2.0 GEOLOGY

Vale's Southern System consists of iron deposits located in the Quadrilátero Ferrífero (Iron Quadrangle), in the south central part of the State of Minas Gerais. These deposits are hosted by the Iron Formation of the meta-sedimentary Super Group Minas Formation of Precambrian age. The following provides a discussion of the regional geology that is common to the Fábrica Complex, Vargem Grande Complex and the Apolo Project and the exploration activities conducted to develop the information used in resource estimation.

2.1 *Regional Geology*

The Iron Quadrangle contains stratiform iron-deposits of Proterozoic age which are hosted in the southern portion of the Sao Francisco Craton. The Craton is characterized by the Precambrian granite complexes, and the Achaean and Proterozoic volcano–sedimentary sequences. The iron deposits occur within the Iron Formation (Cauê Formation) of the Itabira Group, which together with the Caraça and Piracicaba Groups constitute the Minas Supergroup of Paleoproterozoic age in the Brazilian Shield.

The Minas Supergroup overlies the Achaean Greenstones of the Rio das Velhas Supergroup, which consists of a sequence of meta-volcanic sedimentary rocks of Achaean age. It underlies metamorphic rocks of the Itacolomi Group. The Mafic dikes intrude the stratigraphic column. Figure 2-1 represents a simplified stratigraphic column of the Iron Quadrangle. The Minas Supergroup has been subjected to a long history of geologic events, including uplifting, overturning, intrusions, and compressive and tensile deformations. These geological events created the appropriate structural conditions for the formation of iron deposits.

Three groups make up the Minas Supergroup. The lowest unit, the Caraça Group, is primarily a clastic unit. It consists of quartzite with intercalated phyllite and conglomerate. An erosional unconformity marks the contact between the Caraça Group and the overlying Itabira Group.

The Itabira Group comprises the lower Cauê Itabirite (which contains the main iron deposits of the Quadrilátero Ferrífero), a mix of itabirite (oxide facies of the iron formation) and dolomitic itabirite, with minor phyllite and dolomite. It is overlain by the upper member of the formation, the Gandarela Unit. It consists of dolomite and minor limestone, dolomitic itabirite, itabirite and dolomitic phyllite. The uppermost unit, the Piracicaba Group is characterized by clastic sediments which include quartzite, phyllite, and dolomite. The final member of the Supergroup is the Sabará Formation that comprises chlorite schist, phyllite, greywacke, tuff, conglomerate, quartzite, and rare itabirite. The age of deposition of this sequence is estimated to be from 2.6 to 2.12 Ga, while an age of 2.42 Ga has been obtained from a dolomite of the Itabira Group.

2.2 *Structural Geology*

The structure of the Iron Quadrangle district is characterized by domal granitoids, with thrust faulting and associated isoclinal folds, while the Rio das Velhas and Minas Supergroups are interpreted to have been thrust stacked to the west and northwest.

The Minas Supergroup has been subjected to a long history of geologic events, including uplifting, overturning, intrusions, and compressive and distensive deformations that created the appropriate structural conditions for deposition, migration and posterior alteration processes to concentrate the mineralization that has originated the iron deposits.

2.3 *Mineralization*

The main iron ore types in the Iron Quadrangle are:

Hematite: Hematite represents the high-grade ore type within the iron deposit. The iron content varies from 65 to 67 percent. It is either massive or foliated in nature. The hematite is classified according to its physical and chemical characteristics as Compact Hematite, Friable Hematite, and Goethitic / Argilitic Hematite. Its origin is related to hydrothermal or metasomatic processes.

Itabirite: Itabirite is a term widely used in Brazil to denote a metamorphosed iron formation composed of iron oxides (hematite, magnetite, and martite), abundant quartz, very rarely mica, and other accessory minerals. It may be foliated or compact. The un-enriched (poor) itabirites from the Quadrilátero Ferrífero tend to have little magnetite, and composed principally of quartz–hematite, quartz–hematite–carbonate and hematite–carbonate. Itabirite represents the majority of reserves and resources of the Iron Quadrangle deposits. According to Vale, it was originated by silica leaching and residual iron-oxide enrichment process during post-metamorphic weathering cycles. The iron content averages about 45 percent, and occasionally it may reach up to 60 percent. The Itabirite ore is classified according to its physical and chemical characteristics as Compact Itabirite, Friable Itabirite, Goethitic / Argilitic Itabirite or Ochre.

Canga: Canga ore consists of unconsolidated talus material formed by the weathering of the iron formation. The iron content ranges significantly, with generally high concentration of phosphorous and alumina.

Rolados: A second detrital mineralization type. Consists of a ferruginous or lateritic matrix with fragments and blocks of different materials such as hematite, itabirite, quartz; high Fe grade, with high contaminant levels, such as P and Al_2O_3.

2.4 *Exploration*

Vale's exploration programs are designed by two exploration divisions, the Long Term and the Short Term Planning. Long Term Planning is focused on exploration of new deposits and resource development

5.0 PROCESSING

Iron ore processing within the Southern System mines has primarily focused on hematite and high grade itabirite which require relatively straightforward process flowsheets for beneficiation. As a response to strategic plans for increased production and declining reserves of the currently produced high grade ore, Vale plans to commission new processing plants to treat the lower grade, and typically harder itabirite ore. The following sections provide a general discussion of the current beneficiation plants for the Fábrica and Vargem Grande Complexes and the planned plants for treatment of the itabirite ores. The processing plant of the Apolo Project will include both treatment systems. A more detailed discussion of the processing operations and costs for each property is included in Section 8 of this report.

5.1 *High Grade Ore Processing*

The typical processing for higher grade ores in the Southern System Mines consists first of multi-stage dry crushing and screening to produce lump ore, hematitinha, and sinter feed products. The fines or undersize from the above dry processing steps are subsequently treated by wet processing using further screening, classification, high intensity magnetic separation and gravity concentration to produce additional sinter feed and pellet feed. The pellet feed is dewatered in a thickener and filtered. The reground filter cake is then transported to pelletizing plants or sold as pellet feed.

The hematite ROM ore averages about 55 percent Fe for Fábrica Complex and 65 percent at the Vargem Grande Complex. Hematite ROM for the Apolo Project is projected to be about 61 percent Fe. Metallurgical recoveries range from about 75 percent for the Fábrica and Apolo projects to 83 percent (for 2008) at the Vargem Grande Complex. Tailings are disposed of in impoundments formed by embankment dams. Tailings grades range from around 50 to 60 percent Fe. Table 5-1 presents a summary of the budgeted 2008 production from each of the hematite processing plants, as well as projected production from the Apolo Project.

TABLE 5-1
Vale
Southern System Mines Reserve Audit
2008 Budgeted Production

	Fábrica Complex		Vargem Grande Complex		Apolo Project[a]	
Product	Proportion	Mt	Proportion	Mt	Proportion	Mt
Lump ore	5%	0.931	14%	4.878		
Hematitinha	4%	0.651	8%	2.84		
Sinter feed	32%	5.766	53%	18.605	50%	16.1
Pellet feed	27%	4.924	12%	4.176	25%	7.9
Tailings	33%		13%		26%	

(a) planned production

Vale estimates the processing cost per tonne of product for the Fábrica operations for 2008 was R$ 4.02 (US$ 2.23) and R$4.63 (US$ 2.58) for the Vargem Grande Complex processing operations. Processing costs for the Apolo Project hematite plant are projected to be R$5.5 (US$ 3.06).

A discussion of the processing plant design and operation is presented in Section 8. Overall, Pincock considers the ore processing facilities to have well designed flowsheets for the ore that is being treated. The plants and equipment appeared to be well maintained and housekeeping was generally good.

5.2 *Proposed Itabirite Processing Plants*

In order to both increase production of pellet feed during the remaining period of hematite production and to allow continued mining of the lower grade itabirite from the Southern System mines, Vale plans to construct and startup new itabirite processing plants at the Fábrica and Vargem Grande Complexes and to include an itabirite plant as part of the Apolo project. The itabirite plants will be expanded in phases at each operation. Table 5-2 summarizes the projected development and capacity of the plants.

TABLE 5-2
Vale
Southern System Mines Reserve Audit
Itabirite Plant Schedule and Production Capacity

	Fábrica Complex		Vargem Grande Complex		Apolo Project	
	Year	Production [a]	Year	Production [a]	Year	Production [a]
Phase 1	2014	10	2011	10	2015	8.2
Phase 2	2016	10				
Total		20		10		8.2

(a) Production is final pellet feed produced

As noted in Table 5-2, the Vargem Grande Itabirite Plant will be the first to come on line, followed by the first phase of the Fábrica itabirite Project and then the Apolo Project. The overall mineral processing technology that will be utilized for processing itabirite ores is proven and well developed at other Vale Mines nearby in Brazil and does not represent a pioneering experiment. The flowsheets for the three projects are not identical to other plants because of the unique mineralogical characteristics of each iron deposit. However, the individual unit operations processing steps and equipment have been used in other plants and Vale has carefully selected and successfully evaluated these in pilot plant scale testing to design the process, validate the flowsheet and to size the process equipment. Vale also has the benefit of using the actual data and operating costs from some of their other operating processing plants to use in establishing realistic and reliable performance and cost predictions for the itabirite ore processing. Also, because Vale has recently been building other new plants and expanding older plants they have recent and reliable information for making the capital cost estimates for the new plants. All of the above combined provides for a good confidence level in the planned itabirite ore processing projects.

In general terms, the itabirite processing will consist of three stages. The first stage consists of crushing, screening and stockpiling of the ore in homogenization piles. In the second stage of the process the crushed ore is reclaimed from the homogenization stockpile and fed to the dry tertiary and quaternary screening and crushing. The third stage of the process is all wet processing and that is where the separation of iron minerals from waste minerals takes place. The crushed ore is to be ground in large ball mills in a closed circuit with a hydrocyclone classifying system. Underflow from the hydrocyclones will return to the ball mills for additional grinding and the overflow will report to a desliming circuit to produce flotation feed and slimes tailings. The flotation feed will pass through a series of flotation cells to concentrate the iron product which is then dewatered by thickening followed by vacuum filtration. Tailings produced in the flotation process are discharged to tailings impoundment dams.

Capital and operating costs for the itabirite projects are summarized in Table 5-3. As noted previously, the level of engineering that has been completed is variable due to the time until the projects will be brought on line. The Vargem Grande plant is most advanced, with a feasibility study level (FEL3) cost estimate having been recently completed. The recent experience gained by Vale in constructing projects such as the Brucutu project provides a basis for reliable cost estimation and analysis for purposes of demonstrating economic viability in reserve definition. Economic sensitivity analyses are discussed for each project subsequently in Section 8 and show the projects to be financially viable.

TABLE 5-3
Vale
Southern System Mines Reserve Audit
Itabrite Plant Capital and Operating Costs

	Estimated Capital Cost (US$ millions)	Estimated Operating Costs (US$/tonne product)
Fábrica Complex	849.00	7.62
Vargem Grande Complex	1.18	8.05
Apolo Project	1.03	8.02

8.0 FÁBRICA MINING COMPLEX

The following presents a discussion of the specific aspects of the Fábrica Complex. The Fábrica Complex, consisting of the João Pereira and Segredo Mines were acquired by Vale in 2003 from Ferteco Mineração, S.A. The João Pereira mine operations date to 1956 and the Segredo Mine began production in 1984.

8.1 *Geology*

The Fábrica mining complex is situated along a south-trending limb of the Iron Formation in the southern portion of the Iron Quadrangle. João Pereira and Alto Bandeira mines are situated within a 40 km long east-west trending limb of the Dom Bosco syncline of the Iron Formation (see Figure 8-1). The Segredo Mine consists of the Ponto 2, Ponto 3, Area 10 and Segredo deposits. The mine area is surrounded by the western portion of the Dom Bosco syncline, near the Moeda syncline.

The stratigraphic sequence of the region consists of five geological units:

- Gneisses of the Achaean crystalline basement;
- Phyllites and quartzites of the Rio das Velhas Supergroup;
- The Iron Formation, metasediments and orthoquartzites of the Minas Supergroup;
- Quartzites and meta-conglomerates of the Itacolomi Group;
- Recent cover, including "Canga," laterite and "Rolados."

The crystalline basement rocks are banded gneisses, migmatites, and granites of various compositions, and the metamorphic complexes of Bonfim and Belo Horizonte. The Rio das Velhas Supergroup (from the base to the top) is composed of the Nova Lima group and the Maquiné group. The Nova Lima group consists of phyllites, graphitic phyllites, sericite schists, metagreywackes, mafic and ultramafics, Algoma type iron formations, metacherts and dolomites. The bottom of the Maquiné group is defined by an erosional unconformity. Basal conglomerates are overlain in turn by massive quartzites, schists, sericite–quartz schist, and phyllites.

The Minas Supergroup consists of the Caraça, Itabira, Piracicaba, and Sabará Groups. The Caraça group is made up of the Moeda and Batatal Formations and occurs in a continuous belt in the western portion of the area in the Serra da Moeda. The Moeda Formation is composed of metaconglomerates, phyllites, and fine grained quartzites with sericite and muscovite. The Batatal Formation is composed of sericitic phyllite, and lesser metachert, iron formation and graphitic phyllite.

The Itabira Group is represented by the Cauê and Gandarela Formations. From the base, the Cauê Formation is composed of itabirites, dolomitic itabirites, and amphibolitic itabirites, and is approximately 200 m to 400 m thick. The Gandarela Formation forms a gradational contact with the Cauê Formation and is composed of dolomitic phyllites, dolomites and phyllites.

The Piracicaba Group of rocks crop out along the entire length of the Serra do Curral, and are represented from the bottom to the top by the Cercadinho, Fecho do Funil, Taboões, and Barreiro Formations. The Cercadinho Formation is composed of quartzites, ferruginous quartzites, phyllites, and dolomites. The Fecho do Funil Formation is composed of dolomitic phyllites, phyllites, and impure dolomites. The Taboões Formation consists of fine-grained, equigranular orthoquartzites, whereas the Barreiro Formation is composed of predominantly phyllites and graphitic phyllites.

The Sabará Group crops out to the north of Serra do Curral, and is composed of sericitic phyllites, chlorite and biotite schists, metagreywackes, quartzites, felsic quartzites, iron formations, itabirites and metaconglomerates with intercalations of dolomites. The Itacolomi Group is composed of phyllites, silicic phyllites, and quartzites. Mafic intrusives are found in granite–gneiss complexes. The intrusive rocks are in the form of dikes, plugs, and small stocks, and may reach up to 500 m in length. The Itacolomi Group is composed of phyllites, quartzitic phyllites, metaconglomerates, quartzites, and ferruginous quartzites, which are very similar to itabirites.

The structural history of the area is a result of five tectonic events, divided into principal deformation phases. The first three phases are related to the Trans-Amazonian or Minas Orogeny (Endo et al., 2004) and denoted as E1. These phases are responsible for the penetrative deformation fabric of the Minas Supergroup. E1 is characterized primarily by a schistosity S1, parallel to bedding, and a second schistosity, oblique to the first, representing the axial plane of folds generated in two successive deformation events, D1 and D2. Phase D1 was responsible for generating recumbent folds (F1) at the regional scale, transported on a basal decollement surface (the Curral Nappe). Phase D1 was also responsible for overturned stratigraphy, with the Cauê Formation on top of the Sabará Group.

The Phase D2 is characterized by a coaxial refolding event (F2) of the F1 folds. A third phase of deformation, superimposed on the Minas Supergroup, is represented by kink banding with an east–west orientation.

Subsequent to the first three deformation phases, structures related to orogenic collapse formed with successive nucleation of high-angle normal faults with a north-south orientation (E2). Following orogenic collapse, intrusion of mafic bodies occurred (E3). The Brazilian event (E4) is attributed to banding and crenulation cleavages with north-south orientation and merging to the west (D4). Phase D5 is related to event E5, generating a system of east–west and north–south trending grabens, with later deposition of Tertiary sediments into the grabens.

8.2 *Resource Models*

The João Pereira and Segredo resource models were previously audited by Pincock in 2005. The new drilling campaign added an additional 126 and 106 holes in Segredo and João Pereira models, respectively. Vale updated the models by incorporating the new data (4236 samples from Segredo and 6593 samples from Joao Pereira) obtained from the drilling campaign launched during 2004-2007 period. The Segredo model includes the existing Segredo mine area along with adjacent Area 10 which will be incorporated into the ultimate Segredo pit.

8.7 *Processing*

8.7.1 General Discussion

The Fábrica ore processing plant presently treats hematite or and some high grade itabirites from the João Pereira and Segredo Mines. The current plant produces lump ore, hematitinha, sinter feed and pellet feed. Some of the pellet feed is used on to feed the on-site Fábrica pellet plant. It was reported by Vale that there is enough hematite available to blend with higher grade itabirites for the current plant production until 2020. In 2008, it was expected that 18.2 million tonnes of ore would be treated to produce 12.3 million tonnes of products for a mass recovery of 67.5 percent. The production rate is expected to increase to 12.5 mtpy in 2009 and to 14.5 mtpy in 2010. The additional 2.0 mtpy will be from a small dry processing plant that will be added as a capital project. In 2014 the production is expected to reach 24.5 mtpy with the start up of the first 10 mtpy low grade itabirite plan (1a ITM I Fábrica). Another 10 mtpy itabirite plant (2a ITM I Fábrica) expansion scheduled for startup in 2016 is in Vale's long range plans.

The following sections present a review of the existing process plant and the proposed itabirite projects.

8.7.2 Existing Fábrica Plant Flowsheet and Costs

The process is typical of other Southern System Mines. There are three stages of dry primary, secondary and tertiary crushing and screening that produce lump ore, hematitinha and sinter feed products. The first two stages are open circuit and the third is closed-circuit. The fines or undersize from the above dry processing steps are treated by wet processing in further screening, classification, high intensity magnetic separation and gravity concentration to produce additional sinter feed and pellet feed. The pellet feed is dewatered in a thickener, reground in a ball mill and filtered. These concentrates are reground not for liberation but to create a finer particle size for pelletizing. The reground filter cake is conveyed to the pelletizing plant where it is converted into pellets. The processing flowsheet is shown in Figure 8-8.

The ROM ore averages about 55.2 percent Fe. Typical product splits as a percent of ROM and product quality are shown in Table 8-8, but can vary a little from year to year.

The ROM ore grade for Fábrica is lower in iron content than other hematite plants and the ore mineralogy is a little more difficult to treat. The flowsheet is a somewhat more complex as a result. ROM blending from the two mines is very important for a stable and efficient operation in the processing plant. The metallurgical recovery of iron is reported to be about 76 percent, which is lower than some of the other hematite plants and may be due to the ore mineralogy.

Vale's senior management has decided that the Northern System Mines at Carajas will produce more sinter feed and less pellet feed. This decision means that Vale will have to produce more pellet feed from the Southern System Mines to replace the loss from Carajas and to be able to maintain market share. The Fabrica itabirite project is the second of the new projects to produce pellet feed with the Vargem Grande itabirite being the first of the new plants. The design philosophy is based on the unique mineralogical characteristics of itabirite and is somewhat similar to the process that will be used for the new Vargem Grande itabirite plant. Both plants will have some features that utilize new technology but will also have standard equipment and practices used in other itabirite plants.

The processing plant is designed to process 25 mtpy ROM to produce the 10 mtpy of pellet feed. The ROM ore grade is 41.1 percent Fe and the final pellet feed product is 66.5 percent Fe. The mass recovery is 39.8 percent and the iron recovery is 64.3 percent, which is quite low for a processing plant of this type. The majority of the iron losses (approximately 60 percent) are in the slime tailings which assay about 43.5 percent Fe which is higher in iron content than the incoming ROM ore.

Process Plant and Equipment

The process within the new plant will consist of three stages. The first stage consists of a single vibrating grizzly and primary crusher operating dry in an open circuit. The product passes directly to the second step of the first stage which is secondary screening and crushing. There are four vibrating screens and two cone crushers operating dry in open circuit to produce a 50 mm product which is put into a homogenizing stockpile. The system is designed to handle 4206 tph.

In the second stage of the process the crushed ore is reclaimed from the homogenization stockpile and fed to the dry tertiary and quaternary screening and crushing. There is tertiary cone crusher operating in closed circuit with six vibrating screens. The product goes to the last stage of dry processing where it is screened and crushed with ten vibrating screens and five cone crushers operating in closed circuit. It is assumed the ore is crushed to 12 mm in size (0.5 inches) for the next stage of wet processing starting with ball mill grinding. The flowsheet for the third stage of wet processing is shown in Figure 8-9.

The third stage of the process is all wet processing and that is where the separation of iron minerals from waste minerals takes place. Details of all the wet processing equipment were not available. Information available includes four large ball mills (18 ft x 29 ft). The ball mills grind the finely crushed product in closed circuit in a double hydrocyclone classifying system with the underflow returning to the ball mill for more grinding. The overflow goes into a three stage hydrocyclone desliming circuit for preparing flotation feed. The ball mill circuits generate a ground ore product with a size consist of about 0.105 mm (105 microns or 150 mesh).

The hydrocyclone desliming circuit produces two products; flotation feed and slime tailings. The flotation feed from the desliming passes through two conditioning tanks where the flotation reagents are added. The flotation takes place in four steps of rougher, scavenger, cleaner and recleaner flotation machines with recycling of the intermediate products. The recleaner concentrate is the final concentrate product and the second scavenger froth (overflow) is the final tailing. The flotation concentrate is fine screened before thickening in a conventional thickener. The thickener underflow is further dewatered in vacuum disc filters and the thickener overflow is recycled back to the plant as process water. The flotation tailing joins the slime tailings that have been thickened and both are pumped together to the tailings pond.

Some chemicals are used for flotation and are added into the conditioners which are directly ahead of flotation. Caustic soda (NaOH) is added to control pH, solubilized starch is added to depress the iron minerals and amine is added to float or remove the silicious waste. The process is known as reverse flotation where the non-valuable minerals are floated and removed leaving behind a clean, high grade iron ore concentrate.

Process Plant Capital and Operating Costs

The project is expected to be completed and producing at full capacity in 2014 at an estimated capital cost of US$ 849 million. This is one of the highest capital costs per tonne of annual production at US$ 85/ tonne compared to all of the other planned Vale projects but is lower than some of the other itabirite projects. The Vargem Grande itabirite project is US$ 118/tonne, Apolo is US$ 96/tonne and the non-itabirite projects such as Serra Sul and Carajas North are US$ 55/tonne and US$ 42/tonne, respectively. PAH believes the estimated capital cost is realistic for the purposes of this reserve audit.

The operating cost per tonne of pellet feed at the Fábrica itabirite plant is estimated at $US 7.62/tonne for only the processing. This is fairly close to the cost of $US 8.05/tonne that Vale estimates for the more advanced Vargem Grande project. The Fábrica operating cost estimate is more at a Prefeasibility Study level while the Vargem Grande is a Feasibility level cost estimate. However, PAH feels that this cost estimate has been carefully prepared and is in line with quoted costs from other similar Vale plants such as Feijão at US$ 9.01/tonne. For the Fábrica itabirite plant, PAH estimates that the grinding, flotation and vacuum filtration will be +/- US$ 5.25/tonne or about 65 to 70 percent of the processing cost. In summary, although this project has not been developed to a full Feasibility Study level PAH believes the projected operating cost has been carefully estimated and prepared and is reasonably accurate for purposes of establishing the economic viability of the future processing of itabirites.

8.7.4 Discussion

It is the opinion of PAH that the planning for the processing plant proposed at the Fábrica operation for treating the low grade itabirite ore is realistic and is based upon sound and reliable technology and equipment. Vale has much recent experience with estimated capital costs because of all the recent expansion and construction. The operating costs are considered realistic and are largely based and comparable to other similar Vale plants. Projections of the product quality indicate the pellet feed should be of very high quality and should compete strongly in the pellet feed market.

The operating costs are much higher than the hematite plants where very little grinding and beneficiation must be done. Therefore, the mass recoveries at the hematite plants are double the itabirite plants so the greater volume of product reduces the unit production cost. However, although the processing costs