Republic of Madagascar
Ministry of Mines (MM)

Final Report
of
the Geological Mapping and Mineral Information System Project for Promotion of Mining Industry in the Republic of Madagascar

Abridgment

February 2012

Japan International Cooperation Agency (JICA)

Sumiko Resources Exploration & Development Co., Ltd.
Nippon Koei Co., Ltd.

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List of Abbreviation

Abb.	Official Name
AERP	Exclusive Authorisation to Reserve a Prospect
AIST	Agency of Industrial Science and Technology
APSM	l'Agence de Promotion du Secteur Minier
ASTER	Advanced Spaceborne Thermal Emission and Reflection radiometer
BCMM	Bureau du Cadastre Minier de Madagascar
BIF	Banded Iron Formations
BGR	Bundesanstalt für Geowissenschaften und Rohstofte
BGS	British Geological Survey
BPGRM	Base de Données pour la Gouvernance des Ressources Minérales
BRGM	Bureau de Recherches Géologiques et Minières
CAPEX	Capital Expenditure
CEOS	Committee on Earth Observation Satellites
CGIM	Committee of Large-scale Mining Investments
CGS	Council for Geoscience, South Africa
C/P	Counterpart
DdG	Direction de la Géologie
DEM	Digital Elevation Model
DGM	Direction Generale des Mines
EITI	Extractive Industries Transparency Initiative
ERSDAC	Earth Remote Sensing Data Analysis Center
ESRI	Environmental Systems Research Institute, Inc.
FS	Feasibility Study
FTM	Foiben-Taosarintanin' i Madagasikara
GAF	GAF AG
GIS	Geographic Information System
HDF	Hierachical Data Format
HPAL	High Pressure Acid Leach
ICP-AES	Inductively Coupled Plasma Atomic Emission Spectrometr
ICP-MS	Inductively Coupled Plasma Mass Spectrometry
IMF	International Monetary Fund
JICA	Japan International Cooperation Agency
JOGMEC	Japan Oil, Gas and Metals National Corporation
J/V	Joint Venture
LGIM	la Loi sur les Grands Investissements Miniers
Ma	Million years ago

MAP	Madagascar Action Plan
MEM	Ministry of Energy and Mines
MGA	Madagascar Ariary
MINETEC	International Institute for Mining Technology
Mining INDABA	Meeting of Investing in African Mining Conference
MM	Ministry of Mines
MMH	Ministry of Mines and Hydrocarbones
OIF	Organisation Internationale de la Francophonie
OJT	On-the-job training
PALSAR	Phased Array type L-band Synthetic Aperture Radar
PDAC	Prospectors and Developers Association of Canada
PDF	Portable Document Format
PE	Mining Licences
PGRM	Projet de Gouvernance des Ressources Minérales
PR	Exploration Licences
PRE	Small-scale Mining Licences
PRSM	Projet de Réforme du Secteur Minier
PRSP	Poverty Reduction Strategy Paper
QMM	QIT Madagascar Minerals
REE	Rare Earth Elements
RGB	Red Green Blue (color model)
SADC	South African Development Community
SAR	Synthetic Aperture Rader
SHRIMP	Sensitive High-Resolution Ion Microprobe
SIE	Selective Ion Electrode
SIMH	Salon International des Mines et des Hydrocarbures
SIMS	Secondary Ion Mass Spectrometry
SRTM	Shatlle Radar Topography Mission
SWIR	Short Wavelength Infrared Radiometer
TIFF	Tagged Image File Format
TIR	Thermal Infrared Radiometer
USGS	U. S. Geological Survey
UTM	Universal Transverse Mercator
VNIR	Visible and Near Infrared Radiometer

Chapter 1 Introduction

1.1 Background of the Project

The Government of the Republic of Madagascar has been promoting a comprehensive national policy, aiming at the major goal of poverty reduction through economic growth. In order to realize this policy, it was recognized that the promotion of mining activities is crucially important, focusing on the large-scale mining development by introducing foreign capitals investment. The obvious effort shown by the Government of Madagascar for this national policy has been highly evaluated by the international community. World Bank has supported this nation through PRSM since 19999 and PGRM since 2003. PGRM has ended at the end of December 2010.

Under the circumstance, Malagasy government asked Japan for implementation of technical cooperation project with the aim of promoting resource development. Responding to the request, both Governments of Japan and Madagascar agreed to implement the “Geological Mapping and Mineral Information System Project for Promotion of Mining Industry in the Republic of Madagascar”, and signed the Minutes of Meeting on July 23, 2008, and the Scope of Work on September 29, 2008, respectively.

1.2 Objectives of the Project

In order to promote mining sector of Madagascar, major objectives are designed in this Project as follows:

(1) Objective 1: Revision of 1:100,000-scale geologic maps (8 quadrangles)

On the basis of scientific development in recent decades, such as clarification of evolution of the Gondwana Continent and development of analytical methods, 8 quadrangles of 1:100,000-scale geologic maps in southern Madagascar will be revised. In addition, geoscientific data, such as geochemical distribution of 64 elements, as well as absolute age determination by SHRIMP, will be collected and analyzed, in order to serve the needs of mineral exploration in the future by clarifying geologic setting of the survey area.

(2) Objective 2: Remote sensing for geologic mapping survey and construction of a Geographic Information System (GIS)

The entire territory of Madagascar will be covered for satellite image analysis and the results will be stored as the database in the Geographic Information System (GIS), together with other various data. Then, the geoscientific information will be integrated to improve the geoscientific information infrastructure, thereby contributing to the promotion of investments in minerals exploration and development in Madagascar.

(3) Objective 3: Technology transfer to the counterpart (C/P) personnel in Madagascar

In Madagascar, where some large-scale mineral development projects are in progress, it is expected that the mining activities will be more vitalized in the near future. Therefore, it is required to further enhance the technical level of technical staff of the Ministry of Energy and Mining (MEM), the C/P Organization of this Project.

The technology transfer will be made effectively through on-the-job training (OJT) in a series of works in this Project, and technology transfer seminar for remote sensing and GIS technology will be organized.

1.3 Survey area of the Project

The surveyed area for the tasks of remote sensing and GIS database preparation is whole Madagascar Island. On the other hand, for the revision of 1:100,000-scale geological maps and geochemical exploration, and OJT technology transfer the area to be surveyed is 8 official quadrangles of 1:100,000-scale topographical map with code, I58, I59, I60, J58, J59, J60, K58 and K59). Figure 1.1 indicates the locality of the 8 quadrangles of the survey areas.

The area of each quadrangle is around 1,400 km^2 square and total area of 8 quadrangles is 11,200 km^2. The outline of the 8 quadrangles has 6 apexes with coordinations as follows;

1. latitude 23˚12’ south and longitude 45˚18’ east
2. latitude 23˚12’ south and longitude 46˚12’ east
3. latitude 24˚00’ south and longitude 46˚12’ east
4. latitude 24˚00’ south and longitude 45˚54’ east
5. latitude 24˚24’ south and longitude 45˚54’ east
6. latitude 24˚24’ south and longitude 45˚18’ east

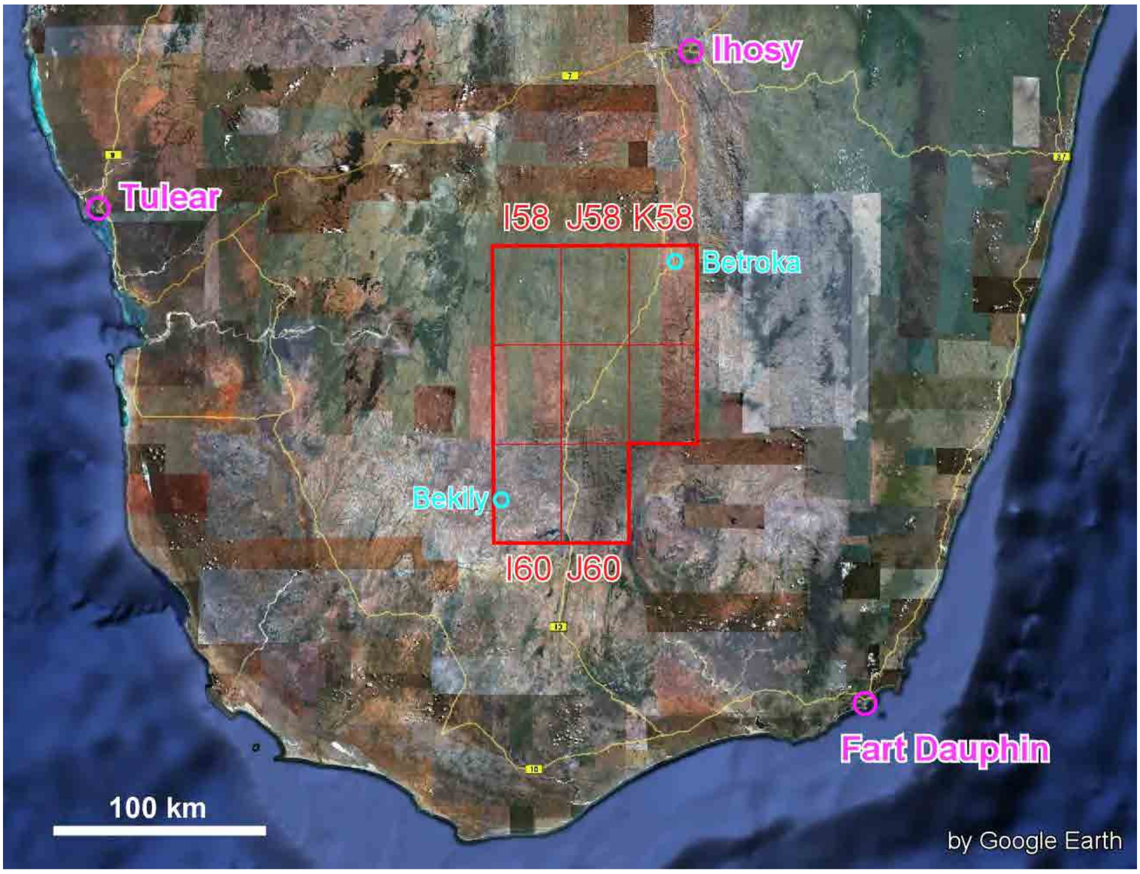


Figure 1.1 1:100,000-scale geological survey area of the Project (red-framed 8 areas)

1.4 Tasks of the Project

The following 9 main tasks are planned to be implemented in the Project:

(1) Collection and analyses of fundamental information
- Confirmation of economical development and poverty reduction plans in Madagascar
- Collecting and analyzing information related to the current status of the mining sector

(2) Analysis of geologic remote sensing data
- Analyzing ASTER and PALSAR data with consideration for 1:100,000-scale geological mapping

(3) Geologic mapping (8 quadrangles at 1:100,000-scale)
- Geological field survey
- Geological mapping
- Geological structural mapping
- Revising 1:100,000-scale geological maps of 8 quadrangles

(4) Geochemical exploration for stream sediments
- Same areas with geological mapping

- Chemial analysis of stream sediments
- Statistical analysis

(5) Construction of GIS database on geological and mineral resource information
- Construction of GIS database and integration to PGRM database

(6) Technological transfer through on-the-job training (OJT)
- Geological survey
- Geochemical exploration
- Remoto sensing data analysis

(7) Organization of technology transfer seminars
- Remote sensing data analysis
- GIS database construction

(8) Organization of Workshops
- 4 times in total
- Interpretation of the results derived from the Project
- Hearing C/P comments

(9) Participation in international investment congresses
- Support for C/P to publish the results related to the Project at INDABA and PDAC

1.5 Schedule of the Project

The Project was conducted from 2008 through 2011, including missions in Madagascar started in 2009. The First- to Fourth-stage Works in 2009 were carried out in Antananarivo. The Fifth and Sixth-stage Works in 2010 and the Seventh-stage Works in 2011 comprised mainly the field works. Details are as follows;

(1) First year (2008)

All works were conducted in Japan.

(2) Second year (2009)

First-stage Works: 19th May - 31st May 2009 (13 days)
Second-stage Works: 20th Jun - 10th Jul 2009 (21days)
Third-stage Works: 28th Sep - 6th Nov 2009 (40 days)
Fourth-stage Works (Part 1): 12th Jan - 29th Jan 2010 (18 days)
Fourth-stage Works (Part 2): 22nd Feb - 28th Feb 2010 (7 days)

(3) Third year (2010)

Fifth-stage Works (Reconnaissance field survey): 15th Jun - 9th Jul 2010 (25 days)
Sixth-stage Works (Field survey Phase 1): 27th Jul - 5th Dec 2010 (132 days)

(4) Fourth year (2011)

Seventh-stage Works (Field survey Phase 2):14th May – 23rd Nov 2011 (194 days)
Eighth-stage Works (Part 1): 22nd Jan – 11th Feb (21 days)
Eighth-stage Works (Part 2): 26th Feb – 9th Mar (13 days)

1.6 Framework of implementation of the Project

1.6.1 Structure of JICA Project Team

Members of the JICA Project Team and their assignments are shown in Table 1.1.

a) ONUMA Takumi: Leader (Overall coordination of the Project, satellite image analysis, Geological remote sensing, GIS)

b) TOGASHI Yukio: Leader (Overall coordination of the Project)

c) NINOMIYA Atusi; Geological remote sensing, GIS, Generalization of geology

d) ETO Masatoshi: Geology A (1), (Structural geology)

e) ISHIZAKI Shunichi; Geology A (2), (Structural geology)

f) TAKEUCHI Seiji; Geology B, Geochemical exploration

g) RAMBELOSON Roger: Geology C (Resource evaluation) <Local member>

h) OGURA Nobuo: Project coordinator (1) (Interpreter)

i) TAKEDA Masahiro: Project coordinator (2) (Assistance for Remote sensing)

j) ISHIKAWA Hiromasa: Project coordinator (3) (Assistance for Geology)

k) HARA Masahiro; Project coordinator (4) (Assistance for GIS)

Table 1.1 JICA Project Team Members and Assignments

Name	Title	Work Stage	Duration
ONUMA Takumi	Leader / Promotion of coordination, Satellite image analysis	Fifth	15th Jun – 9th Jul 2010 (25 days)
		Sixth	31st AUG – 24th Sep 2010 (25 days)
		Sixth	4th Nov – 5th Dec 2010 (32 days)
		Seventh	14th May – 24th May 2011 (11 days)
		Seventh	17th Aug – 15th Sep 2011 (30 days)
		Seventh	19th Oct – 23rd Nov 2011 (36 days)
		Eighth	22nd Jan – 11th Feb 2012 (21 days)
		Eighth	26th Feb – 9th Mar 2012 (13 days)
TOGASHI Yukio	Leader / Promotion of coordination	First	19th May – 31st May 2009 (13 days)
		Second	30th Jun – 10th Jul 2009 (11 days)
		Third	28th Sep – 10th Oct 2009 (13 days)
		Fourth	22nd Feb – 28th Feb 2010 (7 days)
ONUMA Takumi	Geological remote sensing / satellite image analysis / GIS	First	19th May – 31st May 2009 (13 days)
		Second	20th Jun – 10th Jul 2009 (21 days)
		Third	28th Sep – 6th Nov 2009 (40 days)
		Fourth	12th Jan – 29th Jan 2010 (18 days)
		Fourth	22nd Feb – 28th Jan 2010 (7 days)

NINOMIYA Atsushi	Geological remote sensing / GIS	Sixth Seventh Seventh Eighth Eighth	31st Aug – 26th Nov 2010 (88 days) 14th May – 7th Jun 2011 (25 days) 17th Aug – 15th Nov 2011 (91 days) 23rd Jan – 5th Feb 2012 (14 days) 26th Feb – 9th Mar 2012 (13 days)
ETO Masatoshi	Geology A / Structural Geology (1)	First Third	19th May – 31st May 2009 (13 days) 28th Sep – 10th Oct 2009 (13 days)
ISHIZAKI Shunichi	Geology A / Structural Geology (2)	Fifth Sixth Seventh Eighth	15th Jun – 9th Jul 2010 (25 days) 27th Jul – 24th Sep 2010 (60 days) 14th May – 28th Aug 2011 (107 days) 23rd Jan – 5th Feb 2012 (14 days)
TAKEUCHI Seiji	Geology B / Geochemical exploration	First Fifth Sixth Seventh Eighth	19th May – 31st May 2009 (13 days) 15th Jun – 9th Jul 2010 (25 days) 27th Jul – 26th Nov 2010 (123 days) 14th May – 23rd Nov 2011 (194 days) 22nd Jan – 11th Feb 2012 (21 days)
RAMBELOSON Roger	Geology C / Resource evaluation	First Second Third Fourth Fifth Sixth Seventh Eighth Eighth	21st May – 29th May 2009 (9 days) 22nd Jun – 7th Jul 2009 (14 days) 30th Sep – 3rd Nov 2009 (12 days) 24th Feb – 26th Feb 2010 (3 days) 17th Jun – 7th Jul 2010 (21 days) 29th Jul – 24th Nov 2010 (113 days) 16th May – 20th Nov 2011 (184 days) 22nd Jan – 4th Feb 2012 (14 days) 28th Feb – 1st Mar 2012 (3 days) joined in the field, partly intermittent
OGURA Nobuo	Project coordinator (1) / Interpreter	First	19th May – 31st May 2009 (13 days)
TAKEDA Masahiro	Project coordinator (2) / Assistance for Remote sensing	Third Fourth	28th Sep – 6th Nov 2009 (40 days) 12th Jan – 29th Jan 2010 (18 days)
ISHIKAWA Hiromasa	Project coordinator (3) / Assistance for Geology	Fifth Sixth Seventh	15th Jun – 9th Jul 2010 (25 days) 27th Jul – 26th Nov 2010 (123 days) 14th May – 28th Aug 2011 (107 days)

HARA Masahiko	Project coordinator (4) / Assistance for GIS	Sixth Seventh	22nd Nov – 5th Dec 2010 (14 days) 11th Nov – 23rd Nov 2011 (13 days)

1.6.2 Counterpart Organization

The C/P Organization of Madagascar side is Ministry of Mines (MM), previously the Ministry of Mines and Hydrocarbons (MMH) or the Ministry of Energy and Mines (MEM). In actuality, MM's General Direction of Mines (Direction Generale des Mines : DGM) and Projet de Gouvernance des Ressources Minerales (PGRM) perform as the central consultative body for fundamental issues. During

It is informed that the structure of the Ministry of Energy and Mines (MEM), the C/P Organization of this Project, has been modified into new structure where the former function was divided into two new Ministries: the Ministry of Mines and Hydrocarbons (Ministère des Mines et des Hydrocarbures: MMH) and the Ministry of Energy (Ministère de l'Énergie), and after that MMH became the Ministry of Mines (MM). The official C/P Organization of this Project is now MM. The persons involved are listed in Table 1.2.

Some of counterpart members participated in the Fifth-stage and Sixth-stage Works in 2010, and the Seventh-stage Works in 2011 as a part of OJT. Details are shown in Table 1.2.

Table 1.2 Counterpart member

Name	Organization/Appointment	Event participated
RAKOTOTAFIKA Gérard	DGM General Director of Mines (present)	Official meeting, Workshop, Seminar
ANDRIAMASY Raphaël	DGM General Director of Mines (previous) General Secretary	Official meeting, Workshop
RASOAMALALA Vololonirina	DdG Director of Geology (present)	Official meeting, Workshop, Seminar Mining INDABA 2012, PDAC 2012
RANAIVOARIVELO Andriamanantena	DdG Director of Geology (previous)	Official meeting, Workshop, Seminar Field work from 21 Jun to 3 Jul 2010
RASAMIMANANA Georges	DdM Director of Mines (present)	Official meeting, Workshop, Seminar

RAZANANIRINA Henri	DdM Director of Mines (previous)	Official meeting, Workshop, Seminar
RAMAROLAHY Jonasy	PGRM Coordinator	Official meeting, Workshop, Seminar
RAKOTOMANANA Dominique	PGRM Head of Geology and Goephysic Section (previous)	Official meeting, Workshop, Seminar Field work from 21 Jun to 3 Jul 2010
RANDRIAMANANJARA Herve	DdG Geologist	Workshop, Seminar, PDAC 2012 Field works from 2 Aug to 16 Nov 2010 and from 21 May to 24 Oct 2011
RANDRIAMALALA Zonantenaina	DdG Geologist	Workshop, Seminar Field works from 19 Sep to 16 Nov 2010 and from 21 May to 24 Oct 2011
SAHOLIARIMANANA Voahanginiaina	DdG Geologist	Workshop, Seminar, Mining INDABA Field works from 2 Aug to 18 Sep 2010 and from 22 Aug to 24 Oct 2011
RAKOTOVAO Soatsitohaina	DdG Geologist	Workshop, Seminar Field work from 2 Aug to 18 Sep 2010
RASAMOLIARISOA Marinah	DdG Geologist	Workshop, Seminar Field work from 21 May to 20 Aug 2011
RAZAFIMAHARO Prosper	DdG Geologist	Workshop, Seminar Field work from 19 Sep to 16 Nov 2010
RAMANOHISON Hary	PGRM Responsible of BPGRM	Workshop, Seminar Field works from 5 Sep to 18 Sep 2010 and from 26 Aug to 6 Sep 2011
RANDRIAMANIRAKA Richard	PGRM Geologist	Workshop, Seminar Field work from 5 Sep to 18 Sep 2010

1.7 Works in Madagascar

1.7.1 Outline

The works in Madagascar started in 2009. Total of 8 stages of the works were performed in Madagascar by the end of 2011. The First- to Fourth-stage Works in 2009 were carried out in Antananarivo. The Fifth and Sixth-stage Works in 2010 and the Seventh-stage Works in 2011 comprised mainly the field works. Figure 1.2 shows location map of the survey area.

(1) First-stage Works

Duration: 19th May - 31st May 2009 (13 days)

Area: Antananarivo

Activity: Submission of Inception Report, First Workshop, Collection and analysis of basic information

(2) Second-stage Works

Duration: 20th Jun - 10th Jul 2009 (21days)

Area: Antananarivo

Activity: Satatellite data analysis, Summarization of geology and mineralization of the survey area

(3) Third-stage Works

Duration: 28th Sep - 6th Nov 2009 (40 days)

Area: Antananarivo

Activity: Satellite data analysis, GIS database preparation, Planning of reconnaissance field survey, First Technology Transfer Seminar on Remote Sensing and GIS

(4) Fourth-stage Works (Part 1)

Duration: 12th Jan - 29th Jan 2010 (18 days)

Area: Antananarivo

Activity: Satellite data analysis, GIS database construction

(5) Fourth-stage Works (Part 2)

Duration: 22nd Feb - 28th Feb 2010 (7 days)

Area: Antananarivo

Activity: Submission of Progress Report, Second Workshop, Exchange of opinions on the direction of the Project in the future

(6) Fifth-stage Works (Reconnaissance field survey)

Duration: 15th Jun - 9th Jul 2010 (25 days)

Area: Antananarivo, Field survey area

Activity: Geological field excursion, Collection of information about social and natural circumstance around the survey area

(7) Sixth-stage Works (Geological survey Phase 1)

Duration: 27th Jul - 5th Dec 2010 (132 days)

Area: Antananarivo, Field survey area (4 areas, J58, J59, K58, K59)

Activity: Geological survey, Geochemical exploration, Ground truth for result from satellite image analysis

(8) Seventh-stage Works (Geological survey Phase 2)

Duration: 14th May – 23rd Nov 2011 (194 days)

Area: Antananarivo, Field survey area (4 areas, J58, J59, K58, K59)

Activity: Third Workshop, Geological survey, Geochemical exploration, Ground truth for result from satellite image analysis, Geological Mapping, GIS database preparation, Draft final report

(9) Eighth-stage Works (Part 1)

Duration: 22nd Jan – 11th Feb 2012 (21 days)

Area: Antananarivo, Cape Town (South Africa)

Activity: Fourth Workshop, Second Technology Transfer Seminar on Remote Sensing and GIS, GIS database preparation, Participation in Mining INDABA, Final report

(10) Eighth-stage Works (Part 2)

Duration: 26th Feb – 9th Mar 2012 (13 days)

Area: Antananarivo, Toronto (Canada)

Activity: Final report, Participation in PDAC

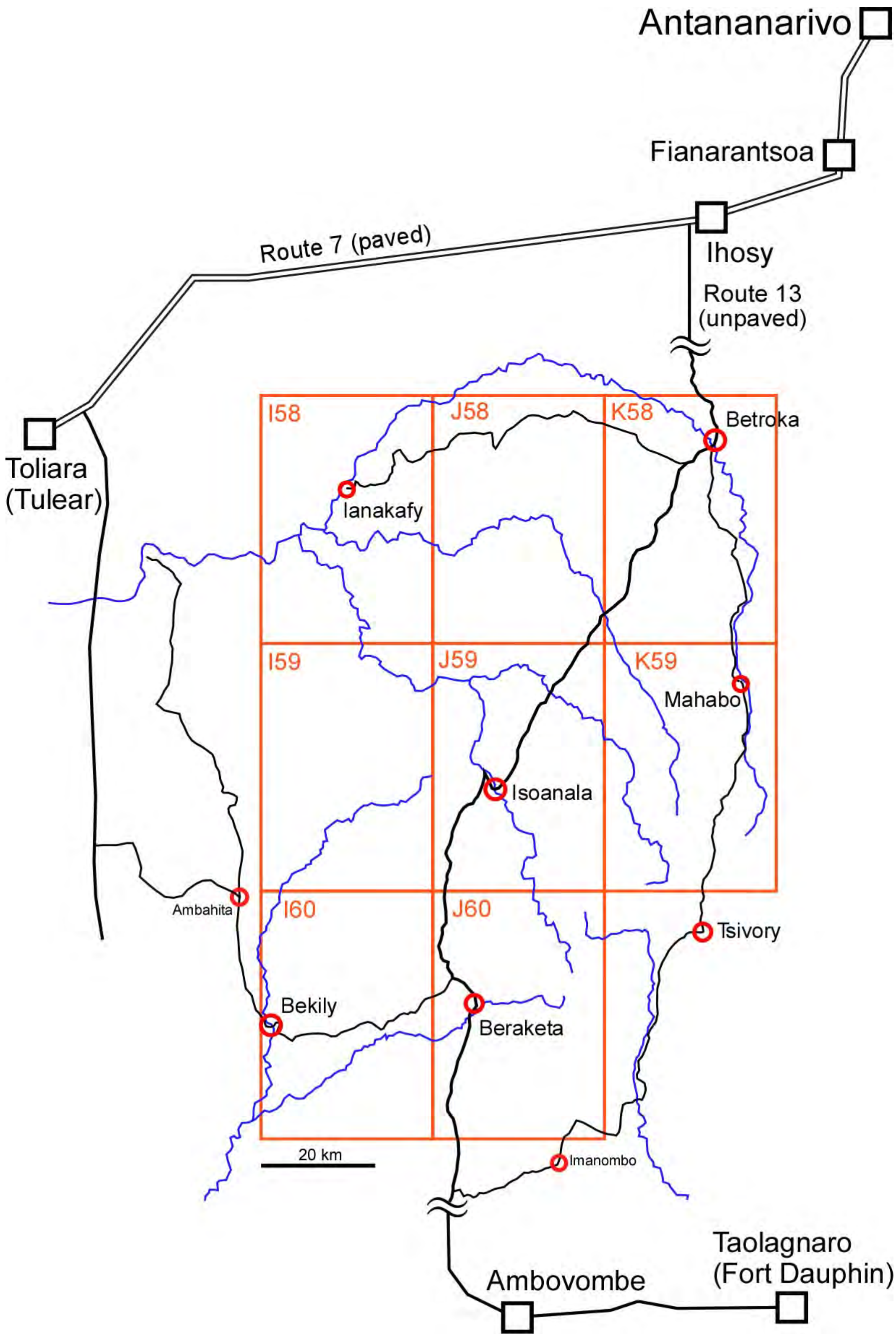


Figure 1.2 Location map of the Survey area (red-framed 8 areas)

1.7.2 Workshop

Following four workshops were held to discuss and report the progress of the Project.

(1) First Workshop

Date: 26th May 2009 in the First-stage Works

Place: PGRM Library, Antananarivo

Content: Presentations of interpretation about the Project by 5 JICA members (Togashi, Onuma, Eto, Takeuchi, and Rambeloson)

Participants: 14 Counterparts, 6 JICA members, 2 staffs from JICA Madagascar office, 1 other: total 23 persons

(2) Second Workshop

Date: 24th Feb 2010 in the Fourth-stage Works

Place: PGRM Library, Antananarivo

Content: Presentation related to the progress of the project in 2009 and plan of the reconnaissance survey in 2010 by 3 JICA members (Togashi, Onuma, and Rambeloson)

Participants: 4 Counterparts, 3 JICA members, 1 staffs from JICA Madagascar office: total 8 persons

(3) Third Workshop

Date: 18th May 2011 in the Seventh-stage Works

Place: PGRM Library, Antananarivo

Content: Presentation related to the progress of the project in 2010 and plan of the survey in 2011 by 6 JICA members (Onuma, Ninomiya, Ishizaki, Takeuchi, Rambeloson, and Ishikawa)

Participants: 19 Counterparts, 6 JICA members, 2 staffs from JICA Madagascar office: total 27 persons

(4) Fourth Workshop

Date: 27th Jan 2012 in the Eighth-stage Works

Place: Carlton Hotel, Antananarivo

Content: Presentation of final result of the project by 5 JICA members (Onuma, Ninomiya, Ishizaki, Takeuchi, and Rambeloson).

Participants: 65 Counterparts, 5 JICA members, 3 staffs from JICA Madagascar office, 13 persons from the Press: total 86 persons

1.7.3 Technology Transfer Seminar

Following two seminars were held in Madagascar for the purpose of transferring technology of Remote Sensing and GIS.

1) First Remote Sensing Seminar

Date: Four days from 19 to 22 October 2009

Place: Library of PGRM, Antananarivo

Lecturers:

19 to 21 October: Dr. Ryoichi KOUDA, Geological Survey of Japan, AIST

22 October: Mr. Takumi ONUMA, JICA Project Team

Participants: 17 persons in total

Contents:

a) 19th - 21st Oct

Theory and example of optical remote sensing, (ii) Introduction of image processing and GIS, (iii) Installation of Free & Open source GIS software (QGIS), (iv)GIS and Image analysis of DEM data by QGIS, (v)Theory and example of Microwave remote sensing

b) 22nd Oct

Introduction of satellite data used in the JICA project, (ii)Examples of analytical results of the data, (iii)Examples of airbone hyperspectral data analysis

2) Second Remote Sensing Seminar

Date: Two days from 30 to 31 January 2012

Place: Library and computer room of PGRM, Antananarivo

Lecturers:

30 January: Mr. Takumi ONUMA (Leader / Overall coordination of the Project, satellite image analysis, Geological remote sensing, GIS))

31 January: Mr. Seiji TAKEUCHI (Geology B / Geochemical exploration) and Mr. Takumi ONUMA

Participants: 9 persons in total

Contents:

a) 30 January

Analysis of satellite image over the survey area, Analysis of ASTER data used by ENVI software

b) 31 January

Analysis of geochemical data, Method of making GIS database of the results on this project used by ArcGIS software

1.7.4 Participation in Mining INDABA

JICA team members and counterpart members attended the annual conference Mining INDABA, held on February in South Africa. In this conference, the results of this project and mineral resources in Madagascar were presented by booth of JICA team and by counterpart presentation.

Date: Four days from 6 to 9 February 2012

Place: Cape Town International Convention Centre, Cape Town, South Africa

Contents:

a) Booth

Geological map and geochemical map of this project area, PALSAR mosaic image of Madagascar, Mineral resources map of Madagascar, and other related materials for distribution

b) Presentation

Date: 8 February

Presenter: Dr. RASOAMALALA Vololonirina (Director of Geology, MM)
Mr. RAZAFIMANDIMBY Olivier (PGRM)

Title: Geological context and available geological data of Madagascar

1.7.5 Participation in PDAC

JICA team members and counterpart members attended the annual conference PDAC, held on March in Toronto, CANADA. In this conference, the results of this project and mineral resources in Madagascar were presented by booth of JICA team and by counterpart presentation.

Date: Four days from 4 to 7 March 2012

Place: Metro Toronto Convention Centre, Toronto, CANADA

Contents:

a) Booth

Geological map and geochemical map of this project area, PALSAR mosaic image of Madagascar, Mineral resources map of Madagascar, and other related materials for distribution

b) Presentation

Date: 6 March

Presenter: Dr. RASOAMALALA Vololonirina (Director of Geology, MM)
Mr. RAZAFIMANDIMBY Olivier (PGRM)

Title: Geological context and available geological data of Madagascar

1.8 Modification of the initial Plan

The modifications of the initial plan are summarized below;

(1) Commence of First-stage Works

Although the First-stage Works was planned to be started in February 2009, its beginning was postponed to May 2009 due to the political circumstance of Madagascar.

(2) Duration for the field survey

Although the field survey was planned to be started in 2009, its beginning was postponed to 2010 due to the political circumstance of Madagascar. The completion of the Project was also changed to 2011. In reference to this change of the duration, Minute of D (M/D) was concluded on 18th June, 2010.

(3) Survey area

The reconnaissance survey in the Fifth-stage Works in Madagascar revealed the impossibility of the survey in the areas, L58 and L59 because the areas are mountainous, inhabitant is scarce and the road for the car is not available. JICA team proposed alternative areas I60 and J60 instead of the L58 and L59 with consideration of the geology and the natural resources and discussion with C/P (Figure 1.1). JICA Madagascar office and MMH accepted the proposal and concluded “Amendment on the Minutes” to change the survey areas on 16th Jul 2010.

1.9 Works in Japan

First- to Fifth-stage Works were conducted in Japan since 2008, the first year of this project, to the final year 2011. These works mainly were composed of making annual reports. Details of these works and other activities conducted in Japan are shown in next section.

(1) First-stage Works in Japan

Period: February, 2009

Contents: Collection and analysis of basic information, Consideration of basic policies, methodology, and schedule of the Project activities, Formulation of the Inception Report, Other preparatory works

(2) Second-stage Works in Japan

Period: February, 2010

Contents: Formulation of the Progress Report

(3) Third-stage Works in Japan

Period: February, 2011

Contents: Formulation of the Interim Report

(4) Fourth-stage Works in Japan

Period: December, 2011

Contents: Formulation of the Draft Final Report, Formulation of the Map

(5) Fifth-stage Works in Japan

Period: February, 2012

Contents: Formulation of the Final Report

1.10 Other activities in Japan

1.10.1 Technical support committee

Technical Support Committee has been established with four academic specialists from Japan, listed below, in order that the scientific outputs of this Project may keep sufficient academic standards. Three committees were held as follows:

Members:
- -Professor Makoto ARIMA, Dean, Graduate School of Environment and Information Sciences, Yokohama National University
- -Professor Syuichi Rokugawa, Graduate School of Engineering, The University of Tokyo
- -Dr. Chikao KURIMOTO, Director, Institute of Geology and Geoinformation, Geological Survey of Japan, National Institute of Advanced Industrial Science

and Technology (AIST)

-Professor Masaru YOSHIDA, President, the Gondwana Institute for Geology and Environment

(1) First technical support committee

Date: 17th Aug 2009

Place: Office of Sumiko Consultants Co., Ltd.（at that time）

Presenter: Dr. Yukio TOGASHI (Leader)

Committee member: Dr. Makoto ARIMA, Dr. Chikao KURIOMTO, Dr. Masaru YOSHIDA

Content: Explanation about new schedule of this project in accordance with the change of the schedule of field works, and outline of the survey area

(2) Second technical support committee

Date: 10th May 2011

Place: Office of Sumiko Resources Exploration & Development Co., Ltd.

Presenter: Mr. Takumi ONUMA (Leader), Dr. Atushi, NINOMIYA, Mr. Seiji TAKEUCHI

Committee member: Dr. Makoto ARIMA, Dr. Syuichi ROKUGAWA, Dr. Chikao KURIOMTO, Dr. Masaru YOSHIDA

Content: Explanation about the result of the survey in 2010 and discussion

(3) Third technical support committee

Date: 27th Mar 2012 (plan)

Place: Office of Sumiko Resources Exploration & Development Co., Ltd.

Presenter: Mr. Takumi ONUMA (Leader), Dr. Atushi, NINOMIYA, Mr. Seiji TAKEUCHI

Committee member: Dr. Makoto ARIMA, Dr. Syuichi ROKUGAWA, Dr. Chikao KURIOMTO, Dr. Masaru YOSHIDA

Content: Explanation about the final result of the survey and discussion

1.10.2 Scientific Seminar

Scientific seminar was held as follows for the purpose of collecting latest scientific information on geology and mineral deposit of Madagascar.

(1) First seminar

Date: 6th Feb 2009

Place: Office of Sumiko Consultants Co., Ltd.（at that time）

Lecturer: Dr. Yutaka TAKAHASHI（Chef Researcher, Advanced Industrial Science and Technology）

Content: Geological mapping and metamorphic petrology in Madagascar

(2) Second seminar

Date: 30th Apr 2009

Place: Office of Sumiko Consultants Co., Ltd.（at that time）

Lecturer: Mr. RAKOTONANDRASANA Thierry（Doctoral student, Graduate School of Environment and Information Sciences, Yokohama National University）, international student from Madagascar (at that time)

Content: Geological Survey in Southern Madagascar - Prospects and Problems

1.10.3 Collaborative research with AIST

Sumiko Resources Exploration & Development Co., Ltd. (SRED) has collaborated with National Institute of Advanced Industrial Science and Technology (AIST) for standardization of geological map since 2009.

Three members from Geological Survey of Japan, AIST, Dr. Yutaka TAKAHASHI, Dr. Yukari MIYASHITA, and Dr. Mutsuki AOYA visited the area of Madagascar for the geological survey for two times, July through August 2010 and August 2011, for three to four weeks each. During their field work, they took rock samples to the laboratory in Japan for microscopic observation. The results of the observation were provided to JICA team and contributory to making a geological map. They joined JICA team during their stay in Isoanala in the middle of August 2011, and discussed local geology of the survey area.

1.10.4 Others

Professor Makoto ARIMA, Graduate School of Environment and Information Sciences, Yokohama National University, one of the members of technical support committee, has been studying geology and geological structure of southern Madagascar since 2004. He is engaged in field geological work in southern Madagascar in September every year with his students. JICA team had an opportunity to meet his study group in Bekily, southwestern town in the survey area, and discuss geology of this area. JICA team keeps in contact with his study group to discuss geology even after field work.

Chapter 2 Basic information on the mineral resources and mining industry

2.1 The State's policy on mining industry

Since the independence from France in 1960, the economy of Madagascar remained weakened because of the political upheaval and the introduction of the socialist policies. However, in 1996, the structural adjustment loan of the IMF and the World Bank began, and the macro-economy became considerably stable.

The government of Ravalomanana, inaugurated in 2002, issued the Poverty Reduction Strategy Paper (PRSP) in 2003 for the reduction of poverty. In November 2004, the government announced "Madagascar Naturally", the vision of the national development. Moreover, in November 2006, it integrated these long-term programs in the action plan called the Madagascar Action Plan (MAP) (2007~2012). In 2005, Madagascar affiliated itself in the South African Development Community (SADC). Thus, it started to take part in the international community. As a result of these active policies, the economy of Madagascar maintained the annual growth rate of approximately 5% for the period of 2004-2008.

During this time, "Reinforcement and development of the mining sector", leading directly to the increase in the direct investment from abroad, continued actively with the "Reduction of poverty via the economic growth" as the principal aim to be reached. In this context, the nine items below were regarded as the themes of priority.

1) Eliminate existing impediments for mining production
2) Define plans to finance infrastructure
3) Improve laws and regulations on mining sector
4) Promote the exploration and exploitation of mining and hydrocarbon reserves
5) Build capacity to manage oil and mining resources
6) Educate, inform and train small-scale gemstone miners
7) Involve citizens in design and monitoring of new projects
8) Reduce the rate of excise duty
9) Simplify administrative procedures for investors

However, following the inauguration of the provisional government replacing the Ravalomanana government in March 2009, the political upheaval emerged, and Madagascar became internationally isolated. Consequently, the economy remained stagnant. Even, at the beginning of the year 2012, this situation continues. The economic growth rate in 2009 fell into 0.6% ; it was 2.6% in 2010. As a result of the political upheaval in 2009, the Ministry of Energy and Mines (MEM) was divided into the Ministry of the Mines and the Ministry of the Energy, and after, the Ministry of Mines become the Ministry of the Mines and Hydrocarbons (MMH) which become the Ministry of Mines (MM) again in November 2011.

In May 2011, MMH held the first "International Fair of the Mines and Hydrocarbons (*Salon International des Mines et des Hydrocarbures* = SIMH)", during three days, with the local and foreign companies as sponsors. In this fair, the potential of the natural resources of Madagascar, the current situation of mining industry, the development projects, and the environment for the investment, were reported. Many companies presented the exhibition booths.

At the end of 2006, the procedure to obtain the certification of the Extractive Industries Transparency Initiative (EITE) launched in order to maintain the high transparency of the mining sector and to invite foreign investment. As of March 2011, Madagascar was certified as one of the candidate countries of ITIE (24 countries on the whole). The big companies such as QMM (Rio Tinto, Ilmenite), KRAOMA (Chromite), Sherritt (Nickel, Cobalt), Exxon Mobil (Oil) are supporting this project.

2.2 Project of the World Bank

With the assistance of the World Bank and other organizations, the Reform Project of the Mining Sector (*Projet de Réforme du Secteur Minier* = PRSM) was carried out from 1999 to 2002, for the economic development of Madagascar, especially for the exploitation of the underground resources. The purpose of this project was to arrange the law and the tax system in the mining sector, to improve the environment of investment and the lack of geological information, being based on the state-of-the-art technology. Moreover, as a second phase of this project, from 2003 to 2010, the Project of Governance of the Mineral Resources (*Projet de Gouvernance des Ressources Minérales* = PGRM) was carried out with the assistance of the World Bank, etc. The total amount of this project rose to 54 million US$.

Within the framework of PGRM, the geological research agencies of several countries, such as USGS (USA), BGS (England), BRGM (France), BGR-GAF (Germany) and CGS (South Africa) carried out the geological and geochemical surveys in the zones assigned to each agency. Figure 2.1 shows the geographical position of these surveys. The items carried out in these surveys include the update of the geological map at 1: 100,000 scale (approximately 150 sheets), the geochemical survey on the sediment of riverbed, the compilation of the geological map at 1:500,000 scale, the airborne magnetic survey and the radioactive prospecting, etc. By the way, for the period finishing in June 2012, the update of the geological map at 1:1,000,000 scale covering the entire Madagascar was accomplished.

In July 2008, PGRM held in Antanarivo the conference for three days, making a report on the result of the study and the potential of the mineral resources, etc.

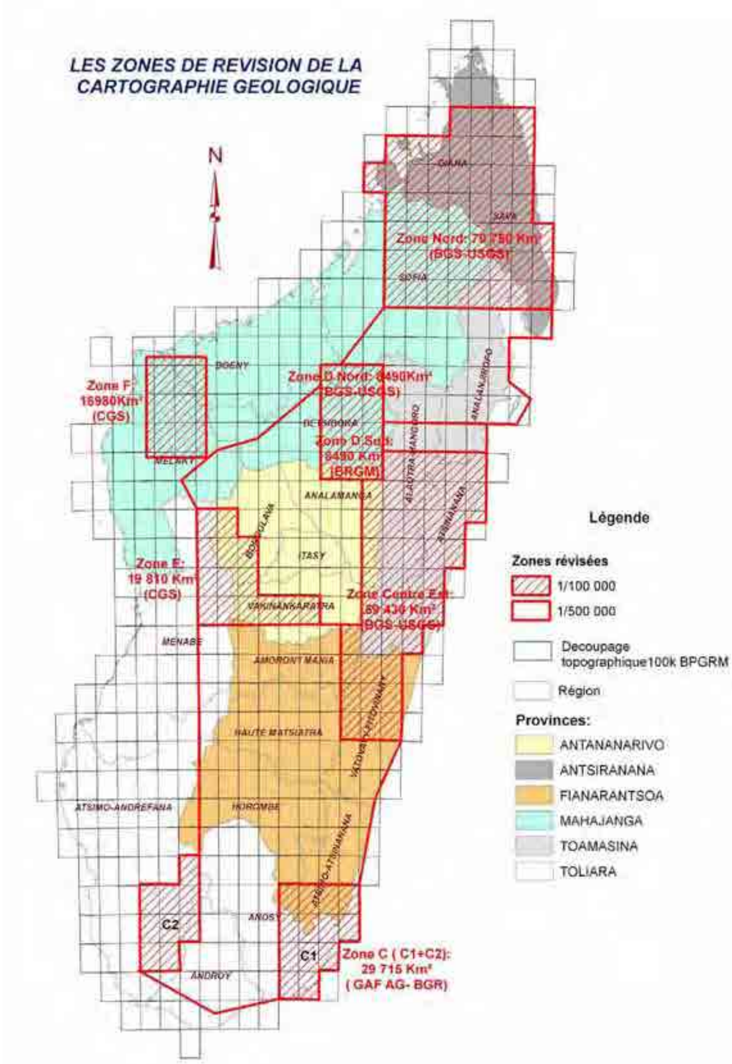


Figure 2.1 Position of the geological survey zone of PGRM

2.3 Natural resources

It is said that Madagascar has the potential of various resources. However, up until now, the exploitation of the resources has not been made sufficiently, and the mining industry is still in the process of development. The resources exploited until today are the chromite of high quality, the strongly crystallized graphite and mica, the gems, and the stone. The other resources whose potential have been confirmed include gold, nickel, cobalt, titanium (ilmenite), bauxite, iron, copper, lead, zinc, manganese, platinum, the element of rare earths, uranium, coal, oil, etc. Figure 2.2 shows the potential of the mineral resources in Madagascar.

The principal mineral resources produced today are the ilmenite and zircon exploited by QMM (Rio Tinto / Government of Madagascar), and the chromite by KRAOMA (National company). In 2012, the production of nickel-laterite and cobalt by the Ambatovy Project

(Sherritt/Sumitomo Corporation/Korea Resources/SNC-Lavalin) is expected. Besides these resources, the gold and the gems are exploited by the small mines and the artisanal miners. But, their current situation is not clear.

From 2008 to 2009, the world economic crisis emerged, and in 2009, there was the political upheaval in Madagascar. Consequently, the production of the mineral resources and the gems of Madagascar fell abruptly. However, the launching of the production of ilmenite by QMM played the big role on a global scale.

(1) Chromite

KRAOMA is the only national mining company in Madagascar, producing the chromite concentrate and the chromite solid mass, among which 100,000~140,000t is annually exported. In 1998, Madagascar was the tenth country in the world concerning the production of chromite. The production of chromite ore was 150,000t, whose chromite content was 50%.

In 1948, the chromite was discovered for the first time in the area of Andriamena, in the Northwest of Madagascar. The exploitation started in 1968. Up until now, the chromite has been mainly produced by the mines of Ankazotaolana and Bemanevika, and the estimated reserves are approximately 3 million tons. The mine of Ankazotaolana was closed in 2007. After the closure, the mine of Bemanevika started again in 2005. It was again closed in October 2008, and restarted in May 2009. The life expectancy of the mine of Bemanevika is estimated at 15 years. The total annual production of chromite was 122,260t in 2007, 84,000t in 2008, and 60,000t in 2009. It decreases year by year.

(2) Graphite

Graphite is present at Ambatolampy in the Center, in the neighborhoods of Ampanihy in the Southwest, and at Manampotsy in the East, etc. of Madagascar. Etablissements Gallois S.A. is the largest producer, operating three mines on the east coast. Other companies include Etablissements Izouard, Etablissements Rostaing, Société Arsene Louys, and Société Minière de la Grande Île.

The annual production was 100,000t in 1995, 130,000t in 2000, 150,000t in 2005, and 50,000t in 2010. The reserves are estimated at approximately 940,000t. The reduction of the production is due to the higher price of oil product used for drying, and the depletion of the high grade-ores.

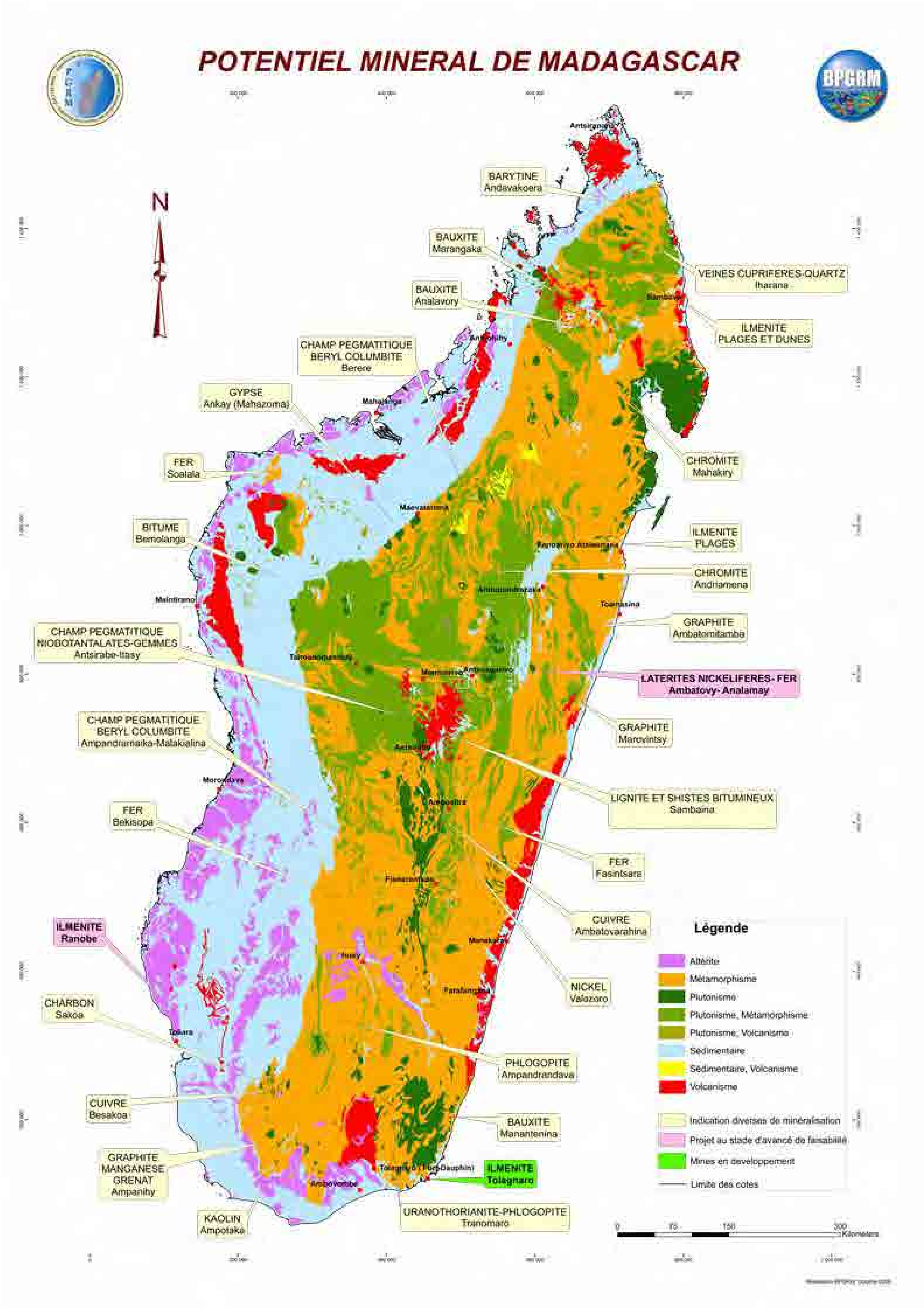


Figure 2.2 Potential map of mineral resources (made by PGRM)

(3) Mica

The mica resources include an enormous quantity of phlogopite, and muscovite in the small-scale ore deposit. Recently, only phlogopite is exploited. The ore deposit of mica exists in Ambarata, Ampandrandava, Benato, and Maniry Miary in the South of Madagascar. The mine of Ampandrandava is operated by SOMIDA, and the mine of Maniry Miary, by Exploitation Minière DELORME.

The annual production was 546t in 2005, 1,349t in 2007, 1,233t in 2008, and 358t in 2009.

(4) Gold

The ore deposit of gold is recognized in many areas of Madagascar. The principal ore deposits exist at Ampanihy in the South, Ambilobe and Andavakoera in the Northeast, Maevatanana on the east coast, and Miandrivazo in the West. However, the large ore deposit has not been discovered. The majority of the gold are exploited by the small mine and artisanal miners.

The annual production was 10kg in 2005, 72kg in 2008, and 70kg in 2009. But, these figures don’t include the production of artisanal mining. In fact, it is estimated that approximately 1~2t of gold is annually produced.

(5) Titanium

It is well-known that Madagascar is rich in titanium resources. On the coast of the Tolagnaro sector in the Southeast, there exist the ilmenite and the zircon containing titanium, and the monazite containing rare earths in the beach sand. Around Tolagnaro, three ore deposits have been confirmed, and the total reserves are 75 million tons of ilmenite and 700,000 tons of zircon, with 60% of TiO_2.

In the ore deposit of Tomasina on the east coast, the reserves are estimated at 12 million tons of ilmenite and 70,000 tons of zircon, with 48% of TiO_2. Moreover, there exist the similar ore deposits at Morombe and Tambohorano on the west coast, at Ranobe in the South, and in the northern region.

The company QMM began the production at the ore deposit of Tolagnaro in January 2009, producing 240,000t of ilmenite, 5,000t of rutile, and 8,000t of zircon. In 2012, it is planning to produce 750,000t of ilmenite, 25,000t of rutile, and 15,000t of zircon.

(6) Nickel and cobalt

In the North and East of Madagascar, the basic igneous rock distributes widely, the existence of the resources of nickel and cobalt being expected. The ore deposit of the niekel-laterite at Ambatovy in the Center-East is likely to begin the production in first quarter of the year 2012. The reserves of this ore deposit are 125 million tons, with 1.04% of Ni. The capacity of annual production is 60,000t of nickel and 5,600t of cobalt.

The prospecting advances in the ore deposit of the niekel-laterite at Valozoro in the Center-South, whose reserves are estimated at 11 million 500 thousand tons with 1.6~1.7% of Ni. In addition, in the region of Alaotra to the north of Ambatovy, exists the ore deposit whose reserves are estimated at 1 million 600 thousand tons, with 1.3% of Ni.

(7) Copper

Medium size copper deposits are confirmed at Ambatovarahina in the Center, Besakoa in the South, and Daraina at the northern border of Madagascar. Reserves of the deposit of Ambatovarahina are estimated at 250,000t, with 4.75% of Cu. The reserves of Besakoa are estimated at one million tons, with 0.6% of Cu. For the former, the small-scale exploitation was examined, but it is said that the latter is not profitable.

At Ambodilafa in the East-Center, the prospecting began in 2009 for nickel-copper-platinum, and the drilling survey was carried out in 2010. The nickel-copper prospecting at Ampanihy and the drilling survey of nickel-copper at Vohibory were respectively carried out in the Southwest.

(8) Iron

Several iron deposits have been confirmed in various areas of Madagascar. The deposit of Soalala in the Northwest contains the reserves of 3 million 600 thousand tons, with 35% of Fe. The deposit of Betioky in the Southwest contains the reserves of 30 million tons, with 24% of Fe, and 1 million 300 thousand tons, with 10~14% of Fe. The deposit of Fasintsara in the East-Center contains the reserves of 30 million tons, with 36% of Fe, and 75 million tons, with 34% of Fe. Fenoarivo deposit in the East-Center contains the reserves of 100 million tons, with 30~40% of Fe. The deposit of Ambatovy contains the reserves of 30 million tons, with 46~47% of Fe. The deposit of Ambonimahavonjy contains the reserves of 15 million tons, with 30~40% of Fe. Moreover, there exist the small deposits at Alaotra, Mantasoa, and Maevatanama, etc.

The deposit of Soalala is estimatted to be the most profitable. The exploitation of the deposits of Ambatovy and Ambohimahavonjy were examined in the past.

(9) Aluminium

The ore deposit of bauxite, the raw material of aluminium, is present at the coastal part of the Southeast of Madagascar. The deposit of Manantenina contains the reserves of 165 million tons, with 41% of $Al^{2}O^{3}$, considered as the most promising bauxite resources. The reserves of the Farafangana deposit are estimated at 100 million tons, with 37% of $Al^{2}O^{3}$, and that of the Ankaizina deposit, at 55 million tons, with 40.7% of $Al^{2}O^{3}$. The deposit with low content was discovered in the Northwest of Antananarivo. Its reserves are estimated at 10~15 million tons.

(10) Rare earth element (REE)

In the eastern part of Ampasindava peninsula in the North of Madagascar, Tantalus Rare Earths AG started in 2009 the large-scale prospecting, covering Nb-Ta-REE. At Ambatofinandrahana in the Center of Madagascar, there exists the rare earth deposit contained in monazite and bastonasite.

(11) Gems

Recently, Madagascar becomes famous as a country producing the gems such as emerald (Beryl), ruby (Corundum), sapphire (Corundum). Emerald is produced near Mananjary at the coastal part of the East; Ruby, at Andilamena in the Northeast, and at Vatomandry on the east maritime coast; Sapphire, at Ilakaka, Manombe, and Sakara in the Southwest, and at Marosely in the North. The production of the beryl in quartz was 30t in 1998, 12t in 2005, and 12t in 2009. The deposits of relatively large size were discovered in pegmatite, at Ambatofinadrahana, Ampandremaika, Malakialina, and Tsaratanana in the Center. The other deposits are at Betafo Antsirabe and Miandribaza in the Center, and at Itrongay in the South.

Tsavorite (green grossularite) is produced at Behara in the South. Demantoid (green andradite) is produced at Antetezambato in the North, since March 2009.

The gems are produced in general by the artisanal miners, and the current situation such as the quantity of production is not clear.

(12) Quartz

In Madagascar, the following types of quartz are produced as the ones having the commercial value; rock crystal, amethyst, citrine, pink quartz, smoky quartz, and industrial quartz. In March 2008, Norcross Madagascar Group (USA) began the production of amethyst at Ambatonrazaka in the northeastern region. The citrine is produced at Mananara and Maroantsetr; pink quartz, at Ampandramaika, Andrianampy, and Samiresy; smoky quartz, in the neighborhoods of the Antongil bay. Industrial quartz is produced in Kaandreho, Mananara, and Maroantsetra.

(13) Stone

Feldspar-Labrador is a kind of feldspar, having the unique play of color, named Labrador effect. It is used as jewelry and building material. Feldspar-Labrador of high quality is produced in Madagascar and Norway. EUROMAD (Italy), MAGRAMA (Italy), SQNY (India), and NMG (USA) produce feldspar-Labrador originated in the intrusive rock of anorthosite, in the neighborhoods of Ianapera and Maniry in the South of Madagascar. The annual production was 4,200t in 2005, 4,200t in 2007, and 4,600t in 2009.

Moreover, the calcareous rock and the marble are also produced.

(14) Coal

In 2009, Straits Resources (Australia) signed the contract on the prospecting of the coal deposit at Sakamena and Sakoa in the southwestern region of Madagascar. Meanwhile, in January 2009, Uranio (Australia) decided the cancellation of the coal project of Imaloto in the southwestern region, because of the world economic crisis.

(15) Oil

In 2010, Madagascar Oil (USA) carried out drilling at Tsimiroro in the Northeast of Madagascar, building the pilot facilities for the production of oil. Reserves are estimated at 600 million barrel. Madagascar Oil and Total S.A. (France) began the prospecting of tar sands at Bemolanga in the Northwest. The reserves are estimated at 2.5 billion barrel.

Moreover, Vanco Energy, Energy Sterling, and Exxon Mobil, etc. carry out the prospecting on the ground and offshore in the West of Madagascar.

(16) Uranium

In Madagascar, many companies carry out the prospecting of uranium, and they pay attention to its potential. UMC Energy plc (England) carried out the prospecting at Folakara in the Northwest of Madagascar, but then suspended it, following the political upheaval in 2009.

2.4 Projects of the exploitation of resources

The principal projects of exploitation of the mineral resources carried out in Madagascar are as follows. From 2008 to 2009, the world economic crisis emerged. Moreover, in 2009, there was the political upheaval in Madagascar. Consequently, most of the projects and exploitation of the resources were suspended. However, the prospecting started again recently.

(1) Tolagnaro

- For the period between the end of 1980s and the beginning of 1990s, Rio Tinto (Canada) discovered the resources of the heavy mineral sand (ilmenite, zircon) at Tolagnaro (Fort Dolphin) on the southeastern coast of Madagascar. This ore deposit is constituted of three adjacent deposits, namely Mandenan, Petriky, and Sainte Luce.
- The company QMM, joint venture between the subsidiary company of Rio Tinto and the government of Madagascar, exploited the mine. The government of Madagascar owns 20% of the interests. In the first production, there isn’t any obligation of the government for these interests of 20%. Then, if the government does not finance the cost of project, its share in the interests will decrease.
- In August 2005, the exploitation of mine was decided, and the construction of port started in 2008. The production launched in January 2009.
- The life expectancy of the mine is more than 40 years. The reserves of ilmenite are more than 75 million tons, and the maximum annual production is 2 million tons.
- The capital expenditure (CAPEX) increased to 1,200 million US$, compared to the original amount of 850 million US$.
- The ilmenite of this zone contains the titanium dioxide whose content is as high as 60% ; its quality is very high compared to the resources of other countries. In the factory in Canada, these resources are refined into chloride slags, with 90% of titanium dioxide. Then, they are dispatched to the international market of the titanium raw material, being used to manufacture the pigment in painting and plastic industries.

(2) Ambatovy

- In 1995, Phelps Dodge (currently FCX, USA) carried out the prospecting of the nickel-laterite deposit, arising in the ultrabasic rock, distributed in the East-Center of Madagascar, and confirmed a large-scale deposit.
- Phelps Dodge launched the project of Ambatovy JV with Implats (South Africa). In May 2005, Dynatec Corp (Canada) acquired the interests of Phelps Dodge; in August 2005, Sumitomo Corporation took part in it. In January 2006, Implats withdrew; in October 2006, KORES (South Korea) and SNC-Lavalin (Canada) took part in it. Consequently, the percentage of the interests becomes as follows: Dynatec: 40%, Sumitomo Corporation: 27.5%, KORES: 27.5%, SNC-Lavalin: 5%. In June 2007, Dynatec was acquired by Sherritt International (Canada).
- The proven and probable reserves are 125 million tons, with 1.04% of Ni, and 0.099% (Cut-off grade, 0.8%) of Co.
- According to FS in February 2005, the life expectancy of the mine is 27 years, and the annual production capacity is as follows: Ni: 60,000t, Co: 5,600t, Ammonium sulfate: 210,000t.
- At the mine mouth, the open pit mine and the procession plant of ores were built. The slurry of concentrate is transported by the slurry pipeline with length of approximately 220km, up to the factory HPAL, near Toamasina.
- The production of this mine is expected to begin in first quarter of the year 2012.
- In the original project, the capital expenditure (CAPEX) was 3.4 billion US$, but in February 2009 they were increased to 4.52 billion US$.
- Sumitomo Corporation is in charge of the general management of the project, marketing, and financing. During 15 years, it retains the share right of 30,000t, equivalent to half of the annual production of nickel metal.

(3) Bekisopa

- The magnetite deposit exists around Bekisopa in the Center-South of Madagascar.
- In the past, the prospecting was carried out by BRGM, the government of Madagascar, and the United Nations. The deposit of Bekisopa East is composed of the magnetite, whose sulphur and phosphorus content is low. The quantity of resources is estimated at 150 million tons, with 25~65% of Fe, and 45% of the average content.
- In 2007, Cline Mining (Canada) carried out the airborne magnetic survey and the ground geophysical survey, discovering some new deposits. In 2008, this company carried out the drilling survey. However, as a result of this survey, the deposit was not considered to be profitable.

(4) Soalala

- The banded iron formation (BIF) is distributed in the neighborhoods of Soalala in the Northwest of Madagascar.
- In September 2009, Hong Kong Wisco Guangxin Kam Wah Resources (hereafter named HKWG, China) announced that through the international tender it had acquired the right of

prospecting and exploitation in the iron ore deposit of Soalala.

- The surface of this mining field is 431.25km^2, with 360 million tons of resources, and 35% of Fe. This deposit, the largest iron ore deposit in Madagascar, is regarded as the most profitable.
- HKWG is a joint venture, by Wuhan Iron and Steel Group Corp. (Wisco), Kam Hing International Ltd Holdings., and Guangdong Foreign Trade Group Co., Ltd. (Guangxin). Wisco and Guangxin are controlled respectively by the government of China and the regional government Cantonese.
- In 2008, Wisco and Guangxin founded a joint venture, for the exploitation of the iron ore mine in Madagascar. It is planning the exploitation of this iron-titanium deposit of Bekisopa, having already finished FS. Thus, this company invested actively in Madagascar.

(5) Tantalus

- There exists the REE deposit of the type Skarn, accompanying the igneous activity of alkaline rock, at the eastern part of Ampasindava peninsula, in the North of Madagascar.
- During the period of 1980s and at the beginning of 1990s, ex-USSR carried out the geological, geochemical, geophysical surveys, and the pit drilling. In 2008, Zebu Metals did the airborne magnetic survey and the radioactive prospecting.
- In 2009, Tantalus Rare Earths AG (Germany) obtained the mining field, beginning the geochemical survey. Since 2010, this company has carried out the drilling survey.

(6) Nickel Valley

- In 2006, Pan African Mining Corp (current Asia Thai Mining Corp., Thailand) confirmed the nickel-laterite deposit, just under the ground level, in the ultrabasic rock with length of 1,000m and width of 250m, in the North of Madagascar. The zone neighboring the mining field is called “Nickel Valley”.
- As a result of auger boring survey, was seized the deposit with width of 2m, with 0.5~2.6% of Ni.

(7) Dabolava

- Since 2005, Pan African Mining Corp (current Asia Thai Mining Corp., Thailand) has carried out the prospecting of a gold deposit, at Dabolava in the West of Madagascar.
- According to the drilling survey in phase 2 in 2007, were seized the deposit of a width of 9.5m with 11.99 g/t of gold, the one of a width of 2.33m with 5.10 g/t of gold, and the one of a width of 1.72m with 23.96 g/t of gold.

2.5 The laws and regulations relative to the mining industry

In August 1999, the mining code (law No.99-022) was newly enacted for the simplification and the transparency of the mining sector, the eradication of the conflict, and the management of the extraction right. The promulgation of this code brought the rationalization and the consolidation of the mining activity, increased at the time by the major mineral resources companies, the local companies, and the small extraction companies. In 2000, the Office of Mining Land Register of Madagascar (*Bureau de Cadastre Minier de Madagascar* = BCMM) was founded, having for goal to manage the register of the extraction right, in a public and advanced way. In 2005, the mining code was partially revised. Nevertheless, its basic policy and idea did not change.

In October 2002, the Law on the Large Scale Mining Investments (*Loi sur les Grands Investissements Miniers* =LGIM) was enacted, in order to promote the large-scale mining industry, and to entrust the prospecting to the companies adapted technically and financially. This law protects the investment exceeding 200 million US$, allowing legal and tax incentives.

Consequently, two large projects were launched: the exploitation of nickel-cobalt at Ambatovy, and that of titanium-iron and heavy mineral sands at Tolagnaro. The deposit of Tolagnaro began the production in 2009.

2.5.1 Revised points of the mining code

(1) Reduction of the surface unit of the extraction right
(2) The State’s withdral from the production activity
(3) Definition of the small size mining company
(4) Role of the regional authority
(5) Royalties
(6) Suspension of the environmental research
(7) Revision of the permission of prospecting
(8) Protection of the placer gold miners
(9) Mining right for the radioactive material

2.5.2 Mining license

There exist four types of mining licenses that the Office of Mining Land Register of Madagascar (BCMM) delivers. The cost of license is determined according to the “unit of surface” of 625m×625m (approximately 0.4km^2); it is revised every year in accordance with the exchange rte of IMF for Malagasy-Ariary (MGA). It takes 35 days after the advance payment to obtain the license. The preliminary evaluation of the environmental assessment by the Ministry of the Environment is the condition for the delivery of license.

The mining royalties are 2% of the amount of the product sales. Small mining license, exploration license, and mining license are the dominions which are rentable and collaterized against the mortgages.

(1) Exclusive Authorization to Reserve a Prospect (AERP)

1) To deliver the exclusive right of prospecting in the perimeter of license
2) Maximum Surface: 38,400 units of surface (approximately 15,000km^2)
3) Valid for at most three months
4) Necessary as a preliminary evaluation before the request for prospecting and exploitation

license

(2) License of prospecting (PR)

1) To deliver the exclusive right of prospecting in the perimeter of license

2) Maximum Surface: 25,600 units of surface (approximately 10,000km^2)

3) Valid for five years, and possible to be renewed twice respectively for three years

(3) License of exploitation (PE)

1) To deliver the exclusive right of prospecting, exploration, and exploitation in the perimeter of license

2) Maximum Surface: 2,560 units of surface (approximately 1,000km^2)

3) Valid for 40 years, and possible to be renewed several times respectively for 20 years

(4) License reserved to the small-scale mining (PRE)

1) To deliver the exclusive right to start at the same time the prospecting, exploration, and exploitation in the perimeter of license

2) Maximum Surface: 256 units of surface (approximately 100km^2)), divisible in four separated blocks

3) Valid for 8 years, and possible to be renewed several times respectively for 4 years

2.5.3 The Law on the Large-Scale Mining Investments (LGIM)

In October 2002, the Law on the Large-Scale Mining Investments was enacted in order to promote the large-scale mining project in Madagascar, and to entrust the prospecting to the companies qualified technically and financially. This law made it possible to establish the attractive and unique system of law, customs, and foreign currency exchange. However, in Madagascar, the investment in the large-scale mining has not sufficiently advanced in the actual situation where the economic competition intensifies among the mining countries. One of the factors was that the criteria of qualification for the large-scale mine were too high. Thus, in 2005, the criteria of qualification dropped to 50 billion MGA (approximately 25 million US$), compared to the previous amount of 200 billion MGA (approximately 100 million US$). Following this revision, the number of projects covered by this law increased. Nevertheless, this amount of criteria rests still high, restricting the number of project.

The incentives in this low are as follows.

1) Ensure the investment exceeding 200 million US$, in the light of the law, the tax, t the customs, and the provision on the exchange of foreign currency.

2) Period of tax exemption for the first five years of exploitation, stipulated by the law concerned, as an incentive.

3) Exonerate 25% of the income tax for the mining companies, and furthermore 10% if the value is added to the product in Madagascar.

4) Stipulate the international arbitration in case of conflict.

2.6 Problems

2.6.1 Problems in the development of mining industry

Recently, the legal regulation relating to mining industry in Madagascar has been well developed. The unification of the data on the potential of the mineral resources and the update of the geological map were carried out by PGRM. The mineral resources have attracted the glances of the whole world. Indeed, the prospecting of the mineral resources was carried out everywhere by many foreign companies. However, from 2008 to 2009, the world economic crisis emerged. Moreover, since 2009, there was the political upheaval in Madagascar. Consequently, most of the prospecting projects of mineral resources were suspended. However, there exist some good news for the economy of Madagascar: The project of ilmenite at Tolagnaro by QMM began in 2009, and the project of nickel-laterite at Ambatovy is expected to launch at the beginning of 2012. The realization of such large-scale development projects of the resources could be the starter for other new projects. In this sense, the political and economic stability of the State is required.

In the countries where the development is going on, the small-scale mining becomes often an obstacle. It is also the case in Madagascar. In particular, gold and the gems are actually extracted by the artisanal miners, which is likely to be the obstacle for the prospecting and the exploitation of mines in the coming years.

It is said that there exists the potential of various mineral resources in Madagascar. But are not published, the latest geochemical data covering the vast zone, nor the data of the promising zones of mineralization. For example, PGRM carried out the prospecting, selecting the zones of high potentiality, but the data of the geochemical survey are not published; the systematic evaluation is not carried out either. If these types of data are published, the activity of the prospecting for resources will become more active.

2.6.2 Problem of environment

The project of ilmenite at Tolagnaro by QMM was admired as the mining model having the sense of responsibility in the country where the development is going on. However this project is criticized at the same time, being the threat to the diversity of the living creatures, causing the increase of poverty and the damage to the local economy. It is also criticized in that this company does not keep its public promise according to which it should carry out mining, having the sense of the responsibility for the environment and the society. The ecologist asserts that it should be necessary to take the urgent measures for alleviating the bad effect caused by this project.

With regard to the project of nickel-laterite at Ambatovy, the ecologist asserts that mining causes the harmful effects for the forest, which is biologically rich, but is facing the threat.

Chapter 3 Geological survey

3.1 Summary

Parallel to the geochemical survey, we carried out the geological survey in the sixth field survey in 2010 and the seventh field survey in 2011. We observed geology and minerals at the outcrop of rocks, measuring the geological structure. Where necessary, we took the samples of rocks. The result of the observation of outcrop was recapitulated as the route map. For the representative samples of rocks, we carried out the laboratory test such as the measurement of absolute age, the chemical analysis of whole rock, and the observation of the flake of rocks by the microscope.

The zones of study are eight sectors follows: I58, I59, I60, J58, J59, J60, K58 and K59. With regard to the number of laboratory test, 16 samples were analyzed respectively for the measurement of absolute age, the chemical analysis of whole rock, and 244 samples for the observation of the flake of rocks by the microscope.

3.2 Survey method

3.2.1 Geologic survey

We have carried out the geological survey parallel to the geochemical survey. If we found a representative outcrop on the way to the sampling point of the geochemical survey of the sediment in the riverbed, we observed the outcrop. Moreover, we carried out from time to time the geological excursion and the complementary geological survey, intensifying the density of the survey. In the geological survey, we observed the rock and the geological structure, by carrying out the recording of geology (name of rocks, constituent minerals, metamorphic facies, combination of metamorphic rocks, etc), the measurement of the geological structure (strike and inclination such as foliation, lineation, stratification, fault, dike), the sampling of the rocks for the laboratory test or the expertise. In addition to these contents of observation, we noted the date and hour of the survey, weather, and UTM coordinates of GPS in the prescribed sheet of recording. In the base camp, we recapitulated as the route map the lithofacies and the geological structure in the topographic map enlarged to the scale of 1:50,000. The position of the geological survey is presented in Figure 3.1.

With regard to the measurement of the geological structure, we measured the direction of strike and the angle and the direction of inclination, for the representative foliation at the outcrop. Moreover, when the oblique movement of dike and fault was recognized on the foliation, we measured this dike and inclination, where necessary. Since the study zone has the deviation angle of approximately 20° of western deviation, we considered these directions of strike as the angle against the true north, namely the angle of deviation being corrected. During the measurement of GPS, each member of the study team obtained UTM coordinates of the outcrop where we carried out the geological recording, using GPSmap 60CSx of the company

Garmin.

At the beginning of the survey in a study zone, all the members of the JICA study team and C/P made the geological excursion. Before recapitulating the route map, all the members observed and expertized the samples of rock that each group of study had taken. Thus, we shared the results of observation and expertise of rocks so that there may be no difference in recording among the members of study team. These activities are important even as an on-the-job training of C/P. During the appraisal of rocks and minerals, the members of C/P worked under the direction of Dr. Rambeloson, member of the study team of JICA (former professor of geology, the University of Antananarivo).

3.2.2 Creation of the geological map

We elaborated the geological map at 1:100,000 scale, according to the route map recapitulating the result of the geological field survey, the result of the laboratory test, the satellite image, the existing geological map, and the document concerning the geology. For the geological division, we followed basically that of the geological map of PGRM. However, for the layer to which this geological division cannot be applied, we created the new geological unit, according to the specification of PGRM.

The recapitulation of geology and geological structure are shown in Table 3.1. The geological plan and the (decreased) geological cross section for all the eight sectors are shown in Figures 3.3 and 3.4.

3.2.3 Laboratory test

The laboratory test is constituted of the observation of the flake of rocks by the microscope, the measurement of absolute age, and the chemical analysis of whole rock. The measurement of absolute age and the chemical analysis of whole rock are important as basic data to clarify the development history of the geological structure in the study zone. The position of sampling for the laboratory test is presented in Figure 3.2.

(1) Observation of the flake of rocks by the microscope

As samples for the observation of the flake of rocks by the microscope, we selected in total 236 rocks in all the eight sectors when all the members of the team and C/P made the observation and appraisal of the samples of rocks. The creation of the flake of rocks and the observation by the microscope were entrusted to MMH, organization of C/P.

(2) Measurement of the absolute age

The number of the samples for the measurement of absolute age of rocks is in total 16 for all the eight sectors. These samples were selected so that they may cover the entire study zone, and that we can obtain knowledge on the age of the formation and the metamorphism of the principal metamorphic rocks, and the age of the formation of the igneous rocks.

Since there does not exist analysis laboratory that can measure the age in Madagascar, we entrusted the test to the National University of Australia in 2010, and to Geochronology Japan

Inc. in 2011. Table 3.2 shows the result of measurement of the absolute age of the rocks.

(3) Analysis of the entire rock

The number of samples for the analysis of whole rock is in total 16 for all the eight sectors. Among them, ten samples are the same as those of the measurement of the absolute age. The result of the analysis of whole rock is presented in Table 3.3.

There does not exist a suitable chemical laboratory in Madagascar. So, just like the geochemical survey, we requested the chemical analysis from the laboratory of ALS Chemex in Johannesburg, Republic of South Africa, taking account of the expenses of analysis, of the precision and reliability of analysis, and the transport costs of the samples.

The elements for the analysis of whole rock are the following 52 elements.

(1) 13 principal elements (ICP emission spectrometry)

SiO_2, Al_2O_3, Fe_2O_3, CaO, MgO, Na_2O, K_2O, Cr_2O_3, TiO_2, MnO, P_2O_5, SrO, BaO

(2) Loss on ignition (Gravimetric method)

L.O.I.（Loss On Ignition）

(3) 38 microelements (ICP mass spectrometry)

Ag, Ba, Ce, Co, Cr, Cs, Cu, Dy, Er, Eu, Ga, Gd, Hf, Ho, La, Lu, Mo, Nb, Nd, Ni, Pb, Pr, Rb, Sm, Sn, Sr, Ta, Tb, Th, Tl, Tm, U, V, W, Y, Yb, Zn, Zr

3.3 Geology of the study zone

The majority of rocks in the study zone are the gneiss and the granite. Both are regarded as the rocks currently constituting the earth's lower crust. The gneiss is the metamorphic rock whose origin is the sedimentary rock, and the foliation is well developed. The granite is the igneous rock whose origin is the magma.

The gneiss is the rock whose origin is the sedimentary rock. Being formed in the neighborhoods of the ground surface, the sedimentary rock is brought to the profound part of the earth's crust, where, under the condition of the high temperature and the high pressure, it undergoes the metamorphism and at the same time the deformation. The minerals as the principal elements of the gneiss in this zone are quartz and feldspar. As secondary elements, it contains garnet, biotite, magnetite, sillimanite, cordierite, graphite, etc. The size of mineral particle is in general less than 5mm. The quantity ratio of quartz and feldspar is different according to each gneiss. The combination and the quantity ratio of minerals as secondary elements are also different by each gneiss. That is why, at the outcrop, we recorded this mineral combination and its quantity ratio, in the decreasing order, classifying the gneiss by the quantity ratio of quartz and feldspar and by the quantity ratio of minerals as secondary elements.

The granite (Initial: Gr.) has also quartz and feldspar as the principal components. However, the minerals are relatively coarse-grained (about less than 4cm) and present the composition representing the crystallization of magma, such as the porphyritic composition whose megacrystal is the idiomorphic feldspar. Thus, the granite can be distinguished from feldspathic or quartz gneiss whose origin is the sedimentary rock. As a mineral of secondary component, it tends to include biotite and magnetite. The combination and the quantity ratio of the minerals of secondary component are variable. In most of the time, the granite undergoes the deformation with the neighboring gneiss. We call this type of granite Granitic gneiss (Initial: GrGn). Moreover, is distributed also Augen gneiss (Initial: AugGn), a kind of granitic rock, rich in megacrystal of feldspar (approximately less than 4cm of diameter), deformed considerably in most of the time. The felsitic plutonic rock, made up mainly of feldspar, not containing any quartz, is Syenite (Initial: Sy). Exceptionally, is distributed, the charnockite (Initial: Chk), granitic rock containing orthorhombic pyroxene.

Pegmatite (Initial: Peg) is the felsitic rock, often distributed. It is also the igneous rock whose origin is the magma. The mineral combination is almost identical to that of the granite. But one of its characteristics is the very coarse grain. Pegmatite contains quartz and the feldspar whose diameter is more than several centimeters. It is very rare that pegmatite occurs all alone in the extent of outcrop (size of several meters~several tens of meters). In the majority of cases, it occurs in the shape of layer, lenticular vein, or dike in the gneiss and the granite.

We can consider two types of magma having formed the granite. One is the magma whose origin is the partially molten sedimentary rock, following the metamorphism at high temperature having formed the gneiss whose origin is the sedimentary rock. The other is the magma having been formed at some other place, penetrating into the gneiss. But it is difficult to distinguish both of them only by the observation at the outcrop. In certain granite, the foliation develops.

Although its volume is modest, is often distributed, the mafic gneiss such as pyroxenite (Initial: Px) containing pyroxene and amphibolite. Having the form of lens of a few meters of major axis and less than 1 meter of minor axis, the majority of this rock exists in the gneiss whose origin is the sedimentary rock. In the southwestern part of this study zone, the carbonate rock and pyroxenite occur, being closely related each other in the way of migmatite.

There exists Migmatite (Initial: Mgm) as a rock being distributed in a characteristic way throughout the present zone. It is the rock in which the part of gneiss and that of granite mix irregularly. It is recognized in all types of gneiss. This rock is regarded as having been formed by the partial fusion of gneiss, following the high-temperature metamorphism.

Table 3.1 is the recapitulation of geology and geological structure of the study zone. The geological map for the whole zone of study, the geological cross section, and the legend of the two maps are presented respectively in Figures 3.3, 3.4, and 3.5.

3.4 Geological structure of the study zone

Figure 3.6 presents schematically the geological structure traced from the satellite image and the data of strike and inclination obtained at the outcrop. The red line in Figure 3.6 traces the border between the zones whose color is different one another in the satellite image. The black line traces the linear topography. The direction of the prolongation of diamond mark means the direction of strike at the outcrop. With regard to the color code, red means the inclination towards the west; blue, the inclination towards the east; yellow, the vertical inclination; green, the direction of east-west. For the round mark within the diamond mark, black means the high angle and white, the low angle, with the threshold angle of 50°. With regard to the overall geological structure, it is recognized approximately from Figure 3.6 that there exists the anticlinal structure, open widely towards the east, in the east-north part of the study zone. In the central part, there is the structure of low angle and inclination towards the east. In the western part, there exists the synclinal structure, tilted towards the west, in the direction of south-north. Moreover, several folds of relatively small size are seen in the southeastern and southwestern parts of the study zone.

3.5 Mineral resources in the study zone

As mentioned in chapter 2, there exist many types of mineral resources in Madagascar. However, according to the study of Besairie in 1960s and the deposit map of Razafinimparany (1978), the potential of the mineral resources in this study zone is not sufficiently high. Indeed, although the potential of phlogopite is high in the study zone, the types of mineralization of other mineral resources are very limited, and of small scale. Even in the result of the geochemical survey mentioned later on, significant geochemical anomaly is scarcely recognized.

The only mine existing in the study zone is the mine of Ampandrandava, producing phlogopite. This mine is located in the northwestern part of sector J60. Its operation is still going on, by extracting the gallery. Many traces of the wells for the small size extraction of phlogopite by the residents are recognized everywhere within the study zone. The shear zone of Beraketa (Voronkafotra) running the length from south to north in the central part of the study zone might be related to the formation of these mica deposits.

At the west side of the study zone, there exists the domain of Vohibory, with the shear zone of Ampanihy as the border. The mineralization of sulphide ore such as chalcopyrite is known in the shear zone of Ampanihy. The mineralization of several mineral resources such as gold, chromite, nickel is known in the domain of Vohibory. The prospection of deposit is carried out there. At the eastern part of the study zone, the presence of mineralization of gold and uranium-thorium is known.

The mineral resources that might be present in the study zone are magnetite (Fe), monazite (REE, U, Th), graphite (C), phlogopite, and precious stones. The position and the geology of these sites of mineralization are as follows. Figure 3.7 presents the map of geological resources in the study zone.

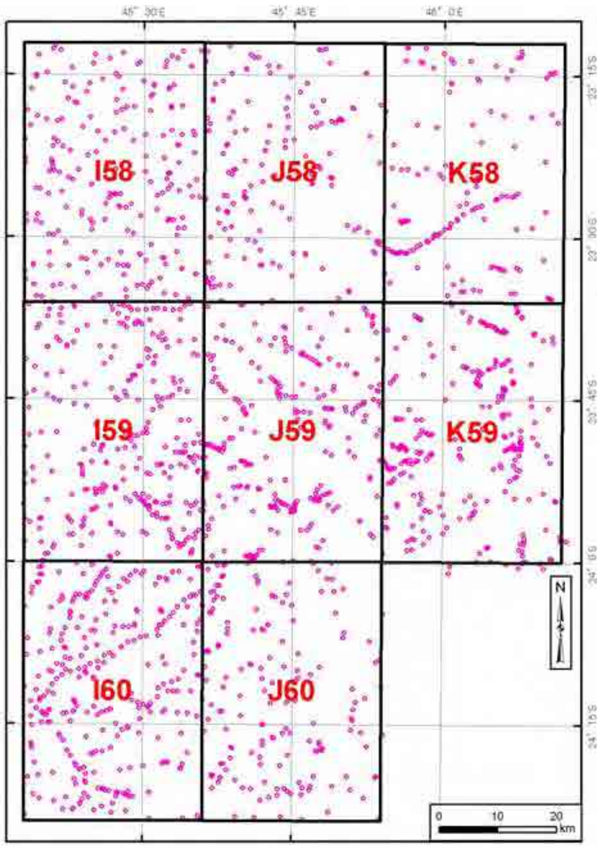


Figure 3.1 Map of the position of the geological survey

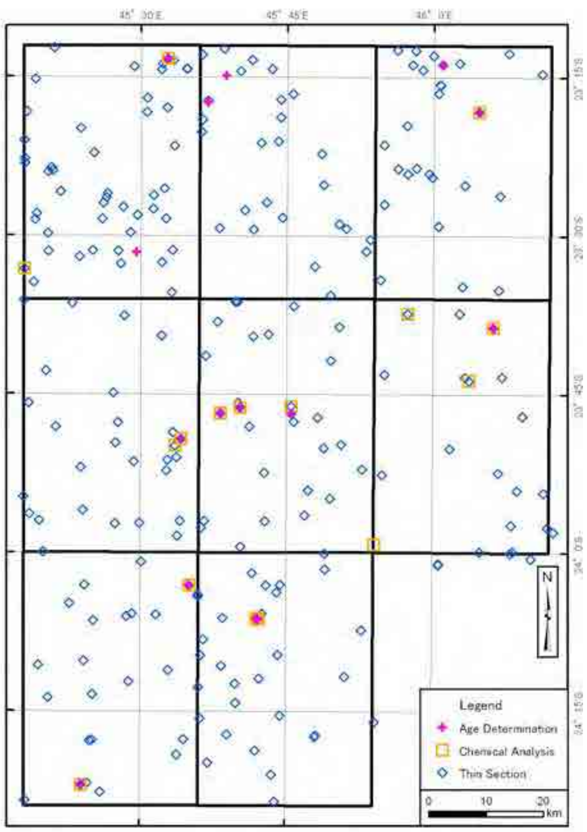


Figure 3.2 Position of sampling for the laboratory test

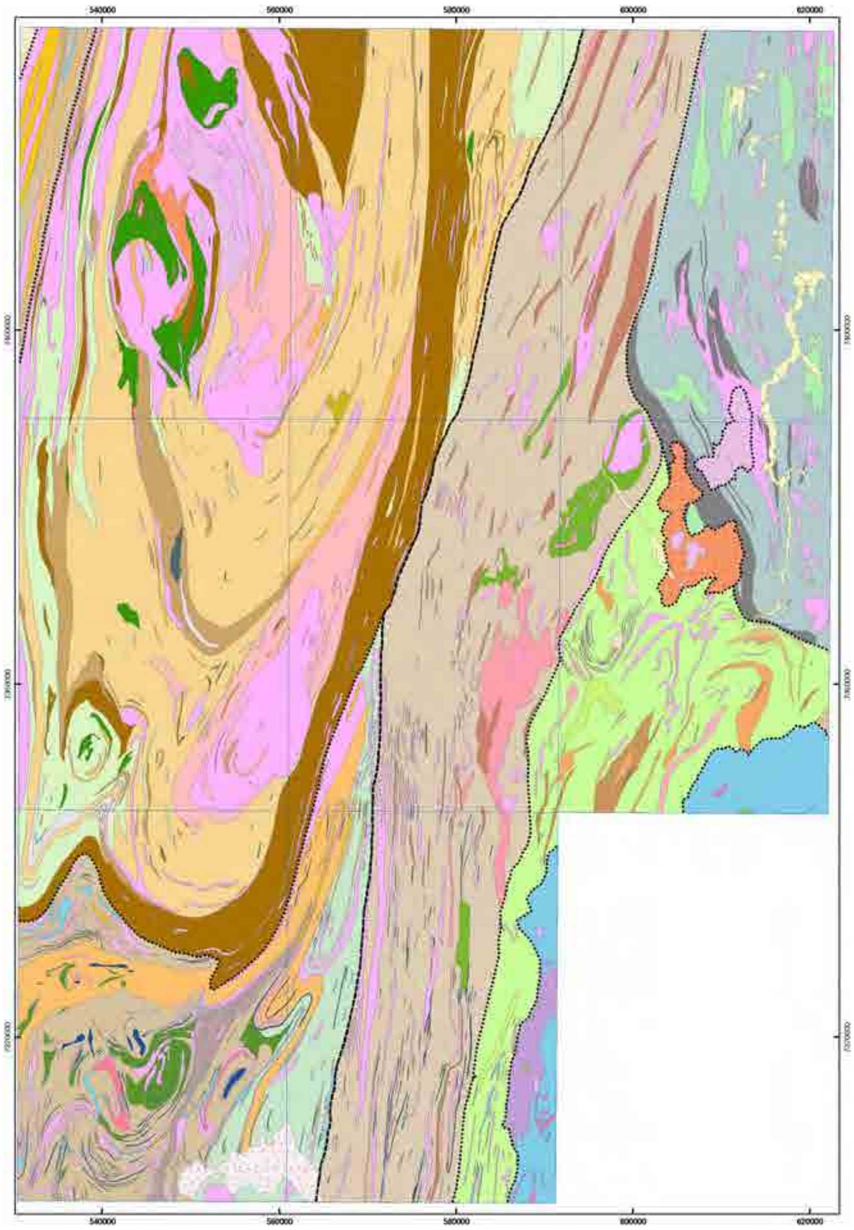


Figure 3.3 Geological map

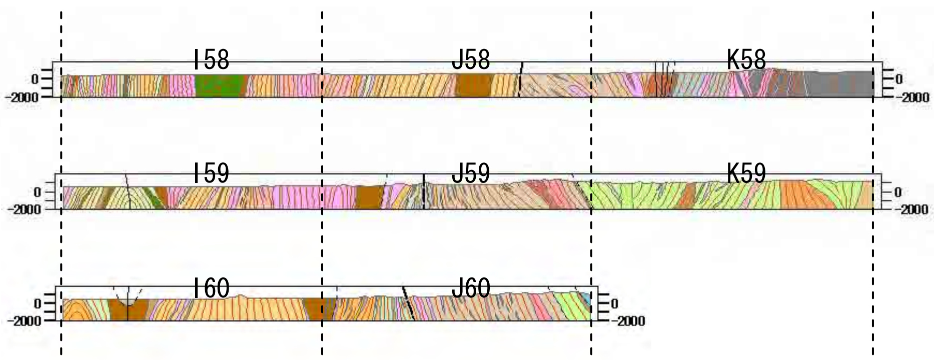


Figure 3.4 Geological cross section

Figure 3.5 Legend of Geological map

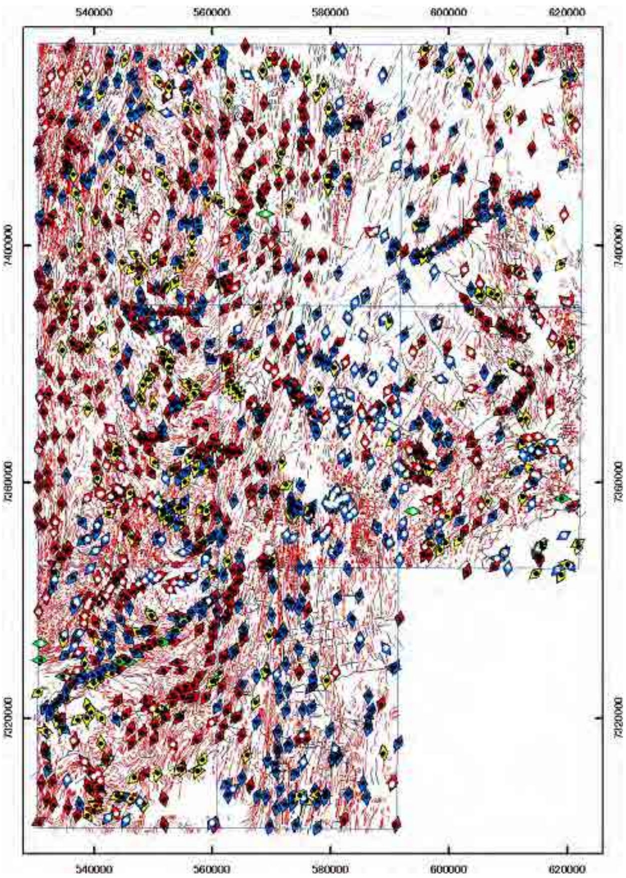


Figure 3.6 Map of geological structure

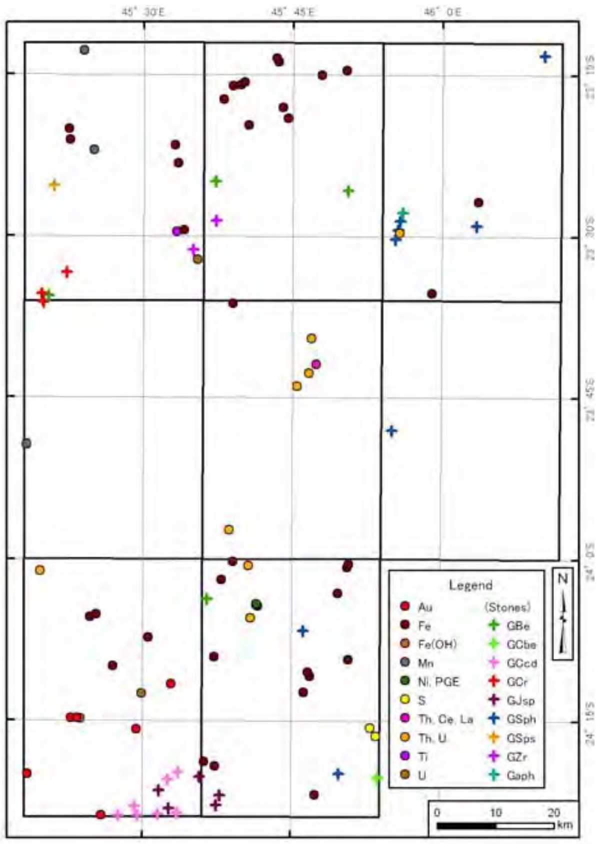


Figure 3.7 Map of mineral resources

Table 3.1 Recapitulation of geology and geological structure

Domain	Sub-domain	Area	Geology	Geoligical Structure
Anosyan	I	K58, K59, J60	Pelitic gneiss with minor granitic gneiss, mignatite, and pssamitic gneiss	Anticlinal structure trending E-W.
	II	K59, J60	Pelitic gneiss with minor granitic gneiss and mignatite	Small fold structure holding random direction are widely distributed.
	III	K58, K59, J58, J59, J60	Pelitic gneiss with minor granitic gneiss, mignatite, and garnet-bearing gneiss. Stratiform granitic gneiss are dominated in southern part.	Dominant NNE-SSW trending and slightly E-inclined structure in the center and northern part. N-S trending and highly E-inclined structure in southern part.
Androyan	IV	J59, J60, I60	Pelitic gneiss with stratiform granitic gneiss in eastern part, while amphibole-bearing gneiss, gneiss, and carbonate rock closely related with pyroxenite are occurred in western part.	Small fold structure are widely distributed.
	V	J58, J59, J60, I58, I59, I60	Garnet-bearing gneiss and augen gneiss characterized by feldsper phenocryst.	Synclinal structure trending N-S or NNE-SSW.

Table 3.2 Geochronological data

Sample	UTM-E (m)	UTM-N (m)	Domain	Subdomain	Area	Lithology /Legend	Age (Ma)	Remarks
N037	610,140	7,422,339	Anosyan	I	K58	Migmatite	535.7±5.6	surprisingly homogeneous age of zircon rim
						nPIKBt	2445±11	inheritance or problem with particular high-U spot
N053	612,581	7,384,686	Anosyan	intrusion	K59	Syenite	532±11	difference caused by Pb-loss ?
						KAsy	580±11	
							1900-2000	inheritance
R051	603,834	7,430,676	Anosyan	III	K58	Quartzite	576	metamorphic
						nPHRTt	2032-2266	inheritance
Z066	577,310	7,369,787	Anosyan	III	J59	Gneiss nPHRTt	531.3±4.1	metamorphic
Z201	571,150	7,333,995	Anosyan	III	J60	Gabbro	2307±340	older intercept (grain# 1)
						nPHRAm	2794±58	older intercept (grain# 2, 3)
Z202	571,459	7,333,855	Anosyan	III	J60	Granitic gneiss	480±40	younger intercept
						nPAAg	1781±31	older intercept
Z204	540,445	7,305,086	Androyan	IV	I60	Quartzite	542±19	younger intercept (grain# 3)
						mPMKLl	556±19	younger intercept (grain# 5)
							563±15	younger intercept (grain# 1, 7)
							588±23	younger intercept (grain# 8)
							2112±43	older intercept (grain# 8)
							2226±25	older intercept (grain# 1, 7)
							2508±35	concordia age (grain# 4.1)
							2713±59	older intercept (grain# 5)
							2732±29	concordia age (grain#2, 6)
							2988±29	older intercept (grain# 3)
Z205	537,110	7,332,273	Androyan	IV	I60	Garnet gneiss	564±12	concordia age (grain# 1)
						mPIMAl	2023±15	concordia age (grain# 2)
Z232	552,685	7,310,057	Androyan	IV	I60	Granitic gneiss	572±32	younger intercept
						mPMKLl	2314±66	older intercept
N013	564,922	7,369,867	Androyan	V	J59	Granitic gneiss nPAAg	542.2±7.7	Two possibilities (1)A single age population with inheritance (2)Two age populations
							578.2±7.5	
R065	566,026	7,428,866	Androyan	V	J58	Quartzite	521.2±7.4	new zircon growth within the quartzite
						mPIMAl	3714	inheritance
R069	562,904	7,424,249	Androyan	V	J58	Granite	541.1±7.2	high-U contents part
						nPAAg	590±11.5	low-U contents part
							908±15	exotic core, 207Pb/206Pb age
R097	568,336	7,370,904	Androyan	V	J59	Augen gneiss mPIMVb	540.5±5.1	last phase of zircon crystallisation
Z206	558,097	7,365,404	Androyan	V	I59	Granitic gneiss nPAAg	541.3±2.2	concordia age
Z258	555,848	7,431,874	Androyan	V	I58	Augen gneiss mPIMVb	563.1±9.6	concordia age
Z283	550,279	7,398,051	Androyan	V	I58	Granitic gneiss	540±40	younger intercept
						nPAAg	2091±34	older intercept

Table 3.3 Result of the chemical analysis of rocks (principal components)

Sample	N013	N037	N068	R069	R097	R051	R065	N053
UTM-E(m)	564922	610140	612581	608284	603834	566026	562904	568336
UTM-N(m)	7369867	7422339	7384686	7375442	7430676	7428866	7424249	7370904
Rock	Granite	Granite	Granite	Granite	Granite	Quarzite	Quarzite	Syenite
SiO2	72.2	74.1	63.2	72.2	63.7	89.7	86.7	62.9
Al2O3	13.55	13.70	15.70	14.00	13.25	5.60	5.03	19.25
Fe2O3	2.69	0.57	4.03	1.61	7.33	0.59	0.92	2.72
CaO	1.38	0.79	4.47	1.17	3.42	0.06	0.09	2.66
MgO	0.27	0.13	2.41	0.26	1.30	0.05	0.93	0.76
Na2O	2.37	2.09	3.99	2.44	2.55	0.36	0.43	6.06
K2O	5.83	7.08	4.16	6.41	4.12	1.58	3.14	4.67
Cr2O3	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
TiO2	0.39	0.03	0.67	0.29	1.44	0.15	0.21	0.94
MnO	0.01	0.01	0.05	0.01	0.05	0.01	0.01	0.06
P2O5	0.07	0.07	0.36	0.08	0.54	0.02	0.02	0.08
SrO	0.03	0.03	0.04	0.05	0.06	<0.01	<0.01	0.06
BaO	0.11	0.18	0.11	0.26	0.20	0.08	0.10	0.20
LOI	0.69	0.29	1.09	0.50	0.20	0.49	0.50	1.08

Sample	Z201	Z202	Z204	Z205	Z206	Z207	Z258	Z279
UTM-E(m)	571150	571459	540445	559432	558097	557026	555848	530714
UTM-N(m)	7333995	7333855	7305086	7339778	7365404	7364303	7431874	7395206
Rock	Gabbro	Granitic gneiss	Quartzite	Garnet gneiss	Granitic gneiss	Granitic gneiss	Augen gneiss	Granitic gneiss
SiO2	48.8	72.4	96.8	74.4	72.7	70.6	68.0	74.5
Al2O3	14.25	12.85	0.33	13.65	13.00	14.45	14.80	13.50
Fe2O3	12.10	2.91	2.54	1.40	3.29	3.07	3.42	2.41
CaO	11.50	1.35	0.02	1.06	1.12	1.98	2.38	1.34
MgO	7.93	0.26	0.02	0.20	0.31	0.34	0.82	0.11
Na2O	2.30	3.03	0.01	3.21	2.37	2.45	3.72	2.81
K2O	0.42	5.00	0.03	4.91	5.83	5.42	4.96	5.10
Cr2O3	0.03	<0.01	0.01	<0.01	<0.01	<0.01	<0.01	<0.01
TiO2	0.83	0.35	0.34	0.10	0.43	0.36	0.59	0.18
MnO	0.18	0.04	<0.01	0.05	0.01	0.01	0.02	0.02
P2O5	0.06	0.05	<0.01	0.02	0.07	0.11	0.24	0.03
SrO	0.02	0.02	<0.01	0.02	0.03	0.07	0.16	0.05
BaO	0.03	0.15	<0.01	0.08	0.11	0.33	0.27	0.19
LOI	1.00	0.90	0.00	0.30	0.50	0.80	0.80	1.20

Chapter 4 Geochemical survey

4.1 Overview

The geochemical survey was carried out in parallel with the geological survey during 6th stage field works in FY 2010 and 7th stage works in FY 2011. The river sands of stream sediments were collected as geochemical samples and were subjected to the chemical analysis. The number of components analyzed was 52. The statistical analysis was processed for the assay results. The geochemical maps including the cumulative frequency diagrams were made for 23 elements and the geochemical anomalies were extracted against the representative 7 elements.

The geochemical survey area is composed of 8 areas; I58, I59, I60, J58, J59, J60, K58 and K59. The number of geochemical samples collected is 280 in one area, namely, 2,240 in 8 areas, and it means that the density of sample is one sample per 5 km^2.

4.2 Method of the survey

4.2.1 Selection of sampling site

The sampling sites were arranged based on the 1:100,000-scale topographic maps and satellite images, which should cover the whole survey area with dispersion as much as possible in considering the distribution of river system. As a rule, sampling sites were placed at 2 points in the upstream side of the river junction. The planning locations of these sites were put into GIS and then the GIS data was utilized in the field works.

4.2.2 Collection of samples

The coordinates of planning locations in the GIS data were taken into GPS handhelds (GPSmap60CSx by Garmin), then the survey team reached the sampling site by using the GPS handheld. The sampling place was decided around the planning location in searching the appropriate site where the suitable river sands were deposited. The coordinate of the sampling point was measured by the GPS handheld and was filled in the description sheet prepared. The location map of sampling sites for all eight areas is shown in Figure 4.1.

The stainless steel sieve with 10 mesh (opening 1mm) was used for sand sampling. About 100 grams of fine sands passed through the sieve were collected in the special paper bag and were air-dried in the base camp. The samples were sent to the laboratory in Johannesburg of ALS Chemex.

4.2.3 Chemical analysis

In considering the analytical cost, accuracy and reliability and the sample transportation cost, the chemical analysis was subcontracted to ALS Minerals in Johannesburg South Africa, because there was no proper laboratory in Madagascar.

The components of chemical analysis were the following 52 elements. The analytical method of fluorine was Fusion-SIE and the method of other 51 elements was ICP-MS by aqua regia digestion as multi-element analysis package. As a pre-treatment before analysis, samples were screened by 180μ (80 mesh) sieve.

* 52 elements analyzed : Au, Ag, Al, As, B, Ba, Be, Bi, Ca, Cd, Ce, Co, Cr, Cs, Cu, Fe, Ga, Ge, Hf, Hg, In, K, La, Li, Mg, Mn, Mo, Na, Nb, Ni, P, Pb, Rb, Re, S, Sb, Sc, Se, Sn, Sr, Ta, Te, Th, Ti, Tl, U, V, W, Y, Zn, Zr, F

4.2.4 Statistical analysis

The basic statistics (maximum, minimum, mean, median and standard deviation) were calculated for each element from the assay results of 52 elements in all eight areas. When mean and standard deviation were calculated, for convenience, the half value of the detection limit value was adopted against the value under the detection limit and the upper limit value was adopted against the value over the upper limit.

The geochemical maps based on the statistical data were created for the following 27 elements which were composed of 24 elements of the PGRM specification plus Rb, Th and Be. The multi variant statistical analysis was executed for 40 elements excluding 12 elements which had a lot of samples under the detection limit values. The cumulative frequency diagrams and histograms were created and the geochemical anomalies were extracted for the representative seven elements representing the geochemical features in the geological survey area. The basic statistics is shown in Table 4.1 and 4.2.

The Japanese software of EXCEL-Tokei 2010 of SSRI was used for the statistical analysis and the Grapher Ver.8 of Golden Software was used to draw graphs and ArcGIS of ESRI was used to create the geochemical maps.

(a) 27 elements for statistical analysis

Au, Ag, As, Ba, Bi, Cu, Ce, Hg, La, Mn, Mo, Nb, Ni, Pb, S, Sb, Sn, Te, U, V, W, Y, Zn, F, Rb, Th, Be

(b) representative 7 elements

Ce, Pb, Te, Bi, Be, U, Au

4.2.5 Creation of geochemical maps

Based on the results of the statistical analysis of assay results, the geochemical maps integrating all eight areas with the scale of 1:200,000 were created for the 27 elements mentioned above. The assay results were divided into nine classes as the boundaries of the following cumulative percentage in the geochemical maps of PGRM, where each class was represented by the size of the symbols with mono color. This cumulative percentage was the value cumulated from the lower value of the assay results. The larger value of this percentage means the higher assay results with larger symbol and the smaller value means the lower assay results with smaller symbol.

* Dividing value : 99.0%, 97.5%, 95.0%, 90.0%, 80.0%, 70.0%, 50.0%, 25.0%

Because the geochemical map of PGRM is created in condition of the printing with A0 size, it is very difficult to read them when the size of this map is reduced to the scale of A4 report size. Therefore, the assay results are divided into five classes represented by the color and size of the symbol in the geochemical map of this report. The dividing values of classes in these maps are 97.5%, 95.0%, 70.0% and 50.0%. These four values are mostly equivalent to relatively the M+2.5σ, M+2σ, M+σ and M (M is mean and σ is standard deviation) in the normal distribution. The geochemical maps of Ce, Pb, Te, Bi and Be are shown in Figure 4.2 to 4.6.

4.2.6 Creation of cumulative frequency diagrams and histograms

The geochemical map of PGRM with the scale of 1:200,000 includes the histogram of assay results. The geochemical map of this project includes not only the histogram but also the cumulative frequency diagram of assay results. The cumulative frequency diagram is very effective to interpret the geochemical data and to extract the unit population besides the normal distribution. The typical cumulative frequency diagram and histogram are shown in Figure 4.7.

The number of class in histogram is 20 to 30 by the division of antilogarithm of assay results based on the PGRM specification. The horizontal axis is the logarithm of assay results and the vertical axis is the normal probability distribution in the cumulative frequency diagram. The assay results are directly plotted without class division in the plot of cumulative frequency diagram. Therefore, the number of plot is normally large, but the graph is interpreted with high accuracy because the cumulative frequency curve is faithfully drawn. The cumulative percentage in the vertical axis increases downward and the plot of cumulative frequency convexes downward in this graph. If there is mineralization, a geochemical anomaly appears normally in the higher value of the graph. That is why the shape with the trail in the high value side is easily and intuitively understood. The cumulative frequency diagram is necessary to extract the geochemical anomaly mentioned below.

4.2.7 Consideration of geochemical features

Based on the results of the statistical analysis, the geochemical maps and the cumulative frequency diagrams and also the results of geological survey, the geochemical features in the geological survey area were considered. The outline of the consideration is shown in Table 4.3.

4.2.8 Extraction of geochemical anomalies

The cumulative frequency diagrams were created for the representative seven elements (Ce, Pb, Te, Bi, Be, U, Au) and the geochemical anomalies were extracted based on the statistical viewpoint. The summarized map for the geochemical anomalies of these seven elements is shown in Figure 4.8.

As the cumulative frequency diagram has the normal probability distribution in the vertical axis, the cumulative frequency curve of the normal distribution population becomes the straight line. If some of unit populations exist, the cumulative frequency curve of each unit population is originally the straight line, but the composed curve of these straight lines is drawn as a whole.

Therefore, in case that the geochemical background population without the mineralization and the geochemical anomaly population with the influence of the mineralization coexist, the geochemical anomaly population is detected in the higher value side. The dividing value between the background population and the anomaly population based on the shape and the inflection point of the cumulative frequency curve is referred as the threshold value. The samples with higher contents than the threshold value for the representative seven elements are classified to the geochemical anomalies.

4.3 Statistical analysis of assay results

4.3.1 Calculation of basic statistics

The basic statistics of maximum, minimum, mean, median and standard deviation were calculated for each element from the assay results of 52 elements in all eight areas. When mean and standard deviation were calculated, for convenience, the half value of the detection limit value was adopted against the value under the detection limit and the upper limit value was adopted against the value over the upper limit. The basic statistics of 27 elements mainly of the PGRM specification is shown in Table 4.1 and the basic statistics of other 25 elements is shown in Table 4.2.

The analytical values are low in general and the values indicating the mineralization are not recognized. The elements, which have relatively high maximum, are La, Ce, U, Th, Rb, F, Mn, and S. La and Ce are the rare earth elements and are included in bastnaesite and monazite. Both minerals are included in granite and gneiss and become an ore of thorium with much U and Th. Rb is commonly included in pegmatite and fluorite of fluorine mineral is also produced in pegmatite. As mentioned above, it is thought that the high values of La, Ce, U, Th, Rb, F are caused by the plenty of pegmatite in the geological survey area. The high value of Mn is thought to indicate the concentration by lateritization like Fe. It is unknown about S.

4.3.2 Multi variant statistical analysis

The analytical values under detection limit values exceed ten percent in 13 elements (Tables 4.1 and 4.2). The factor analysis of multi variant statistical analysis was processed for other 39 elements plus Au, namely 40 elements in total.

Forty elements are divided into seven groups by the factor loadings up to the sixth factor. As the elements in parentheses have the negative value of factor loadings, they show the opposite behavior of other elements.

- Group A：Ga, Sc, Al, Tl, Co, Li, In, Y, Fe, Rb, Be, Zn, Pb, Se, K, Mn, Cu, Sn
- Group B：La, Ge, Ce, P, F, Th, Ti
- Group C：Ca, Sr, Ba, Mg, (V), (Cr)
- Group D：Ni, Na, (La), (Ce), (Th)
- Group E：Nb, Mo
- Group F：Zr, Hf

・Group G：Au, Ag, U

The geological factors indicated in each group are as follows.

・Group A：Rock facies (metamorphic rocks on the whole)

・Group B：Pegmatite

・Group C：Acidic igneous rocks – basic igneous rocks

・Group D：Monazite

・Group E：Nb minerals (columbite) accompanied by pegmatite

・Group F：Metamorphic rocks originated from sedimentary rocks (especially quartzite)

・Group G：Elements without contribution for special factor

Note: Group D indicates the factor of the negative value of factor loadings.

4.4 Geochemical features in the survey area

The distribution features of 27 elements in the survey area are divided into 6 groups. However, some elements have the features of several groups together and have unclear features. The features of each group and the representative elements belonging to each group are described below. The elements in parentheses have relatively week relation.

1) Group I / Anosyan : Ga, Be, Zn, Pb, Sn, Rb, (Cu, Mn, Y)

The group I has a tendency that the analytical values are high in Anosyan domain. As points of relatively high values do not have the concentrated distribution, these elements indicate simply the difference of rock facies or domains. The group I corresponds almost to the group A of multi variant statistical analysis.

2) Group II / Androyan : La, Ce, F, Th, Ca, P, Th, (Mn, Mo, Nb)

The group II has a tendency that the analytical values are high in Androyan domain. Points of relatively high values are intensively distributed in augen gneiss (mPIMVb), and those of some elements are also distributed in syanite (KAsy), magnetite gneiss (mPIMZb) and pelitic gneiss (mPIMIt). The group II corresponds to the group B of multi variant statistical analysis and also to the group E and a part of group C (positive factor loadings).

3) Group III / pelitic : Ni

The group III has a tendency that the analytical values are high in pelitic gness crossing over both Anosyan and Androyan domains. The group III corresponds to the group D of multi variant statistical analysis.

4) Group IV / Tsivory : Hg, Te, Zr, (V)

The analytical values are high in Tranomaro group (nPIKTn) and Amboatavo group (nPABAb). Pelitic gneiss is distributed in these areas, and igneous rocks of basalt, rhyolite, charnockite and micro granite are also distributed. The group IV corresponds to the group F of multi variant statistical analysis and also to a part of group C (negative factor loadings).

As points of relatively high values of Te and Hg are intensively distributed, these may indicate the enrichment related to igneous activity.

5) Group V / uniform : Ag, Au, U, (As, W)

The group V indicates the generally uniform distribution with a poor regional bias, and points of relatively high values do not have the concentrated distribution. Therefore, it is thought that the group V indicates the geochemical background unrelated to geology and mineralization. The group V corresponds to the group G of multi variant statistical analysis.

6) Group VI / unique : Bi, S, (Ba, Sb)

The group VI has the unique distribution different from the above groups.

Bi : Points of relatively high values of Bi are much intensively distributed in the part of Amboatavo group (nPABAb) in the southwest of K59 area. These may indicate some sort of the enrichment. Mica gneiss including Sapphirine is distributes around there.

S : The analytical values are high around the zone from the center to the northeast, the southwest corner and northeast corner of the survey area. These distributions have no relation to the geology.

4.5 Geochemical anomalies in the survey area

4.5.1 Extraction method of geochemical anomalies

It is known from experience that the geochemical data generally shows the log-normal distribution. Based on this phenomenon, it is possible to divide "geochemical background population" and "geochemical anomaly population", namely to extract "geochemical anomaly" (Sinclair, 1976 and Otsu, et al., 1984). The analytical method is as follows.

1) To calculate the frequency of each analytical value and the cumulative frequency without the class division of analytical values.
2) To plot the above data on the cumulative frequency diagram, where the vertical axis indicates the normal probability of cumulative frequency and the horizontal axis indicates the logarithm of assay results. The normal distribution is shown as the straight line on this diagram.
3) To decide the threshold value to divide the background population and the geochemical anomaly population from the plot pattern of cumulative frequency curve.
4) The boundary of both populations is recognized as an inflection point of the curve on the cumulative frequency diagram in typical case. It is a local minimum on the histogram. Refer to Figure 4.7.

The distribution of geochemical anomalies are shown in Figure 4.8.

4.5.2 Distribution of geochemical anormalies

The distribution and features of geochemical anomalies of the representative seven elements (Ce, Pb, Te, Bi, Be, U and Au) are described below. m is mean and σ is standard deviation.

(1) Ce

The threshold value is 280 ppm and close to the value of m+3σ.

Ce belongs to the group II indicating that points of relatively high values are distributed in Androyan domain. The geochemical anomalies are distributed in Androyan domain, especially much in augen gneiss. There are five points of the highest analytical value (more than 500 ppm). They are scattered and not necessarily concentrated in the augen gneiss. La and Th show the similar distribution of geochemical anomalies as Ce.

(2) Pb

The threshold value is 21 ppm and close to the value of m+2σ. Pb shows the typical and distinctive bimodal graphic pattern reflecting the difference of domains. However, the threshold was selected as the geochemical anomaly is the small population having the highest value.

Pb belongs to the group I indicating that points of relatively high values are scattered in Anosyan domain. The geochemical anomalies are mainly distributed in Anosyan domain. The highest analytical value point (142 ppm) is located near Betroka in the northeast of the survey area and in pelitic gneiss.

(3) Te

The threshold value is 0.075 ppm but is slightly uncertain. This value is more than the value of m+3σ.

Te belongs to the group IV indicating that points of relatively high values are distributed in the southeast of the survey area. The geochemical anomalies are intensively distributed in the south end of K59 area. The highest analytical value point (0.15 ppm) is located in the southeast of K59 area and in charnockite.

As the geochemical anomalies are concentrated in the small area, they are thought to be related to the igneous rocks which are distributed much around this area. As the analytical value of the anomaly is too low, the potential is also low. Hg shows the similar distribution of geochemical anomalies as Te.

(4) Bi

The threshold value is 0.10 ppm but is slightly uncertain. This value is close to the value of m+3σ.

Bi belongs to the group VI indicating that points of relatively high values are uniquely distributed. The geochemical anomalies are intensively distributed in the southwest end of K59 area. However, the highest analytical value point (0.83 ppm) is located not in this area but in the west of I59 area and in garnet gneiss.

As the geochemical anomalies are concentrated in the small area, they are thought to be related to the igneous rocks. As the analytical value of the anomaly is too low, the potential is also low.

(5) Be

The threshold value is 1.80 ppm and close to the value of m+3σ.

Be belongs to the group I as Pb, indicating that points of relatively high values are distributed in Anosyan domain. The geochemical anomalies of Be are scattered in Anosyan domain, but do not overlap with those of Pb. The highest analytical value point (8.12 ppm) is located in the west of K58 area and in pelitic gneiss.

(6) U

The threshold value is 3.0 ppm and close to the value of m+2σ.

U belongs to the group V indicating that points of relatively high values are uniformly distributed. The geochemical anomalies are scattered in the whole of the survey area. However, some anomalies of U overlap with those of Ce (La, Th). The highest analytical value point (36.1 ppm) is located in the southwest end of I60 area and in granitic gneiss.

(7) Au

The threshold value is 0.0032 ppm and close to the value of m+1.5σ.

Au belongs to the group V as U, indicating that points of relatively high values are uniformly distributed. The geochemical anomalies are also scattered in the whole of the survey area. However, the anomalies of Au do not overlap with those of U. The highest analytical value point (0.0531 ppm) is located in the center of K58 area and in pelitic gneiss. As the analytical value of the anomaly is extremely low, there is no potential of Au.

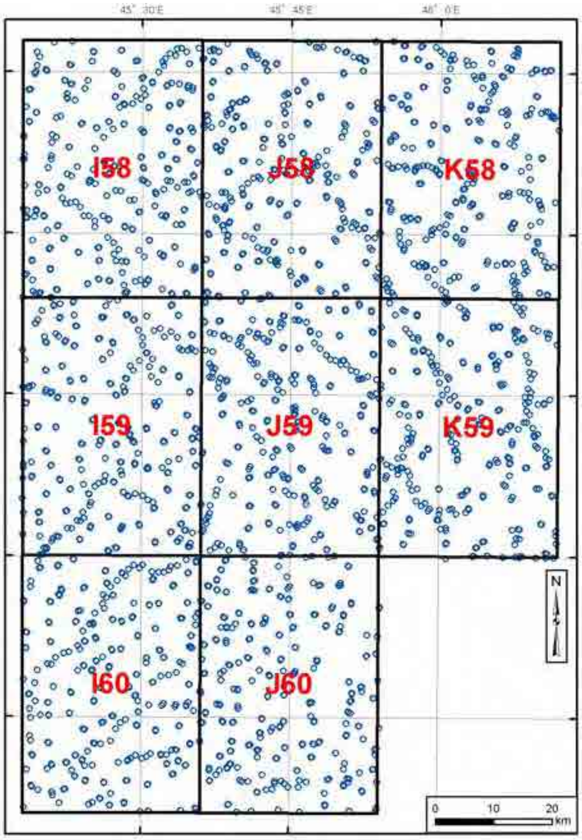


Figure 4.1 Location of the geochemical samples

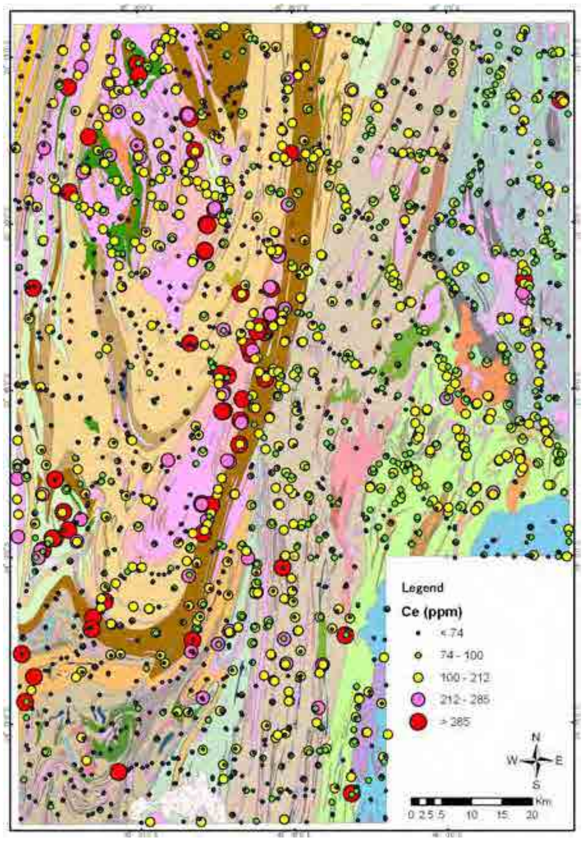


Figure 4.2 Geochemical map - Ce

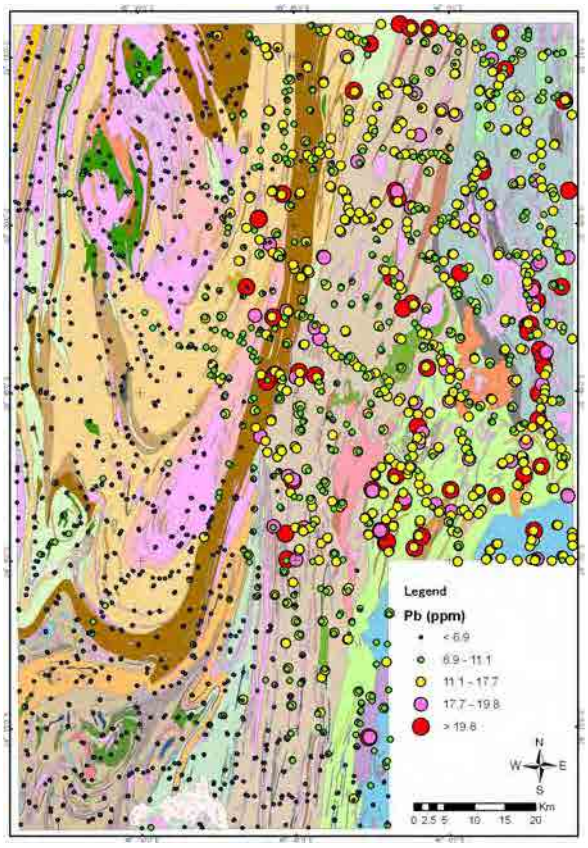


Figure 4.3 Geochemical map - Pb

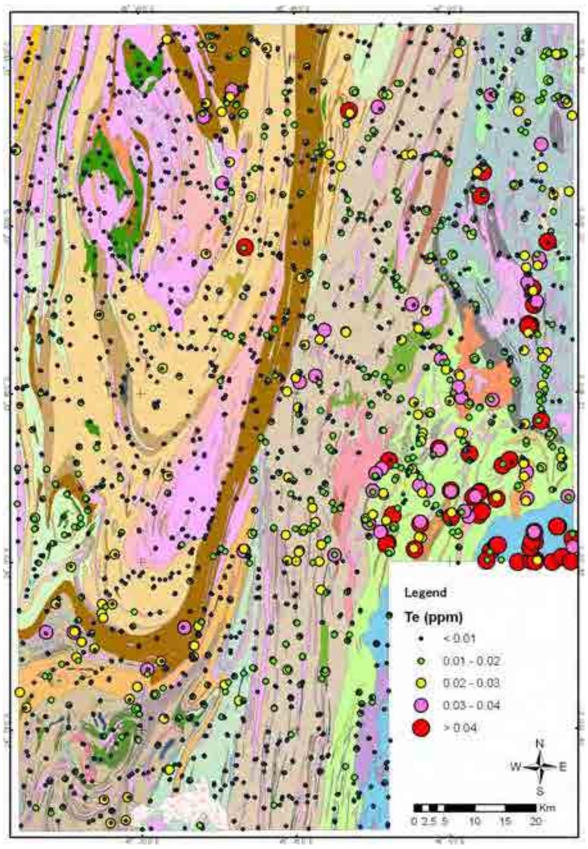


Figure 4.4 Geochemical map - Te

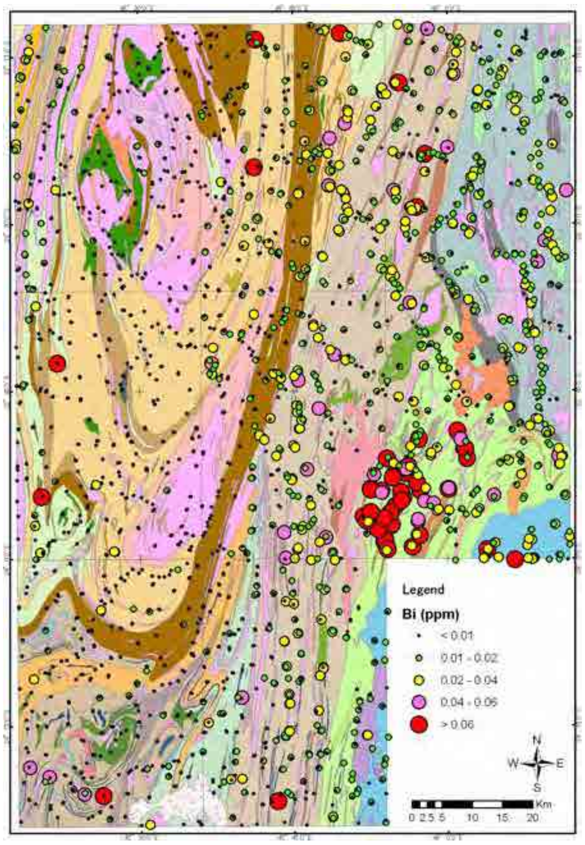


Figure 4.5 Geochemical map - Bi

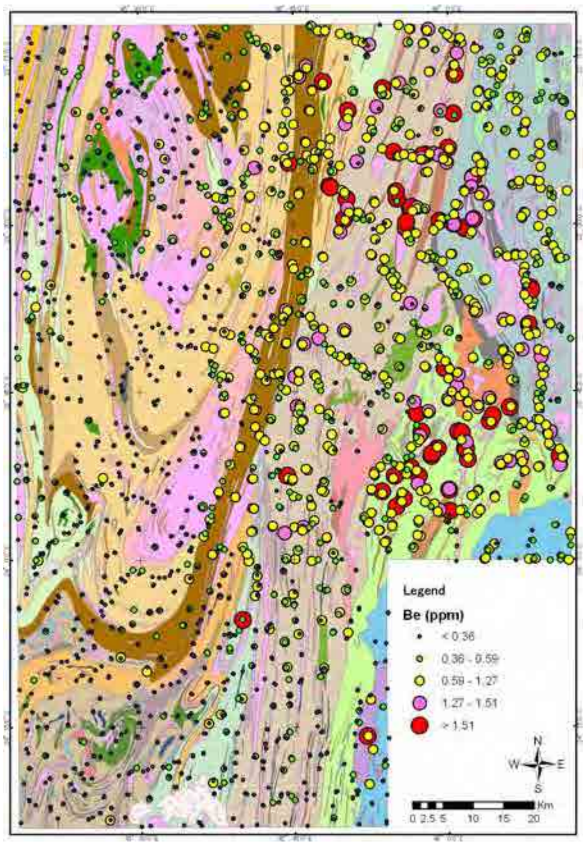
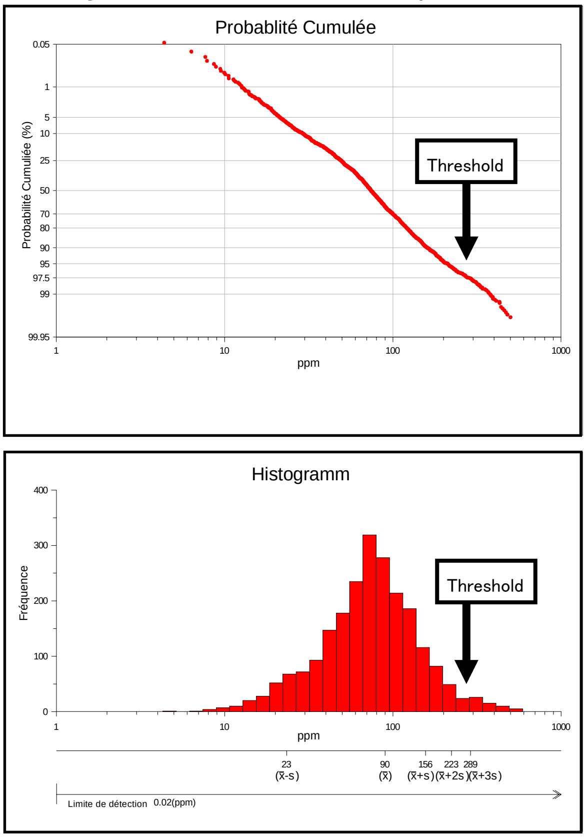


Figure 4.6 Geochemical map - Be



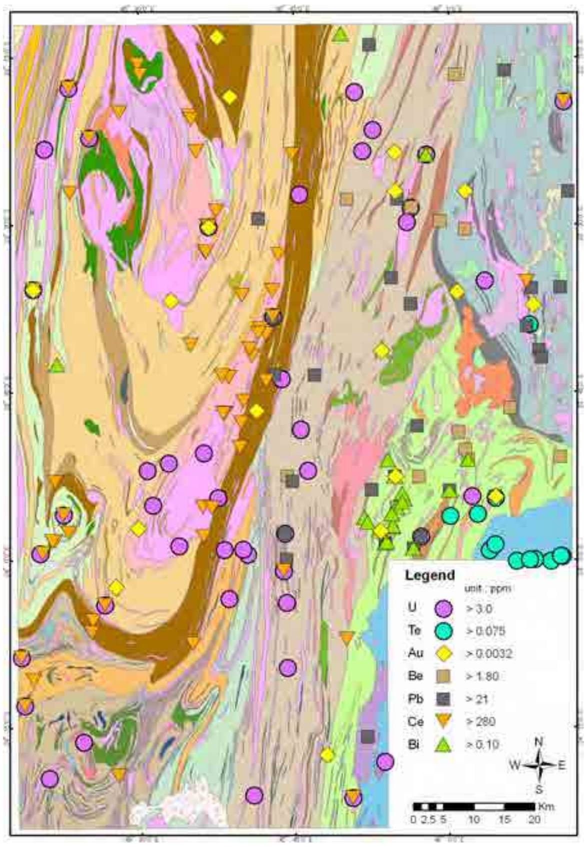


Figure 4.7 Cumulative frequency diagram (upper left) and histogram (lower left)

Figure 4.8 Synthetic map of geochemical anomalies (right)

Table 4.1 Basic statistics of assay results of geochemical samples (27 elements)

Element	Unit	DL	NLD	Maximum	Minimum	Mean	SD	CC	Mean/CC
Ag	ppm	0.002	88	0.187	<0.002	0.010	0.010	0.08	0.12
As	ppm	*1	472	1.81	<0.02	0.16	0.15	1	0.16
Au	ppm	0.0002	625	0.0531	<0.0002	0.0006	0.0017	0.003	0.20
Ba	ppm	0.5	0	635	12.5	86.1	63.1	250	0.34
Bi	ppm	0.01	235	0.83	<0.01	0.02	0.02	0.06	0.29
Cu	ppm	0.01	0	77.3	0.6	9.29	6.69	75	0.12
Ce	ppm	0.02	0	>500	4.38	89.83	66.49	33	2.72
Hg	ppm	0.005	867	0.194	<0.005	0.014	0.019	0.08	0.18
La	ppm	0.2	0	280	1.7	41.4	32.4	16	2.59
Mn	ppm	1	0	6350	15	284	304	1400	0.20
Mo	ppm	0.01	0	7.84	0.04	0.37	0.32	1	0.37
Nb	ppm	0.05	0	10.9	0.07	0.83	0.53	11	0.08
Ni	ppm	0.1	0	107.5	0.9	13.5	8.7	105	0.13
Pb	ppm	0.01	0	142	0.77	7.99	6.10	8	1.00
S	%	0.01	787	2.86	<0.01	0.02	0.13	0.026	0.79
Sb	ppm	*2	1089	0.9	<0.003	0.014	0.021	0.2	0.07
Sn	ppm	0.2	91	31	<0.2	1.6	1.8	2.5	0.63
Te	ppm	0.01	671	0.15	<0.01	0.01	0.01	0.01	1.36
U	ppm	0.05	4	36.1	<0.05	0.80	1.12	0.91	0.88
V	ppm	1	0	683	3	59	46	230	0.25
W	ppm	*3	355	1.49	0.0071	0.0791	0.0888	1	0.08
Y	ppm	0.05	0	55.3	1.02	9.47	5.94	20	0.47
Zn	ppm	0.1	0	148	0.8	16.6	10.3	80	0.21
F	ppm	20	0	4600	30	373	374	625	0.60
Rb	ppm	0.1	0	110.5	0.8	13.7	12.8	8	1.71
Th	ppm	0.1	0	650	0.6	31.9	44.0	3.5	9.12
Be	ppm	0.05	0	8.12	0.05	0.50	0.43	1.5	0.33

note/ DL: Detection limit, NLD: Number of data less than DL

SD: Standard deviation, CC: Composition of continental crust

*1 : 0.02 in I58,I59,I60 and J60 / 0.1 in J58,J59,K58 and K59

*2 : 0.005 in I58,I59,I60 andJ60 / 0.02 in J58,J59,K58 and K59

*3 : 0.0001 in I58,I59,I60 and J60 / 0.05 in J58,J59,K58 and K59

Table 4.2 Basic statistics of assay results of geochemical samples (25 elements)）

Element	Unit	DL	NLD	Maximum	Minimum	Mean	SD	CC	Mean/CC
Al	%	0.01	0	4.81	0.11	0.91	0.66	8.41	0.11
B	ppm	10	2239	20	<10	5	0.3	10	0.50
Ca	%	0.01	5	4.19	<0.01	0.20	0.22	5.29	0.04
Cd	ppm	0.01	480	0.18	<0.01	0.01	0.01	0.098	0.14
Co	ppm	0.1	0	67.8	0.5	7.8	4.9	29	0.27
Cr	ppm	0.5	0	438	4	48.8	37.9	185	0.26
Cs	ppm	0.05	625	1.89	<0.05	0.17	0.18	1	0.17
Fe	%	0.01	0	19	0.13	2.39	1.49	7.07	0.34
Ga	ppm	0.05	0	18	0.49	5.00	3.22	18	0.28
Ge	ppm	0.05	151	0.71	<0.05	0.12	0.07	1.6	0.07
Hf	ppm	0.02	15	0.68	<0.02	0.09	0.07	3	0.03
In	ppm	0.005	39	0.289	<0.005	0.019	0.013	0.05	0.38
K	%	0.01	2	0.65	<0.01	0.07	0.05	0.91	0.08
Li	ppm	0.1	0	17.4	0.2	2.4	1.9	13	0.19
Mg	%	0.01	0	1.39	0.01	0.13	0.08	3.2	0.04
Na	%	*4	107	0.215	<0.001	0.022	0.020	2.3	0.01
P	%	0.001	0	0.823	0.002	0.041	0.065	0.105	0.39
Re	ppm	0.001	2086	0.003	<0.001	0.001	0.0003	0.0005	1.14
Sc	ppm	0.1	0	15.6	0.4	3.8	2.4	30	0.13
Se	ppm	0.1	105	1.9	<0.1	0.4	0.2	0.05	7.44
Sr	ppm	0.2	0	553	0.9	13.0	18.1	260	0.05
Ta	ppm	0.01	1972	0.02	<0.01	0.01	0.002	1	0.01
Ti	%	0.001	0	0.472	0.007	0.078	0.055	0.54	0.14
Tl	ppm	0.02	215	0.51	<0.02	0.09	0.08	0.36	0.24
Zr	ppm	0.5	8	28.6	<0.5	2.8	2.6	100	0.03

note/ DL: Detection limit, NLD: Number of data less than DL

SD: Standard deviation, CC: Composition of continental crust

*3 : 0.01 in I58,I59,I60 and J60 / 0.001 in J58,J59,K58 and K59

Table 4.3 Summary of the geochemical features

Element	Group	High value area	Low value area	Correlation	Remarks
Ag	uniforme	scattered	scattered		Low potential
As	(uniforme)	W of I58 and I59, J60	E of I59, I60		Low potential
Au	uniforme	scattered	scattered	Ce(weak)	Scattered anomaly
Ba	(unique)	E of I58, J58	I59, J60	Mn, Co(mod.)	Intensive high-value points
Bi	unique	SW of K58	Androyan		Intensive anomaly
Cu	(Anosyan)	W of J58, J59	I58, I59, I60	Co, Sc(mod.)	Low potential
Ce	Androyan	Androyan	Anosyan	La, Th, Ge(high)	Intensive high-value points
Hg	Tsivory	S of K59	Androyan		Intensive high-value points
La	Androyan	Androyan	Anosyan	Ce, Th, Ge(high)	Intensive high-value points
Mn	(Anosyan)	J58, J59, K58, K59	I58, I59, I60	Co, Al, Ba, Tl(high)	Low potential
Mo	(Androyan)	NW of I58, near Beraketa shear zone	I59, K58, K59	Nb(weak)	Intensive high-value points
Nb	(Androyan)	I58, NW of J60	I59, J58, J59, K59	Ti(high)	Low potential
Ni	pelitic	SE of J59, W of J60, K58, K59	I58, I59	Cr, Fe(high), Co, Ga, Sc, V(mod.)	Low potential
Pb	Anosyan	Anosyan	Androyan	Tl(high), Al, Ga, Rb, Sc(mod.)	
S	unique	NW of I58, S of I60, J58, N of J59, K58	I59, J60		related to igneous activity
Sb	(unique)	I58, J58, N of J59, J60	I59, I60		Low potential
Sn	Anosyan	J59, K59	I58, I59, I60, J58		Intensive high-value points
Te	Tsivory	S of J59	I58, I59, I60, J60		Intensive high-value points
U	uniforme	near Beraketa shear zone	N of I59	V(weak)	Scattered high-value points
V	(Tsivory)	S of K59	I58, I59, J58	Cr, Fe(high), Ga, Ni(mod.)	Low potential
W	(uniforme)	I58, E of K59	N of I59, J58	Bi(weak)	Low potential
Y	(Anosyan)	E of J59, S of K59	I58, I59, I60, J60	Be, Sc(high), Al, Ga, In, Li, Tl(mod.)	Low potential
Zn	Anosyan	NW of I58, J59, K59	I59, I60	Co, In, Sc(mod.)	Low potential
F	Androyan	E of I58, W of J58 and J59	I59 and Anosyan	P(high), Ca(mod.)	
Be	Anosyan	E of J58, W of K58, K59	Androyan	Al, Li, Rb, Sc, Tl, Y (high), Ga, In(mod.)	
Rb	Anosyan	E of J58, K58, K59	J60 and Androyan	Al, Li(high), Be, Ga, K, Pb, Sc(mod.)	Low potential
Th	Androyan	Androyan	Anosyan	La, Ce(high)	

Chapter 5 Remote Sensing Data Analysis

5.1 Kinds and amount of data

Five kinds of satellite data; ASTER L1B, ASTER L3A, PALSAR L1.5, PALSAR L4.1 and LANDSAT data, are analyzed. ASTER L1B, PALSAR L1.5 and LANDSAT data are analyzed through the whole of Madagascar. ASTER L3A and PALSAR L4.1 data are analyzed for the area of 1/10,000-scale geological survey. Amount of the satellite data is as follows.

(1) ASTER L1B data : 341 scenes, provided by PGRM

(2) ASTER L3A data : 13 scenes, bought by JICA

(3) PALSAR L1.5 data : 251 scenes, bought by JICA

(4) PALSAR L4.1 data : 19 scenes, bought by JICA

(5) LANDSAT data : 34 scenes, provided by PGRM

ASTER L3A and PALSAR L4.1 data in the 1/100,000-scale geological survey area were analyzed in FY 2009. As a part of the survey area was replaced by the result of the reconnaissance survey in FY2010, some data were newly purchased and all data were analyzed again.

ENVI Ver.4.7 and IDL Ver.7.1 of ITT VIS, ArcGIS Ver.9.3 and Spatial Analyst of ESRI and Geomatica Ver.10.2 of PCI were used for data analysis.

5.2 ASTER L1B data

(1) Contents of the data

- Data acquisition : free supply from PGRM
- Amount : 341 scenes (for the whole of Madagascar)
- Data format : HDF
- Number of band : 9 bands in total (3 bands of VNIR and 6 bands of SWIR)
  Five bands of TIR are lacking.
- Ground resolution : 15m in VNIR, 30m in SWIR
- Scene range: 60 km square area
- Observation date : from August 2000 to March 2005

(2) Contents of the analysis

As a pre-processing of the data, the resolution of SWIR data was resized to 15 meters and the data file composed of nine bands of VNIR and SWIR was created, and then the image was rotated by its metafile data. Because the data areas of each band have some gaps in both sides of the path, the data file within the area where the data exist through all nine bands was newly created. Then the polygon data file of this actual data area was created. The location map of ASTER L1B data (Figure 5.2) was created after these pre-processing.

As obvious in Figure 5.2, the ASTER L1B dataset of PGRM is distributed throughout Madagascar, but do not cover the entire area of Madagascar with some gaps between scenes and with many overlaps of scenes. There are some gaps even in the geological survey area. As the header information of these ASTER L1B data, which is necessary in order to project the map, is insufficient, the orthorectifcation of these data is impossible. If these data are simply put into GIS, gaps between the satellite image and topographic map occur and gaps between the satellite images become large.

As the problems described above are identified, it is decided that the mosaic treatment and the data processing against ASTER L1B data are not executed.

Indexes of ASTER data filename were added to each polygon data of scene area and then the filename can be searched on GIS. New shapefiles were created by the union of these polygon data according to the date when ASTER images were taken, and then it becomes easy to handle the data. As a result of above treatments, it becomes possible to recognize the accurate area and location of the data and to identify the filename of the data on GIS.

(3) Results of the analysis

341 files with the rotation of 9 bands which combine 3 bands of VNIR and 6 bands of SWIR were created. Though having the coordinate, these data are non-orthoimage. As these data were created, it is possible to make a band ratio image between VNIR and SWIR bands.

The polygon data of each scene area were created, indexes of the filename were added to these polygon data and one shapefile was created by the union of all polygon data.

5.3 ASTER L3A data

(1) Contents of the data

As the problems were recognized in ASTER L1B data of PGRM, ASTER L3A ortho-data covering the geological survey area were newly purchased.

- Data acquisition : purchased from ERSDAC
- Amount : 16 scenes (for the 1/100,000-scale geological survey area)
- Data format : HDF
- Number of band : 14 bands in total (3 bands of VNIR, 6 bands of SWIR and 5 bands of TIR)
- Ground resolution : 15m in VNIR, 30m in SWIR, 90m in TIR
- Scene range: 60 km square area
- Observation date : from October 2001 to April 2006
- Remarks : DEM data is included. Data is the orthoimage.

(2) Contents of the analysis

As a pre-processing of the data, the resolution of SWIR data was resized to 15 meters and the data file composed of nine bands of VNIR and SWIR was created. Because the data areas of each band have some gaps in both sides of the path, the data file within the area where the data exist through all nine bands was newly created. Then the polygon data file of this actual data area was created. The location map of all 16 scenes of ASTER L3A is shown in Figure 5.1.

Sixteen scenes of ASTER L3A are divided into five groups according to the date when these images were taken. The union data of VNIR and SWIR and the data of TIR were processed for the mosaic treatment, and the five mosaic data files were respectively created. Three kinds of band composite images and two kinds of band ratio images were created from these mosaic data.

The total mosaic data was created from these five mosaic data in the works of FY 2009. No cloud was distributed in the western two mosaic data, but clouds were widely distributed in some part of the eastern three mosaic data. Therefore, the masks of clouds were processed in the overlapping zone of the scenes with clouds. As a result of this mask processing, the distribution of the clouds was almost disappeared in the K59 and L59 areas, and was reduced by half in the K58 area. However, the clouds remained in one third part of the geological survey area because there are no images with few clouds in the K58 area. The band ratio images and the PCA analysis images were created against the total mosaic image. However, the significance to make the total mosaic image was poor, because the difference of color tones between scenes was obvious and the boundary of scenes was easily recognized.

As a part of the geological survey area was changed after the reconnaissance survey in FY 2010, it became necessary to obtain some additional data covering the I60 and J60 areas and to reanalyze all data. On the other hand, the L58 and L59 areas with many clouds were excluded and the necessity to make the total mosaic image declined. Based on the results of FY 2009, it is decided that the mosaic processing is executed not for the total data but only for the five groups of data. The contents of data processing in FY 2010 are as follows.

As a pre-processing of the union data of VNIR and SWIR, the information unrelated to the geology was masked in the mosaic data. The targets of the mask are vegetation, clouds and shadows. Normalized Difference Vegetation Index for vegetation, sum value of VNIR data (band 1 to 3) for clouds and sum value of SWIR data (band 4 to 9) for shadows were calculated, and then the masks were created by the proper threshold values. Two kinds of band composite images and two kinds of band ratio images were created from the dataset with these masks.

The band composite image, where band 3, band 2 and band 1 are respectively assigned to red, green and blue, is shown in Figure 5.3. The band composite image, where band 4, band 6 and band 1 are respectively assigned to red, green and blue, is shown in Figure 5.4. The band ratio image, where band 7 / band 6, band 3 / band 4 and band 2 / band 1 are respectively assigned to red, green and blue, is shown in Figure 5.5. The band ratio image, where band 5 / band 6, band 6 / band 8 and band 5 / band 4 are respectively assigned to red, green and blue, is shown in Figure 5.6. The square region without data is recognized in these figures. This indicates the wide area of clouds.

The same pre-processing was executed to TIR data, and the band ratio images and the PCA images were created from the dataset with masks. The band composite image, where band 13, band 12 and band 10 are respectively assigned to red, green and blue, is shown in Figure 5.7.

(3) Results of the analysis

The red parts indicate the vegetation and the green parts indicate the laterite, and the geological structures with NNE-SSW to N-S strike are clearly recognized in Figure 5.3. As the vegetation areas are located mainly along the rivers, the existence of river system is easily recognized. The laterite is widely distributed in the east part of the J58 area, the north part of the

J59 area and the west part of the K58 area.

The band composite of Figure 5.4 is normally used to identify the acidic hydrothermal alteration minerals. The magenta color indicates the existence of these minerals. As there are no parts and pixels with the magenta color tone, it is thought that the acidic hydrothermal alteration minerals hardly exist in the geological survey area.

Figures 5.5 and 5.6 are created to recognize the differences of rock facies. The boundaries of rock facies is easily recognized as the difference of the color tone in Figure 5.5. The distribution of outcrop, laterite and soil are also visible in Figure 5.6.

Figure 5.7 is created to recognize the rock facies with much silica. The red parts indicate the distribution of quartzite. The continuous distributions with the narrow and long shape are recognized in the northwestern part and the southwestern part of the geological survey area. The distribution of these red parts is harmonious with the geological observation in the field.

ASTER data is effective to identify the distribution of laterite and quartzite and the differences of rock facies.

5.4 PALSAR L1.5 data

(1) Contents of the data

- Data acquisition : purchased from ERSDAC
- Amount : 251 scenes (for the whole of Madagascar)
- Data format : GeoTIFF
- Number of band : 1 band of HH polarization
- Ground resolution : 6.25m
- Observation mode : high resolution mode
- Off-nadir angle : 34.3 degrees
- Polarization : HH single polarization
- Scene range: 70 km square area
- Observation date : from February 2008 to July 2009
- Remarks : Data is the orthoimage.

(2) Contents of the analysis

The polygon data files of actual data areas in all 251 scenes were created. When they were put into the GIS database, the new polygon data files combined by each path were created and the indexes of the filename were added to these files in order to handle them with ease. The location map of PALSAR L1.5 data is shown in Figure 5.8.

If the mosaic data is created from all 251 scenes with the original resolution, the file size becomes around 100 GB and it is not easy to handle it. Therefore, the resolution was changed to 25 meters in order to reduce the file size in the mosaic processing for the whole of Madagascar. The mosaic image of all scenes is shown in Figure 5.9. The resolution is 12.5 meters for the 1:100,000-scale geological survey area shown in Figure 5.10.

The lineaments were automatically extracted by PCI-Geomatica software against the mosaic image of the geological survey area in FY 2009. The lineaments were extracted in the changes of some parameters by trial and error, but the reliability of the automatic extraction was not so high in general despite the high accuracy in some parts. Therefore, the geological structure shown in Figure 3.6 was created by the visual interpretation of the satellite images of ASTER, PALSAR and so on.

(3) Results of the analysis

The detailed geological structures are clearly recognized in Figure 5.10. The structures with NNE-SSW to NNW-SSE strikes are distinct in the west region of the geological survey area and the structures with NNE-SSW and WNW-ESE strikes are distinct in the east region. This difference of main strikes in both regions reflects the difference of structural domain (Androyan and Anosyan). The circular and arcuate structures, which were recognized in the southwestern region, indicate the folding structures of the metamorphic rocks.

It is difficult to recognize the precision of the mosaic image of Madagascar in Figure 5.9 with small-scale around 1:7,000,000. However, the very clear and detailed image is able to be recognized when the map scale becomes the same as the geological map.

5.5 PALSAR L4.1 data

(1) Contents of the data

- Data acquisition : purchased from ERSDAC
- Amount : 32 scenes (for the 1/100,000-scale geological survey area)
- Data format : CEOS (TIFF) with Geo-reference
- Number of band : 4 bands of HH/HV/VV/VH polarization
- Ground resolution : 25m
- Observation mode : polarimetry mode
- Off-nadir angle : 21.5 degrees and 23.1 degrees
- Polarization : four types of polarization, HH, HV, VV and VH
- Scene range: 35km × 70 km square area
- Observation date : from March 2009 to February 2010

(2) Contents of the analysis

All of 32 scenes data were orthorectified by using SRTM DEM with 90m resolution. The mosaic image shown in Figure 5.11 was created from all 32 scenes. The ortho data of PALSAR L4.1 was not supplied when these data were purchased, but it is available now.

The polarization composite image, where HH polarization, HV polarization and VV polarization are respectively assigned to red, green and blue, is shown in Figure 5.11.

(3) Results of the analysis

The same geological structure is recognized in Figure 5.11 as in the image of PALSAR L1.5 shown in Figure 5.10. The structures with NNE-SSW to NNW-SSE strikes are distinct in the west region of the geological survey area and the structures with NNE-SSW and WNW-ESE strikes are distinct in the east region.

PALSAR L4.1 data has more information than PALSAR L1.5 because PALSAR L4.1 data is the full polarimetric data. The green color parts indicate vegetation and the bright tone parts indicate steep slopes, and the dark tone parts indicate flat areas in Figure 5.11. The vegetation area is clearly recognized in the color image.

Although PALSAR L4.1 data has lower resolution compared to PALSAR L1.5 data, the geological structures are sufficiently legible. There is an advantage that the color image of PALSAR L4.1 is easier to recognize the structures.

5.6 LANDSAT data

(1) Contents of the data

- Data acquisition : free supply from PGRM
- Amount : 34 scenes (for the whole of Madagascar)
- Data format : ERDAS IMAGINE (IMG)
- Number of band : 6 bands in total (4 bands of VNIR and 2 bands of SWIR)
- Ground resolution : 30m
- Scene range: 120 km square area
- Observation date : from October 1999 to May 2002
- Remarks : Data is the orthoimage.

(2) Contents of the analysis

The polygon data files of actual data areas in all 34 scenes were created. Location map of LANDSAT data is shown in Figure 5.12.

The band composite images were created and the mosaic image of these images was created. The band composite image, where band 3, band 2 and band 1 are respectively assigned to red, green and blue, is shown in Figure 5.13.

(3) Results of the analysis

The image shown in Figure 5.13 is called as a natural color image and is similar to the image which is looked through human eyes. Therefore, the green color parts indicate vegetation and the brown color parts indicate soils with sparse vegetation. It is recognized that vegetation is poor in the central highland area and is rich in the eastern seaside area in Madagascar, and that the forest area with dark green color is narrowly distributed along the slope zone between the highland and the eastern seashore.

Clouds are absent or rare in most of 34 scenes, but clouds are widely distributed in a few scenes of the northeastern seashore area. This region has the most rainfall in Madagascar and belongs to the tropical rain forest.

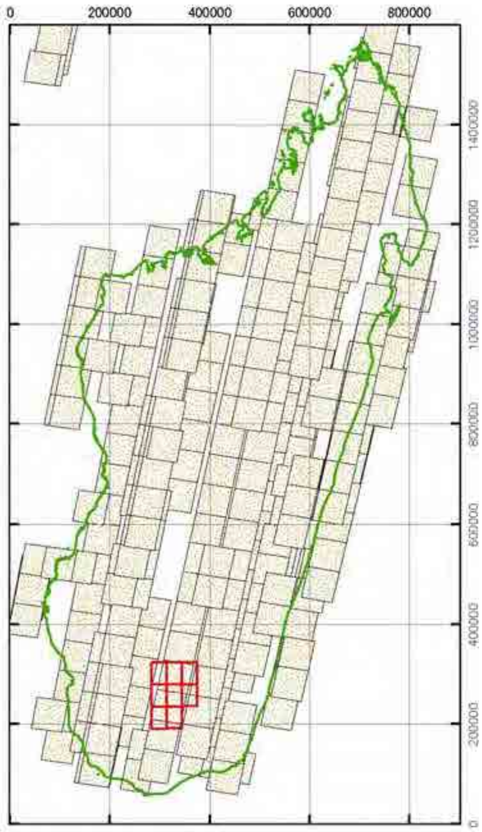


Figure 5.1 Location map of ASTER L1B data

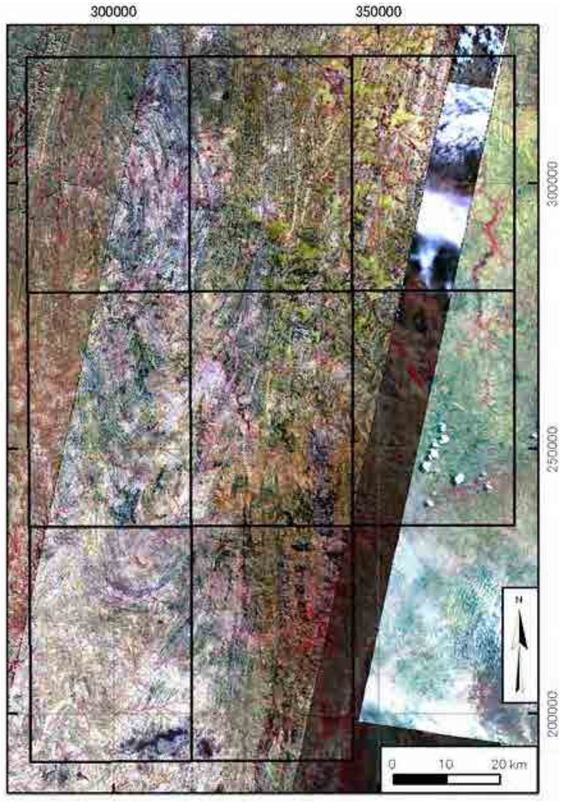


Figure 5.2 Band composite image of ASTER L3 data (RGB=B3,B2,B1)

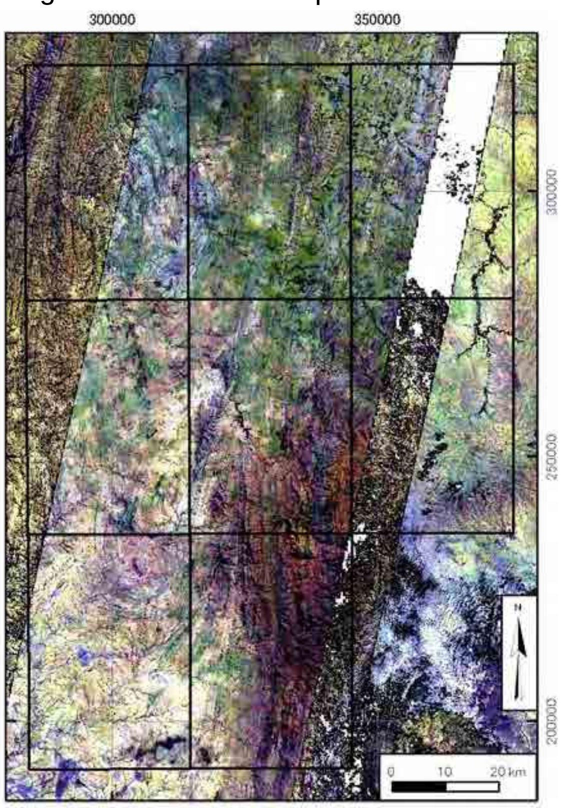


Figure 5.3 Band composite image of ASTER L3 data (RGB=B3,B2,B1)

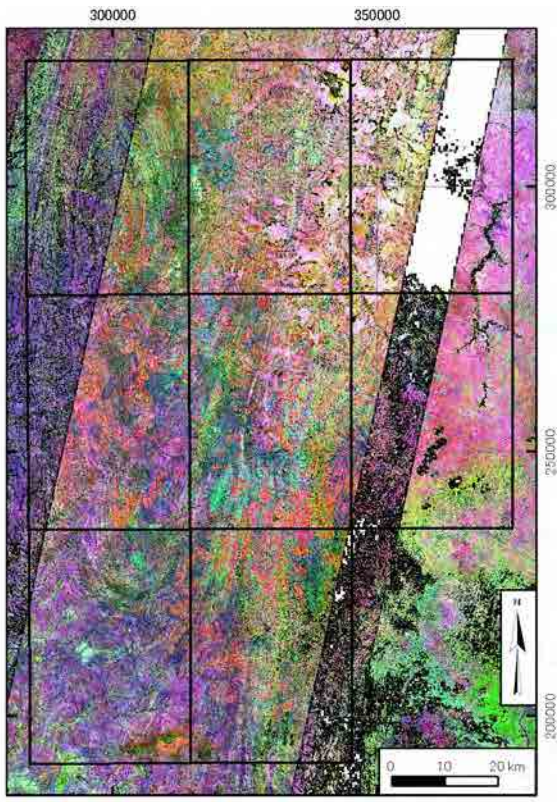


Figure 5.4 Band ratio image of ASTER L3 data (RGB=B4,B6,B1)

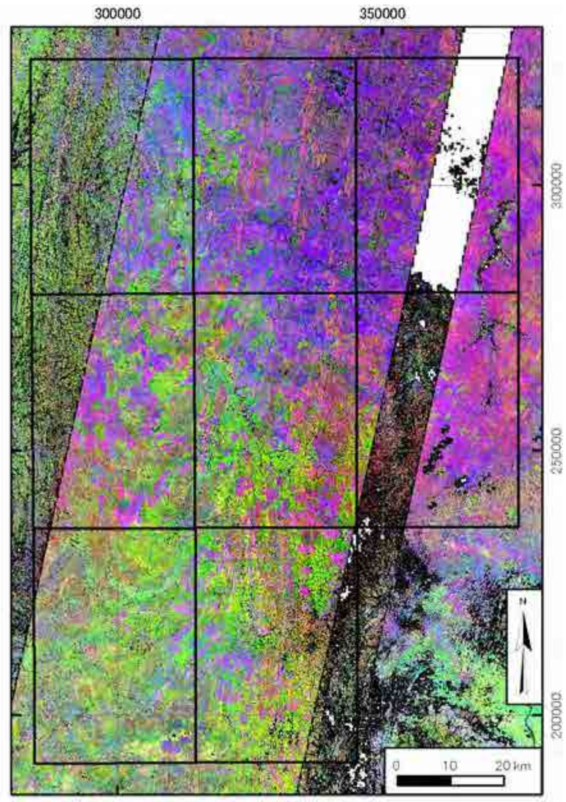


Figure 5.5 Band ratio image of ASTER L3A data (RGB=B5/B6, B6/B8, B5/B4))

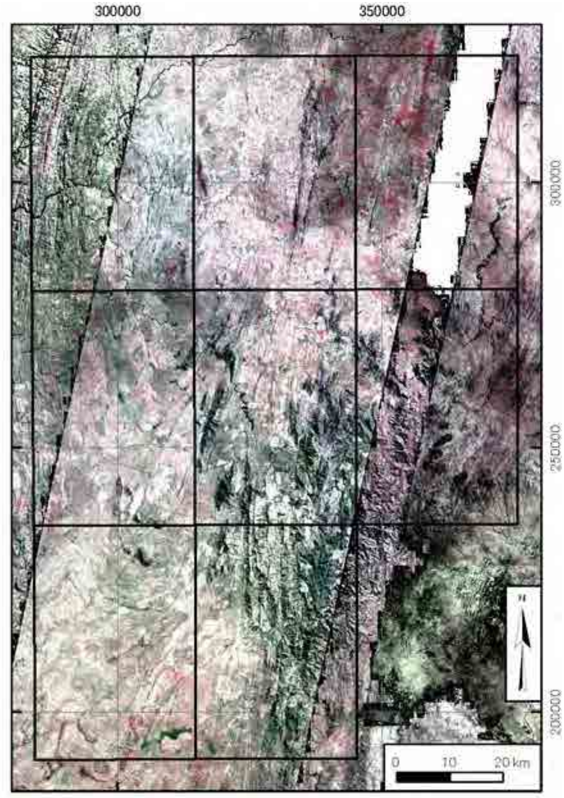


Figure 5.6 Band composite image of ASTER (RGB=B13, B12, B10)

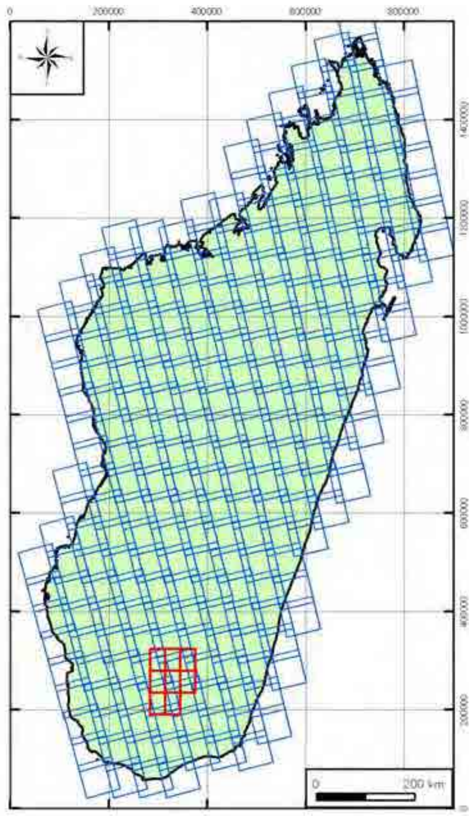


Figure 5.7 Location map of PALSAR L 1.5 data

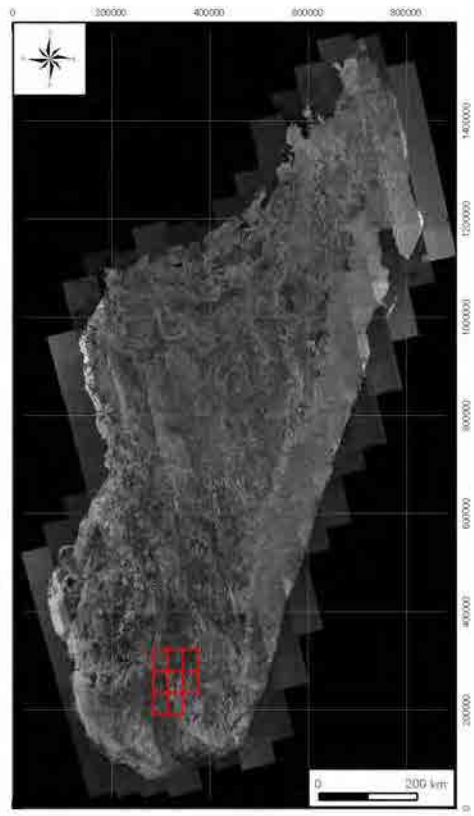


Figure 5.8 Mosaic image of PALSAR L1.5 data (Whole of Madagascar)

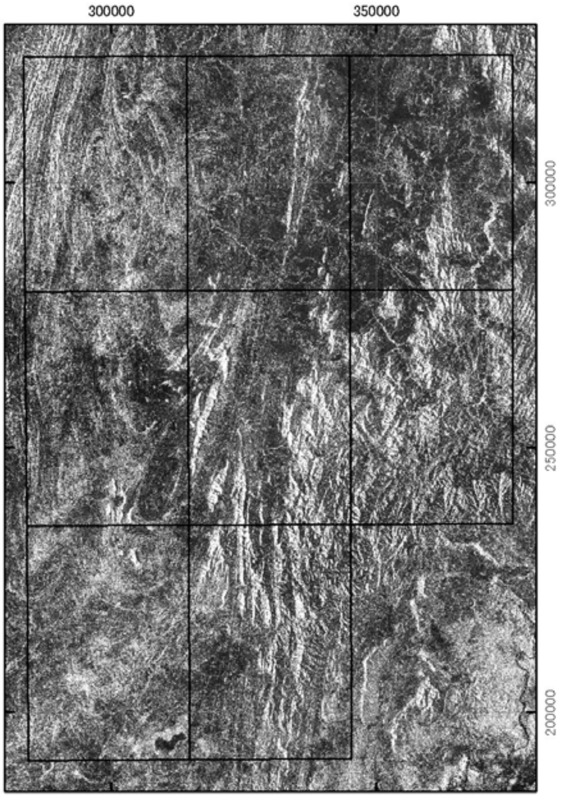


Figure 5.9 Mosaic image of PALSAR L1.5 dat

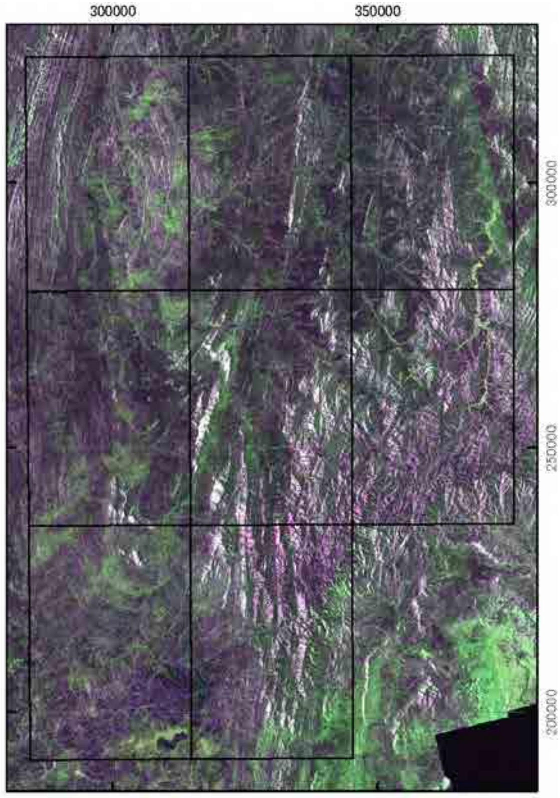


Figure 5.10 Polarimetry composite image of PALSAR L4.1 data (RGB=HH,HV,VV)

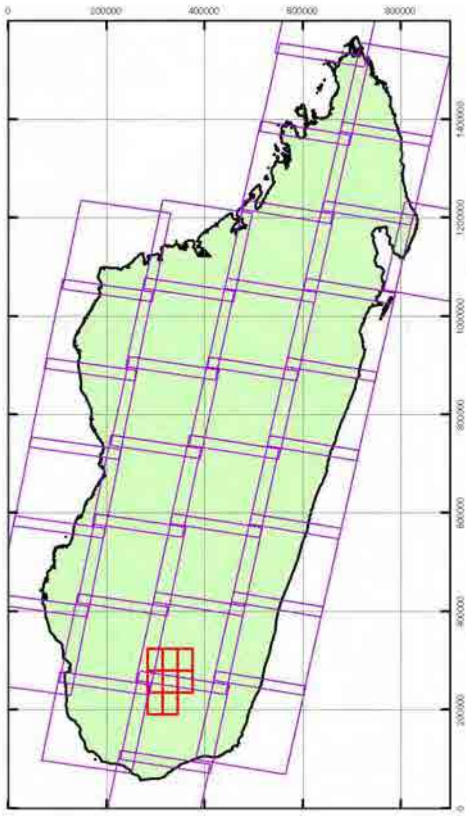


Figure 5.11 Location map of LANDSAT data

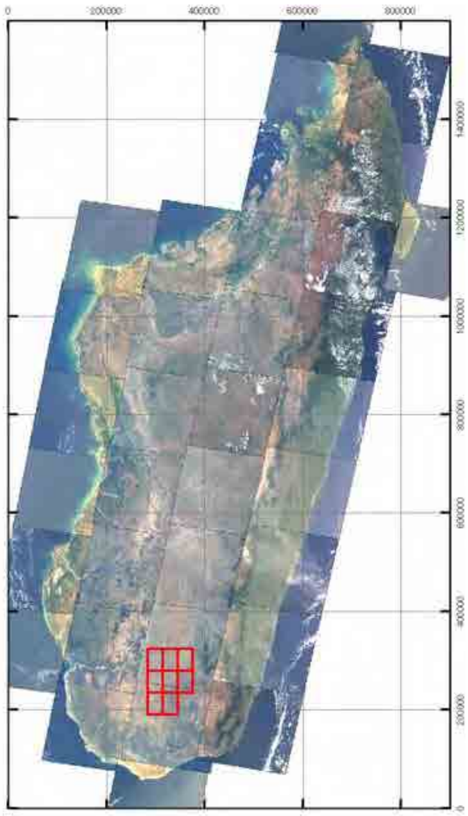


Figure 5.12 Band composite images of LANDSAT data (RGB=B3,B2,B1)

Chapter 6 GIS Database Construction

6.1 Contents of the database

As the GIS database of the PGRM was constructed by the ArcMap files of ESRI and the personal geodatabases, the database of this project was constructed in the same way as the PGRM database. The personal geodatabase of ESRI is composed of the shape files (polygon, polyline and point data), the table files and the raster data, and is actually stored as the Access database of Microsoft.

6.1.1 Kinds of the database

The data composing the database of this project are the results of geological survey, the geological maps and the mineral resources map, the results of the geochemical survey and the geochemical maps, and the satellite data and the results of remote sensing data analysis. Contents of each data are described below in Clause 6.2.

6.1.2 Specification of the database

The geological maps and the geochemical maps are created by ArcMap files (MXD files), which manage the various kinds of the constituent data. The eight sheets (eight ArcMap files) of the geological map with the scale of 1:100,000 are created. Each one sheet combining eight sheets (one ArcMap file) of the mineral resources map and the geochemical map with the scale of 1:200,000 are created.

The geological maps and the geological sections are the vector data, and are created by the shape files of polygons and polylines. The mineral resources map and the geochemical maps are created by the shape files of points, and are drawn on the simplified geological map. The histograms and the cumulative frequency graphs in the geochemical maps are the meta file data created by the Grapher software.

The satellite data are the raster data and have the formats of HDF, GeoTIFF, CEOS and ERDAS IMAGINE. The analytical results of these data have the formats of GeoTIFF and ERDAS IMAGINE. The data of each scene area of the satellite data are the shape files of polygons.

6.1.3 Geographic coordinate system

As the PGRM database adopted the map projection of Madagascar-Laborde-Tan1925 which is typically used in Madagascar, the same projection is used in this project to create the geological maps, the mineral resource map, the geochemical maps and the database. On the other hand, because the ASTER and PALSAR data have the geographic coordinate system of WGS1984-UTM used as an international standard, the analytical results of these data maintain the WGS1984-UTM system.

6.2 Data of the survey results

6.2.1 Geological survey

(1) Geological map (product for printing)

(a) Files for each survey area

- Geological map : ArcMap file (ESRI MXD file)

  File name of I58 : Carto_JICA_Geologie_100k_I58.mxd

  Files are created in each survey area and composed of eight ArcMap files in total.

(2) Geological data of the geological maps and the geological sections

(a) Files for all eight survey areas

- Geological map : polygon and polyline data, ESRI shape file
- Geological structure and lineament map : polyline data, ESRI shape file
- Dip and strike data : point data, ESRI shape file
- Location and contents of geological observation : point data, ESRI shape file

(b) Files for each survey area

- Geological section : polygon and polyline data, ESRI shape file
- Geological legend : figure and text data on ArcMap, ArcMap file

(3) Constituent data of the geological map

(a) Files for all eight survey areas

- Geographic data : polyline and point data, ESRI shape file
- LANDSAT color composite image : raster data, TIFF file
- Airborne magnetic survey data : raster data, TIFF file
- Airborne radiometric survey data : raster data, TIFF file
- Index data : polygon and polyline data, ESRI shape file

(4) Mineral resources map (product for printing)

(a) Files for all eight survey areas

- Mineral resources map : ArcMap file (ESRI MXD file)

  File name : Carto_JICA_Resources_200k.mxd

  PC image of ArcMap showing the mineral resources map is shown in Figure 8.4.

(5) Data in the mineral resources map

(a) Files for all eight survey areas

- Location and contents of mineral resources : point data, ESRI shape file
- Location of survey area : polygon data, ESRI shape file
- Geological map : polygon and polyline data, ESRI shape file
- Geological legend : figure and text data on ArcMap, ArcMap file
- Geographic data : polyline and point data, ESRI shape file
- Index data : polygon and polyline data, ESRI shape file

6.2.2 Geochemical survey

(1) Geochemical map (product for printing)

(a) Files for all eight survey area

- Geochemical map : ArcMap file (ESRI MXD file)
  File name of Au : Carto_JICA_Geochem_200k_Au.mxd
  Files are created in each element and composed of 24 ArcMap files in total.

(2) Geochemical data of the geochemical maps

(a) Files for all eight survey areas

- Location and analytical value of geological samples : point data, ESRI shape file
- Location of survey area : polygon data, ESRI shape file

(b) Files for each element

- Histogram and cumulative frequency graph : Windows meta file data
  File name of Au : Carto_JICA_Geochem_Figure_Au.wmf
  Files are created in each element and composed of 24 files in total.

(3) Constituent data of the geological map

(a) Files combining all eight survey areas

- Geological map : polygon and polyline data, ESRI shape file
- Geological legend : figure and text data on ArcMap, ArcMap file
- Geographic data : polyline and point data, ESRI shape file
- Index data : polygon and polyline data, ESRI shape file

6.2.3 Remote sensing data analysis

In general, the filename of satellite data includes the date and time when it was acquired and the identification number. The filename of the original satellite data is used the default name as possible and the filename of the analyzed data is given the simplified name which should be intuitively and easily recognized. In the following filename, yyyy represents the Christian Era, yy is the last two digits of the year, mm is month, dd is day, hh is hour, mm is minute, ss is second, and ### and #### represents the identification number.

(1) Original data

(a) ASTER L1B data (PGRM data)

- HDF format, non-orthoimage : 2 types of 341 files
  AST_09_003mmddyyyyhhmmss0000000.hdf0 (data from band 1 to band 3)
  AST_09_003mmddyyyyhhmmss0000000.hdf1 (data from band 4 to band 9)

(b) ASTER L3A data

- HDF format, orthoimage : 16 files
  AST3A1_yymmddhhmmssyymmdd####

(c) PALSAR L1.5 data

- GeoTIFF format, orthoimage : 251 files
  PASL150yymmddhhmmssyymmdd####.tif

(d) PALSAR L4.1 data

- CEOS format, non-orthoimage : 32 files
  PASL410yymmddhhmmssyymmdd####.dat

(e) LANDSAT data (PGRM data)

- ERDAS IMAGINE format, orthoimage : 34 files

  p###r###_yyyymmdd_lab_123457.img

(2) Analyzed data

(a) ASTER L1B data

- Raster data of nine bands combined : ERDAS IMAGINE format : 341 files

  AST_M_mmddyyyyhhmmss.img

- Polygon data of the data region : ESRI shapefile : 1 file

  Areas_ASTER_PGRM.shp

(b) ASTER L3A data

- Raster data of nine bands combined : ERDAS IMAGINE format : 16 files

  AST3A1_yymmddhhmmssyymmdd####.img

- Mosaic data : ERDAS IMAGINE format : 5 files

  AST_J_050713_W1_mosaic.tif

  AST_J_011006_W2_mosaic.tif

  AST_J_060206_W3_mosaic.tif

  AST_J_060411_W4_mosaic.tif

  AST_J_011022_W5_mosaic.tif

- Analyzed data : GeoTIFF format : 5 types of 5 files

  AST_J_yymmdd_mosaic_B321.tif

  AST_J_yymmdd_mosaic_B461.tif

  AST_J_yymmdd_mosaic_B76_34_21.tif

  AST_J_yymmdd_mosaic_B56_68_54.tif

  AST_J_yymmdd_mosaic_B131210.tif

- Polygon data of the data region : ESRI shapefile : 16 files

  AST3A1_yymmddhhmmssyymmdd####.shp

(c) PALSAR L1.5 data

- Mosaic data (for whole Madagascar) : GeoTIFF format : 1 file

  PALSAR_L1_mosaic_madagascar.tif

- Mosaic data (for 1/100K geological survey area) : GeoTIFF format : 1 file

  PALSAR_L1_mosaic.tif

- Polygon data of the data region : ESRI shapefile : 1 file

  Areas_PALSAR_L1.shp

- Polygon data of the data region in each path : ESRI shapefile : 1 file

  Path####.shp

(d) PALSAR L4.1 data

- Analyzed data : GeoTIFF format : 32 files

  PASL410yymmddhhmmssyymmdd####_hhhvvv.tif

- Mosaic data : GeoTIFF format : 1 file

  PALSAR_L4_mosaic.tif

(e) LANDSAT data

- Analyzed data : GeoTIFF format : 2 types of 2 files
  - p159r076_19991017_lab_B321.tif
  - p159r076_19991017_lab_B741.tif
  - p159r077_20000528_lab_B321.tif
  - p159r077_20000528_lab_B741.tif
- Polygon data of the data region : ESRI shapefile : 1 file
  - Areas_LANDSAT.shp

6.3 Existing data collected

6.3.1 Geological data

(1) Geological GIS data

1 dataset : ESRI shapefile : provided by PGRM

South of Madagascar

(2) Geological map of new version with the scale of 1:500,000

2 sheets : PDF data : provided by PGRM

Map code : No.10 (Fianarantsoa) and No.11-12 (Ampanihy and Tôlanaro)

(3) Geological map of new version with the scale of 1:100,000

5 sheets : PDF data : provided by PGRM

Map code : H58 (Benenitra), H59 (Ianapera), H60 (Fotadrevo), M59 (Ranotsara Sud) and M60 (Esira)

(4) Geological map of old version with the scale of 1:100,000

18 sheets : TIFF data : provided by PGRM

Map code : H57-I57 (Benaha - Sakalama), H58 (Benenitra), H59 (Ianapera), H60-I60 (Fotadrevo - Bekily), I57-J57 (Sakalama - Jangany), I58 (Ianakafy), I59-J59 (Bevary - Isoanala), J57 (Jangany), J58-K58 (Isakoa - Betroka), J60 (Ampandrandava), K57-L57 (Iritsoka - Taperapia), K59-L59 (Mahabo - Babaria), K60 (Tsivory), L58-M58 (Belenalena - Begogo), L59 (Babaria), L60-M60 (Mahaly - Esira), M57-N57 (Jakora - Soakibany) and M59 (Ranotsara du sud)

6.3.2 Geographical data

(1) Topographic map with the scale of 1:100,000

28 sheets : GeoTIFF data : JICA bought at FTM

Map code : H57, H58, H59, H60, H61, I57, I58, I59, I60, I61, J57, J58, J59, J60, J61, K57, K58, K59, K60, K61, L57, L58, L59, L60, M57, M58, M59 and M60

(2) Topographic map with the scale of 1:500,000

11 sheets : GeoTIFF data : SRED bought at FTM

Map code : No.1 to No.12 (whole Madagascar)

6.3.3 Geophysical data

(1) Analyzed images of the airborne magnetic and radiometric survey

96 files (12 data in 8 areas) : TIFF data : provided by PGRM

Map code : I58, I59, I60, J58, J59, J60, K58, and K59

Chapter 7 Technological Transfer Activities

7.1 Overview

One of the major objectives of this Project is the technology transfer activity to C/P personnel. In this project, technology transfer was promoted by OJT in the field as well as indoor works, and by seminar. OJT was held through geological survey, geochemical exploration, and remote sensing data analysis. Technology transfer seminar were also held twice in the fiscal year 2009 (second year) and 2011 (final year).

The main technical areas as the target for the technology transfer are 1) determination of rocks and minerals in the field, 2) comparison satellite image with real geology in the remote sensing ground truth, 3) analysis and interpretation of satellite image using computer. In the seminar, trainees received theoretical concept of remote sensing, the way of data processing, and the use of related software.

7.2 Technological transfer activities in the field

Six geologists from MMH were involved in the geological survey and geochemical exploration and two geologists from PGRM joined remote sensing ground truth in the Sixth-stage Works 2010 (Geological survey Phase 1) and Seventh-stage Works 2011 (Geological survey Phase 2).

In the geological survey and geochemical exploration, 3 among 5 counterparts stayed in the field at all times. JICA members were always accompanied by counterpart members and taught the way of observation of rocks and minerals, measurement of geological structure, collecting stream sediment, description of geology, and handling GPS device. Before starting geological survey, JICA members and counterpart members went to the field for geological excursion all together. In front of the outcrop, counterpart members described the observational data on the description card. At the base camp, JICA members discussed rock identification with counterparts before mapping geology, and shared the results. Dr. Rambeloson, ex-professor in Antananarivo University and one of the JICA members in this project, provided expert opinions for identification of rocks and minerals. Counterpart members were involved in the field work for 107 days (including 6 days for move) in the Sixth-stage and 156 days (including 11 days for move) in the Seventh-stage.

As for remote sensing ground truth, Mr. ONUMA, JICA member, conducted the ground truth of the remote sensing data analyses with 2 counterparts during the field survey. By comparing satellite image with real geology seen in the field, Mr. ONUMA gave C/Ps instructions in the method of the remote sensing data analyses and of the interpretation of the analytical results, and the identification of the rocks and minerals. Counterpart members were involved in the field work for 14 days (including 5 days for move) in the Sixth-stage and 12 days (including 5 days for move) in the Seventh-stage.

7.3 Technological transfer through indoor works

The remote sensing data analyses and GIS data construction were performed by the JICA member in charge in the JICA's working place in the PGRM office, Antananarivo.

At the same time, the JICA member in charge demonstrated the way how to analyze the satellite data and how to operate the software on the PC. The C/Ps analyzed the ASTER data existed in the PGRM with method which they learned.

With respect to geological cartography, JICA member demonstrated the way how to create geological plane map based on route map and cross section map based on geological structure.

7.4 Technology Transfer Seminar

Two Technology transfer seminars were held in the Third-stage Works (FY2009) and Eight-stage Works (FY2011).

First Technology Transfer Seminar on Remote Sensing and GIS was held in October, 2009, responding to an official letter from MEM to the JICA project Team on July 7, 2009. Madagascar had not been invited to the seminar held in the JOGMEC Remote Sensing Center in Botswana in July 2009 for SADC member countries, due to the political confusion of this country ever since 2009. Even in 2011, the center has not accepted Malagasy trainees. With this in mind, the two seminars held in this project were welcomed by counterpart organization. Second Technology Transfer Seminar was held in January, 2012 on scheduled.

(1) First Technology Transfer Seminar on Remote sensing and GIS

Regarding technology transfer seminar on remote sensing and GIS requested from counterpart organization, Dr. KOUDA, a member of Geological Survey of Japan, National Institute of Advanced Industrial Science and Technology (AIST) was invited to this seminar as a lecturer. Dr. KOUDA lectures geological engineers about emote sensing and GIS at JOGMEC Remote Sensing Center in Botswana and International Institute for Mining Technology (MINTEC) in Kosaka town, Akita Prefecture, JAPAN, every year. The contents of this seminar were based on the lectures above. In the latter of this seminar, Mr. ONUMA, in charge of geological remote sensing and GIS in this project, also gave a lecture.

Date: Oct 19 (Mon) to 22 (Thu) 2009, four days

Place: Library of PGRM, Antananarivo

Lecturers:

19 to 21 October: Dr. Ryoichi KOUDA, Geological Survey of Japan, AIST

22 October: Mr. Takumi ONUMA, JICA Project Team

Participants: 17 persons in total

Contents:

a) 19th Introduction of image processing and GIS, Installation of Free & Open source GIS software (QGIS), Theory and example of optical remote sensing

b) 20th GIS and Image analysis of DEM data by QGIS, Theory and example of Thermal Infrared remote sensing

c) 21st GIS and Image analysis of DEM data by QGIS, Theory and example of Microwave remote sensing, Example of analytical results in intertropical vegetation area

d) 22nd Introduction of satellite data used in the JICA project, Examples of analytical results of the data, Examples of airbone hyperspectral data analysis

Handouts: Materials listed below were provided to participating counterparts.

a) Presentation files and data of Dr. KOUDA (CD-R)

b) Data related to Open source GIS software QGIS (CD-R)

c) Presentation files of Mr. ONUMA (CD-R)

d) Remote Sensing Note (5 of Printed book)

Others: Many participants discussed vigorously and evaluated this four days seminar. Counterpart organization aspired that this kind of seminar was held continuously in this project. In this first seminar, contents of the lecture were on theoretical basis. And counterpart organization requested more practical training in the second seminar.

(2) Second Technology Transfer Seminar on Remote sensing and GIS

Date: Jan 30 (Mon) to 31 (Tue) 2012, two days

Place: Library and computer room of PGRM, Antananarivo

Lecturers:

30 January: Mr. Takumi ONUMA, Leader / Satellite image analysis

31 January: Mr. Seiji TAKEUCHI, Geology B / Geochemical exploration
Mr. Takumi ONUMA

Participants: 9 persons in total

Contents:

a) 30th

Analysis of satellite image over the survey area, Analysis of ASTER data used by ENVI software (Mr. ONUMA)

b) 31st

Analysis of geochemical data (Mr. TAKEUCHI)

Method of making GIS database of the results on this project used by ArcGIS software (Mr. ONUMA)

Handouts: Presentation files were provided to participating counterparts.