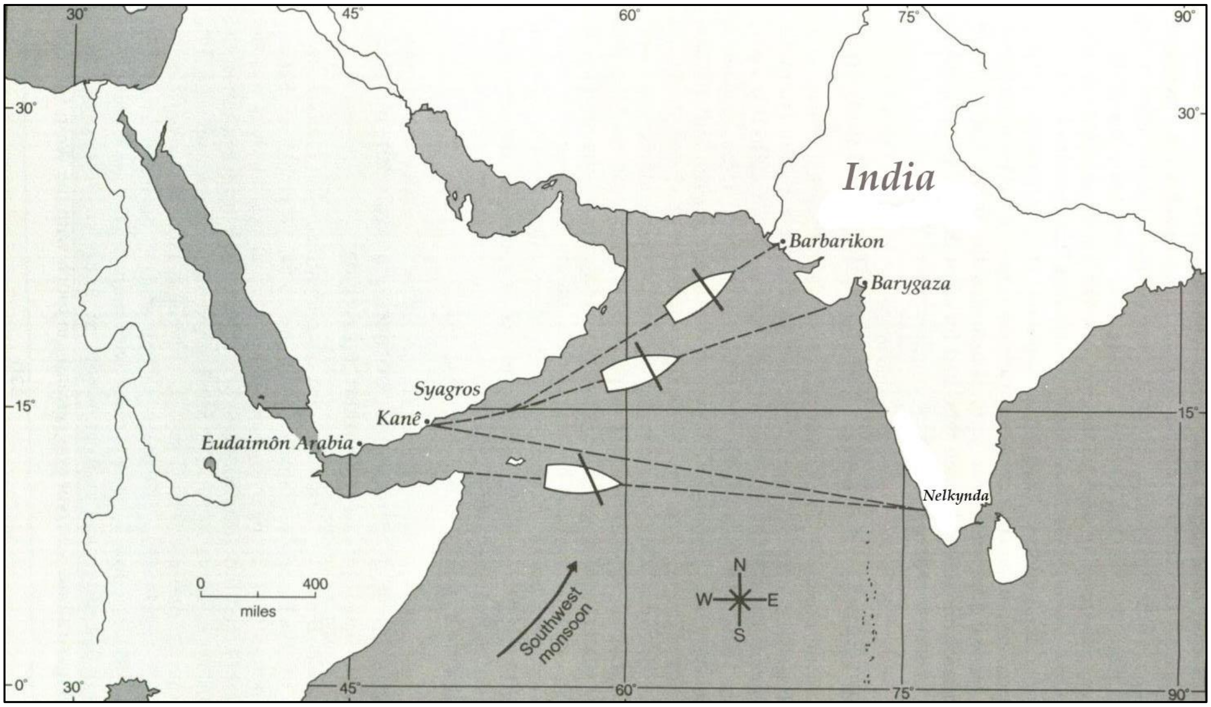

Fig. 2.1 Trading routes to India, after Casson 1989.

Long-distance trade with Arabia and India was greatly facilitated by the use of the monsoon winds, which enabled merchants trading with India to travel there directly rather than make a long and dangerous coastal voyage. Prior to this, few ships made the trip directly and cargoes were transshipped from Indian and Arab ships at one of the southern Arabian ports. The *Periplus Maris Erythraei*, for instance, mentions a time when there were no direct sailings from Egypt to India and all cargo was transshipped at Aden.[92] After the discovery of the monsoon winds by Greek seamen, Mediterranean ships made the crossing directly.[93] Vessels arrived in India in September or perhaps early October, depending on when they had initially departed.[94] Ships left for the return voyage,

[92] Young, 2001, 19.
[93] Nicholas (1959, 16) comments that the 'discovery' of the monsoon winds as a way to cross the Indian Ocean directly is attributed to a Greek named Hippalos in the first century B.C.E. though the full-scale utilization of these winds by Greek and Roman sailors didn't occur until the following century; Young, 2001, 19.
[94] Casson 1991, 9.

according to the *Periplus*, at the onset of the northeast monsoon in early November, though vessels could leave as late as December or January.

The *Periplus of the Erythraean Sea*, however instrumental and crucial to the study of maritime trade in this region, is not the only textual source relevant to this discussion. Chinese sailing directions in the *Hou Han-Shou* (the Historical Book of the Han Dynasty), written between the second century B.C.E. and the second century C.E., clearly attest that the country Yibuchen lay south of India.[95] A late Tang Dynasty document written in the eighth century, *The Sea Route from Guangzhou to Countries in the Indian Ocean*, is more helpful in that it describes a venture from Canton to a variety of places in the Indian Ocean, including Sri Lanka, providing approximate sailing times in 'Li' or days.[96] These documents help clarify the extent of Sri Lanka's maritime connections.[97]

INDIAN OCEAN TRADE: THE COMMODITIES

Roman traders typically used coin to acquire such exotic eastern goods though gemstones, fabrics, corals, and mineral powders such as antimony, sulfide, and yellow orpiment were also traded.[98] Large quantities of raw materials including glass, copper, tin, and lead were also in demand in Sri Lanka.[99] Additionally, iron is mentioned in Pliny's *Natural History* as well as in the *Periplus of the Erythraean Sea* where 'Indian iron and steel' are specifically denoted.[100] The *Periplus* specifies that in Barbarikon, a port on India's northwest coast, traders could purchase costus (used as a medicine), bdellium, *lykion*, nard (a medicinal unguent occasionally used in cooking), turquoise, lapis lazuli, silk, cloth, yarn, and indigo clothing. These items could be purchased by Western merchants or exchanged

[95] Quang-Qi 1989, 13-14.
[96] Quang-Qi 1989, 16.
[97] Weerakkody 1997, 5; Gokhale 2004, 135; Tomber 2008, 144.
[98] Weerakkody 1997, 5; McLaughlin 2010, 42.
[99] McLaughlin (2010, 42-51) supports this by drawing on Pliny's assertion that India was bereft of copper and lead and traded its gems and pearls for such raw materials.
[100] Plin. *HN* 34.41.

for printed fabric, multicolored textiles, peridot, coral, storax (a resin used in medicines), perfumes, frankincense, glassware, silverware, and wine.[101] Roman money – written in the *Periplus* as δηνάριον (denarii) – could be exchanged in the port for local currency at a profit.[102] Following India's coastline south to Barygaza, a port and industrial center, the author of the *Periplus* indicates that there was a market for foreign wine, metals (including copper, tin, and lead), coral, peridot, cloth, storax, yellow sweet clover, raw glass, realgar, sulfide of antimony (used primarily for the eyes, both as a cure for sores and as a cosmetic applied to the lids and lashes), and gold and silver currency.[103] Barygaza exported nard, costus, bdellium, ivory, onyx, agate, *lykion*, cloth, silk, yarn, long pepper, among other items brought from nearby ports.[104] Further south, Muziris and Nelkynda were markets for peridot, multicolored textiles, sulfide of antimony, coral, raw glass, copper, tin, lead, wine, realgar, orpiment, grain, and a 'great amount of money'.[105] Lionel Casson comments that 'money,' or Roman coinage, was emphasized in the *Periplus* in reference to these two ports to underscore the necessity of having silver and gold currency to purchase goods at Muziris and Nelkynda; elsewhere bartering seems just as prominent a strategy.[106] Muziris and Nelkynda exported pepper, fine-quality pearls, ivory, Chinese silk, Gangetic nard, malabathron – a kind of cinnamon from trees in northeastern India – as well as a variety of transparent gems, diamonds, sapphires, and tortoise shell.[107] While the author rarely comments on the volume of the trade with India, he does write at one point that the vessels departing Muziris and Nelkynda carry full loads due to the quantity of pepper and malabathron they pick up at these two ports.[108] Pliny, whose figures owe more to Stoic moralizing on the cost of luxury than to imperial customs receipts, attests that 50 million *sestertii* per year were sent to India to pay for goods;

[101] Casson 1989, 191-193.
[102] Huntingford 1980, 48.
[103] *Periplus* 49.
[104] *Periplus* 49.
[105] *Periplus* 56.
[106] Casson (1989) comments that one of two things may have been happening to create a situation where currency was more desirable than goods: either Mediterranean merchants were out of said goods to trade by the time they reached such eastern ports or that eastern goods were expensive enough that it was necessary to pay outright for them.
[107] *Periplus* 56.
[108] *Periplus* 56.

elsewhere in his *Natural History* he claims that 100 million *sestertii* were spent yearly upon all the goods imported from India, China, and Arabia.[109] Pliny also quotes prices of 4-15 *denarii* per pound for various types of pepper, 40-75 *denarii* per pound for nard leaves, and 300 *denarii* per pound for cinnamon.[110]

Literary complaints about eastern luxuries and corrupt 'luxurious' living developed alongside a steady market for such eastern goods. Propertius (c. 45-15 B.C.E.) for instance, who condemns Indian gold, Red sea pearls, Tyrian purple, and Arabian cinnamon and criticizes imported beauty aids – perfume, make-up, jewelry, hair-dye, and diaphanous garments – draws on an established 'anti-cosmetic' tradition in his poetry. Ovid (c. 43 B.C.E.-17 C.E.), similarly mentions silks, decorated cotton, pearls and various gemstones, as well as other decorative materials such as shells, tortoiseshell, coral and ivory, perfumes and unguents, and writes that a 'middle way' should be found between neglect and over-refinement.[111] Culinary items, including pepper, cinnamon, and cassia, for example, are also mentioned. Such goods would have been coming to Rome from the Far East, from Arabia and India, at a time contemporaneous with the Godavaya shipwreck.

Gary Young, who has studied the various routes and communities involved in Roman commerce with the East, cautions against indiscriminately denoting such products as 'luxury goods,' or assigning the demand for such items wholly to a Roman taste for *luxuria*. While some goods were indeed luxury goods, many commodities had medicinal or religious applications. Frankincense and myrrh, for example, were predominantly items of religious significance, burned in honor of the gods at temples and at funerals for centuries.[112] Literary evidence for the use of eastern trade goods in the manufacture of medicines includes Dioscorides' (c. 40-90 C.E.) *De Materia Medica*, which dates

[109] Plin. *HN* 6.26; 12.84.
[110] Plin. *HN* 12.28.
[111] Gibson, 2007.
[112] Young 2001, 16.

from approximately 65 C.E. and is one of the most comprehensive ancient treatises concerning the medicinal uses of many eastern trade items. Eastern goods were especially prized for their perceived properties as antidotes, which made them useful for cleansing wounds, defeating infections, and as preventives against poisoning. In his writings, Theophrastus (c. 372-288 B.C.E.), for one, noted the power of pepper as an antidote.

Any discussion of Indian Ocean trade would be incomplete without the wealth of information that has been gained from archaeological excavation work; together with literary references such resources help contextualize the material carried onboard the Godavaya shipwreck. A commercial relationship between India and the western world is confirmed by abundant archaeological evidence, including excavation work carried out successively in 1945 by Mortimer Wheeler, in 1947-48 by Wheeler and J.M. Casal, and in 1989-1992 by Vimala Begley at the port of Arikamedu. Arikamedu, one of the emporia of Roman trade on India's Coromandel Coast, has come to be regarded as essential for the study of overseas commerce with the Mediterranean world during the so-called "Indo-Roman" trade period – a term that has prompted some controversy.[113] Indisputable evidence for commerce with the Mediterranean exists in fragments of transport amphorae, cups and plates of terra sigillata, ceramic lamps and unguentaria, blue glazed faience and glass bowls found at the site.[114] Two-thirds of the amphora fragments found at Arikamedu during the 1941-50 excavations come from wine jars, suggesting that wine was a principal commodity sent to India from the Mediterranean. Many of the fragments originated in Roman Greece, from the island of Kos, though fragments of Knidian and Rhodian amphorae have been found as well. Fragments of pseudo-Koan amphorae, originating in Campania, have led to the suggestion that wine from Greece was later supplanted at Arikamedu by an

[113] Begley 1996a; Gurukkal (2013) debates the relevance of the term "Indo-Roman trade" in discussing that trade and the communities and participants involved.
[114] Margabandhu 1983; Begley 1996a.

Italian imitation.[115] In addition to wine jars, fragments of Spanish jars for *garum* sauce and olive oil have been found as well.[116] Sherds of terra sigillata, a slipped Roman ware, found in the 1989-92 excavations at Arikamedu and dated to the first quarter of the first century C.E., are thought to represent personal possessions, novelty items, or gifts.[117] While typically considered part of the assemblage indicating resident foreigners, a sherd found with "megalithic" writing has caused speculation that some terra sigillata pieces were sold, bartered, or gifted to the local population.[118]

Pattanam, a site on India's southwest coast recently identified as ancient Muziris, has also provided evidence for Indo-Roman trade; Mediterranean contact is represented by readily identifiable ceramic material, including a Dressel 2-4 amphora, as well as other finds of imported Roman amphorae and related fine wares. [119] Such artifacts date from between the late first century B.C.E. to the fourth century C.E. Remnants of Roman glass bowls, fragments of painted glass objects, and glass pendants discovered at the site are also suggestive of personal belongings rather than merchandise.[120] Evidence further supporting the supposition that Muziris may have had a Roman 'merchant colony' comes from the *Tabula Peutingeriana*, a medieval map depicting the Roman world as it was in the first century C.E. This map shows a building marked as *Templum Augusti* (Temple of Augustus) at Muziris. Young argues that such a structure would have been built only by subjects of the Roman Empire, likely ones who either lived in Muziris or who spent a significant portion of their time there. Young further argues that the presence of foreign merchants is supported by the *Periplus*, in a passage that mentions "enough grain for those concerned with shipping, because the merchants do not use

[115] Will 1996, 318; Begley (1996a, 22) writes that such shipments in amphora jars date between the first century B.C.E. and the first century C.E.
[116] Casson (1991) suggests that the city may have been home to merchants involved in forwarding Indian goods to such places as Muziris and Nelkynda, where Mediterranean ships could pick them up; Begley 1996a; Will 1996.
[117] Will 1996.
[118] Begley 1996a, 18.
[119] Selvakumar et al. 2009.
[120] Gurukkal 2013.

it."[121] These merchants who do not use grain are thought to be Indians who would instead have eaten rice, whereas 'those concerned with shipping,' are thought to have been resident foreigners.[122]

Roman commodities also passed through Vasavasamudram,[123] an ancient port north of Arikamedu, and Alagankulam,[124] a port city south of Arikamedu.[125] In northwest India, long-distance maritime connections during the last decades of the first century B.C.E. and the early years of the first century C.E. are supported by findings of Mediterranean amphora fragments found off Bet Dwarka Island.[126] Nevasa, in western India and excavated between 1954 and 1956, and again between 1959 and 1961, offers additional evidence for commercial interaction between the Mediterranean and India.[127] Fragments of Italian Dressel 2-4 amphorae – a distinctive ware used primarily to transport wine – dated to between 25 B.C.E. and 100 C.E., and a sherd thought to belong to a late Rhodian amphora, constitute some of the best evidence the site has to offer for Mediterranean contact.[128]

In Sri Lanka, at sites such as Anuradhapura, Tissamaharama – where Roman amphorae and Islamic glazed wares have been discovered – and Mantai, there is evidence supporting Sri Lanka's involvement in early trade networks, primarily with India.[129] Sri Lanka's close relationship with its northern neighbor, India, is particularly important to understanding the region's commercial networks. The Buddhist chronicles, the *Dipavamsa* and *Mahavansa*, written in the fourth and sixth centuries, attest to the arrival of Prince Vijaya and his Sinhalese followers from northern India in the

[121] Young 2001, 30.
[122] Young 2001, 30-31.
[123] Nagaswamy and Abdul Majeed 1978.
[124] Nagasawamy 1991, Kasinathan 1992.
[125] Sidebotham 1996, 110-111.
[126] Gaur et al. 2005; Gaur and Sundaresh 2006.
[127] Gupta et al. 2001.
[128] Gupta et al. (2001) argue that the Dressel 2-4 amphorae type can be seen as evidence for long distance trade contacts in the last decades of the first century B.C.E. and early years of the first century C.E.
[129] Carswell 1991; Coningham 1999, 2006, Weisshaar et al. 2001; Ray 2003; Coningham and Gunawardhana, 2013.

sixth century B.C.E.[130] Archaeologically there is much evidence to tie the two countries together. Mantai, for example, situated at the northwest tip of Sri Lanka and occupied from the fifth century B.C.E. to the 11th century C.E., represents a major point of contact between South India and Sri Lanka with excavation work supporting extensive trade.[131] Such contact is relevant to the proposed thesis work here as the glass found onboard the Godavaya shipwreck is thought to have originated in South India.[132] In fact, many of the artifacts found onboard the Godavaya shipwreck – ceramics, stone querns, glass ingots, and iron ingots – suggest a close association with southern India.

Indo-Roman commerce is also well-represented at such sites as Berenike, on Egypt's Red Sea coast, where fieldwork has shown that the port functioned "as a conduit for merchandise, people, and ideas passing between Egypt and the Mediterranean basin on the one hand and the Red Sea and Indian Ocean littorals on the other."[133] Textile finds at Berenike include pieces of a sail and rope fragments, which originated from India; such material supports 'direct' trade and may mean that vessels like the Godavaya ship or others like it could have sailed across the Indian Ocean to Africa or Egypt.

Archaeological finds at Arikamedu and other sites verify that imported western goods were brought to India's eastern coast as well as to its more accessible western one. These commodities may not have been transported in Roman vessels, however. Casson argues that Indian vessels rather than Mediterranean ones handled India's east coast trade, utilizing small craft, which hugged the coastline, to shuttle back and forth between the subcontinent's east and west ports. Shipments of goods arriving from the Mediterranean were received once a year, in ports on India's west coast, in September or early October.[134] These goods were then forwarded, likely by Indian merchants, to India's east coast

[130] Juleff 1998, 11.
[131] Carswell and Prickett 1984; Carswell 1991; Sidebotham 1996.
[132] Lawler 2014.
[133] Young 2001, 13; Sidebotham 2002, 217.
[134] Casson 1991, 11.

ports. While taking part in the trade required a formidable amount of capital in the west, there were opportunities for small-scale operators on India's east coast.

Participation in such commerce was hugely profitable to justify the risk and expense involved. The *Muziris Papyrus*, discovered in 1985, which constitutes part of an agreement drawn up in Muziris between a second century C.E. creditor and a merchant, underscores the enormity of the investment represented.[135] The document concerns a shipment of goods, including nard, ivory, and textiles – items frequently found among India's exports – and a calculation of their value.[136] Originally thought to be the remains of a maritime loan, the document may instead represent a separate contract between the two parties concerning the security of the goods involved, drawn up once the commodities had arrived from India.[137] Given the effort and time involved in shipping goods from India to Egypt in the second century C.E., it has been suggested that the papyrus represents a supplementary agreement meant to detail precisely the responsibilities of the borrower from the moment the shipment arrived safely at its Red Sea port.[138] The papyrus additionally underscores the monetary investment involved in Mediterranean trade with India.[139]

TRADE BEYOND THE INDIAN OCEAN

Evidence for Indian merchants trading in 'western' ports exists in the form of little-publicized epigraphical fragments from the Red Sea port of Quseir al Qadim (Myos Hormos). Graffiti inscriptions with Tamil names in Tamil-Brahmi script as well as an ostracon with a Prakrit inscription recording the goods or personal possessions of individuals traveling or residing in Egypt indicate the

[135] Casson 1990, 196; Gurukkal 2013.
[136] Casson 1991, 10; Gurukkal 2013.
[137] Casson 1990, 202-204.
[138] Casson 1990, 202-205.
[139] Casson 1990; Sidebotham (2011, 212-218) comments that the value of the nard, ivory, and textiles carried onboard was almost 7 million drachmas; Gurukkal 2013, 193.

presence of Tamil speakers on Egypt's Red Sea coast.[140] These have been dated to the second or third century C.E.[141] Such documents, though fragmentary, help corroborate and personalize the corpus of Greco-Roman sources concerning the flourishing trade between India and the Roman Empire. Non-Roman pottery sherds found at Khor Rori in Oman[142] and at Berenike in Roman Egypt[143] may also be indicative of active participation by Indian or other easterners in the Mediterranean; such evidence contests arguments against the direct participation of South Indian merchants in overseas commerce.[144]

Some ancient merchants may have traveled as far as China in search of profitable commerce. Given that the voyage to India was relatively commonplace in the first century C.E., it seems more than plausible that a few sailed further east. This is supported by Chinese court records, which detail visits by Roman traders to Southeast Asia and China. The most famous of these accounts is found in the *Hou Han-Shou*, or Annals of the Later Han Dynasty, a far eastern source compiled in the fifth century C.E. by Fan Yeh of the Sung Dynasty (420-477 C.E.). These annals, which cover the period between 23 C.E. and 220 C.E., record that in 166 C.E. an embassy from king *An-tun* from *Ta-ch'in* (alternately *Ta-ts'in*) arrived from Annam (Vietnam) and sent gifts of ivory, rhinoceros horn, and tortoiseshell to the Han court. *Ta-ch'in*, or *Ta-ts'in*, has been identified by Friedrich Hirth as the Chinese name for the Roman East and *An-tun* as the Chinese rendering of Antonius.[145] Ferguson additionally comments that the term *Ta-ts'in* was generally applied to mean those from the Mediterranean and underscores this as applicable to the Seleucid kingdom, to Nabataean traders, to the Egyptian empire of

[140] Saloman 1991, 734; Begley 1996a, 23.
[141] Salomon (1991, 731) writes that the Tamil speakers identified may have originated from South India.
[142] Sedov and Benvenuto 2002, 192.
[143] Begley and Tomber 1999
[144] Gurukkal (2013, 201) contends that the direct participation of South Indian merchants in the Indo-Roman trade was "socio-economically untenable, incompatible and anachronistic" given how systematized contemporary Mediterranean trade was.
[145] Hirth's (1885, vi) interpretation is that the ancient country of *Ta-ts'in*, called *Fu-lin* during the middle ages, was not the Roman Empire with Rome as its capital, but merely its oriental part, such as Syria, Egypt, or Asia Minor.

Alexandria, and to Rome and its domain.[146] The *Hsi-yü-chuan*, i.e. "traditions regarding Western Countries," part of the *Hou Han-Shou*, contains a description of the westernmost countries described in Chinese literature prior to the Ming dynasty.[147] Mentions of storax, glass, and precious stone architectural ornaments, foreign ambassadors, and dangerous road conditions with tigers and lions causing travelers to resort to caravans, suggested to Hirth that *Ta-ts'in* was not Rome itself, but one of its eastern provinces.[148] Hirth further presumed from such records that goods went by Chinese junks from Annam to Taprobanê, or the coast of Malabar, whence they were shipped to the Red Sea.[149] This account may provide evidence of Roman merchant activity in the area of Southeast Asia, and such activity is additionally attested in later Chinese records. The *Liang shu*, which chronicles some of the events of the period following the collapse of the Han Dynasty in 220 C.E., records that in 226 C.E. Chi'in Lun, a merchant from *Ta-ch'in*, arrived in *Chiao-chih* (the Han province of northern Vietnam) and was sent on to the court of the Wu Emperor at Nanjing. Although the work's compilation in the later seventh century C.E. renders its accuracy about events some 400 years earlier somewhat questionable, it is still worth mentioning here. These same annals indicate that merchants from *Ta-ch'in* were active in parts of Cambodia and Vietnam. Discoveries of Roman gold medallions at the trading port of Oc-eo, near Ho Chi Minh City in Vietnam, give greater credibility to Chinese and Roman sources that speak of Roman trading activity in Southeast Asia, especially in the second century C.E. Recent finds of Mediterranean artifacts in Thailand, Vietnam, Malaysia, and Indonesia further support contact between these areas and the western world. Young writes that in the Antonine period and later, some Roman traders may have begun to journey further than India and Sri Lanka and launched trading activity in the region of Indo-China and perhaps as far as China, although such contacts were "presumably rare."[150]

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[146] Ferguson 1978, 585.
[147] Hirth 1885, 3-4.
[148] Hirth 1885, 5.
[149] Hirth 1885, 178.
[150] Young 2001, 34.

CONCLUDING REMARKS

Such textual sources, while not exhaustive due to the nature of this thesis, nonetheless indicate the existence of complex trading networks that spanned vast distances and involved a great many traders and their vessels. The *Periplus Maris Erythraei*, a work par excellence, is one of the best resources documenting commercial activity in this part of the world in the early first centuries C.E. Greco-Roman writings, Mediterranean mercantile documents, including the abovementioned papyrus concerning a shipment from Muziris to Alexandria, Indian and Sri Lankan literature, and Chinese court records all attest to a rich and complex long-distance trade conducted on a considerable scale. Archaeology, however, may be in the best position to answer specific questions about this period of Indo-Roman trade. Bopearachchi, though writing nearly 20 years ago, commented that Sri Lanka's ancient harbors have seen only limited exploratory excavations and partial publication.[151] The Godavaya shipwreck, contemporaneous with common ongoing trading practices described by the author of the *Periplus*, by Pliny in his *Natural History*, and demonstrated archaeologically in India and Sri Lanka, represents a unique opportunity to augment current understanding of ancient seafaring and trade in this region.

[151] Bopearachchi1 1997, xvi.

CHAPTER III

IRON PRODUCTION AND EXCHANGE IN ANTIQUITY

Our understanding of ancient iron technology in Sri Lanka is based upon intersecting veins of research, both from the island and from its nearest neighbor, India. Archaeological excavations of iron production sites on the island and experimental research – notably Gillian Juleff's experimental reconstruction of an ancient furnace which utilized seasonal wind power and her subsequent smelting trials – as well as metallurgical studies conducted throughout the country provide tangible clues into how iron was crafted in the past. Literary sources, particularly the writings of classical Greek and Roman scholars and geographers, Chinese exploratory texts and sailing directions, and the island's own chronicles and inscriptional evidence are only the proverbial tip of the iceberg. Ethnographic studies published between the 17th and early 20th centuries which detail smelting techniques observable in Sri Lanka and nearby countries have further elucidated the subject, providing a clearer picture of the production of iron in southeastern Asia in antiquity. Such studies have done much to foster an interdisciplinary approach and have significantly expanded existing research. It is in that aim of fostering future research that this chapter gathers some of the many sources that have contributed to our current understanding of this subject, while simultaneously formulating a framework to contextualize the material carried onboard a second century B.C.E.-first century C.E. shipwreck recently found off the island's southeast coast.

IRON PRODUCTION PROCESSES IN SRI LANKA

Iron first became known to man in a very low-carbon form and may have been initially discovered in the "guise of high-iron slags or bears or salamanders of iron occasionally produced in furnaces for lead or copper."[152] In other words, it was discovered as a by-product of lead or copper smelting.

[152] Wertime 1980, 2.

Because iron's processing requires higher temperatures than that of copper, early iron objects tended to be wrought items with a high percentage of slag inclusions.[153]

Three distinct iron ore deposit types have been identified in Sri Lanka. These include copper and magnetite deposits on the island's east coast, magnetite ore and quartzite deposits along the west coast, and lateritic ores in the southwest (Fig. 3.1).[154]

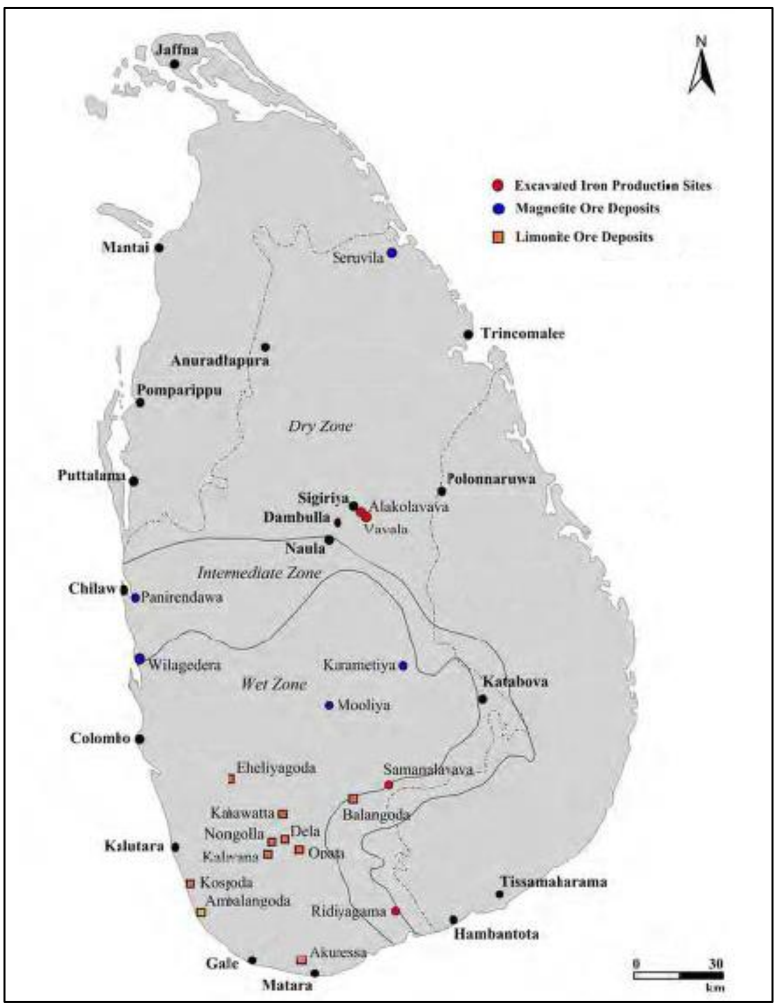

Fig. 3.1 Ancient iron ore deposits in Sri Lanka, after Solangaarachchi 2011.

[153] Tripathi 2001, 2; Wertime 1980, 2.
[154] Juleff 1998, 19.

Ancient iron producers used hematite (Fe_2O_3), limonite ($Fe_2O_3nH_2O$) and, to a lesser extent, magnetite (Fe_3O_4) ores.[155] The extracted ore was dressed, an initial refining process done to discard the less useable material, before it was transported to the smelting village or other production site. It was also frequently roasted, i.e. piled in heaps and allowed to dry – a process that resulted in the expulsion of much of the water content, along with carbon dioxide and volatile components like sulfur.[156] Hematite and limonite were more frequently utilized by early iron smelters as these ores were not compact, meaning lower temperatures could be used to reduce the ores. To reduce non-compact ores like hematite and limonite, temperatures of approximately 1200° C needed to be reached; to reduce magnetite a much higher temperature of 1800° C was required.[157] Reduction in antiquity involved heating the iron ore to as high a temperature as could be achieved. Because this was below the melting point of the metal a 'bloom' or amalgamation of low-carbon iron and slag would be created, which then had to be further worked, often by hammering, before an object could be forged from the metal. Additionally, both hematite and limonite ores tended to be relatively free of sulfur and phosphorus and could be worked more easily by the iron worker.[158]

Nodular iron stone, distributed throughout Sri Lanka's dry zone, may have been an "additional source of raw material" available to the early iron smelter.[159] Deposits of nodular iron stone have been found in southeastern Sri Lanka, with some deposits near the ancient Ruhuna capital of Tissamaharama and also near the urn burial site of Kataragama. In the 1880s, nodular iron stone and gravel were found extensively during excavations written about by Henry Parker.[160] Additionally these have since been located in the upper Walawe region.

[155] Solangaarachchi 2011, 60.
[156] Solangaarachchi 2011, 80.
[157] Solangaarachchi 2011, 68.
[158] Seneviratne 1985, 142.
[159] Seneviratne 1985, 138.
[160] Parker 1884.

Magnetite may have been marginally used by the early iron smelter because of what Sudharshan Seneviratne writes are "certain practical differences associated with exploiting and working this ore," one of which has to do with mining the ore.[161] A number of magnetite deposits in Sri Lanka have to be exploited through deep mining, making them much less accessible to early smelters.[162] For instance, a magnetite deposit at Panirendawa, located on the island's west coast, is some 80 to 500 feet below the surface. At Seruwila, south of Trincomalee, on the east coast, there is a magnetite deposit nearly 200 feet below the surface.[163] Additionally, even where magnetite has been found close to the surface, in Seruwila, it has been determined that the ore was not being exploited. This particular copper/magnetite deposit was quarried for copper rather than iron, likely due to the constraints of limited technology.[164] Seneviratne further writes that the deposit at Seruwila contains sulfide ores.[165] Any sulfur left in the metal during iron smelting tends to affect the metal's working properties, making the metal brittle when red hot due to its sulfur content and, as a consequence, difficult to forge.

Throughout antiquity, writes Joseph Needham in discussing iron and steel technology in east and southeast Asia, iron smelting was conducted in small-scale furnaces filled with alternating layers of iron ore and charcoal.[166] Wood, in some cases paddy husk (or milled rice husks which were easily combustible), was used as fuel.[167] The iron was heated – the melting point of iron is 1534° C, and the furnace could be heated to a temperature of 1200-1250° with the help of a natural or forced draft – to the point that slag could be tapped off, leaving a purer 'iron' behind.[168] The reduced iron, produced as

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[161] Seneviratne 1985, 142.
[162] Seneviratne 1985, 142.
[163] Seneviratne 1985, 142.
[164] Seneviratne 1985, 144.
[165] Seneviratne 1985, 144.
[166] Needham 1980, 510.
[167] Solangaarachchi (2011, 60) cites John Davy's and Ananda Coomarawamy's ethnographic studies of iron smelting in Sri Lanka; Tripathi and Tripathi (1994) also indicate that paddy husk has long been used as a fuel for iron working in India.
[168] Solangaarachchi 2011, 60-72.

a lump or bloom, was a mixture of solid iron, iron slag, and pieces of unburnt charcoal.[169] The bloom was then hammered on an anvil to remove the slag still embedded in it.

ARCHAEOLOGICAL EVIDENCE FOR EARLY IRON SMELTING IN SRI LANKA

Evidence for early iron smelting in Sri Lanka is supported by archaeological excavation work primarily carried out in the 1980s and 1990s. While archaeology's inception on the island can be dated to the creation of Sri Lanka's Archaeology Department in 1890, many of the earliest archaeological studies revolved around the royal centers and monastic communities of the Early and Middle Historic periods.[170] More recently, scholarly attention has expanded from establishing an island-wide chronology to formulating specific research questions that focus on urban and rural settlements, irrigation, iron production, etc. Archaeological excavations at Anuradhapura, Sigiriya, and Ibbankatuva, near Dambulla – to name just a few – have unearthed a wide variety of sites where ancient iron was produced or worked. Such studies have subsequently established the 9th century B.C.E. as the earliest known date for iron smelting in Sri Lanka.[171] Archaeological research conducted at Anuradhapura in the late 1980s and early 1990s, i.e. Robin Coningham's work, is fundamental to a discussion of the island's iron as the site contains some of the earliest dated examples of ancient iron working. Coningham's (1999) volume on Anuradhapura documents six seasons of excavation and post-excavation fieldwork carried out on a single trench – referred to as Anuradhapura Salgaha Watta 2 or ASW2 – between 1989 and 1994. Carried out under the auspices of the Anuradhapura Citadel Archaeological Project (ACAP) by a collaborative Sri Lankan-British team, the fieldwork provided a significant amount of evidence for smithing (as opposed to smelting). Smithing "involves the removal and consolidation of the metallic lump in the furnace."[172] This

[169] Solangaarachchi 2011, 73.
[170] Mogren 1999, 108.
[171] Juleff (1998, 13) discusses finds from the excavations of the Anuradhapura Citadel that support this date; Solangaarachchi (2011) highlights a ninth-tenth century B.C.E. slag sample from Sigiriya.
[172] Coningham 2006, 77.

involves taking an iron bar or object (already previously worked) and further working it to attain a desired shape, typically by heating and hammering it, although cold working – altering the metal's structure through mechanical stress – was also done. Only two types of iron-working slag have been identified at ASW2: silicate slag created during the smithing process and what Coningham calls 'hearth bottom.' 'Hearth bottom' is slag that dripped around the hearth as it was being worked and then consolidated, taking on the shape of the hearth as it cooled. Coningham writes that smelting of the iron must have occurred elsewhere.[173] The earliest of these iron-working residues were dated to the first half of the first millennium B.C.E., making it among the earliest evidence for iron working on the island.[174]

In 1988 the Settlement Archaeology Research and Collaboration Project (SARCP) was created and began fieldwork around the royal center at Sigiriya (occupied from the 3rd century B.C.E. to the 10th century C.E.) and the monastery of Dambulla, both south of Anuradhapura, in the island's interior. Of particular relevance here is research done by Svante Forenius and Rose Solangaarachchi at Dehigaha-ala-kanda, a site west of Sigiriya in the Kiri Oya valley, singled out because of a substantial amount of iron slag found across the surface of the site.[175] A 4x4m test excavation was done of the site's southernmost slag heap, in which the remains of two well-preserved furnaces were unearthed.[176] In 1991, the excavated area was expanded and three more furnaces were found. These were oval structures constructed of clay and stone slabs in pits carved into the bedrock.[177] On each side of the furnace shaft were found upright stone slabs, thought by the authors to help stabilize the walls.[178] Eight tuyeres – cylindrical clay pipes designed to control air-flow – were found as well, arranged to

[173] Coningham 1999, 9.
[174] Coningham (2006, 78) writes that the site's structural period K begins in the 9th century B.C.E., with this period's occupation period between 840-460 B.C.E. based on radiocarbon samples.
[175] Forenius and Solangaarachchi 1994, 136.
[176] Forenius and Solangaarachchi 1994, 136.
[177] Forenius and Solangaarachchi 1994, 137.
[178] Forenius and Solangaarachchi 1994, 137.

best control the furnaces' temperature during the smelting process.[179] Forenius and Solangaarchchi argue that a natural draft was not used. Instead air was blown in using bellows. Mats Mogren, in discussing the site and its findings, highlights the fact that the natural draft process documented by Gillian Juleff at Samanalawewa – discussed more thoroughly below – was not used at Dehigaha-ala-kanda.[180]

While evidence for roasting iron ore on the site was not found, the authors do think that ore may have been crushed on site. A number of conical holes, described as 15-20 cm wide and 7-15 cm deep with rounded bottoms, were mentioned in the report. It is thought that the holes might be connected to grinding or pounding the ore, perhaps done in order to remove unwanted material from the ore and break it up prior to smelting, similar to what roasting would have achieved.[181] Although Forenius and Solangaarachchi conclude that the amount of iron produced at the site cannot be determined, they do argue that the production of iron at the site should be regarded as being on an industrial scale.[182] Based on the site's pottery, the site was in use over a five hundred year span from the Protohistoric/Early Historic transition until about the fourth century C.E. Radiocarbon dates corroborate this and support iron production from at least the first century B.C.E. until the fourth century C.E.[183]

Dehigaha-ala-kanda is not the only industrial-sized iron production site. Mogren lists three other sites comparable in size to Dehigaha-ala-kanda: one at Kosgaha-ala, approximately 6 km east of Sigiriya, one at Kudagona vava, 11 km south of Sigiriya, and one at Kiralessa, 22 km south-west of Sigiriya.[184] Mogren also mentions 46 sites that were found during the Settlement Archaeology Research and

[179] Forenius and Solangaarachchi (1994, 138) determined that the tuyeres had been attached close to each other in parallel lines from imprints found on some of the furnace wall pieces.
[180] Mogren 1999, 120.
[181] Forenius and Solangaarachchi 1994, 140.
[182] Forenius and Solangaarachchi 1994, 140.
[183] Forenius and Solangaarachchi 1994, 140; Mogren 1999, 120.
[184] Mogren 1999, 121.

Collaboration Project which showed evidence of iron processing, including evidence for furnace walls, smelting slag, forging slag, nearby conical holes, and ore-crushed magnetite. These sites have not been dated, except for Ibbankatuva-Polvatte, where iron smelting was documented from the Early Historic period (600 B.C.E.-300 C.E.).[185] Ibbankatuva-Polvatte, located near Dambulla, was discovered by the Cultural Triangle and the Kommissariat fur Allegemeine und Vergleichende Archaeologie (KAVA) during exploratory work in 1988. Excavations were conducted in 1988, 1990, and 1991.[186] Priyantha Karunaratne, in a 1994 preliminary report on the site, briefly mentions glass beads, glass bangles, and iron slag.[187] Mapagala, another site examined by the Settlement Archaeology Research and Collaboration Project (SARCP) in 1989 and 1990, is located a quarter of a mile south of the complex at Sigiriya and dates from 1000 B.C.E to the 5th century C.E. The site is marked by a number of ruined structures, among which is a circular retaining wall. Archaeological investigations to date the site found iron slag.[188]

Gillian Juleff's 1998 examination of the island's iron production and her subsequent furnace reconstruction and smelting trials constitute a seminal piece of research. According to Juleff, there is direct archaeological evidence for the exploitation of iron at Samanalawewa, as early as the 3rd century BCE.[189] Juleff's work focuses on two distinct smelting technologies that have been identified in Sri Lanka. The earlier and more substantial is represented by what she refers to as west-facing sites – characterized by their (a) exposed hilltop settings with furnaces reliant on strong seasonal winds, (b) distinctive furnace structure, and (c) slag morphologies – and village smelting sites, characterized by their village settings and their small size. Juleff divides Samanalawewa's archaeometallurgical record into two major chronological episodes.[190] The earlier period stretches from the 3rd century B.C.E. (the

[185] Karunaratne (1994, 108) provides radiocarbon dates spanning from 436-226 B.C.E. to 347-534 C.E.
[186] Karunaratne 1994, 107.
[187] Mogren 1999, 116.
[188] Mogren 1999, 118.
[189] Juleff 1998, 35.
[190] Juleff 1998, 214.

Early Historic Period) to the 11th century C.E (or Middle Historic Period) and is characterized by the use of a two-component furnace which developed over time from a small, natural draft structure to a fully-fledged wind-driven system. The second techno-chronological episode extends from the Late Historic period (post-12th century C.E.) to the 20th century and includes two processes: smelting in small, bellows-driven shaft furnaces and crucible steel-refining; both processes appear to have been imported from southern India.[191]

Juleff argues that iron production technology took a major leap forward when monsoon wind power was applied to pre-existing furnace design.[192] The use of wind power enhanced the efficiency of the smelting process by enabling temperatures approaching the melting point of the metal to be reached. However, prior to Juleff's experimental furnace reconstruction and smelting trials in 1994, 'wind-blown' iron smelting had not been "reported with conviction from any part of the world."[193] The use of wind as an energy source to power a furnace was summarily dismissed by scholars as an unreliable system; it was assumed that wind gusts would create fluctuating temperatures within the furnace and subsequently poor smelting results. Juleff first documented wind patterns and velocities over four monsoon seasons. These revealed a pattern of near-mono-directional, high-velocity winds with a mean speed of 31.5 kilometers per hour.[194] Certain trends were noticeable, including less reliable wind conditions at night vs. windier conditions during the morning with a lull in the middle of the day. The furnace utilized by Juleff was reconstructed from archaeological data, with a semi-permanent rear wall aligned north-south and a temporary front wall that had to be rebuilt with each smelt. The first two smelting trials were done as familiarization exercises. The three following trials were carried out in July 1994. Ore, collected from local deposits, was roasted for 30 minutes prior to being placed in the reconstructed furnace in trials four and five, and halved in trial five. Each smelting

[191] Juleff (1998, 214) suggests that these later processes arrived at approximately the same time and as part of the same technological transfer.
[192] Juleff 1998, 218.
[193] Juleff 1996, 61.
[194] Juleff 1996, 60.

trial followed the same procedure and included two hours of preheating the furnace using charcoal, followed by the gradual addition of alternatively layered ore-charcoal charges. The trial was concluded by pushing the front wall of the furnace inwards.

The technology associated with the west-facing sites, i.e. the use of wind power to increase the temperature in the furnace, disappears from the archaeological record at the end of the island's Middle Historic period and gives way to village smelting sites. [195] These sites are discussed more fully in eye-witness accounts written between the 17th and 20th centuries and detailed below.

According to Irmelin Martens (1978), there are three main types of furnaces: a) bowl furnaces, b) shaft furnaces, and c) domed furnaces, with typologies mainly based on the size and the shape of the furnace, the type and the number of tuyeres and bellows, the slag-tapping methods, and the metal refining technology.[196] Juleff comments that the general classification of furnace types in Sri Lanka progresses from a 'less advanced' bowl-type furnace to 'more advanced' shaft furnaces.[197] Solangaarachchi adds that furnace types additionally depended on local geological conditions in the area, the quality and quantity of the raw materials, and the nature and quantity of the output. Recent excavations of Sri Lanka's iron smelting sites have revealed oval, circular semi-elliptical furnace types with bowl or shaft typologies in Samanalawewa, rectangular and circular furnace shapes with shaft or domed construction features in the Sigiriya-Dambulla region, box and elliptical types forging furnaces in Ridiyagama, circular/bowl type furnace structures at Salgahawatta in the Anuradhapura citadel, and chain or row type furnaces in Akurugoda, Tissamaharama.[198]

[195] Juleff 1998, 100.
[196] Solangaarachchi 2011, 73.
[197] Juleff 1996, 174.
[198] Solangaarachchi 2011, 74.

Ultimately, Juleff concludes that “Samanalawewa is not unique.”[199] Furnace structures in the Sigiriya area substantiate Juleff’s assertions that the archaeometallurgical record demonstrated at Samanalawewa is part of a more extensive island-wide tradition. While Juleff argues that the first appearance of the two-part oriented furnaces associated with wind-driven technology occurs in the third century B.C.E. in Samanalawewa, she also writes that it can be assumed that such furnace structures predate the site, possibly by as much as five centuries to the 9th century B.C.E., when iron technology first appeared on the island.

Much scholarly attention on ancient iron in India has previously been devoted to the chronology associated with the metal, with little attention paid to the “mode of production and the techniques of smelting and forging.”[200] More recently, however, this trend has begun to change, as indicated by a number of studies in archaeometallurgy. Different aspects of iron technology in India have been taken up by scholars like Cleere (1963), Banerjee (1965), Hegde (1973, 1991), Bharadwaj (1979), Gogte (1982), Chakrabarti (1985), Sahi (1976), Tripathi (1984-5, 90), Prakash (1984, 86, 1991), Hari Naraian (1990), Chattopadhyay and De (1984). An examination of such sources reveals that iron was produced locally in many parts of the subcontinent. As Tripathi and Tripathi write, “there was more than one center for the origin of iron working in India.” Archaeological evidence for iron working in India has shown that the earliest furnaces date from 1100-1000 B.C.E. to around 800 B.C.E and were generally circular pits.[201] At Pandu Rajar Dhibi (West Bengal), a settlement dated by radiocarbon from 1100-990 B.C.E. to 970-870 B.C.E., slags and a couple of iron objects were associated with ash pits that have since been identified as iron smelting furnaces.[202] Analysis of the artifacts revealed that their smelting was conducted at a low temperature, i.e. below 1100° C, which is typical of early

[199] Juleff 1996, 217.
[200] Tripathi and Tripathi 1994.
[201] Tripathi and Tripathi 1994, 241.
[202] Tripathi and Tripathi 1994, 241.

smelting technology. Another site that has yielded interesting evidence of iron smelting is Khairadih, where a row of three furnaces dating to around 200 B.C.E. has been found.

To summarize, it becomes clear that Sri Lanka had many iron production and processing sites, some of which might be considered large enough to be industrial, throughout the island. Furnace structures varied regionally in shape from oval or circular semi-elliptical furnace types with bowl or shaft typologies, to rectangular, box and elliptical types. These also seem to have been driven by natural draft in some cases – with the monsoon winds, for example, as supported by Juleff's work – and elsewhere, such as in Sigiriya, with bellows and tuyeres. These two techniques may also have been more dependent on location than chronology. For instance, evidence for the wind-driven technology found at 77 west-facing sites in Samanalawewa dates between the third century B.C.E. and the 11th century C.E. whereas the iron production technology evident at Dehigaha-ala-kanda has been dated to between the first century B.C.E. and the fourth century C.E. – demonstrating contemporaneous iron production strategies in Sri Lanka.

EXCHANGE IN ANTIQUITY

Archaeological excavation in Sri Lanka has provided a wealth of evidence supporting the island's involvement in a far-reaching, international trade network. Mantai, for example, is frequently cited as evidence for such trade. The city, situated at the northwest tip of Sri Lanka and occupied from the fifth century B.C.E. to the 11th century C.E., represents a major point of contact between South India and Sri Lanka. Archaeological excavation supports extensive trade between the two countries and early contact is even documented in ancient Sri Lankan chronicles.[203] Further south, in Anuradhapura, excavation has shown that the city served a pivotal role as a centralized manufacturing center.[204] Even in Ibbankatuva-Polvatte, the discovery of local redware pottery alongside resin-coated buff ware

[203] Carswell 1991, 197.
[204] Coningham 1999, 2.

imported from Persia supports this.[205] Mentions of Sri Lanka abound in the writings of Greek and Roman scholars and geographers. Evidence for trade to the East can also be found. Chinese sailing directions in the *Han Shu* (the Historical Book of the Han Dynasty), written between the second century B.C.E. and the second century C.E., indicate that the country 'Yibuchen' (Sri Lanka) lay south of India.[206] A late Tang Dynasty document written in the eighth century, *The Sea Route from Guangzhou to Countries in the Indian Ocean*, additionally describes a venture from Canton to a variety of places in the Indian Ocean, including Sri Lanka, providing approximate sailing times in 'Li' or days.[207] Such documents help support the extent to which Sri Lanka's maritime connections stretched. Though such examples support the existence of generalized trade in the region, there is less direct evidence for iron exchange emanating from the island. While Pliny's *Natural History* and the *Periplus of the Erythraean Sea* contain references to iron, recent archaeological work on an ancient shipwreck located off the island's southern coast may represent one of the most promising examples of the direct trade of metal in the region. Large-scale iron production sites on the island, which have led many scholars to argue for the existence of an extensive trade, have raised more questions than answers. At Dehigaha-ala-kanda, west of Sigiriya, the furnaces and associated iron residues left behind have caused authors Forenius and Solangaarchchi to ask a number of questions. Namely: 'from where was this [smelting] technique emanating?' 'Were there Indian, Iranian, Roman or other connections, transferring their technology, or was it the result of an indigenous development from a protohistoric stage?' and 'Was the iron intended for a local, a distant, or even a foreign market?'[208] Despite such unanswered questions, Mogren's argument that the "iron-producing areas of Sri Lanka must have been of importance for the world-system of the Indian Ocean" should not be disregarded.[209]

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205 Mogren 1999, 116.
206 Quang-Qi 1989, 13-14.
207 Quang-Qi 1989, 16.
208 Forenius and Solangaarachchi 1994, 141.
209 Mogren 1999, 121.

LITERARY EVIDENCE

Archaeological evidence constitutes only part of the available evidence. Literary material can help provide a better understanding of the island's long history with iron and its production. Sri Lanka is mentioned by numerous classical Greek and Roman writers and geographers. These early foreign references to 'Taprobanê' date from the end of the fourth century B.C.E. to the middle of the sixth century C.E. and constitute an invaluable resource for understanding this region of the world and its early maritime trade. The island's location at the midpoint of major sea routes link it with the Middle East and the Mediterranean to the west and China and Southeast Asia to the east and contributed to its being an "entrepot of ancient commerce."[210] The island's numerous natural resources, among which are gems, pearls, muslins, ivory, tortoise-shell, rice, ginger, honey, beryl, amethyst, gold, silver, and other metals, certainly contributed, along with its location, to the island's involvement in both regional and foreign trade networks.[211] Iron, in particular, is mentioned in Pliny's *Natural History* as well as in the *Periplus of the Erythraean Sea*. In Book 34 of Pliny's *Natural History*, it is noted that iron ores can to be found almost everywhere and are worked much in the way that copper is.[212] Foreign iron is especially lauded as exceptional, especially that "made by the Seres, who send it to us with their tissues and skins."[213]

Sri Lanka's ancient chronicles, such as the *Thupavansa*, *Mahavansa,* and *Pujavaliya* – Pali texts which relate the early history of the island and date to the fourth, sixth, and 13th centuries C.E. respectively – attest to the use of iron from at least the Early Historic period onwards. Evidence for using gold, silver, lead, copper, and iron is recorded in such chronicles and in numerous epigraphs.[214]

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[210] Weerakkody 1997, 17.
[211] Weerakkody (1997, 4) draws from Strabo, Pliny, and the anonymous writer of the *Periplus* in listing Sri Lankan commodities; McLaughlin (2010) references Strabo in writing that ivory, tortoise shell and other wares were brought from Sri Lanka to the Indian markets.
[212] Bostock and Riley 1857, 209.
[213] Bostock and Riley 1857, 208.
[214] Solangaarachchi 2011, 54.

Early Brahmi inscriptions (circa second century B.C.E to the first century C.E.), refer to different craftsmen for the various kinds of metal. There are men referred to as *kabara* (ironsmiths), *tabakara* (coppersmiths) and *topasa* (tinsmiths). According to Ananda Coomaraswamy, the iron smelters are called *yamannu* and belong to a low caste.[215] John Davy, who also discusses Sri Lanka's caste system, writes that it is composed of four principle castes, of which iron smelters occupy a low tier in the kshoodra wansè caste and are called *yamanoo*.[216] Sri Lanka's chronicle, the *Culavamsa*, additionally records implements used in the iron production process, including bellows, blowpipe, anvils, hammers, sledge-hammers, axes, hatchets, tongs, etc.[217]

A scene in the *Mahavamsa*, one of the abovementioned Pali texts that relate the history of the island, tells of the consecration of the king Asoka. The work includes a reference to forges and the work within them, stating that, the 'spirits of the air brought garments,' while parrots brought 'wagon-loads of rice,' 'bees brought honey,' and, most importantly – at least for the discussion here – 'in the forges bears swung the hammers.'[218] In a later episode, King Dutthagāmani marches to the city of Vijitanagara approximately 24 miles southeast of Anuradhapura, which has a 'high wall, [and is] furnished with gates of wrought iron, difficult for enemies to destroy.'[219] Iron is also mentioned in the building of a great thūpa, in which iron is laid over a layer of stones, bricks, clay, and cinnabar, over which is constructed crystal, cement, resin, and copper.[220]

Historic and modern sources should also not be disregarded. There are several eye-witness descriptions of indigenous smelting in Sri Lanka, written between the 17th century to the early 20th

215 Coomaraswamy 1961, 31.
216 Davy 1821 (111-112), writes that iron smelters are part of a caste called *Paduas*, whose members have to pay a pecuniary tax and perform a variety of low services, like building walls, thatching roofs, and annually furnishing a certain amount of iron to the king and the chiefs of the districts.
217 Solangaarachchi 2011, 91.
218 Geiger 1964, 28.
219 Geiger 1964, 172.
220 Geiger (1964, 191-192) notes that the word used in the *Mahavamsa* could be either 'ruby' or 'cinnabar.'

century, that describe smelting methods that overlap chronologically with the wind-driven furnace structures examined by Juleff. Bellows-operated systems (which are described in the historic and modern source material) appear to have been used as early as the first century B.C.E., if the evidence at Dehigaha-ala-kanda, west of Sigiriya, is any indication. This date coincides with the date of the Godavaya shipwreck, which has tentatively been dated to between the second century B.C.E and the first century C.E. As such, these sources should not be omitted from a discussion of the island's early iron production. One such description of the iron smelting process in Sri Lanka is that provided by Captain Robert Knox who served in the Honorable English East India Company in 1657 and spent years in Sri Lanka after the vessel he was on lost its main mast on the return voyage to England. While Knox's account covers many different topics, he does discuss iron and writes that it is abundant on the island and that in each town there is a smith to make and mend tools.[221] Sri Lanka, writes Knox, has plenty of iron which is made "of stones" located in several places on the island, approximately four to six feet under the surface. The 'stones' are laid in a heap and burned with wood – a process Knox says makes them softer and better for the furnace.[222] Knox also specifies that there is an art to making the iron. He describes the furnace, with its clay base where charcoal, the so-called iron 'stones,' and more charcoal are laid alternately in layers. The furnace has a back, behind which the iron smelter works the bellows, keeping the fire hot. As the stones are burned, the slag that is in them melts and runs out through a slanting hole at the bottom, leaving a "purer" iron behind. When the dross – mineral waste, in particular scum formed on the surface of molten metal – ceases to appear in the drain at the bottom, the iron is considered 'purified' and is removed from the furnace. According to Knox, the iron is then given 'a chop with an ax' to determine its quality, as the iron is heterogeneous and must be examined visually before it is doused in water.

[221] Knox 1681, 44
[222] Knox 1681, 96.

John Davy's writings, penned during his time in Sri Lanka as part of an army medical staff stationed there between 1816 and 1820, describe the island's mineralogy as "singular and curious."[223] Davy writes that Sri Lanka is accordingly poor in "useful metals," excepting iron and manganese.[224] He writes that he has encountered iron pyrites, magnetic iron ore, something he calls 'specular iron ore,' red hematite, bog-iron ore, and earthy blue phosphate of iron on the island. [225] Red hematite and bog-iron ore are more common on the island and it is from these ores that the Sri Lankans extracted the metal they would later smelt. Like Knox, Davy described the furnace structure, in this case composed of two small furnaces, protected under a thatched shed and made of clay, as being approximately three feet high and three feet wide and set against a wall to protect the bellows system and operators from the heat. The furnaces were loaded with a mixture of iron ore, broken into small pieces, and charcoal.[226] The fire was maintained until the ore was reduced and the fused metal collected. At this point, Davy writes that the iron smelter sold the crude metal, rather than working it further, to a blacksmith who would repeatedly heat and hammer the iron until it was sufficiently malleable.[227]

Historian Ananda Coomaraswamy, writing in 1903 and 1904, described iron smelting at a furnace structure in Hatarabage. The furnace Coomaraswamy investigated was operated by an old man and his sons and was sheltered beneath the thatched roof of a shed that was open on all sides. The furnace was a double one with two openings, "one in front, from which the slag runs out, and through which the bloom of iron is ultimately extracted, and a smaller one behind, through which a blast of air from the bellows is forced into the well, and through which a rod is inserted from time to time to poke and test the iron to see if it is ready."[228] A charcoal fire was started at the bottom of the well and covered

[223] Davy 1821, 17.
[224] Davy 1821, 17.
[225] Davy (1821,17-18) writes that iron pyrites are rare, and can be found at Ratnapoora, in Saffragam, whereas magnetic iron ore can be found in Kandy and the earthy blue phosphate of iron has been procured from Colombo.
[226] Davy (1821, 262) writes that only "the most tractable ores must be selected."
[227] Davy 1821, 262-263.
[228] Coomaraswamy 1961, 34.

with layers of ore and charcoal until the well was filled. Additional iron ore and charcoal were added as the work proceeded, with the occasional release of slag.

The ore, being usually limonite ($Fe_2O_3nH_2O$) though occasionally hematite (Fe_2O_3) was used, is broken up into pieces a little larger than a walnut, and roasted prior to being used in the furnace. Two men – in this case, the smelter's sons – worked the bellows, alternating for three or more hours to keep a continuous blast of air going into the hole leading to the well of the furnace.[229] When the iron was determined to be ready, the sand was cleared away and the bloom pushed out through the opening, at which point the iron was 'cut.'[230] The bloom was then thrown into water and afterwards taken out and left to finish cooling.[231]

A particularly important study that examines the early use of iron in Sri Lanka comes from the investigations of Henry Parker, who was a part of British excavations conducted at Tissamaharama in 1884. The excavation done near the ancient capital yielded a number of iron tools, including wedges, chisels, and a trowel, as well as domestic implements and several weapons. The iron remains were found in a four-foot-deep trench dated to sometime between 200 B.C.E and 50 B.C.E., though the tools may more accurately belong to the first century C.E.[232] Parker writes that two pieces of a long bar of round iron, about three quarters of an inch thick and made by welding together several iron pieces of various thicknesses, may have formed part of a chisel used for cutting stone.[233] Parker also notes a short, rectangular chisel which may have been a 'cold chisel' for cutting iron. He surmises that this was made by wrapping thin plate-iron around the piece or pieces of iron forming the center

[229] Coomaraswamy 1961, 34
[230] Coomaraswamy (1961, 35) writes that the bloom of iron is taken out and beaten with thick sticks before a third man cuts the lump of iron nearly in half so that the quality of the iron may be better examined.
[231] Coomaraswamy 1961, 35.
[232] Parker 1884, 38.
[233] Parker 1884, 40.

and then welding the whole thing together.[234] Several spearheads were also found during the excavation, along with two pieces of iron which Parker suggests were parts of daggers. Parker comments that many large pieces of slag were encountered throughout the excavation, and suggests that the iron used for making the axes and other tools was smelted on the spot. The iron is "so nearly pure that this would present no difficulty."[235]

CONCLUSIONS

Robin Coningham wrote in 2006, that the "study of the antiquity of metal-working in Sri Lanka is still in its infancy."[236] As discussed throughout this chapter, this study, i.e. our understanding of the island's ancient iron technology, is based upon a compilation of research that has been gathered over recent decades. Archaeological excavation conducted within the last 30 years, literary sources from the western and eastern worlds – from classical Greek and Roman scholars and geographers and Chinese exploratory texts and sailing directions – as well as the island's own chronicles, historic and modern eye-witness accounts of smelting in Sri Lanka, and experimental research, have done much to provide clues into how iron was crafted in the past. While our understanding of the production and trade of ancient iron might still be considered nascent at this point in time, that is not to say that there is a dearth of research on this topic. Ultimately, such studies are essential in gradually providing a clearer picture of the production and trade of iron in antiquity. This chapter presents some of the many sources that have contributed to our current understanding of this subject in order to formulate a framework in which to contextualize the metal cargo carried onboard the Godavaya shipwreck.

[234] Parker 1884, 42-43.
[235] Parker 1884, 61.
[236] Coningham 2006, 77.

CHAPTER IV

CONCLUSIONS

IRON ANALYSIS AND CONSERVATION

> Nature, in conformity with her usual benevolence, has limited the power of iron, by inflicting upon it the punishment of rust.[237]

Iron, as Pliny (c. 23-79 C.E.) succinctly points out, does not like to remain iron. Instead iron disintegrates, rusting in the presence of oxygen and moisture on land and corroding under water through an electrochemical process driven by electron exchange.[238] Iron artifacts recovered from a marine environment are typically found with accumulations of fouling organisms – marine life, sand, shells, and other particulate matter – entombing them.[239] This chapter examines the deterioration of iron in a marine environment and discusses potential conservation strategies in relation to the Godavaya shipwreck and its cargo of iron bar ingots. An important goal of this thesis is to outline a series of recommendations to conserve the iron cargo based on comparable case studies of other ancient iron material. This chapter therefore looks to the wealth of conservation literature that exists to formulate such recommendations and consider what might be gained from such work.

THE CHEMISTRY BEHIND DETERIORATION

A variety of factors affect the corrosion of metal under water. These include metal composition, the chemical composition of the water, water temperature, marine growth, seabed composition, the

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[237] Plin. *HN* 34.40.
[238] Turgoose 1982; Barkman 1993, 156
[239] North (1976, 253) comments that iron artifacts removed from the ocean are generally encrusted with a layer of hard concretion, a semi-permeable barrier between the iron and the seawater that affects how the iron corrodes; North and MacLeod 1987; North 1987; Scott and Eggert 2009, 123; North 1976; Selwyn et al. 2001, 110.

position of objects in relation to other shipwreck materials, whether or not the object was covered by sediment, and the extent of water movement.[240] Metal artifacts are notoriously non-homogeneous as impurities in the ore are retained as inclusions within the metal during the reduction process; these can act as avenues for the entrapment of salts and corrosive solutions.[241]

As mentioned earlier, iron corrodes under water via an electrochemical process directed by the flow of electrons between anodic and cathodic locations on the metal's surface.[242] These negatively charged particles form metal ions, or cations. These diffuse into the environment where they combine with anions to form insoluble and electrically neutral products.[243] At the cathode, electrons combine with water and dissolved oxygen to form hydroxyl ions, which react with metal cations to form insoluble corrosion products such as oxides and hydroxides.[244] As iron corrodes, dissolved cations are released from the metal. These insoluble corrosion products travel outward through existing layers of corrosion to the surface, where they are deposited along with minerals contained in the seawater and surrounding sediment to form a solid concretion or encrustation encasing the artifact – which is what has happened to the iron on the Godavaya site. This process of metal ions traveling outward from the metallic core to the surface continues until the artifact is encased within a shell of corrosion products, often to the point where little to no metal remains inside.[245] Once excavated and raised, concreted metal artifacts deteriorate rapidly unless conservation begins.[246]

[240] North and MacLeod 1987, 68.
[241] Robinson 1982, 222; North and MacLeod 1987, 77; Selwyn et al. 2001, 110; Scott and Eggert 2009, 2.
[242] Robinson 1982, 221.
[243] Robinson 1982, 221.
[244] Robinson 1982.
[245] Robinson (1982, 228) writes that these cavities can be used to make casts of the artifact.
[246] North 1987, 207; Scott and Eggert (2009, 155) comment that once artifacts are recovered from underwater sites they require immediate conservation treatment.

IRON CORROSION BY ANY OTHER NAME

The most commonly encountered iron corrosion products include: $Fe(OH)_2$ (ferrous hydroxide), $FeCl_2$ (ferrous chloride), FeS (ferrous sulfide), with FeO(OH) (ferric-hydroxide), Fe_2O_3 (ferric oxide), and $FeCl_3$ (ferric chloride) occurring once artifacts have been raised to the surface and exposed to oxygen.[247] Another dominant corrosion product commonly associated with iron recovered from a marine environment is β-FeO.OH (b-Ferric Oxyhydroxide).[248] β-FeO.OH, γ-FeO.OH, or Fe_3O_4 can form depending on pH and the rate of oxidation.[249] Iron deterioration can also occur in the presence of sulfate reducing bacteria, particularly the strains known as *Sporovibrio desulphuricans* and *Desulphovibrio desulphuricans*, which create hydrogen sulfides as a metabolic process; these sulfides react with existing ferrous ions to form the corrosion products ferrous sulfide and ferrous hydroxide.[250]

TREATMENTS FOR CONSERVING IRON

The removal of chlorides from marine iron corrosion products – present predominantly as FeOCl and $FeCl_3$ – has long been recognized as a major factor in stabilizing artifacts recovered from a marine environment.[251] Strategies to mitigate the deleterious effects of chloride ions and to prevent iron artifacts from disintegrating include immersion treatments, electrolytic reduction (electrolysis), alkaline sulfite treatment, pulsating current, plasma heating, and treatments reliant on heat such as hydrogen reduction and annealing.[252] The majority of these depend on immersing artifacts in an aqueous solution, usually a near-neutral or alkaline one, and waiting for chloride ions to diffuse

[247] Hamilton 1976; Turgoose 1982.
[248] Gilberg and Seeley (1981, 51-52) mention that it has suggested that β-FeO.OH (b-Ferric Oxyhydroxide) forms once the immersed iron object is recovered from the sea and exposed to the atmosphere.
[249] Turgoose 1982, 3.
[250] Hamilton 1976, 12.
[251] Hamilton 1976; North and Pearson 1978, 174.
[252] Selwyn and Argyropoulos 2005; Scott and Eggert 2009, 155; Kergourlay et al. 2011, 2474.

out.[253] The rate at which chloride ions diffuse from archaeological iron into a treatment solution depends on how the chloride ions were initially distributed in the corrosion layer.[254] Two models of chloride distribution have been postulated: 1) a distribution wherein chloride ions are spread uniformly throughout the artifact and 2) an abrupt distribution wherein chloride ions are concentrated at the interface between the iron and the corrosion layer.[255] The uniform model, in which chloride ions are thought to be evenly distributed throughout the corrosion layer in cases where the corrosion of the iron is negligible or has ceased, has been used to describe chloride ions in iron from a marine environment. Chloride ions can also be concentrated at the surface of the corroding iron, particularly if corrosion is still occurring.[256] During treatment, chloride ions have to diffuse from these regions into the solution and their transport is subsequently slowed by the rust layer, meaning that the diffusion of chloride ions into the wash solution is delayed. Conversely, chloride extraction is associated with the morphology of the rust layer in this diffusion model and may be distributed in the rust layer in various forms: inside the pores and cracks as free chlorides, trapped inside the structure of iron hydroxychlorides or adsorbed at the surface of the grains of corrosion products.[257]

The conservation of iron artifacts from a marine environment poses "one of the most serious problems facing the conservation scientist."[258] The presence of chloride ions, trapped both within the lattice structure of the various iron oxyhydroxides and at the interface between the metal and the corrosion layer, promotes further corrosion.[259] Stopping the corrosion of iron artifacts recovered from

[253] Selwyn et al. 2001, 109; Mardikian et al. 2010, 89; Kergourlay et al. 2011, 2474.
[254] Selwyn et al. 2001, 109.
[255] Selwyn et al. 2001, 109.
[256] Turgoose 1982; Selwyn et al. 2001, 111; Kergourlay et al. 2011, 2474.
[257] Kergourlay et al. 2011, 2474; Hamilton (personal communication) contends that the distribution of these chlorides is somewhat immaterial.
[258] Gilberg and Seeley 1981, 50.
[259] Gilberg and Seeley 1981, 54; Keene and Orton (1985, 165) specify that treatments that remove chloride ions make the re-corrosion of archaeological iron much less likely.

a marine site entails removing chlorides that have formed as the iron deteriorated.[260] Keene (1994) argues that there is a correlation between the quantity of chloride removed during treatment and the probability of stability. It is widely assumed that if sufficient chloride can be removed from an archaeological object, then that object will be stable.[261] Conservation strategies to treat underwater iron typically involve the removal of chlorides, with iron artifacts treated in successive solutions and then given protective coatings.[262] Treatment methods fall into two categories: 'washing methods,' in which chlorides are extracted by immersing the object in a solution, typically sodium hydroxide (NaOH), or 'heat treatment methods' in which chlorides are removed by volatilizing, or heating the artifact.[263] Electrolytic reduction is an alternative conservation strategy that involves the creation of an electrolytic cell in which the artifact functions as the cathode, a mild steel 'cage' around the artifact serves as the anode, and an electricity-conducting solution called the electrolyte work together to create an efficient and cost-effective method to conserve metal artifacts.[264] An electrical current from an external direct current (DC) power supply causes the reduction of FeO(OH) to magnetite while electrolytic attraction causes chloride ions to migrate towards the positively charged anode.[265] Artifacts too fragile for electrolytic reduction can be alternatively treated in successive baths of dilute caustic soda solution or in solutions of sodium sesquicarbonate. Alkaline sulfite treatment, which involves the immersion of the object in a heated solution of sodium hydroxide and sodium sulfite in an air-tight container, is another conservation strategy that involves the reduction of FeO(OH) to magnetite.[266] Alternatively, thermal treatments, which involve volatilizing chloride ions, have been around for almost 150 years. Hydrogen reduction is one such method that involves the use of high

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[260] North 1987, 213; Wang et al. state that the presence of Cl^- ions accelerate the deterioration of archaeological iron and that chloride removal constitutes one of the predominant strategies to conserve such material.
[261] Keene (1994, 259-260) similarly asserts that the most effective treatments are those that remove the greatest amount of chloride.
[262] Plenderleith and Werner 1971, 286.
[263] North 1987, 213.
[264] Hamilton 1976.
[265] Hamilton (1976) suggests a range of current densities dictated by each of the three functions of artifact electrolysis: a low density of 1-5mA.cm^{-2} to reduce ferrous corrosion compounds, a medium density of 50mA.cm^{-2} for chloride removal, and a high density of 100mA.cm^{-2} for mechanical cleaning.
[266] North 1987.

temperatures (1060° C) in a reducing hydrogen atmosphere. While hydrogen reduction successfully stabilizes and preserves iron artifacts, eliminating corrosive chloride compounds by sublimation – ferric and ferrous chlorides sublimate at a temperature of 700° C and higher – thermal treatments have been criticized in the conservation literature because such temperatures alter the metallurgical microstructure of the metal, rendering the artifact useless for future metallurgical analysis.[267] Hydrogen plasma reduction involves placing iron artifacts into a quartz discharge tube surrounded by hydrogen gas under low pressure and ionizing that gas into plasma using high-frequency radio waves.

According to Hamilton, "the only way that an iron artifact recovered from the sea can be stabilized is to remove the chlorides from the metal."[268] As discussed, this can be accomplished by electrolytic reduction as well as by a number of other possible conservation techniques. Conservation typically continues until the chloride content of the artifact is reduced to a 'safe' level, with no indication of increasing, at which point the conservation treatment is tentatively assumed complete.[269] However, there is no general agreement on what constitutes a 'safe' level for residual chlorides in marine iron corrosion products.[270]

COMPARATIVE CASE STUDIES

One study that compared conservation treatments and their results examined the chemical immersion and electrochemical treatment of freshly excavated iron ingots raised from two Roman shipwrecks in the Mediterranean Sea. Ingots in the study were immersed in a 20 g L^{-1} NaOH (sodium hydroxide)

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[267] Hamilton 1976; North (1987, 216) writes that in a reducing atmosphere, some of the iron corrosion products are converted back to metallic iron, which improves the mechanical strength of the artifact; Mardikian et al. 2010, 90.
[268] Hamilton 1976.
[269] North 1987, 219.
[270] North (1987, 219) writes that between approximately 200 and 800 ppm Cl^{-} yellow $FeCl_2$ droplets may accumulate on the artifact surface; above approximately 800 ppm Cl^{-} can cause spalling of the graphitized layer and requires additional treatment of the artifact.

solution in a stainless steel tank and maintained in solution at 50° C in an oven or treated by the electrochemical method and wrapped in a stainless steel grid and placed in a 10 g L^{-1} KOH (potassium hydroxide) solution. The main chloride-containing corrosion product identified on the Gallo-Roman ingots was β-Fe2(OH)3Cl.[271] Immersion in a sodium hydroxide solution induced the complete transformation of β-Fe2(OH)3Cl into Fe(OH)2. While the same transformation was observed on the ingots immersed in potassium hydroxide, the transformation was only partial despite a longer immersion time. In conclusion, both alkaline baths led to the dechlorination of β-Fe2(OH)3Cl and the formation of Fe(OH)2.[272]

Another study concerning the effectiveness of immersion treatments include work done by Selwyn and Argyropoulos, whose research examined the effectiveness of sodium hydroxide (NaOH) in removing soluble salts and promoting the long-term stability of archaeological iron. The main driving force for Cl^- ion removal is diffusion, with the Cl^- ions diffusing from a region of higher concentration (at the metal/corrosion interface) to one of lower concentration (the treatment solution).[273] Their work found that sodium hydroxide was effective in promoting the release of Cl^- ions.[274] Selwyn and Argyropoulos recommend immersion in sodium hydroxide as "more effective than other treatment methods."[275]

Another preservation strategy involves the in-situ conservation of artifacts prior to their recovery. One example includes work done by MacLeod on a wrought iron anchor and cast iron carronade from the 1790 wreck of the *HMS Sirius*.[276] The iron anchor and carronade received in-situ electrolysis treatment using sacrificial anodes – a pretreatment strategy that helped to stabilize the artifacts and

[271] Kergourlay et al. 2011, 2480.
[272] Kergourlay et al. 2011, 2480.
[273] Selwyn and Argyropoulos 2005, 82.
[274] Selwyn and Argyropoulos 2005.
[275] Selwyn and Argyropoulos 2005, 82.
[276] Scott and Eggert 2009, 159

ensured that they could be safely recovered and transported.[277] Monitoring on the seabed and in the laboratory showed that approximately 80% of the chlorides had been removed before excavation, highlighting the benefits of this kind of pretreatment should it prove practicable. Such an approach is particularly relevant to the material in Sri Lanka.[278]

CONSERVATION RECOMMENDATIONS

Quite a bit of research has been done to explain the corrosion mechanisms involved in the degradation of archaeological iron.[279] To combat such degradation a number of conservation techniques have been tried over the years. Early conservation treatments for iron included boiling in purified water, reduction using electrolysis, and soaking in sodium carbonate.[280] More recently introduced methods include hydrogen reduction and gas plasma reduction, considered aggressive treatments – heat, in particular, is especially detrimental as it can alter the microstructure and compromise metallurgical analyses.[281] These treatments are also prohibitively expensive, requiring expertly trained staff and costly equipment. Alternative treatments not reliant on chloride extraction include desiccated storage, storage in an atmosphere of vapor-phase inhibitor (VPI), and storage in a nitrogen atmosphere or with an oxygen scavenger; however, these have met with little overall success and typically see the re-corrosion of archaeological iron objects.

Ultimately, for the iron cargo of the Godavaya shipwreck to be thoroughly analyzed, a conservation plan needs to be formulated. The concreted metal cargo will need to be raised and examined, a prospect that involves a number of concerns given the depth of the site and the size of the iron pile. At one point, having a pool-sized space to deposit the iron was discussed. A more likely solution would

[277] Scott and Eggert 2009, 159
[278] Scott and Eggert 2009, 159
[279] Giberg and Seeley 1982; Turgoose 1982a, 1982b, 1985; Keene 1994, 250.
[280] Keene (1994, 250) comments that these early treatments for iron resulted in the re-corrosion of materials within a few years.
[281] Tylecote and Black 1980; Keene 1994, 250; Scott and Eggert 2009, 3.

be to bring the iron up in sections, which would require detailed mapping and drawing of the concreted pile first to decide where the iron could be suitably sectioned. Once recovered, the iron would have to be stored. Hamilton recommends that any iron recovered from a marine environment be stored in an inhibitive aqueous solution, the most common of which include sodium hydroxide, sodium carbonate, and sodium sesquicarbonate – any of which will prevent continued corrosion.[282] Tap water could be used for the storage solution; Hamilton recommends using tap water until the chloride level in the artifacts is less than that of the tap water.[283] Rain water is another option and is particularly useful in a country like Sri Lanka. Additionally, condensation from refrigeration and air conditioning units can also be used for storage and treatment solutions. Following storage, photographs and radiographs need to be taken. As mentioned earlier, the concreted iron pile was only briefly examined during the two excavation season and it was difficult to ascertain what could be trapped within the concretion pile. Radiographs are invaluable for seeing inside encrustations and for serving as a reference once mechanical cleaning is started. Mechanical cleaning can be done using hammers and chisels along cleavage lines to detach the majority of the encrustation and with pneumatic tools in the case of smaller, more complex artifacts that need more careful cleaning. The extracted iron artifacts would then need to be rinsed and evaluated. Raising and preserving two thousand year old iron comes with a host of problems, particularly in that the condition of the iron is a complete unknown at this point in time. The metal cargo may be degraded to the point where it would not survive conservation, making casting the only means of preservation.[284] Any iron with a substantial core could be treated with electrolytic reduction. Electrolytic reduction would be the best and least costly conservation strategy and is an effective, easy to set up treatment. While there is a certain amount of equipment that is required – power supplies, terminal wires and clips, anode material, chloride monitoring equipment, and vats – these are relatively easy to come by and much less expensive than hydrogen reduction or gas plasma reduction. Stoves for boiling rinses and heating

[282] Hamilton 1976, 21.
[283] Hamilton 1976, 25.
[284] Hamilton 1976, 27.

tannic acid and microcrystalline wax, to properly seal the iron against future corrosion, would be needed as well. Finally, chemical disposal would need to be addressed. In Sri Lanka, there are conservation facilities at the Department of Archaeology in Colombo, where the artifacts from the 2012-2013 and the 2014 field season are currently undergoing treatment. While these are primarily ceramic materials and need little more than desalination, the conservation facilities are large enough to accommodate electrolytic reduction setups as well as permanent, long-term storage. Once treated, the iron would need to be stored in dry conditions and relative humidity would need to be maintained.[285]

ANALYZING THE IRON CARGO OF THE GODAVAYA SHIPWRECK

X-ray fluorescence (XRF) is a nuclear technique frequently used in archaeology.[286] It is a non-destructive method – a characteristic that makes their use even more advantageous because despite the size of the concreted iron bar or iron ingot pile in Sri Lanka, the site is in its excavation infancy and there is no way to accurately predict what losses may occur through destructive sampling, not to mention its eventual raising, conservation, and curation. In XRF, an x-ray source is used to irradiate the specimen, causing elements within it to emit characteristic x-rays, the peaks of which are measured by a detection system.[287] The height of the peaks created in a typical XRF energy spectrum corresponds with how much of a particular element is in that sample.

To date, the only analysis of the site's concreted iron has been an examination by SEM-EDS of a small sample which revealed the presence of iron oxide, sulfur trioxide, silicon dioxide, aluminum

[285] Western 1972, 86.
[286] IAEA Radiation Technology Series No. 2 2011, 5.
[287] Ridolfi 2012.

oxide, magnesium oxide, potassium oxide, and calcium oxide.[288] The thesis research done here augments such previous research by examining a small sample from the Godavaya shipwreck, taken in 2012, by XRF and SEM technology. The sample analyzed using the Nautical Archaeology Program's handheld XRF unit found significant amounts of iron as well as trace amounts of calcium – likely from the build-up of concreted material from marine life – and manganese (Fig. 4.1, 4.2, and 4.3). The rhodium peaks in the graph below appear as a result of using the XRF unit.

[288] Chandraratne et al. (2012, 482-483) reveal that 77.54% of the iron sample is iron oxide, 16.48% is sulfur trioxide, and 7.06% is silicon dioxide. Aluminum oxide, magnesium oxide, potassium oxide, and calcium oxide appear in trace amounts.

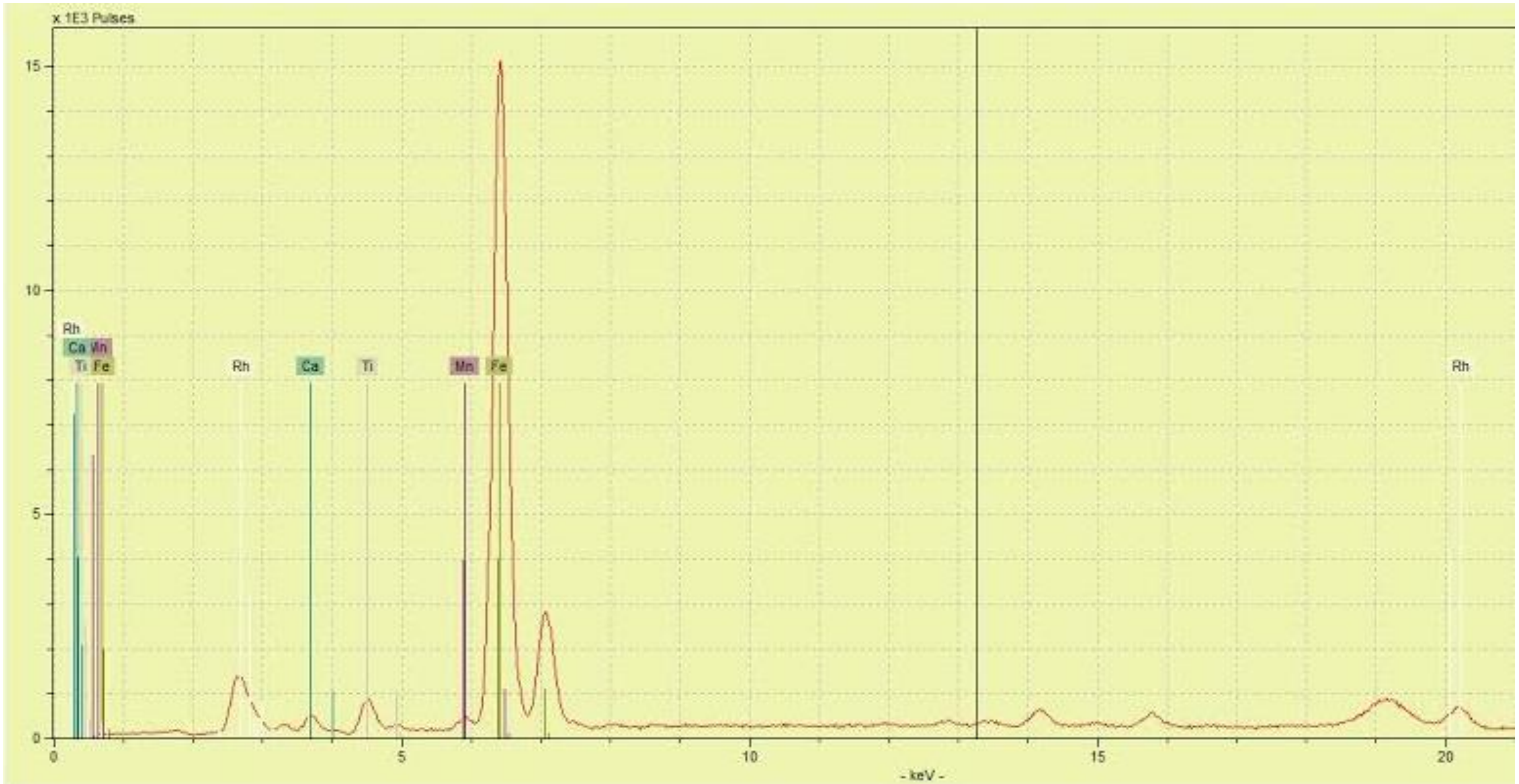

Fig 4.1 XRF spectrum generated from the iron sample.

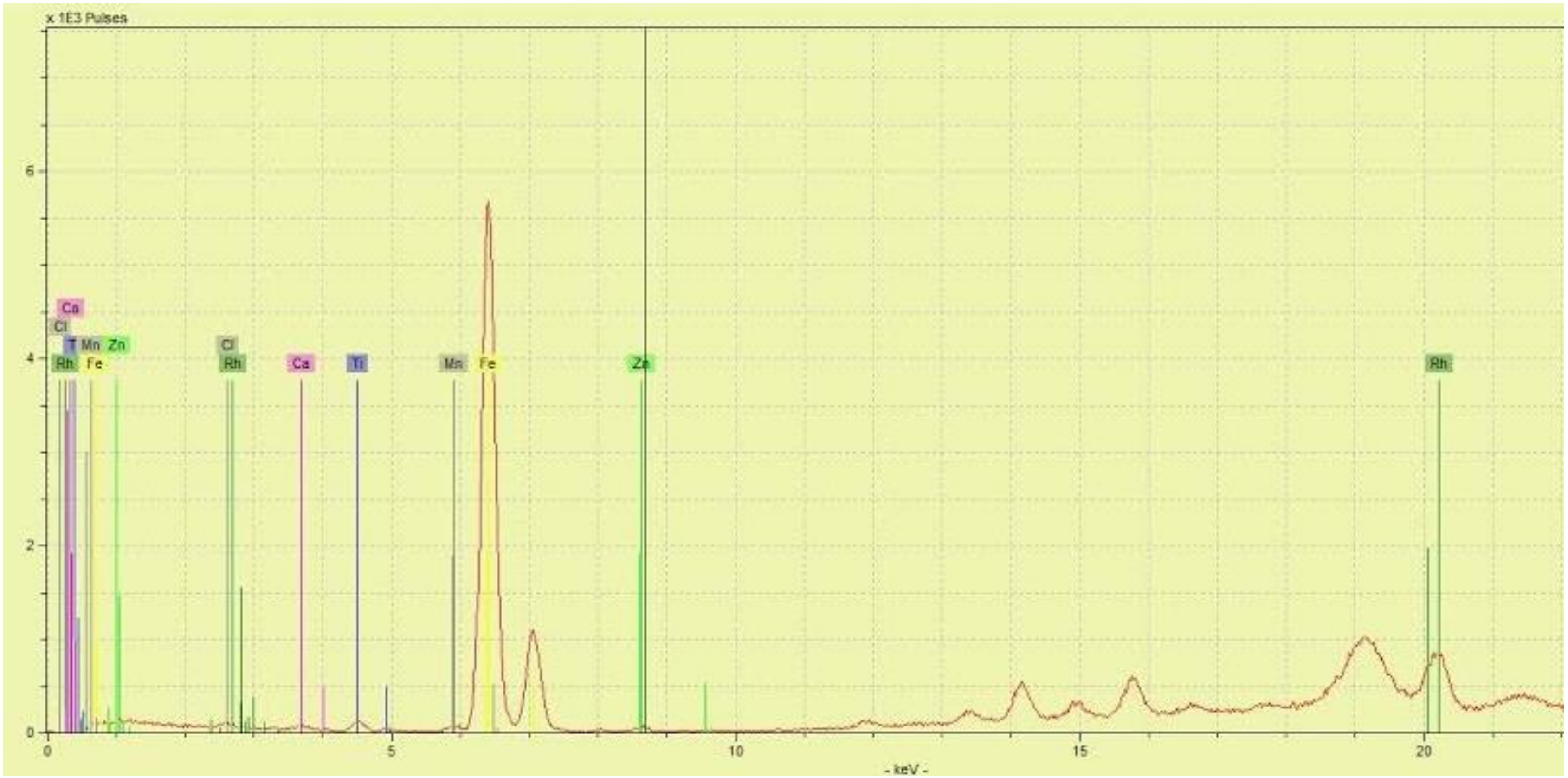

Fig 4.2 Spectrum generated using a piece of the sample that had broken.

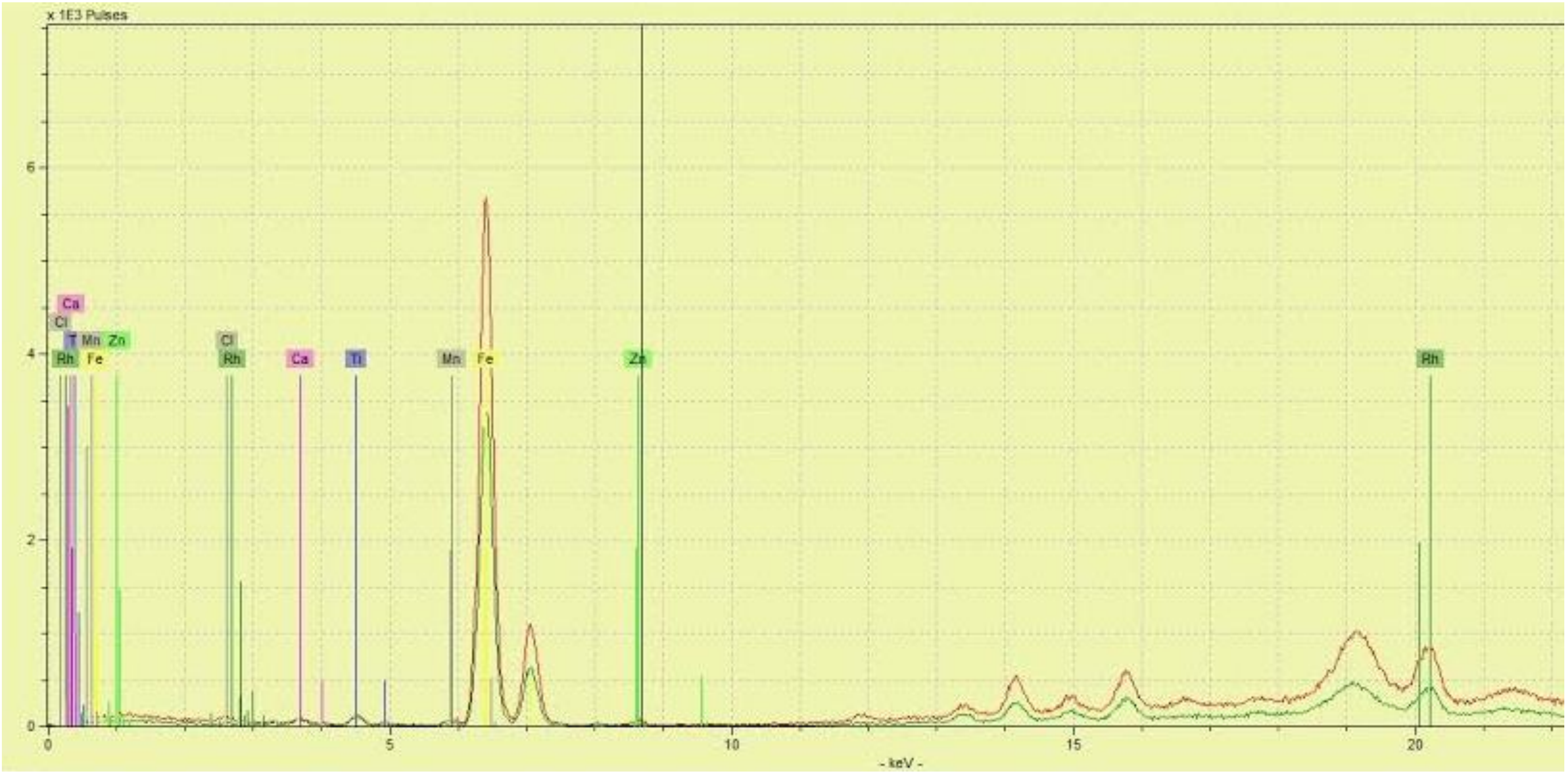

Fig 4.3 Comparison of the two XRF spectra.

RESULTS

X-ray fluorescence (XRF) was utilized in an attempt to determine the major and trace element composition of the shipwreck's corroded iron cargo and provide a more thorough understanding of the material that was being transported (Fig. 4.1, 4.2, and 4.3). The sample was also looked at under magnification (Fig. 4.5). SEM-EDS analysis was done at the Texas A&M University Microscopy and Imaging Center (Fig. 4.4). Such analyses revealed a significant amount of iron in the spectrum, which was expected, as well as traces of manganese, copper, and zinc. Trace levels of calcium, which appear in one of the above spectra, may be from contamination. It is difficult to know whether the trace elements detected in the sample are from the underwater environment or from the metal itself. More analysis of the metal content of the objects and a more detailed study of the underwater environment would be helpful in better understanding the XRF and SEM results. Also worth noting is how potentially misleading the analysis of one sample from a cargo that contained hundreds of ingots is; a substantial amount of variability should be expected, however the only way to accurately combat this is to take more samples, which at present cannot be done.

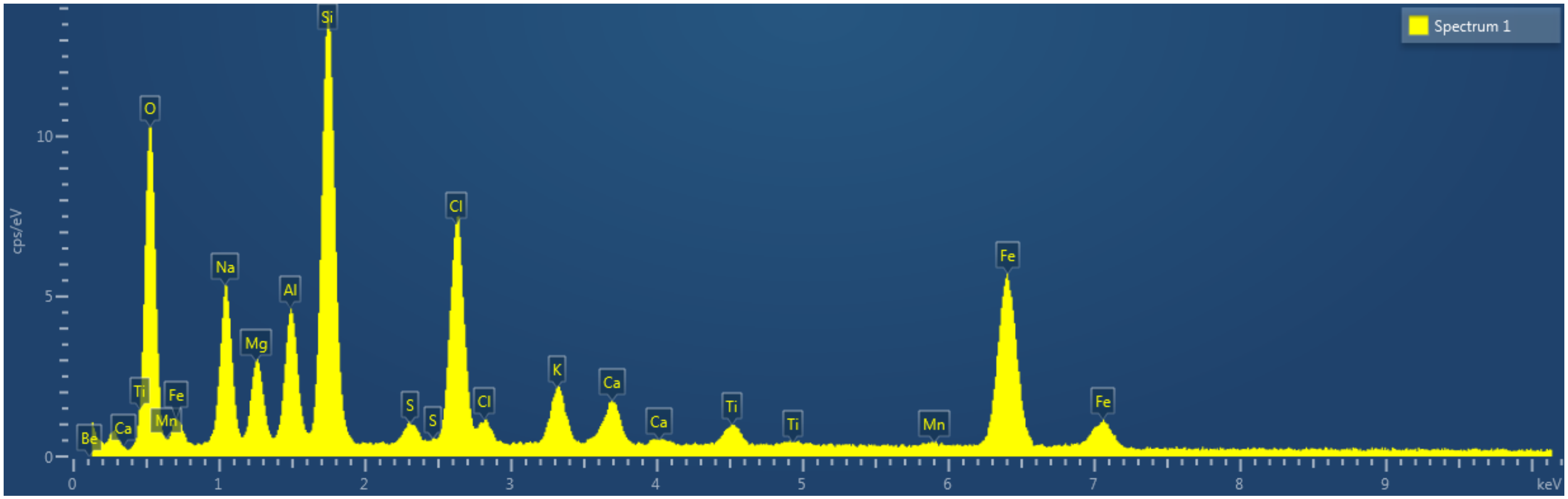

Fig 4.4 SEM-EDS spectrum showing elemental peaks.

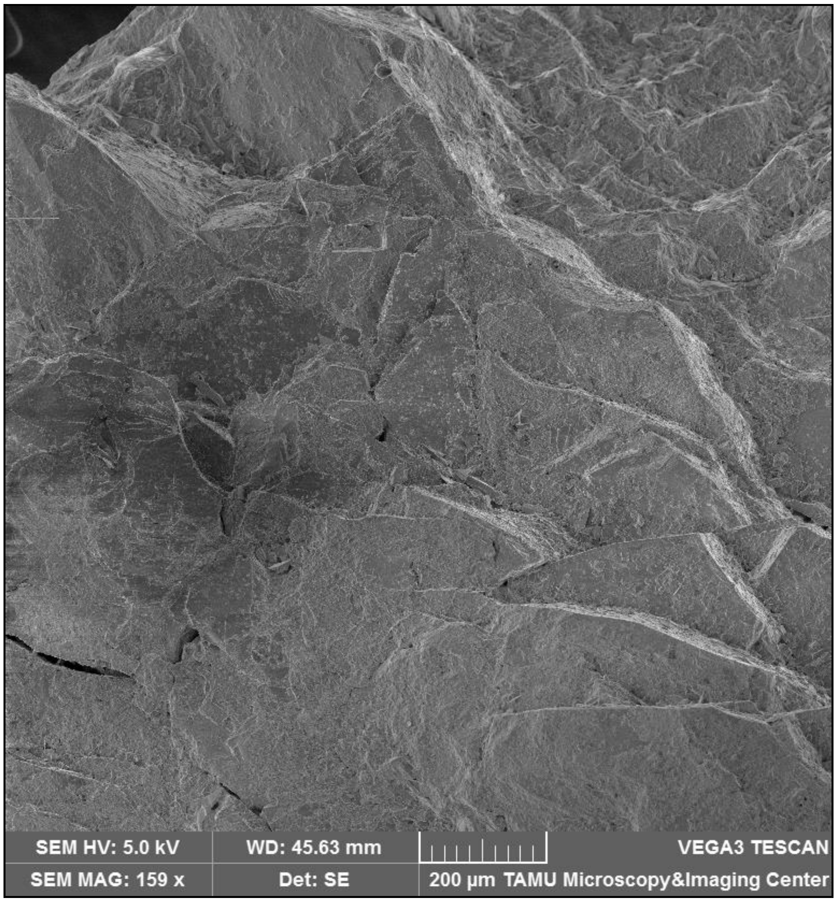

Fig. 4.5 Iron sample under magnification.

FUTURE RESEARCH

The major and minor elements discerned by XRF and SEM-EDS analysis provide some information; however, in the future it would be beneficial to take many more samples from the iron concretion pile. It would be helpful to build a table of the results and to additionally compare the iron carried onboard with ore deposits on the island. This could enable us to possibly provenience the iron.

CONCLUSIONS

Island-wide archaeological excavation, experimental recreations of ancient furnace structures and iron smelting trials, along with ancient literary sources and recent scholarship concerning historical iron working in Sri Lanka have all contributed to our understanding of the antiquity of iron-working on the island. Such sources do little however, to elucidate the nature of the trade of such materials. While the island's role as a linchpin in maritime trade has been enumerated on in the preceding chapters, the recovery of the Godavaya cargo could rewrite the history of iron exchange in this area of the world. As reiterated often in this thesis, the recent archaeological work on the ancient Godavaya shipwreck represents one of the most promising illustrations of the direct trade of iron in the region. Definitively answering where these materials were headed and who was involved in this trade can be addressed only if the Godavaya cargo is raised, placed in a museum, and made accessible for continued research. The last several chapters have presented some of the many sources that have contributed to our current understanding of this subject and this chapter has attempted to offer conservation recommendations that may be employed to ensure that such material is someday available to be studied. Unfortunately, without future funding, time, resources, and continued research, the potential of this shipwreck to inform us about the trade in ancient metals remains limited. This thesis has sought to underscore Sri Lanka's trade relationships, both with India and further abroad, highlighting evidence of trade networks during the period between the second century B.C.E. and the first century C.E. when the Godavaya ship may have been sailing. In it I have sought to contextualize the wreck by briefly examining the materials found onboard in the first few seasons of excavation and by attempting to delve into what information might be gained from a small sample taken from this iron cargo. The Godavaya shipwreck, like other ancient shipwrecks examined by underwater archaeologists, preserves a moment in time. In this case, it provides scholars with solid evidence for the direct trade in iron during this particular time period. While underwater archaeology routinely presents scholars with similar moments in time, as one of the oldest shipwrecks in the Indian Ocean this is a truly unique opportunity to expand our understanding of ancient seafaring and trade in this poorly understood region.

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