CHAPTER 1

INTRODUCTION

1.1 Locality

The Serra do Navio deposit is located in Amapá, the northern most province of Brazil. The Amapá Province is bordered to the south by the Amazon River, to the east by the Atlantic Ocean and in the north and west by French Guiana and Guiana. Serra do Navio manganese deposit and township is located in the central part of Amapá, just to the north west of the Amazon delta at latitude 0º55`30``N and longitude 52º01`00``W (Fig.1.1), about 235 kilometers northwest of Macapa, the main administrative center in the province. The deposit is accessible by dirt road and railway from Macapa.

Serra do Navio has a tropical climate that is typical of equatorial regions. It receives a large, seasonal volume of rain, with very high average annual temperature and humidity. The mean rainfall for 1990 was above 300 mm per month (January – June) and 129.1mm (July – December). The main drainage in the province is by the Amapari and Aguari rivers (Fig. 1.1) that eventually meet up with the Amazon Delta.

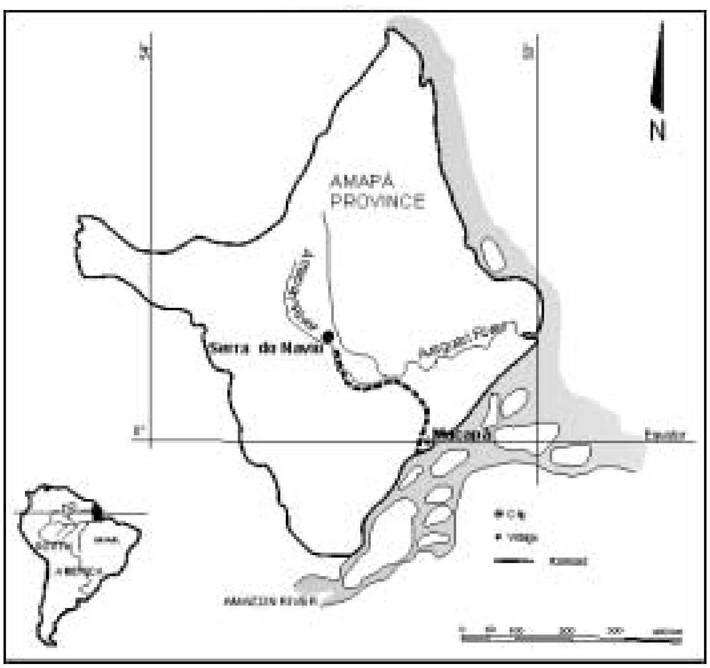

Fig.1.1: Location map of the Serra do Navio deposit, Amapá Province, Brazil.

1.2 Mining History

With proven reserves of over 43 million tons of manganese, production began early in 1957, by *Indústria e Comércio de Minérios S.A* (ICOMI) a company whose stock was held by *Companhia Auxiliar de Empresas de Mineração* (CAEMI) and formed primarily to manage the manganese deposit. By the end of 1969, almost 10 million metric tons of washed ore had been produced. During these early years of production, Serra do Navio was the single most important source of manganese ore to North American and European markets. In 1993, the Serra do Navio deposit produced 467,000 metric tons of manganese ore, about a quarter of Brazil's whole production. Most of the ore was consumed by the Bethlehem Steel Corporation in America. The average grade of the beneficiated ore varied from 48 to 50 weight percent of manganese. By 1997, production waned due to depletion of manganese ore reserves. This, together with a drop in ore grade, high operational costs and environmental strictures led to the closure of the mine in late 1997.

Because of their well-indurated matrix and great resistance to weathering, the lateritic manganese oxide ores were well exposed on hilltops. The ores were composed of manganese oxyhydroxides derived from metasedimentary protore lithologies rich in rhodochrosite, spessartine, rhodonite and tephroite (Rodrigues et al., 1986). Depletion of the supergene enriched manganese oxide ores was complemented by the exploitation of the lower grade protore during the later stages of mining. High-grade manganese oxide ore composed chiefly of cryptomelane and pyrolusite was exploited from a series of pits along a NW – SE directed trend. These pits were designated A-3, A-12, C-1, C-2, C-3, C-5, C-7, C-12, F-3, F-12, T-4, T-6, T-10/10A, T-11, T20, V-1, V-3, and V-4 (Fig. 1.2).

1.3 Background and Objectives

When the Serra do Navio deposit was exploited in the late 50's, production was mainly from the superficial oxide ore bodies. It is widely accepted (Holtrop, 1962; Scarpelli, 1968; Rodrigues et al., 1986; Gebert, 1989 and Costa, 1997) that the mineralogical and geological characteristics of these ores are linked to a lateritic origin.

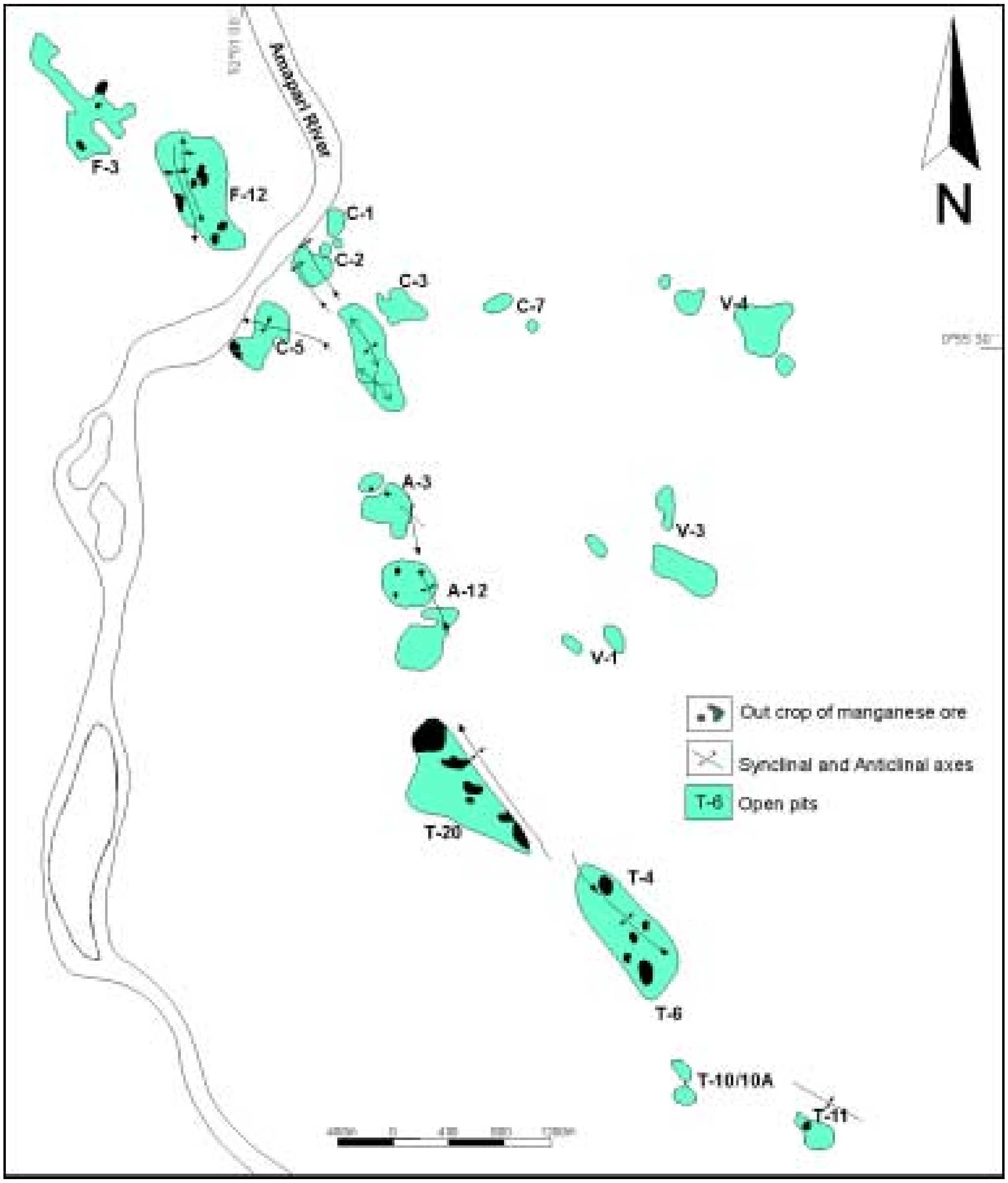

Fig.1.2: Location of open cast sections at the Serra do Navio deposit. Modified from Rodrigues et al. (1986).

It is not the aim of this research project to discuss the origin and features of the supergene enriched ores, and thereby belabor a point that is widely accepted. Rather, the project concentrates on the petrology of the manganese protore and surrounding host rocks. It describes the mineralogical and textural relationships as well as the genesis of the metasedimentary units that contain the manganiferous protore. This information will be used to constrain the p-T conditions of metamorphism. An attempt is also made to establish the mode of deposition of the manganese-rich succession prior to deformation and metamorphism. An understanding of these factors, it is hoped, will aid in understanding the metallogenesis of this deposit.

This project is largely a laboratory and desk-based study. The most relevant open pit for this study was F-12 (Fig. 1.2) from which borehole data is present. A set of 50 samples collected courtesy of Professors Beukes and Gutzmer were studied in detail using various petrographic and geochemical techniques.

1.4 Previous Studies

Several publications describe the geologic setting of the Serra do Navio deposit and the area in the immediate vicinity (Scarpelli, 1968, 1973; Dorr, 1973, and Rodrigues, 1986). However, no coherent model exists to adequately identify and characterize the Mn-bearing sedimentary protolith succession that is obscured by metamorphism, deformation and deep lateritic weathering.

The geology of the Serra do Navio deposit was first described in the early 1950's, and documented in company reports that focused on grades, tonnages, and on metallurgical processing characteristics (ICOMI, 1957).

Arguably the most comprehensive attempt to describe the mineralogical and textural relationships of the ore bearing succession is that by Scarpelli (1968 and 1973). Scarpelli (1973) outlined a stratigraphic framework for the Serra do Navio deposit and showed that the deposit was part of the Amapá series (Table 1.1). Regionally, the deposit is hosted within the Precambrian Guiana Shield, and in the vicinity of Serra do Navio the basement is believed to be composed of Archean granite-gneisses of the Guianese Complex (Rodrigues et al, 1986). Dardenne and Schobbenhaus (2000) recognized that the Vila Nova province occupies the southeastern part of the Guiana Shield. The stratigraphy of this province is best defined in the area of Serra do Navio.

Scarpelli (1973) identified three main types of metamorphic rocks, which controlled the localization of the manganiferous protore. He named these as quartzous, biotitic and graphitic facies. Two manganiferous rock types occurring at the top of the local stratigraphy were called manganiferous protores, silicatic if Mn-silicates were dominant and carbonatic if Mn-carbonates were predominant (Scarpelli, 1968). Based on extensive drill core analysis and mapping of the area around the deposit, Scarpelli (1973) concluded that there was a cyclic repetition of the rock succession. Dorr's (1973) assessment is largely based on Scarpelli's (1968) work but notes genetic and spatial relationship between the different sedimentary facies.

Table 1.1: Stratigraphic column of the Serra do Navio (Scarpelli, 1973)

Series	Group	General Description	Lithologic Units
Amapá	Serra do Navio	Metasediments	Manganese protores Graphitic facies Biotitic facies Quartzose facies
	Jornal	Amphibolites	Amphibolites Schists Quartzites
Basement	—	Gneisses	Gneisses

Scarpelli (1968, 1973) further identified three metamorphic phases – dynamic, thermal and a younger dynamic metamorphism, in that order. The first dynamic metamorphism was of amphibolite facies and was accompanied by minor folding. Thermal metamorphism of hornblende-hornfels facies is recognized by Scarpelli (1973) as a second metamorphic event despite the lack of evidence of intrusive rocks in the vicinity of the deposit. The youngest metamorphic overprint is, according to Scarpelli (1968, 1973), characterized by folding and recrystallization, and again reached amphibolite facies.

Roy (1980), in his treatise on sedimentary hosted manganese deposits of the world, classified the enclosing lithology of the manganese ores at Serra do Navio to be bedded Mn-carbonate – silicate rocks associated with graphite-rich pelitic schists. He described the pre-metamorphic character of the Mn-bearing sediments in very general terms as Mn-carbonate-rich sediments with an admixture of silica, alumina and carbonaceous matter.

Several other studies focus on the origin of the supergene enriched ores. Rodrigues et al., (1986) asserts that the high-grade oxide ores Serra do Navio deposit originated from the accumulation of manganese from a manganese gondite protore, {Gondite is a rock characterized by the presence of lower Mn-oxides in association with Mn-silicates in the total absence of Mn-carbonates and tephroite (Roy, 1980)} during the development of a lateritic profile on an erosional surface. Rodrigues et al. (1986) classifies four ore types: massive, schistous, rolled ore block and the gondite itself. While concentrating on supergene enrichment processes in South America, Costa (1997) also contends that high-grade oxide ores were derived by a lateritic protore composed of rhodochrosite, spessartine, rhodonite and tephroite.

Accurate age determinations on the host rock succession of the Serra do Navio deposit proper are lacking while documented ages for the deposit itself and region are marked by wide variability. Scarpelli (1968) reported K-Ar ages of 1.71– 1.77 Ga on biotite schist. Dorr (1973) also documented similar ages of at least 1.83 Ga in biotite. These ages are assumed to represent the age of the last dynamic metamorphism and folding (Scarpelli, 1973). Older U-Pb SHRIMP ages for the region have recently been reported and are bracketed between 2.1– 1.9 Ga (Voicu et al., 2001), 2.1 – 1.8 Ga (Zhao et al., 2002) and 2.2 – 2.0 Ga (Dantas, et al., 2004) These ages are taken to represent the age of the extensive Trans – Amazonian orogeny, and confirm that the succession is correlateable with the Birimian Supergroup of West Africa (Van Bart, 2001) that hosts numerous important metasedimentary Mn deposits.