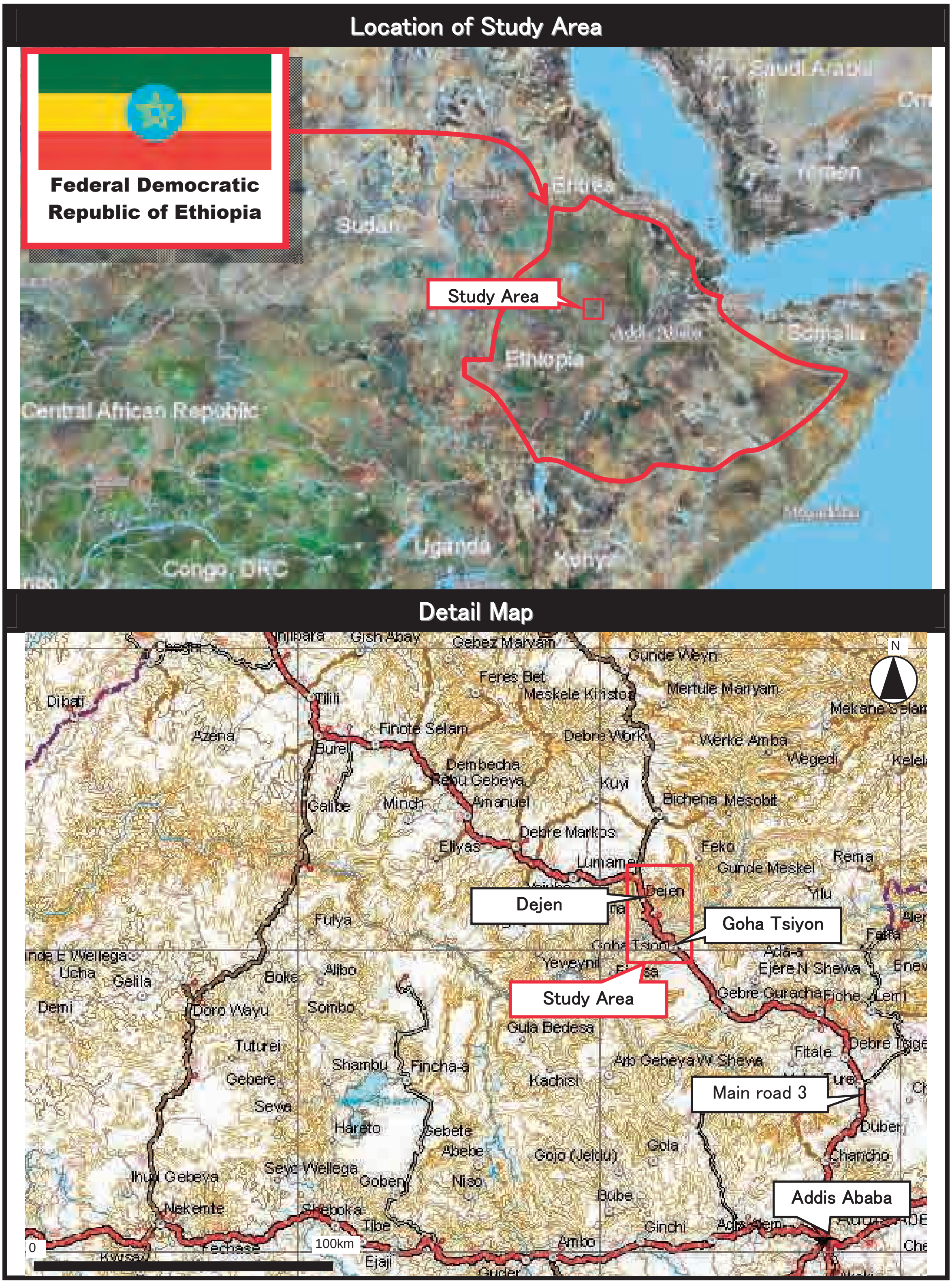
JAPAN INTERNATIONAL COOPERATION AGENCY
GEOLOGICAL SURVEY OF ETHIOPIA

THE PROJECT FOR DEVELOPING COUNTERMEASURES AGAINST LANDSLIDERS IN THE ABAY RIVER GORGE

FINAL REPORT

January 2012

KOKUSAI KOGYO CO., LTD.
JAPAN CONSERVATION ENGINEERS CO., LTD.



Location Map

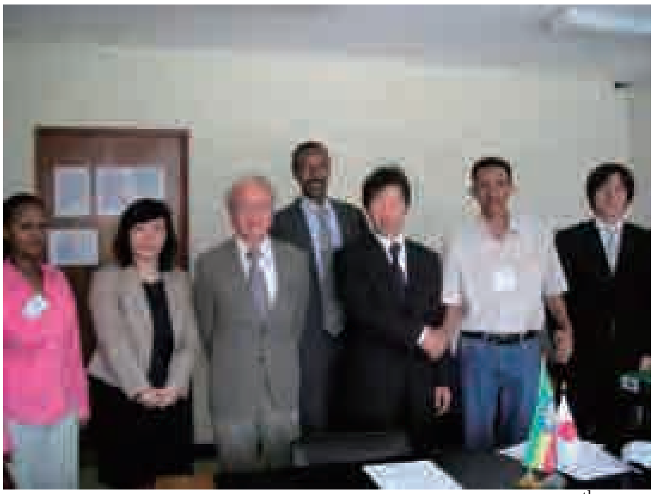
Rate of Currency Translation

1 USD	= 17.29 ETB
	= 77.73 JPY
1 ETB	= 0.0578 USD
	= 4.4955 JPY

ETB: Ethiopia Birr

As of December 1st, 2011

Photos of the Project (1)



After the sign for commencement of the Project, 14th Apr. 2010

Second Joint Coordinating Committee Meeting, 1st Jul. 2010

Seismic exploration at the landslide site

Digging trench for extensometer

Installed extensometer at the landslide

Drilling work at ST.0.800

Photos of the Project (2)

Downloading the rain fall data

Technical transfer on site (Measurement method of cracks), 25th Jan. 2011

Technical transfer on site (Mapping of the location of cracks), 27th Jan. 2011

Technical transfer on site (Data collection of monitoring devices), 18th Feb. 2011

Workshop of the landslide, debris flow and rock fall analysis (Lecture of landslide stability analysis), 25th Feb. 2011

Workshop of the landslide, debris flow and rock fall analysis (Drawing of landslide cross sections), 25th Feb. 2011

Photos of the Project (3)

Workshop of GIS utilization for landslide
18th Mar. 2011

Technical transfer on drilling.
4th Jun. 2011

Technical transfer on drilling. Installation of casing pipes for inclinometer, 12th Jul. 2011

Monitoring data collection of borehole extensometer, 21st Jun. 2011

Monitoring data collection of extensometer
21st Jun. 2011

Technical transfer for connecting casing pipe for inclinometer, 13th Jul. 2011

Photos of the Project (4)

Technical transfer for connecting casing pipe for inclinometer, 13th Jul. 2011

Installation of groundwater level meter, 22nd Jun. 2011

Slip surface on the core at B05-13

Workshop for landslide, debris flow and rock fall analysis, 7th Oct. 2011

Workshop of monitoring and early-warning system, 11th -16th Oct. 2011

Workshop for field survey and integrated analysis, 28th -30th Oct. 2011

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Abbreviations

C/P	Counterpart
CA	Capacity Assessment
DED	District Engineer Division
DEM	Digital Elevation Model
DRMC	District Road Maintenance Contractor
EMA	Ethiopian Mapping Agency
ERA	Ethiopian Roads Authority
GIS	Geographical Information System
GOE	Government of the Federal Democratic Republic of Ethiopia
GOJ	Government of Japan
GPS	Global Positioning System
GSE	Geological Survey of Ethiopia
IC/R	Inception Report
ITR(IT/R)	Interim Report
JCC	Joint Coordination Committee
JICA	Japanese International Cooperation Agency
L/S	Landslide
M/M	Minutes of Meeting
MM	Ministry of Mines
MME	Ministry of Mines and Energy
MoFED	Ministry of Finance and Economic Development
NGO	Non Governmental Organizations
NMSA	The Ethiopia National Meteorological Services Agency
PCM	Project Cycle Management
PDM	Project Design Matrix
PR (P/R)	Progress Report
S/C	Steering Committee
S/W	Scope of Work
The Project	Developing Countermeasures against Landslides in the Abay River Gorge
The Study Team	Japanese Study Team organized by JICA
WWIS	World Weather Information Service

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Chapter 1

Introduction

1 Introduction

1.1 General

This Report covers the results for the Project on Developing Countermeasures against Landslides in the Abay River Gorge (hereinafter the Project) according to the Minutes of Meeting (hereinafter M/M) agreed upon between the Geological Survey of Ethiopia (hereinafter GSE), of the Federal Democratic Republic of Ethiopia (hereinafter Ethiopia) and the Japan International Cooperation Agency (hereinafter JICA) witnessed by the Ministry of Finance and Economic Development (hereinafter MoFED) and Ethiopian Roads Authority (hereinafter ERA) of Ethiopia.

JICA organized a Japanese Study Team (hereinafter the Study Team) consisting of 18 experts of the major fields relevant to the landslide investigation and analysis. The Project commenced in April 2010 and was completed at the end of December 2011. Phase 1 of the Project was executed from April to November 2010. Phase 2 was from December 2010 to April 2011. Phase 3 was from May to December 2011. The Project is implemented during this term based on cooperation with the implementation and counterpart (hereinafter C/P) organizations, mostly from GSE.

1.2 Background of the Project

Main road 3, a major arterial road in the Federal Demographic Republic of Ethiopia (hereinafter, Ethiopia), connects the capital Addis Ababa with Sudan, is part of the Trans-African Highway Network, and is vital to its economy and the livelihoods of its citizens. The stretch of main road 3 that passes through the Abay Gorge steeply climbs nearly 1,500 meters over 40 kilometers. It is plagued by landslides in the rainy season from June to September. Some of these are up to two kilometers wide, putting into jeopardy this vital link. To fundamentally solve this problem it is necessary to implement appropriate countermeasures after clarifying the mechanisms that trigger landslides in this stretch of road.

Despite landslides occurring throughout Ethiopia, until now there has been no organization responsible for surveying landslides. In April 2009, the Geo-hazards Investigation Division, specialized in investigating geo-hazard processes, was established in the Geological Survey of Ethiopia, of the Ministry of Mines and Energy (hereinafter, MME). In light of this background, MME made a request to the Government of Japan for the technical and personnel development of this division so that it can undertake geological surveying, mapping, investigating landslide causes and mechanisms, and planning landslide countermeasures.

In response, discussions—based on the detailed planning survey implemented by the Japan International Cooperation Agency in December 2009—were concluded on 12 December, 2009; wherein the Scope of Work (S/W) and Minutes of Meeting (M/M) were signed. This Project is implemented according to this Scope of Work. Furthermore, the countermeasures, based on the outcomes of this Project, is implemented by the organization responsible for maintaining Ethiopia's roads, the Ethiopian Roads Authority (ERA).

1.3 Objectives of the Project

1.3.1 Superior goal

To figure out the mechanisms triggering landslides in the Abay Gorge along main road 3; and to mitigate human suffering and economic losses by implementing appropriate countermeasures.

1.3.2 Project purpose

- To clarify landslide mechanisms in the Abay Gorge
- To assist GSE to acquire skills to analyze and investigate landslides

1.3.3 Project outputs

The implementation of this Project is expected to achieve the following outputs:

- The project implementing system is established.
- The situation of landslides is identified.
- The geomorphological and geological condition of landslides is identified.
- The landslide characteristics due to seasonal changes are identified.
- The landslide mechanisms are figured out.
- The survey and analysis of disasters other than landslides are conducted.
- The counterpart agencies become familiar with landslide survey and analysis work.

1.4 Scope of the Project

1.4.1 Counterpart

Counterpart organization

• Geological Survey of Ethiopia (GSE), Ministry of Mines

Relevant organizations

• Ethiopian Roads Authority (ERA)

• Ethiopian Mapping Agency (EMA) and others

Beneficiary

• Direct beneficiary: ERA

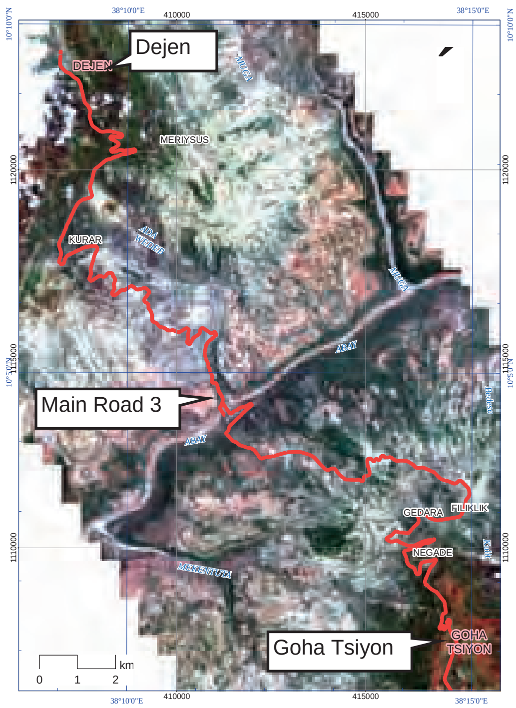


Figure 1.4.1 Project Area Map

1.4.2 Project area

Areas prone to landslides in the Abay Gorge along main road 3 between Goha Tsiyon and Dejen (40.45 km).

Based on topographic analysis using satellite photographs and site reconnaissance, we analyzed five landslide areas as the most dangerous areas to investigate and to take countermeasures, which have high risky landslide areas and the largest potential risk to roads (Figure 1.4.2).

1 L/S00 area
2 L/S05 area
3 L/S22 area
4 L/S27 area
5 L/S28 area

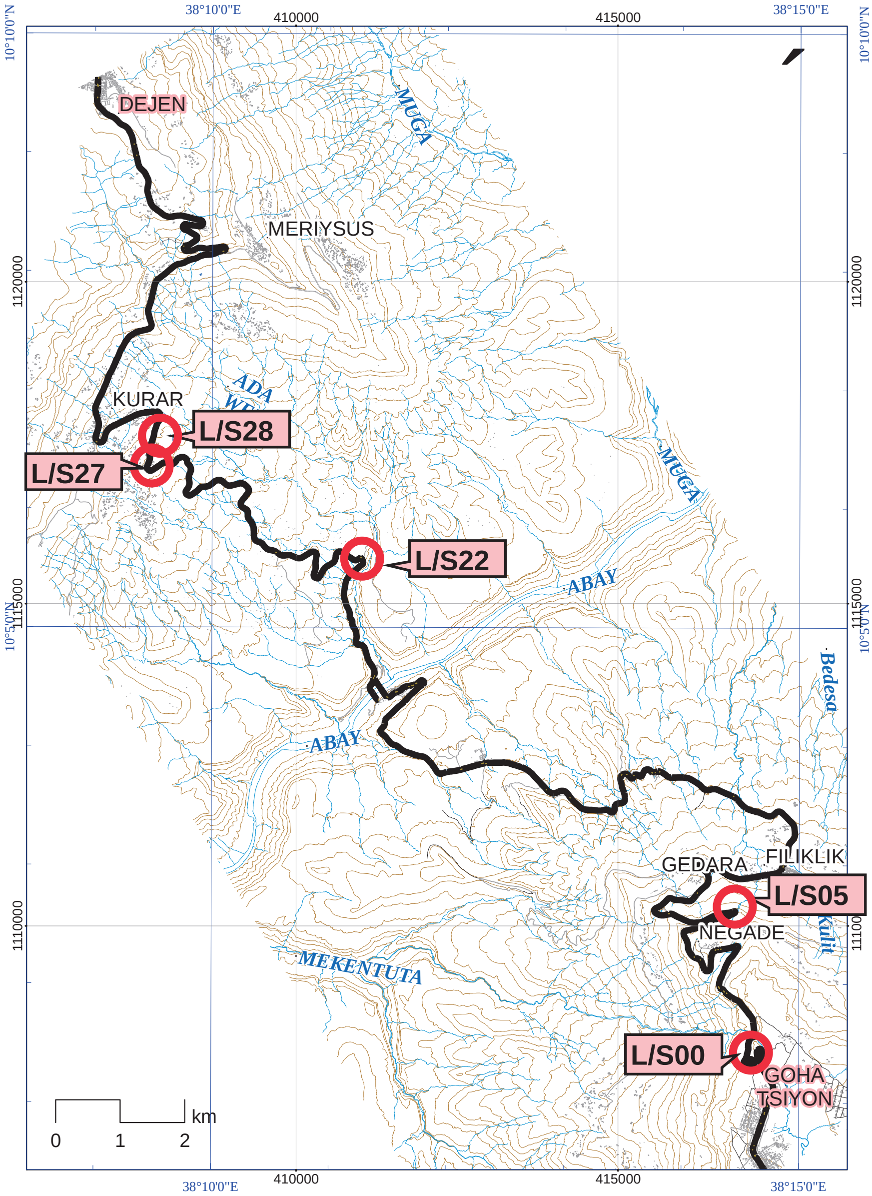


Figure 1.4.2 Location map of the landslide area

1.5 Work plan and schedule

This Project was implemented according to the Scope of Work and Minutes of Meeting agreed upon in Addis Ababa on December 16, 2009; and a method of implementation will be formulated upon fully understanding and considering the content of these documents.

The general work flow of the implementation of the Project for effective and efficient technical transfer, fully taking into account the surveys and analyses for landslides, is summarized in the following Figure 1.5.1. A detailed implementation schedule flowchart based on this is shown in Figure 1.5.2.

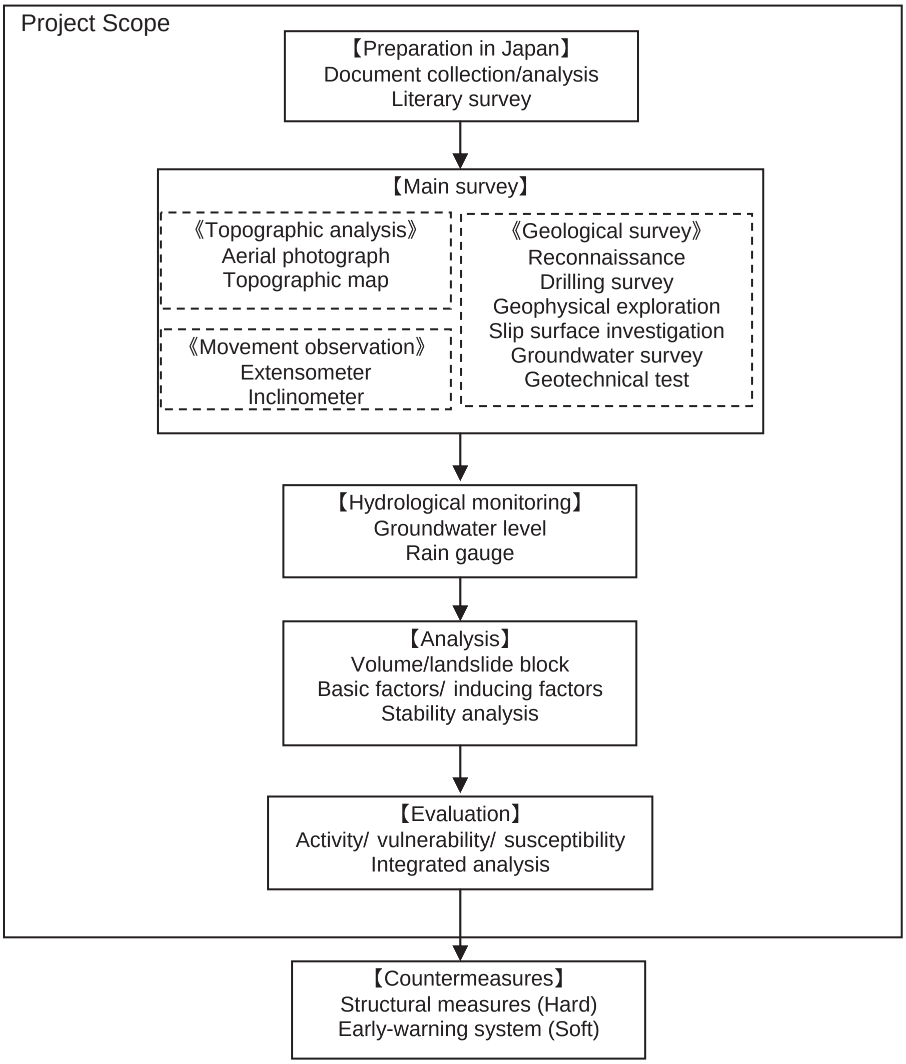


Figure 1.5.1 Flowchart summarizing survey/analysis for landslides

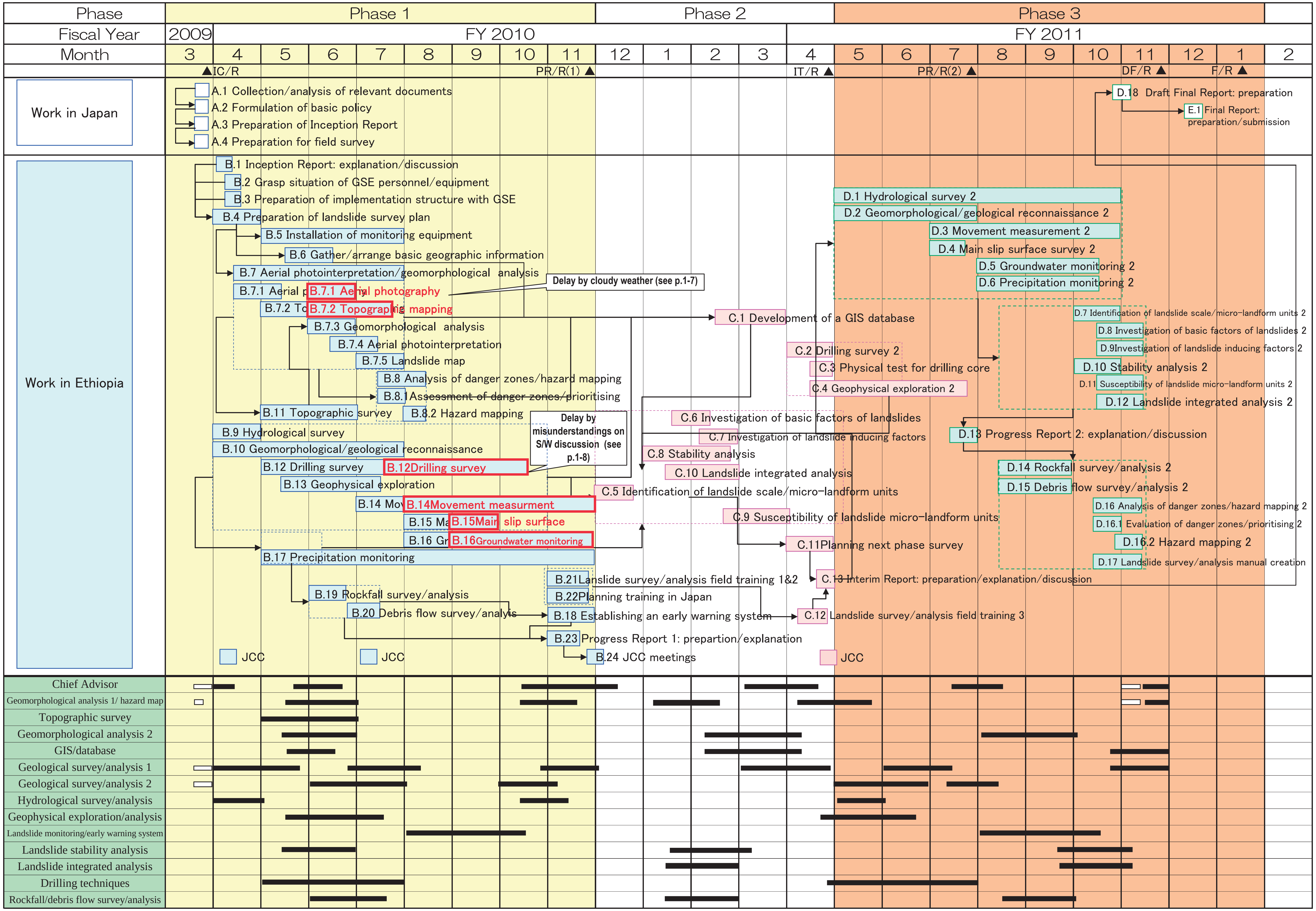


Figure 1.5.2 Detailed implementation schedule flowchart

1.5.1 Major activities

The main works conducted in the Project is summarized as follows;

[Phase 1: March 2010 to November 2010]

1) Preparation work in Japan

- Collection/analysis of relevant documents
- Formulation of basic policy
- Preparation of Inception Report
- Preparation for field survey

2) Work in Ethiopia

- Inception Report explanation/discussion
- Grasp situation of GSE personnel/equipment
- Preparation of implementation structure with GSE
- Preparation of landslide survey plan
- Installation of monitoring equipment
- Gather/arrange basic geographic information
- Aerial photo interpretation/geomorphological analysis
  - *Aerial photography*
  - *Topographic mapping*
  - *Geomorphological analysis*
  - *Aerial photo interpretation*
  - *Landslide map*
- Analysis of danger zones/hazard mapping
  - *Assessment of danger zones/prioritizing*
  - *Hazard mapping*
- Hydrological survey
- Geomorphological/geological reconnaissance
- Topographic survey
  - *Planar survey*
  - *Cross-section survey*
- Drilling survey
- Geophysical exploration
- Movement measurement
- Main slip surface survey
- Groundwater monitoring
- Precipitation monitoring
- Rockfall survey/analysis
- Debris flow survey/analysis
- Landslide survey/analysis field training
- Planning training in Japan
- Progress Report 1: preparation/explanation
- JCC meetings

[Phase 2: December 2010 to April 2011, Work in Ethiopia]

- Development of a GIS (Geographical Information System) database
- Drilling survey 2
- Physical test for drilling core
- Geophysical exploration 2
- Identification of landslide scale/blocks
- Investigation of basic factors of landslides
- Investigation of landslide inducing factors
- Stability analysis
- Susceptibility of landslide blocks
- Landslide integrated analysis
- Planning next phase survey
- Landslide survey/analysis field training 3
- Interim Report: preparation/explanation/discussion
- JCC meetings

[Phase 3: May 2011 to December 2011]

1) Work in Ethiopia

- Hydrological survey 2
- Geomorphological/geological reconnaissance 2
- Movement measurement 2
- Main slip surface survey 2
- Groundwater monitoring 2
- Precipitation monitoring 2
- Identification of landslide scale/micro-landform units 2
- Investigation of basic factors of landslides 2
- Investigation of landslide inducing factors 2
- Stability analysis 2
- Susceptibility of landslide micro-landform units 2
- Landslide integrated analysis 2
- Progress Report 2: explanation/discussion
- Rockfall survey/analysis 2
- Debris flow survey/analysis 2
- Analysis of danger zones/hazard mapping 2
- Evaluation of danger zones/prioritizing 2
- Hazard mapping 2
- Landslide survey/analysis manual creation
- Training in Japan
- Draft final report preparation
- Establishment of Landslide investigation manual
- JCC meetings

2) Work in Japan

- Final report preparation/submission

1.5.2 List of JICA experts and counterparts

The names of the Study Team members and counterparts are listed below. The table indicates the role of each member and their field of expertise.

Table 1.5.1 List of JICA experts and counterparts

No	JICA Experts	Field of Expertise	Counterpart (GSE)	Position
1	Kensuke ICHIKAWA	Team leader (Project Management)	Dr. Getnet Mewa	Senior
2	Satoru TSUKAMOTO	Geomorphological analysis1 /hazard map	Leta Alemayehu	Senior
3	Shozo SHIMODA	Topographic survey	Haile Selassie G/Selassie	Senior
4	Mitsuya ENOKIDA	Geomorphological analysis 2	Melkamu Tegnge	Junior
5	Yoshimizu GONAI	GIS/Database	Yewubnesh Bekele	Junior
6	Takeshi KUWANO	Geological survey/analysis 1	Solomon Gera	Senior
7	Makito NODA	Geological survey/analysis 2	Zulfa Abdurahman	Senior
8	Shoji TSUCHIYAMA	Landslide Monitoring /Early-Waning system	Tesfaye Shewa	Senior
9	Shigekazu FUJISAWA	Hydrological Analysis	Demis Alamerew	Senior
10	Naohiro ISOGAI	Geophysical exploration /analysis	Tadesse Lema Sisay Alemayehu	Senior Junior
11	Shigekazu FUJISAWA*	Landslide stability analysis	Zulfa Abdurahman	Senior
12	Masao YAMADA	Landslide integrated analysis	Yewbnesh Bekele	Junior
13	Takashi SUZUKI	Drilling Techniques	Bayu Wedajo	Senior
14	Yoji KASAHARA	Rockfall/debris flow survey /analysis	Biruk Abel	Junior
15	Kazuo FURUKATA	Project Coordinator	(Tadesse Lema)	
16	Masami TAKAHATA	Project Coordinator	(Leta Alemayehu)	
17	Yosuke YAMAMOTO	Project Coordinator	(Leta Alemayehu)	

** Mr. Fujisawa is assigned to two roles of Hydrogeological Analysis and Landslide Stability Analysis. Therefore, the total number of experts is 17.*

1.5.3 Notable Events in the Project

Most of the planned schedule and tasks were executed in a satisfactory manner and the technical transfer was implemented smoothly. However, some activities were delayed due to natural conditions and a lack of mutual understanding on aspects written in the M/M and S/W, which were signed in December 2009. These issues are described as follows;

a. Delay in Topographic Mapping

The topographic mapping on a scale of 1:5,000 and 1:10,000 shall be compiled based on satellite imagery and aerial photo interpretation, which was to be conducted in April and May. However, cloudy weather conditions during this period prevented any satellite imagery or aerial photography being taken. The accuracy of the data should be 0.5 m to make contour maps at the abovementioned scales, but the Study Team were forced to use manual mapping and a contour map created using DEM (Digital Elevation Model) files from Aster Satellite imagery (accuracy of 7-10m in vertical section and 30m in horizontal section). Accordingly, the Study Team worked with low accuracy maps to represent the results of field survey for almost 2 months. On 10 June 2010, the satellite GEO EYE successfully captured the imagery covering almost the whole area of the targeted site. Since then, the topographical mapping both on ground surface and interpretation of satellite imagery has started. The final topographical map output was finalized on 24 October 2010. Since then, all the survey results were transferred to the maps available at the required accuracy.

b. Delay in Drilling Program

There were some misunderstandings on the undertakings of each country described in the Scope of Work discussed and undersigned on December 2009. The major point was that the budget for the drilling survey was not prepared by the GSE. GSE informed the Study Team that drilling issues should be discussed in more detail before starting the program as the drilling works are very expensive compared to other investigations. Both parties tried to resolve the problem involving relevant authorities such as ERA, MoFED and JICA Ethiopia Representatives, and held a JCC meeting amongst the parties. It was finally granted by JICA headquarters to prepare the budgets for drilling activities by JICA. However, the GSE shall prepare the budgets for the next fiscal year for drilling, and in return to this preparation, the Seminar in Japan will be postponed to the next fiscal year. It took almost 2 months to solve this issue, and accordingly many works related to the drilling were also delayed. The most negative impact of the delay to the drilling was that instruments and devices to monitor the movement of landslides were mostly installed after August, which cannot detect the landslide soil mass movement during the rainy season (starting from around July to September). The final drilling was completed on 15 October 2010. The monitoring period of each site varies on the timing of the drilling. This may affect all the necessary analysis of landslide movement as well as the slope stability analysis. However, the Study Team and the counterparts jointly made maximum effort to catch up the initial schedule.

c. Budget Allocation for the Fiscal Year 2012

Among the outstanding issues, most critical items for the smooth implementation of phase 2 and 3 of the Project are recognized as drilling and budget arrangements. In regard to the 2nd JCC (Appendix), the budget for the drilling shall be arranged by the GSE. However, the Ethiopian fiscal year is starting July 2004 E.C. (2011 G.C.) when the rainy season starts. The past Project experiences indicate that drilling in the rainy season is not effective, and also another rainy season’s monitoring measurement would be lost. Hence it has been concluded that drilling should start well ahead of the rainy season (before June, 2011). In view of this the drilling plan is scheduled to start from middle of April, 2011 G.C. Nevertheless, no budget can be made available before July, 2011 G.C, as we are still in the 2003 E.C (2009-2010 G.C) Ethiopian fiscal year. In addition the drilling activity includes such matters as compensation to the landowner and preparation of access roads. To cope with these matters discussion was held as described below.

Discussion was made whether the GSE can secure the budget within the fiscal time frame of this year (Ethiopian fiscal year 2003), i.e., any remaining budget of GSE program which might be transferred to the Project for early drilling activity. However MoFED representative stressed that it is not possible to transfer the budget among completely different projects. He also suggested the use of external budget from different source of donors or NGO’s (from such funds as those not fully utilized in their different projects). This has been found to be not possible, as the donors have their own restrictions on their usage of the budget.

During the discussion only two options were left. One was to continue the drilling program with the budget from JICA by fully compensating the consumables of the previous drilling program and allocate the remaining budget to drill as many boreholes as can be from the 19 planned ones. The other is to ordinarily prepare the budget for drilling in 2004 E.C (2010-2011 G.C) by GSE, and start drilling after June, 2010 G.C. The first was considered less practical as a certain number of boreholes would still be left incomplete while the second option would be even worse that all the boreholes would be drilled after the important time of the rainy season leading to the same problem as before of losing information at a critical time. Following this, a compromise was put forward by the Study Team.

It was suggested to utilize the remaining budget of the drilling for phase 1, and purchase minimum consumables enough for drilling in the next phase. The rest of consumables would be covered by the budget prepared for the fiscal year of 2004.

In reply, the MoFED confirmed that detailed budget allocations can be rearranged with in the proposed project provided there is sufficient justification made. Detailed explanations and reasonable backgrounds of the usage of the budget were also discussed. With regard to the last option, it was concluded that the most reasonable and demand oriented resolution was to take the following steps.

1. JICA Study Team shall make the detailed calculation on their drilling budget and clarify current balance
2. GSE shall prepare a proposal for budget of drilling for a total of 19 boreholes
3. The drilling section of GSE shall calculate the minimum cost required for drilling of the 19 boreholes.
4. JICA study team shall re-examine the budget anticipated to start drilling in coming April 2011 G.C.
5. At the end of June 2011 G.C (end of Ethiopian fiscal year 2003), the remaining drilling and the consumables expense shall be calculated.

Based on the original budget allocated for the Project by GSE, detail reconciliation will be made between MoFED and GSE to modify the expense items in the budget.

d. Preparation and Execution of Additional Drilling

Since the delay of the drilling program of Phase I, 19 additional drilling was proposed and agreed by the Project members and stakeholders at third JCC. Additional planned boreholes are aimed to clarify the slip plane and to monitor the movement of the landslides. However the proposed sites are mainly located at the center of the farmland which was not able to drill at the rainy season due to the following reasons.

1. It may take some time to secure the target site as compensation and negotiation with the land owner shall be required.
2. Road construction for the drilling rig is required for the target area. But the major components of the land surface to the target site is consists of mud and clay.

Therefore, it is vital to start the drilling works before the rainy season to secure timely work program. At the time of the meeting of JCC 3 and the meeting of JCC4 (10 May 2011) it is therefore emphasized on ERA’s involvement which organization has experiences and heavy machinery on construction of the temporary road for drilling.

Prior to the preparation of the road construction (middle of April 2011), notification and compensation meeting was held with various local government organization and land owners for clarification of procedures for the permission of land use for the drilling work.

At the time of JCC4 held on May 2011, the drilling crew of GSE is ready to work at the site. The ERA started their preparation activities since April for supporting the construction of temporary roads. The drilling crew started their work at the end of May.

However, until the preparation of this report, temporary road construction has not been made. The drilling plan has been revised to drill the accessible targets which the number to be drilled has been modified into 7 instead of 19.

1.6 Landslide survey/analysis manual preparation

A manual on landslide surveys and analysis, based on the results of the Project will be made. The basic outline of the manual is given in Table 1.6.1.

Table 1.6.1 Content of the landslide survey/analysis

Subject	Manual content
1.Preliminary survey	Summary and purpose of the preliminary survey. Basic survey methods such as documentation research and geomorphological analysis.
2.Planning	Summary and purpose of the planning. Method of determining facilities to be preserved in the field reconnaissance, and confirming scale and extent of landslides and their movement aspect. Also, methods regarding the type and location of monitoring equipment installation.
3.Survey	Summary and purpose of the surveys. Detailed description of the types, methods and purpose of observation equipment for surveys of topography, geology, slip surface, ground movement, groundwater, and soil property testing.
4.Analysis	Method of handling and analyzing the data acquired in the surveys. And overall analysis techniques for the field survey results.
5.Countermeasures	Method of reflecting analysis results in road countermeasures.
6.O & M	Method of operating and maintaining the observation equipment

Chapter 2

Natural Condition of the Abay Gorge

2 Natural Condition of the Abay Gorge

2.1 Topography

2.1.1 General landforms

Macro landforms consist of a basaltic lava plateau (Eocene period flood lava), with an elevation of about 2,400 m, and slopes that are dissected by the Abay River. The elevation of the valley bottom at Abay Bridge is 1,060m above mean sea level. The width of the valley is approximately 15 to 20 km at the edge of the lava plateau. The average slope angle from the edge of the lava plateau at the narrowest section is about 9 degrees.

Lateral slopes of Abay Gorge consist of several levels of cliffs, colluvial slopes and denudation slopes. There are seven steps of cliffs observed, and those cliffs are highly resistant to erosion. Three cliffs at the top consist of basalt lava, three cliffs in the middle consist of limestone and shale, and two cliffs at the lower part of the valley consist of sandstone. Many denudation terraces have been formed above the cliffs. Very thin soil layers and some debris washed out from the upper slope have deposited on these denudation terraces. At the foot of the cliffs, gentle slopes with fallen rocks from the cliffs form wide colluvial slopes. Though there are a lot of boulders on the slope surface, the size of the debris becomes smaller as the distance from the slope becomes further. Gentle slopes spread out widely mid-way down the Abay Gorge. These gentle slopes develop on the areas of limestone and shale, which are covered by residual soil and colluvial deposits. Several landslides are apparent at these slopes.

Major tributaries on the slope of Goha Tsiyon side are the Mekentuta River and unnamed river. The Mekentuta River crosses the road at ST.1+150 and flows down in another westerly direction. Several small channels cross the road at Filiklik Village. As the whole slope of this area forms a concave slope, most of the small channels disperse and join the Abay River. The unnamed river flows parallel to the road between ST.17km and ST.18km with steep cliffs of sandstone. The main tributary on the slope of Dejen side is the Ado Wedeb River and its branches. From ST.20km to ST.22km the river flows down parallel to the road with steep cliffs of sandstone. From ST.22km to Dejen, small channels are distributed through the catchment area of Wedeb River and cross the road at several points.

2.1.2 Landform of each segment

a. Vicinity of ST.0+000 to ST.7+00

The elevation of the start point of the Project, at the edge of lava plateau near Goha Tsiyon, is 2,464 m. From ST.0+000 to ST.7+00, the elevation descends from 2,464 to 1,980 m over a short distance (Photo 2.1.1 and 2.1.2). Basaltic plateau forming cliffs and several terraces are observed as shown in the photograph below. The cliffs are 20 to 50 m in height, and the terraces are 200 to 400 m wide. Some parts of the terraces reach a width of 1 km.

Photo 2.1.1 Basaltic plateau forming cliffs and terraces

Photo 2.1.2 Cliffs and terraces

b. Vicinity of ST.7+00 to ST.12+300

The elevation of this section ranges from 1,980 to 1,600 m. Colluvial slopes with talus deposits and debris flow deposits spread widely mid-way down the gorge (Photo 2.1.3). No distinct valleys and channels are seen.

Photo 2.1.3 Gentle slope between 1,980 and 1,600 m elevation on the Goha Tsiyon side

c. Vicinity of ST.12+300 to ST.16+700

The elevation of this section ranges from 1,600 to 1,250 m (Photo 2.1.4). The main part of this section is on areas of limestone and shale with thick colluvial deposits. The lower part of this slope is denudation slope and terrace of sandstone and some parts of the terrace are dissected deeply by river erosion.

Photo 2.1.4 Steep slope between 1,600 and 1,250 m on the Goha Tsiyon side

d. Vicinity of ST.16+700 to ST.22+000

The elevation of this section ranges from 1,250 to 1,100 m, the lowest section between Goha Tsiyon and Dejen (Photo 2.1.5 and 2.1.6). Alternation of sandstone and siltstone is observed on the side of the gorge. Tributaries of the Abay River dissect the sandstone terrace deeply, but the deep tributaries become shallow valleys around 2 to 3 km from the Abay Gorge.

Photo 2.1.5 Abay Gorge bottom between 1,250 and 1,100 m

Photo 2.1.6 Deeply dissected gorge viewed from the Dejen side at 1,250 m

e. Vicinity of ST.22+000 to ST.27+800

The elevation of this section ranges from 1,250 to 1,700m on the Dejen side (Photo 2.1.7). Deep valley with steep slope can be observed. Along the road, there are no many deep valleys on the Dejen side. Shallow valleys are dominant over deep valleys.

Photo 2.1.7 Gentle slope between 1,250 and 1,700 m

f. Vicinity of ST.27+800 to ST.31+850

The elevation of this section ranges from 1,700 to 1,980 m on the Dejen side (Photo 2.1.8). Gentle colluvial slopes with talus deposits and debris flow deposits spread widely mid-way down the Abay gorge. Shallow valleys are dominant over deep valleys.

Photo 2.1.8 Gentle slope between 1,700 and 1,980 m with many landslides apparent

g. Vicinity of ST.31+850 to ST.40.580

The elevation of this section ranges from 1,980 to 2,400 m on the Dejen side of basaltic plateau. In this plateau, cliffs and several terraces are observed as shown in the photograph below, but the width of the terraces are not as wide as the slope on the Dejen side (Photo 2.1.9). Though several terraces can clearly be observed to the east of Dejen Town, terraces are eroded and not clear to the south of Dejen Town.

Photo 2.1.9 Lava plateau, cliffs and terraces between 1,980 and 2,400m on the Dejen side

2.2 Climate

2.2.1 Rainfall

Ethiopia lies between latitudes 3°00’ to 15°00’ north, and longitudes 33°00’ to 48°00’ east. It is a landlocked country surrounded by five nations (Somalia, Sudan, Kenya, Eritrea, and Djibouti).

Two thirds of the country is alpine, at altitudes over 1,500 m to 4,000 m, and has very steep mountains. The Ethiopian alpine belt could be classified in Koeppen's climate zones (Figure 2.2.1). In a revised version by Trewartha, alp climate (sign H) was added. The alp climate in a low latitude area has a small annual range of temperature, and although it maintains the characteristics of low land tropical climates, the temperature is generally low. Moreover, it is comparatively cool throughout a year for its latitude. This kind of climate is called "eternal spring."

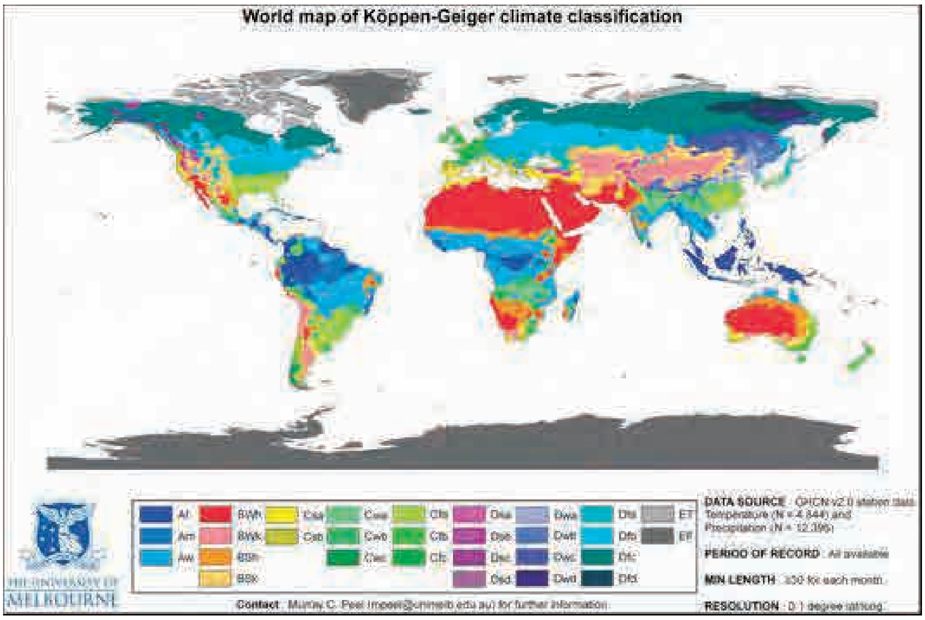


Figure 2.2.1 Köppen-Geiger Climate Classification Map

Abay Gorge, the target area of the Project, is in the upstream of the world's longest river, the Nile, and about 85% of its total volume of water comes from the Blue Nile of Ethiopia. The rainy season in the Abay Gorge is from June to September, with July and August accounting for about 50% of annual precipitation.

Existing rainfall observation records in the Abay Gorge area are 49 years and 34 years for Dejen town and Filiklik village respectively. In addition, the annual average rainfall is 1,394 mm/year and 1,195 mm/year for Dejen and Filiklik respectively (Figure 2.2.2).

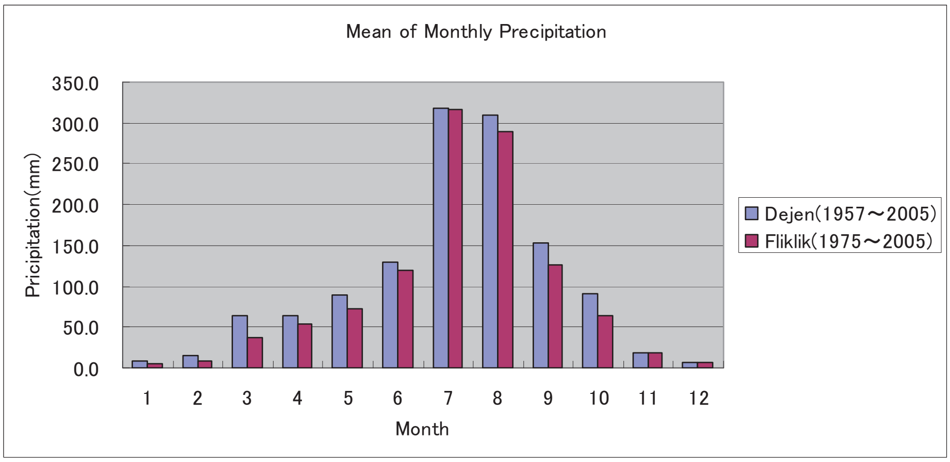


Figure 2.2.2 Mean of Monthly Precipitation

2.2.2 Temperature

According to the data of WWIS (World Weather Information Service), the temperature in Addis Ababa ranges from a minimum of 15℃ and a maximum 25℃ (Figure 2.2.3).

The Abay Gorge has an altitude difference of about 1,000 m from its highlands to lowlands. Given the common calculation of temperature change, 0.6℃ to 0.7℃ per 100m, there will be a difference of 6℃ to 7℃ between high and low lands.

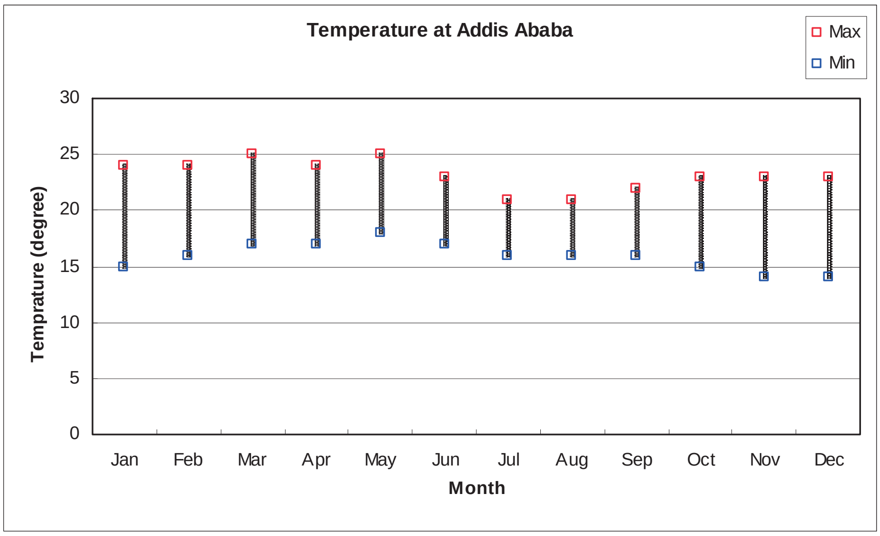


Figure 2.2.3 Annual temperature at variation of the Addis Ababa town

2.3 Geology

The geology of the Abay Gorge area is characterized by stratified sedimentary rocks capped by basaltic plateau. Figure 2.3.1 indicates a general geological map of Ethiopia (Tefera et al., 1996).

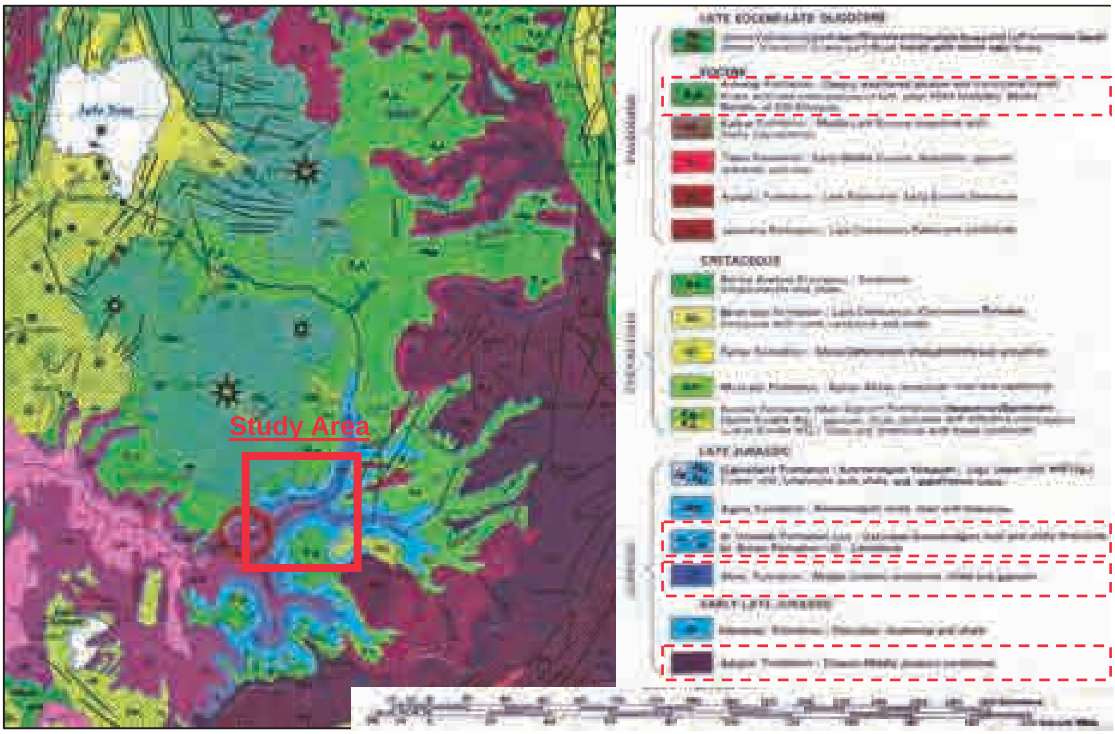


Figure 2.3.1 General geological map of Ethiopia (Tefera et al., 1996)

According to Jepson and Athearn (1961) and Tefera et al. (1996), the geology in the area is mainly classified into four formations. Table 2.3.1 shows the geological classification in the area.

Table 2.3.1 Geological classification in the Abay Gorge (Tefera et al., 1996)

Era	Name	Geology/ Descriptions
Tertiary (Paleogene)	Ashangi Formation	Deeply weathered alkaline and transitional basalt flows with rare intercalations of tuff
Jurassic	Antalo Formation	Limestone
	Abay Formation	Middle Jurassic limestone, shale and gypsum
	Adigrat Formation	Triassic to middle Jurassic sandstone

Although the sedimentary and volcanic rocks in the area are exposed largely as symmetrical stratigraphy on both sides of the Abay River, the detailed sequences are unevenly distributed. The sequence in the area is not disturbed due to major faults and is generally horizontally stratified. However, there are a lot of minor normal faults with a down throw of 1-2 meters. Figure 2.3.2 shows a schematic geological cross section of the Abay area (Ayalew and Yamagishi, 2003). The characteristics of the stratigraphy on the major sequences are also described by Almaz and Tadesse (1994).

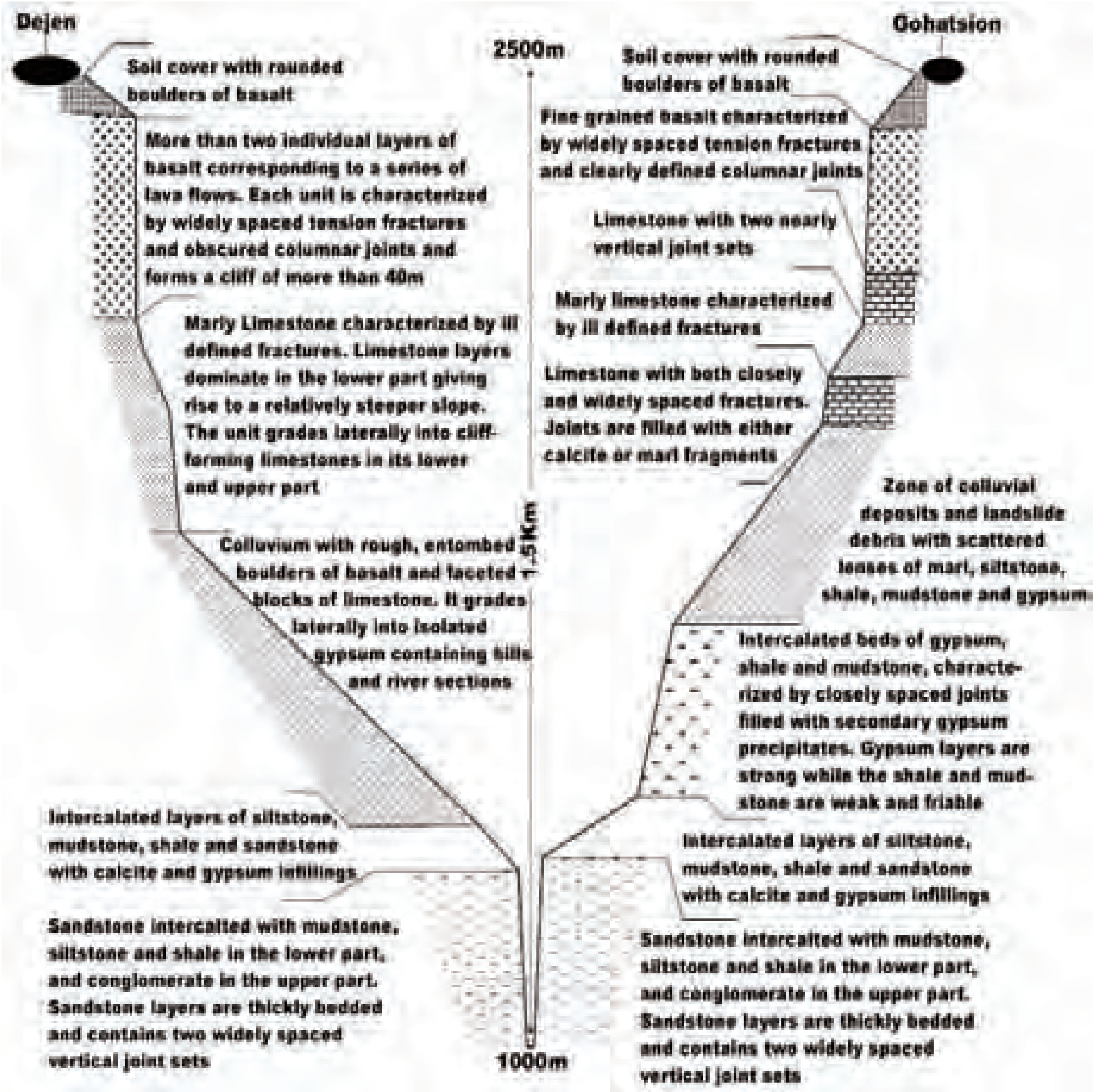


Figure 2.3.2 Schematic geological section in the Abay Gorge (Ayalew and Yamagishi, 2003)

Chapter 3

Landslide Survey

3 Landslide Survey

3.1 Hydrological Survey

3.1.1 Existing data interpretation

The five following meteorological observation stations are in the vicinity of the target area.

Table 3.1.1 Existing data List

Observation station name	Latitude (N)	Longitude (E)	Height (m)	Observation
Goha Tsiyon	10° 00.408'	38° 14.755'	2,500	rainfall, temperature
Filiklik	10° 03.200'	38° 14.886'	1,860	ditto
Dejen	10° 10.2638'	38° 09.0359'	2,420	ditto
Abay Sheleko	10° 06.7507'	38° 09.4057'	1,819	ditto
Yetnora	10° 14.696'	38° 14.696'	2,430	rainfall, temperature, radiation, sunshine, evaporation, humidity, wind direction/velocity

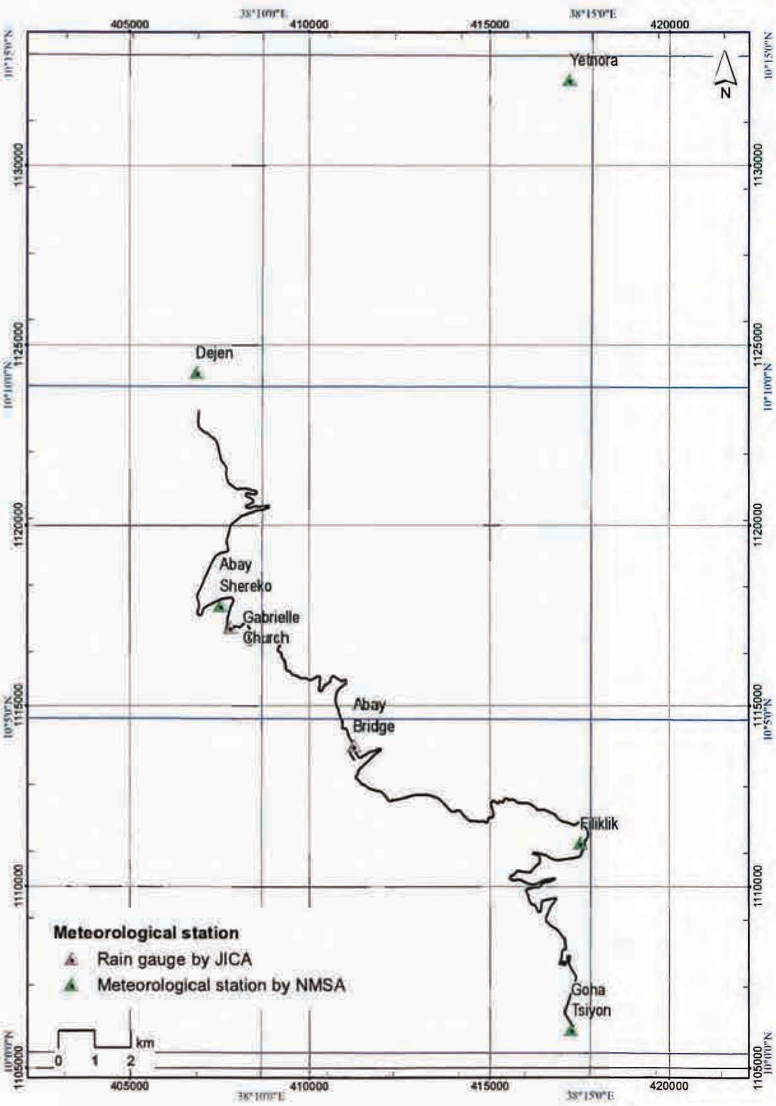


Figure 3.1.1 Location map of metrological station

The above-mentioned observatories are under the jurisdiction of the Ethiopia National Meteorological Services Agency (NMSA), which receives observation data, recorded daily at 9 am, from each observatory on a monthly basis.

NMSA manages the collected observation records with a personal computer, and maintains the data. The data management, however, involves insufficient checks, with abnormal values apparent in the records that are possibly measurement mistakes.

Photo 3.1.1 Existing Meteorology Station

Monthly rainfall data and return period in Goha Tsiyon station are shown in Figure 3.1.2 to 3.1.6.

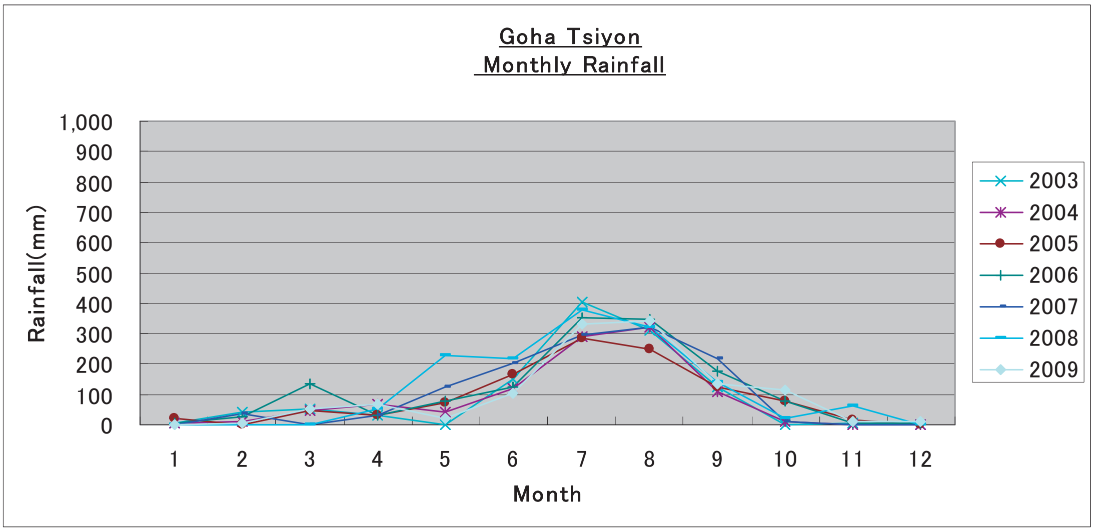


Figure 3.1.2 Monthly Rainfall (Goha Tsiyon)

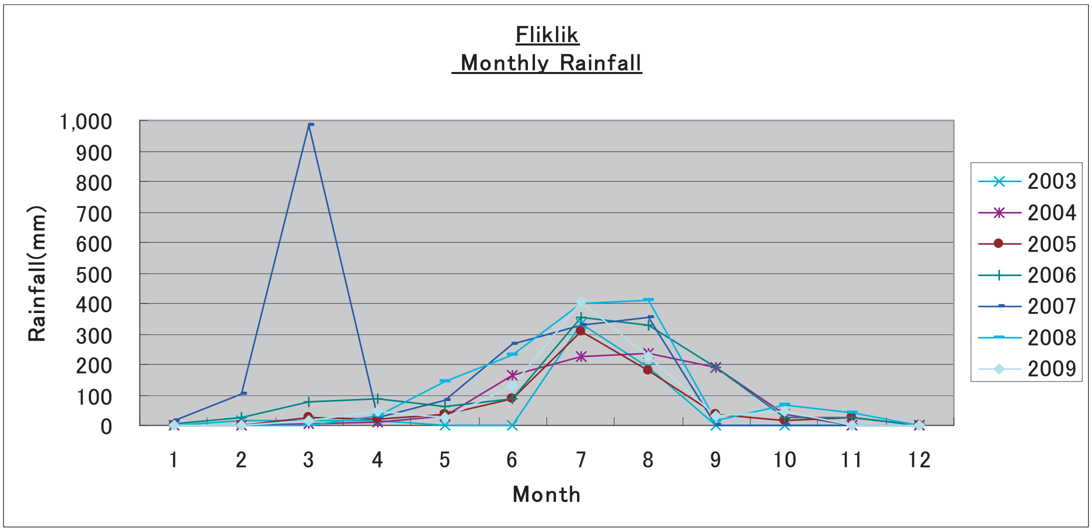


Figure 3.1.3 Monthly Rainfall (Filiklik)

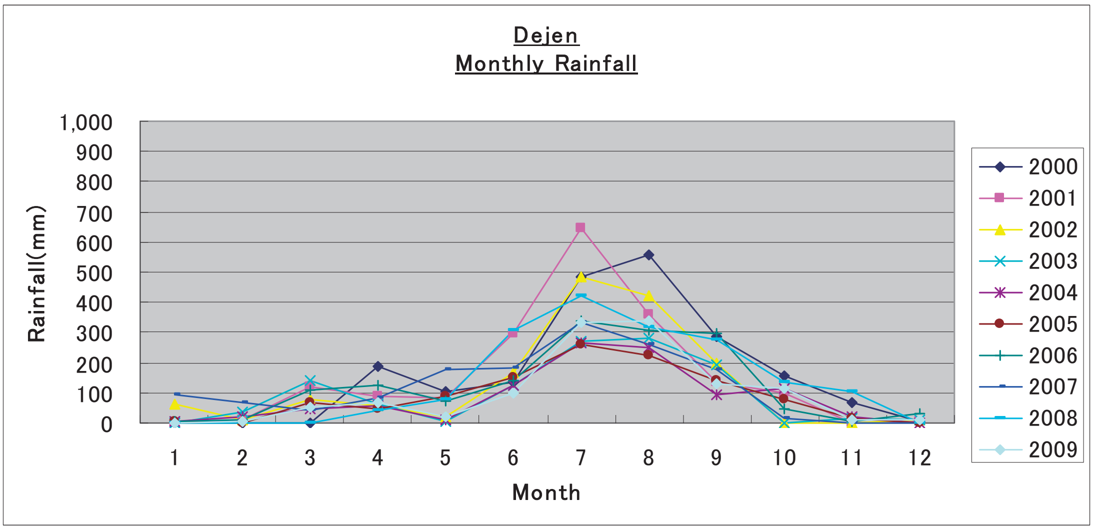


Figure 3.1.4 Monthly Rainfall (Dejen)

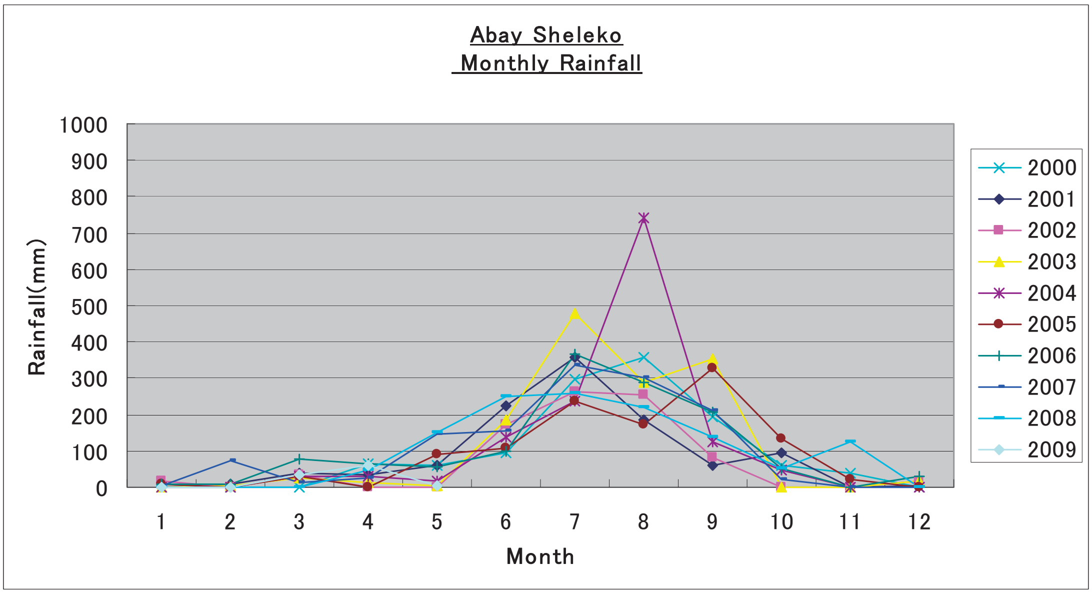


Figure 3.1.5 Monthly Rainfall (Abay Sheleko)

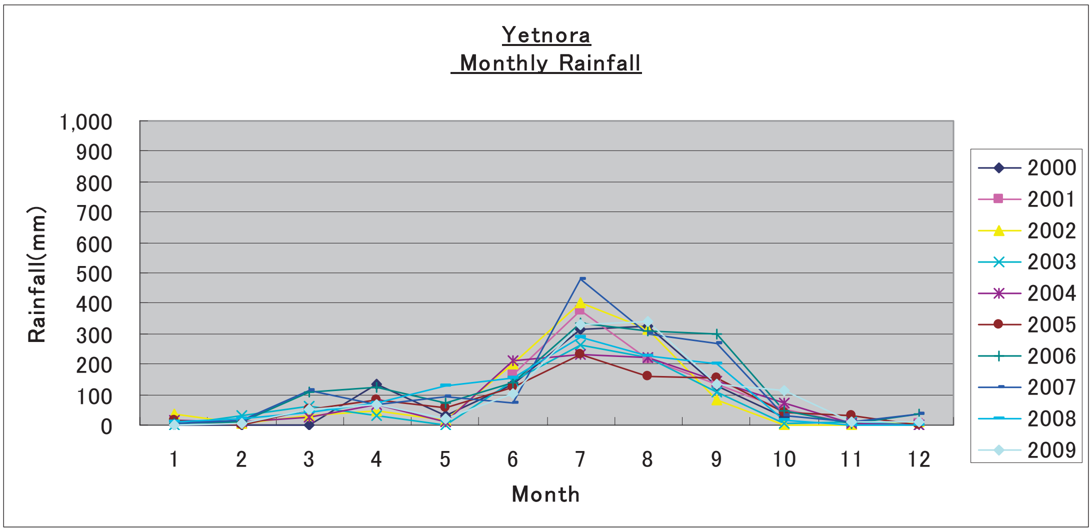


Figure 3.1.6 Monthly Rainfall (Yetnora)

When countermeasures for landslide are planed and designed, target rainfall amount should be set. The target rainfall is generally ether maximum rainfall in the past or calculated probability rainfall as a return period. Table 3.1.2 to 3.1.5 show the calculated probability rainfall as each return period at each site. The values are utilized in design phase for landslide countermeasures.

Table 3.1.2 Return Period (Goha Tsiyon)

Goha Tsiyon Annual Rainfall (mm)

Return Period	Thomas Method	Hazen Method	Gumbel Method
2	1173	1173	1164
5	1342	1320	1326
10	1439	1403	1433
20	1525	1476	1536
30	1572	1516	1595
50	1628	1563	1669
70	1664	1593	1717
100	1701	1623	1769
150	1741	1657	1827
200	1770	1681	1868
500	1857	1753	1999
1000	1921	1806	2098

Goha Tsiyon Annual Maxmam Daily (mm)

Return Period	Thomas Method	Hazen Method	Gumbel Method
2	54	54	54
5	68	66	68
10	76	73	77
20	83	79	86
30	88	83	91
50	93	87	97
70	96	90	101
100	100	93	106
150	104	96	111
200	107	98	114
500	115	105	126
1000	122	110	134

Table 3.1.3 Return Period (Filiklik)

Fliklik Annual Rainfall (mm)

Return Period	Thomas Method	Hazen Method	Gumbel Method
2	1179	1179	1203
5	1746	1657	1719
10	2144	1981	2061
20	2541	2295	2389
30	2775	2477	2577
50	3076	2708	2813
70	3277	2861	2968
100	3493	3024	3131
150	3744	3212	3317
200	3925	3346	3448
500	4520	3782	3866
1000	4991	4121	4182

Fliklik Annual Maximum Daily (mm)

Return Period	Thomas Method	Hazen Method	Gumbel Method
2	42	42	42
5	53	52	55
10	61	58	64
20	67	64	73
30	71	67	78
50	76	71	84
70	79	73	88
100	82	76	93
150	86	79	98
200	88	81	101
500	97	87	112
1000	103	92	121

Table 3.1.4 Return Period (Dejen)

Dejen Annual Rainfall (mm)

Return Period	Thomas Method	Hazen Method	Gumbel Method
2	1495	1495	1486
5	1847	1795	1819
10	2063	1975	2040
20	2260	2137	2251
30	2370	2227	2373
50	2504	2336	2525
70	2591	2406	2625
100	2682	2479	2730
150	2784	2560	2850
200	2856	2617	2935
500	3081	2795	3204
1000	3250	2927	3408

Dejen Annual Maximum Daily (mm)

Return Period	Thomas Method	Hazen Method	Gumbel Method
2	65	65	65
5	87	83	85
10	101	95	99
20	114	106	112
30	122	112	120
50	132	120	129
70	138	125	135
100	145	130	142
150	152	136	149
200	158	140	154
500	175	154	171
1000	188	164	184

Table 3.1.5 Return Period (Yetnora)

Yetnora Annual Rainfall (mm)

Return Period	Thomas Method	Hazen Method	Gumbel Method
2	1087	1087	1077
5	1271	1240	1280
10	1380	1329	1415
20	1476	1407	1544
30	1529	1449	1619
50	1593	1500	1712
70	1633	1532	1773
100	1675	1565	1837
150	1722	1602	1910
200	1755	1628	1962
500	1856	1707	2127
1000	1931	1764	2251

Yetnora Annual Maximum Daily (mm)

Return Period	Thomas Method	Hazen Method	Gumbel Method
2	43	43	43
5	52	50	53
10	57	55	59
20	62	58	66
30	65	60	69
50	68	63	74
70	70	65	77
100	72	66	80
150	74	68	84
200	76	69	86
500	81	73	94
1000	85	76	101

Here, the exceedance probability and the return period are explained for purpose of understanding the significance of hydrological survey in this report.

- **Hazen Plot Method**

Hydrology data *N* are rearranged in order of size, and it is referred to as x_1, x_2, x_3, ..., x_i in order of size. The probabilities of these *N* values occurring are all 1/*N*.

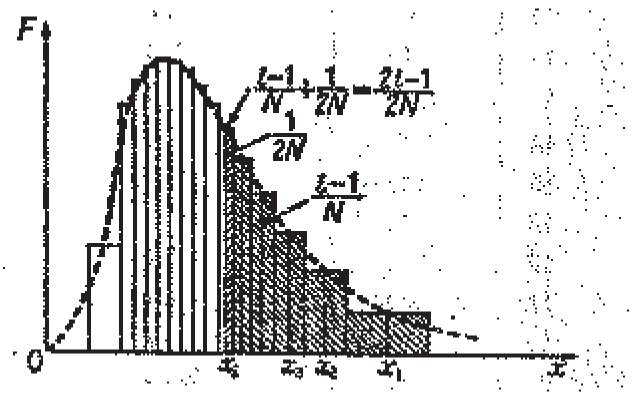


Figure 3.1.7 Exceedance Probability Curve

Taking consideration of the exceedance probability over *Xi*, the area up to *Xi* position is the lower-right-shaded area (*i*-1)/*N* plus the lower-left-shaded area. 1/2*N*, as explained in Figure 3.1.7. It is shown by the following formula.

$$Wi = (i-1)/N + 1/2N = (2i-1)/2N$$

Here, *Wi* is the exceedance probability of the *i*-th size, *i* is the reference value in order from the largest down, and *N* is the total number of reference values. This formula is called Hazen Plot. In addition, the non-exceedance probability formula is as follows.

$$Fi = 1 - Wi = 1 - (2i-1)/2N$$

- **Thomas Plot Method**

Thomas Plot is similar to the Hazen Plot. It is expressed as follows using the same signs.

$$Wi = 1 - Fi = i/(N+1)$$

- **Gumbel Method**

Probability *P*(*y*) which does not exceed the value *X* which has a maximum X_∞ of the arbitrary specimen of infinity number under certain conditions is given by the following formula.

$$P(y) = e^{-e^{-y}}$$

e is a base of a natural logarithm and *y* is a linear function of *X*.

$$y = a(X - b)$$

Although *e* is the base of a natural logarithm and *y* is a linear function of *X*, if it is written as *y*=*a* (*X*-*b*) here, constants *a* and *b* have an average value of *E*(*X*) about the universe of *X*, and a standard deviation of *S*; which have the following relationship.

$$a = 1/0.7797S$$

$$b = E(X) - 0.450S$$

Moreover, it is the average value *X* of a specimen about population mean value *E*(*X*). Population standard deviation *S* is made into the standard deviation sigma, and is represented by the following formula when *T*= 1/*W* (*T*: return period, *W*: exceedance probability).

$$T = 1/(1 - P(y)) = 1/(1 - e^{-e-y})$$

Here, $y=a(X-b)$,
$a=1/0.7797S$
$b=E(X)-0.450S$

As mentioned above, it becomes possible to calculate a return period.

The method of coming up with a return period is to choose a distribution function which best fits the variable quantities. And the parameter of the function is determined using actual data.

There are various methods of calculation according to what kind of function is applied and how the parameters are decided. Although, at present, there is no perfect method of giving an appropriate result in every case, the method that has comparatively high conformity, that which can be used quite easily are used.

3.1.2 Precipitation monitoring

The study team installed two rain gauges (tipping bucket type). The existing rain gauges are mostly installed near the main road. Locations were selected so as to be easy to make observations while being able to be protected against theft, and also being part way between the existing rain gauges. The locations of the newly installed rain gauges are as follows.

Table 3.1.6 Newly Installed Rain Gauges List

Observation station name	Latitude (N)	Longitude (E)	Elevation (m)
Abay Bridge	10°04.6498′	38°11.4483′	1,079
Gabrielle Church	10°06.4308′	38°09.5496′	1,739

Photo 3.1.2 Newly Installed Rain Gauge Station

The duration of the precipitation monitoring on the two sites is as follows. The location of each station is shown in Figure 3.1.1.

Table 3.1.7 The duration of the precipitation monitoring

Station name	Starting day	Missing period	Remarks
Abay Bridge	29.Jun.2010	13.Aug.2010～3.Sep.2010 15 Feb. 2011～26 Mar. 2011 24 Ari. 2011～ 4 Jul. 2011 27 Jul. 2011～ 18 Aug. 2011	Data missing Cable disconnected
Gabrielle Church	2.Jul.2010	14.Jul.2010～23.Jul.2010 23.Aug.2010～18.Oct.2010 7 Dec.2010～1 Feb.2011 3 Aug.2011～19 Sep.2011	No battery Bad electrical contact Data logger trouble

3.2 Topographical Survey

3.2.1 Satellite Imaginary

New satellite imagery from the high resolution Geo-Eye1 (resolution 0.5 m) was taken for the topographic mapping (1/10,000 and 1/5,000).

Imagery was acquired, after waiting for a chance since April, on two days when there was almost no cloud cover, June 3 and 6, 2010. The imagery taken is shown in the figure below. Details of the data are as follows.

- 2 color stereo pairs (total: 4 sheets)
- Coordinate system: WGS84
- Projection method: UTM
- File type: GeoTiff
- Including RPC file

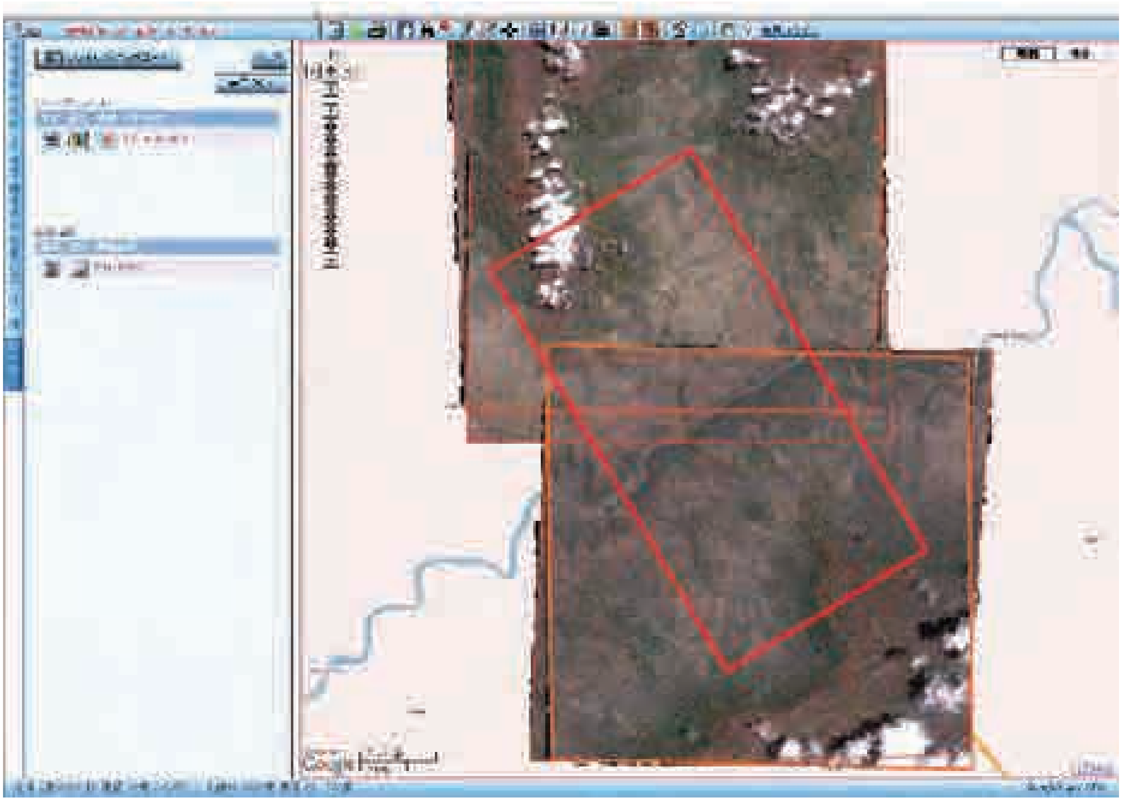


Figure 3.2.1 Acquired imaginary

3.2.2 Topographic mapping

a. Ground control point survey for topographic mapping

Ground control points, horizontal (ground control point survey) and height (ordinary leveling), necessary for aerotriangulation were established along 42 km of Route 3 between Goha Tsiyon and Dejen. The field work was undertaken over 51 days, from May 12 to July 1, 2010; and the number of points established is as follows:

i） Control point survey by GPS: 10 points
ii） Control traverse survey by total station: 60 points
iii） Ground control point survey: 20 points
iv） Ordinary leveling: 84 points

Further, the equipment used was as follows:

- Surveying GPS devices: 3 sets
- Total station: 1 set
- Auto level: 1 set

<u>i) Control point survey by GPS</u>

The fact that there were six public control points and 12 public leveling points by the Ethiopian Mapping Authority (EMA) was confirmed while in Ethiopia, however, these could not be found. Therefore, the control points used by Kajima Corporation to repair the road between Goha Tsiyon and Dejen were used as the basis for mapping. The time spent on data acquisition in the GPS survey for baselines less than 10 km was one hour, while baselines 10 km or longer was two hours. As a result, an accuracy meeting JICA's overseas surveying regulations could be achieved.

<u>ii) Control traverse survey by total station</u>

Traverse points were distributed in the plotting area, along Route 3 between Goha Tsiyon and Dejen, with the control points fixed in the GPS survey used as known points. A fixed traverse was used to link the GPS points on each line. The accuracy of the horizontal positions was within the limits, as shown below.

CP-08 to GPS-02	1/14,245
GPS-02 to GPS-11	1/18,406
GPS-11 to CP-03	1/2,171,340
CP-03 to CP-01	1/27,417

Further, heights were found using the elevation calculation. The output was as follows.

GPS-02 to BM-173	1/143,321

<u>iii) Ground control point survey</u>

The ground control point survey was implemented based on the abovementioned traverse points. Points considered to definitely showing up on the imagery such as the corners of houses and pedestrian crossings were selected, while also maintaining as even a distribution as possible. As a result, all of the ground control points were able to be pricked on the imagery.

iv) Ordinary leveling

The height of each point was found by indirect leveling based on the abovementioned traverse point heights. Effort was made to select points in flat locations and where pricking is definitely possible. As a result, most of the elevation points could be pricked on the images.

b. Digital topographic mapping

The digital topographic mapping implementation - generally using the stereo imagery data acquired in the abovementioned manner - involved various processes such as aerotriangulation, digital plotting and digital editing. The basic specifications for the digital topographic mapping were as follows.

- Digital topographic mapping specifications: In accordance with JICA overseas surveying specifications
- 1/10,000 topographic mapping area and contour lines: An area of 180 km^2 (9 km x 20 km) from Goha Tsiyon to Dejen in the Abay Gorge was mapped. Further, the contour interval (intermediate contour) was 10 m.
- 1/5,000 topographic mapping area and contour lines: An area 300 m either side of the center line of Route 3 from Goha Tsiyon to Dejen (42 km) was mapped (approx. 25.2km2). Further, the contour interval (intermediate contour) was 5 m.
- Topographic map outputs: One hard copy set and one digital data set of both the 1/10,000 and 1/5,000 topographic maps were delivered.

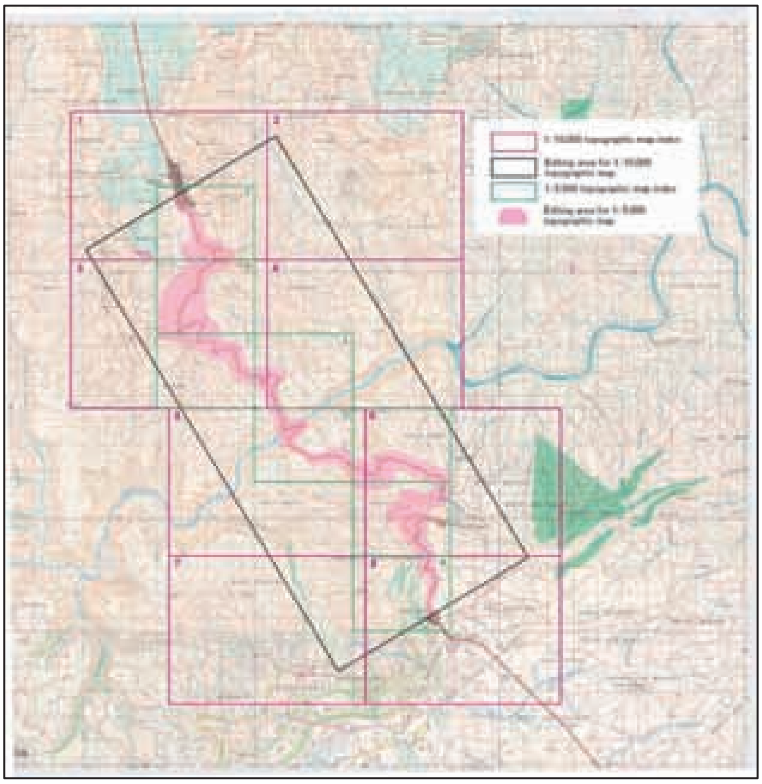


Figure 3.2.2 The area of the topographic mapping

c. Cross-section survey

The purpose of the cross-section survey was to obtain base data for planning the geophysical exploration and considering the landslide stability analysis. The basic specifications and work amount of the cross-section survey were as follows.

- Survey area: Monitoring sites presented after consideration by the Study Team
- Survey items (cross-section location specifications): A maximum area of 500 m from slip surface origin to toe was surveyed
- Outputs: Cross-sections (scale of 1/100 length; 1/200 width)

The cross-section survey actually entailed six cross-sections from Goha Tsiyon to the Abay River (B0-01 to B0-06) and seven cross-sections from the Abay River to Dejen (B0-07 to B0-11). The survey method employed was to determine the elevation and horizontal positions from the base traverse points. Moreover, most of the cross-section lines were surveyed and recorded in the field book by the counterparts. Almost no mistakes were found upon closely investigating the calculation results.

3.3 Preliminary Geomorphologic Survey

3.3.1 Vicinity of ST.0+000 to ST.1+200

A horse-shoe shaped depression surrounds the S-curve in the road near ST.0+000, which is the scarp of an old landslide (A). Within that, several smaller landslides, thought to have occurred more recently, can be identified. Within this large landslide there is a smaller landslide formation (B).

Landslide (C) is interpreted as moving in-line with or obliquely - west-southwest - to the road, judging from the mound near the foot of the moving mass. There is only one river system here (D), which flows from Goha Tsiyon Town.

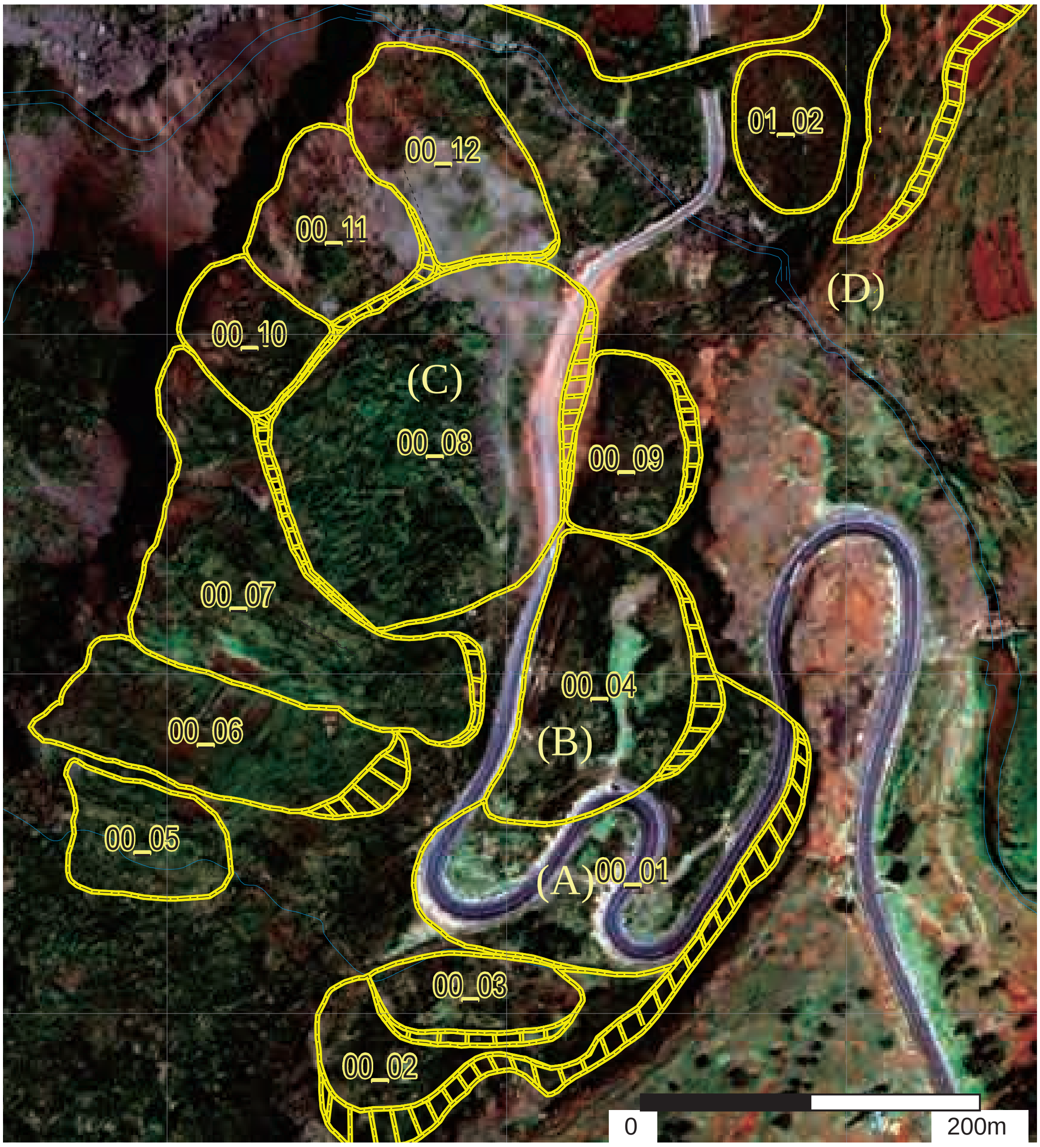


Figure 3.3.1 Satellite image interpretation ST.0+000 to ST.1+200

3.3.2 Vicinity of ST.2+400 to ST.6+000

Many large to small landslides can be confirmed in this area. Steps and cracks can be confirmed at (A), and minor deformations are considered to be active. Steps and cracks are confirmed at (B) also. Three river systems can be confirmed in this area (C) and (D).

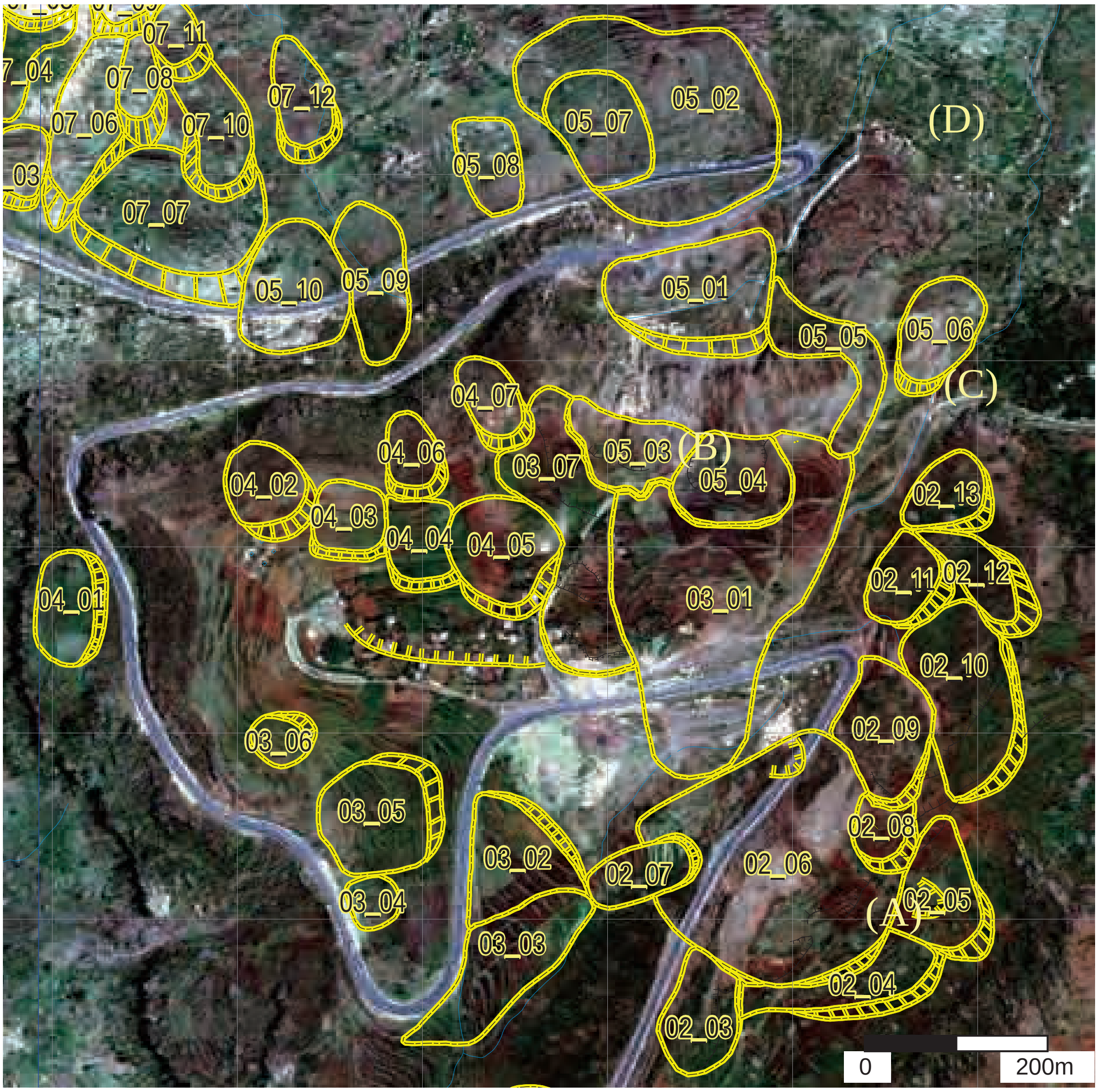


Figure 3.3.2 Satellite image interpretation ST.2+400 to ST.6+000

3.3.3 Vicinity of ST.22+200 to ST.24+700

Small landslides are scattered along the main road in this area. Movements are thought to be continuing recently due to the presence of new cracks in the main scarp at points (A) and (B). Three tributaries (D) to (F) are confirmed for the river system (C).

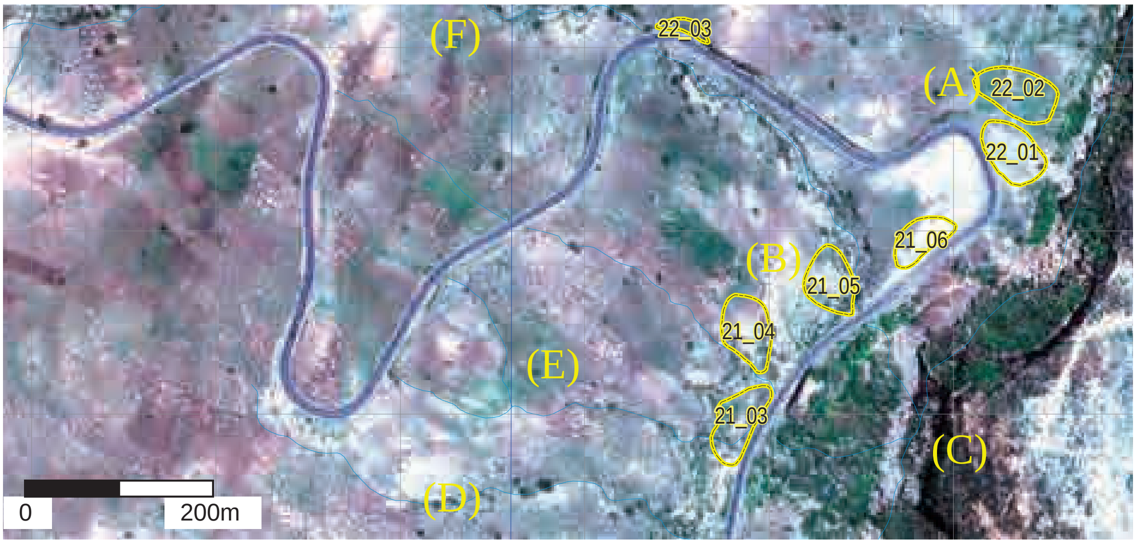


Figure 3.3.3 Satellite image interpretation ST.22+200 to ST.24+700

3.3.4 Vicinity of ST.28+200 to ST.29+700

There are many landslides in this area. Amongst the larger landslides there are overlapping secondary-landslides, many of which continue to be active. There are also many new landslides with main scarps. There are large river systems (A) and (B) surrounding the landslides, while amongst them, there are only a few systems.

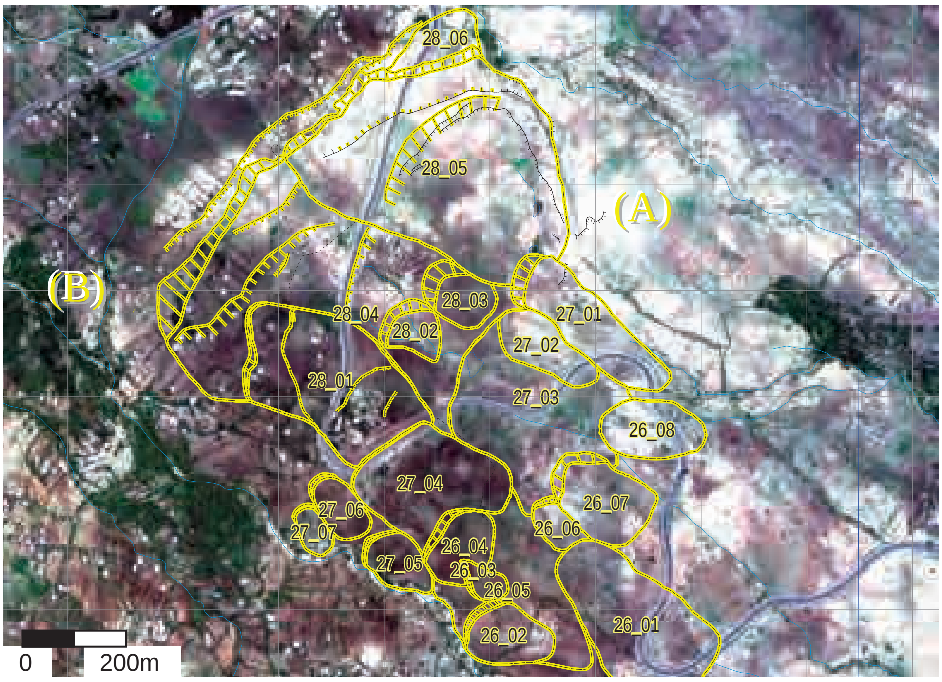


Figure 3.3.4 Satellite image interpretation ST.28+200 to ST.29+700

3.4 Geological Survey

3.4.1 Geology of the landslide area

In this section, the results of the field observation for geological stratigraphy are described.

The area is characterized by the central Ethiopian highlands. Geologically, the gorge is made by thick stratified Mesozoic sedimentary rocks and overlain by a series of basaltic lava flows. Adigrat Formation is covered conformably by Abay Formation and Antalo Formation, which were deposited Middle to Late Jurassic. Ashangi Formation which was deposited during Tertiary covers them partially.

Rock appearance height and its thickness are shown in Table 3.4.1. The details of each formation are explained as follows. Figure 3.4.1 is a geological map of this area as a result of the surveys, and Figure 3.4.2 is a schematic geological section of the Abay Gorge.

Table 3.4.1 Rock appearance height and its thickness

Era	Formation	Rock type	Dejen side		Height difference (m)	Goha Tsiyon side	
			Elevation (m)	Thickness (m)		Thickness (m)	Elevation (m)
			2440		80		2520
Tertiary	Ashangi F.	Basalt and Pyroclastic		380		380	
			2060		80		2140
Jurassic	Antalo F.	Upper limestone		550		500	
			1510		130		1640
		Gypsum		160		130	
			1350		160		1510
	Abay F.	Lower limestone		70		70	
			1280		160		1440
		Siltstone and Shale		40		120	
			1240		80		1320
	Adigrat F.	Sandstone		210		290	
			1030		0		1030

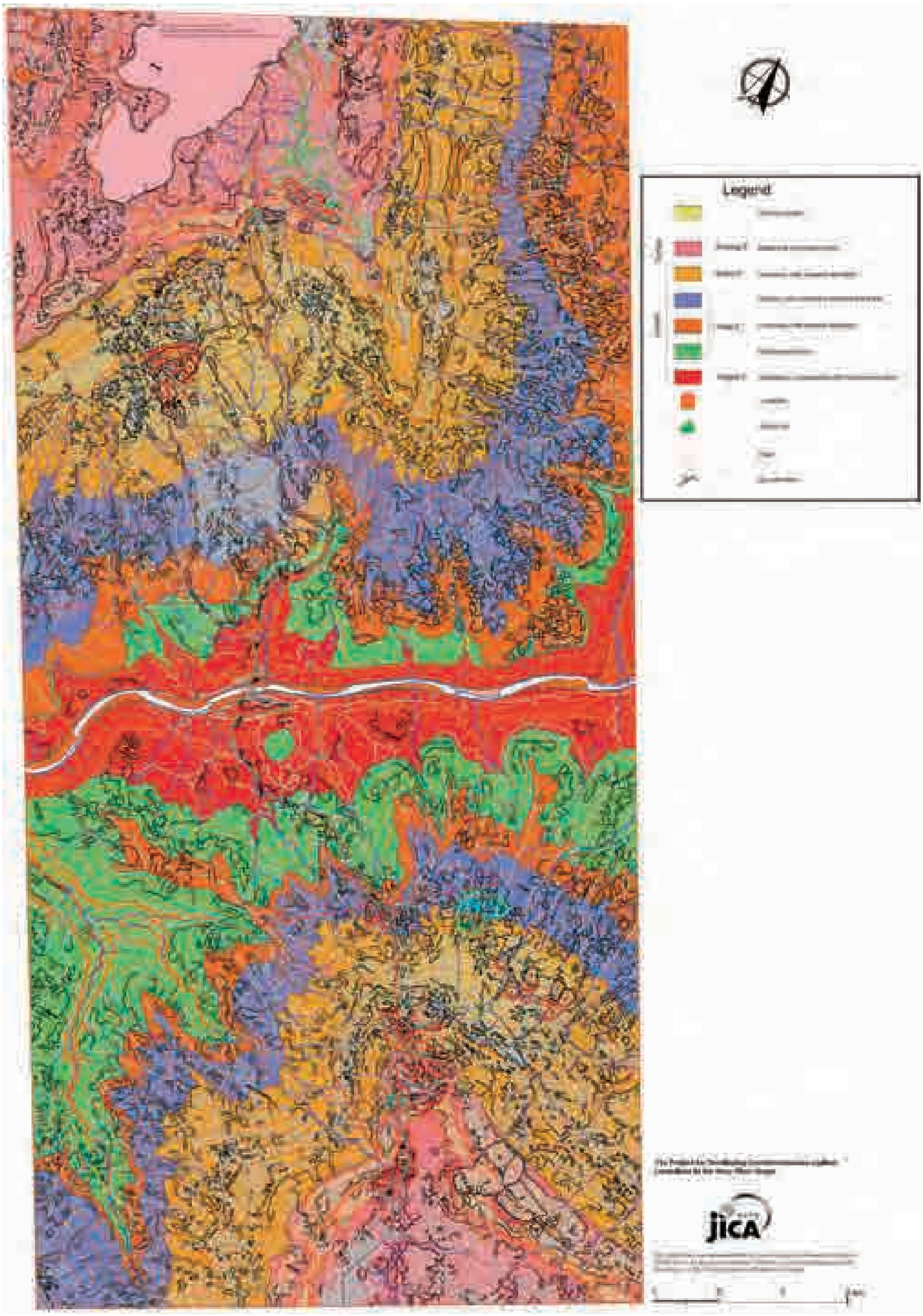


Figure 3.4.1 Geological map of Abay Gorge

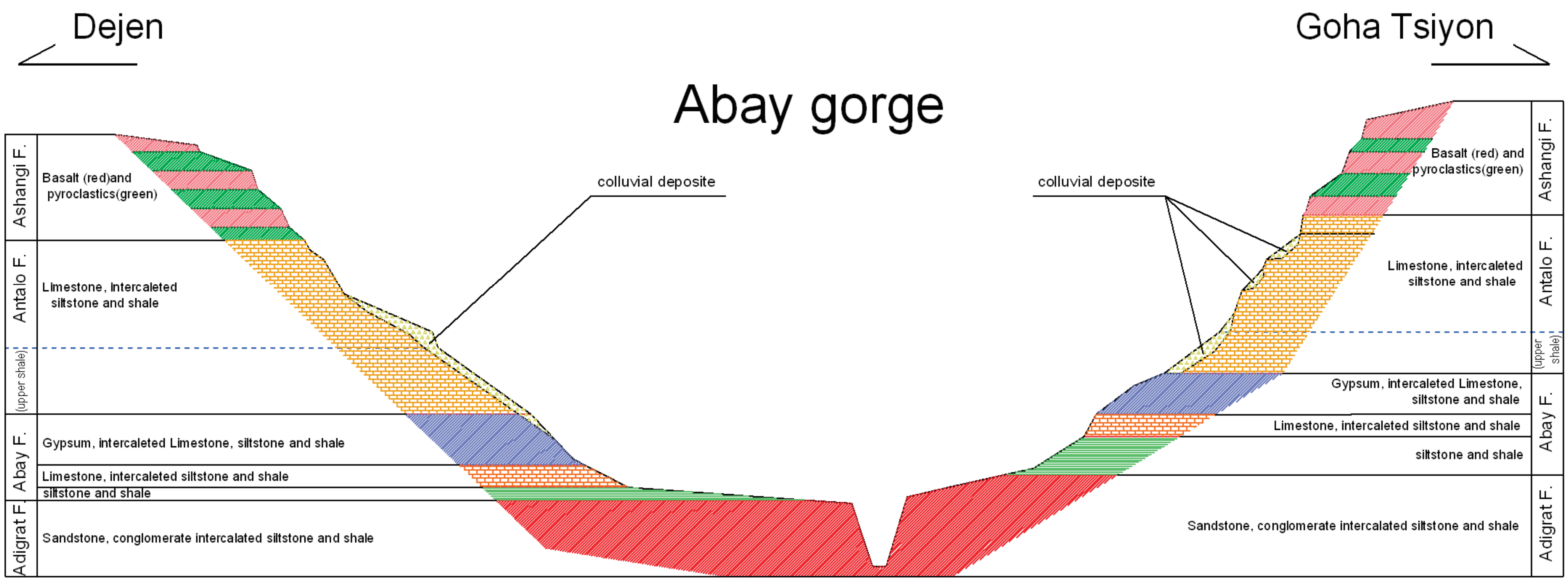


Figure 3.4.2 Geological schematic section of the Abay Gorge (not to scale)

a. Adigrat Formation: Triassic to Middle Jurassic

In this area, the river bank and terrace were made by this formation. The formation thickness is 280m on the Goha Tsiyon side, and about 210m on the Dejen side. The bedding plane is generally horizontal but Goha Tsiyon side and Dejen side has small differences in trend (Figure 3.4.3).

The lower part is basically thinly bedded (5-50cm) and the lowest part of this unit showed greenish silty mudstone and white sandstone alternation of strata at the foot of the Hedase Bridge. The sandstone is cross laminated and 10 to 30cm thick. The silty mudstone is highly consolidated, with alternating, thinly laminated and cross-bedded, each layer is 10 to 60 cm thick (Photo 3.4.1 (1)).

The middle part is characterized by fine to medium grained reddish sandstone sometimes intercalated white quartz sandstone layers. The part also contains limy sandstone (Photo 3.4.1 (2)). This sandstone looks like reddish sandstone in macroscopic observation, but the upper part of this sample reacts with hydrochloric acid (Photo 3.4.1 (3), red circle). Because of these layers, the cliff around sta.20kp+300m to sta.21kp +300 has lots of stalagmite.

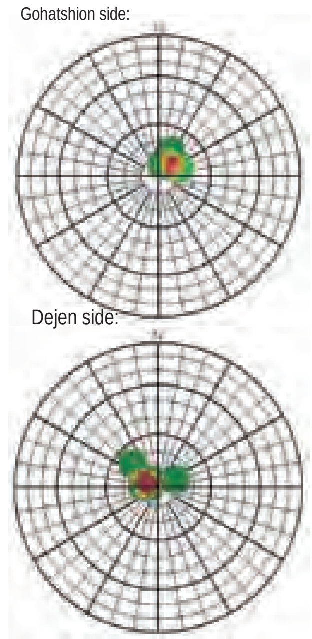
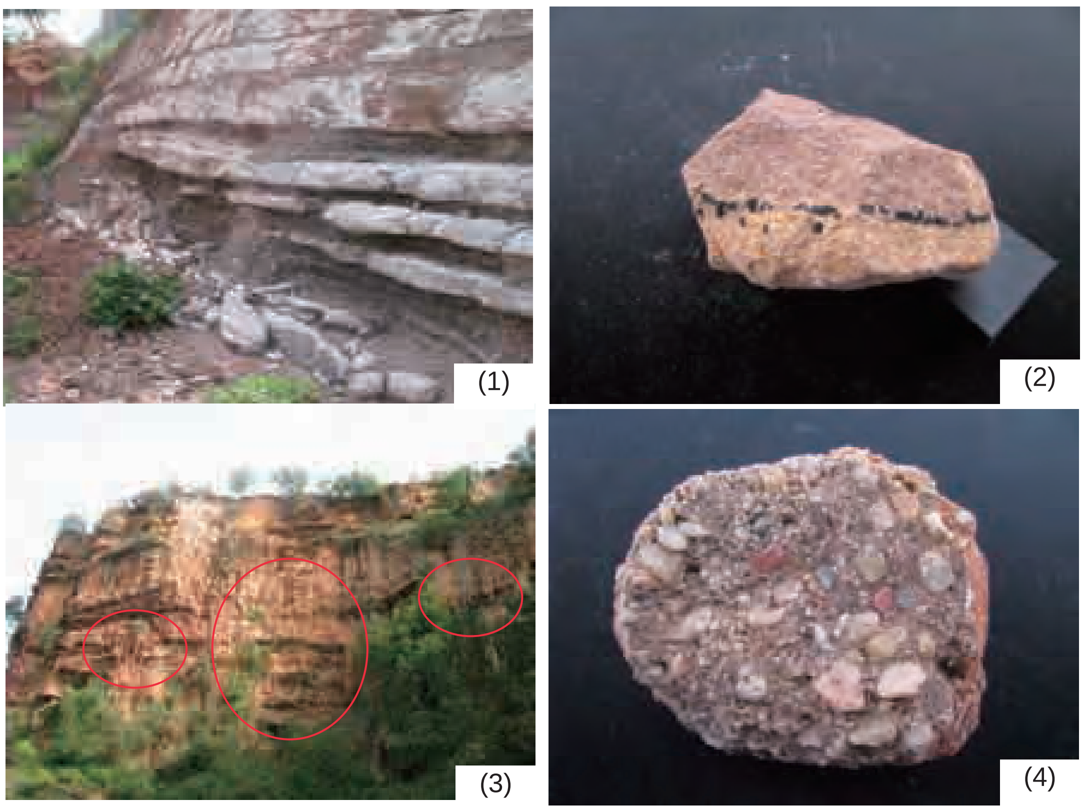


Figure 3.4.3 Comparison of the bedding of both sides on Adigrat Formation



(1) (2) (3) (4)

Photo 3.4.1 View of the sandstone on Adigrat Formation

The upper part is thickly bedded (1-3m) and characterized by thick white sandstone and its conglomerate. The sandstone is basically composed of quartz grain, but sometime contains reddish fragments, including pinkish or slightly reddish color. These white sandstones are sometimes containing rounded to sub-rounded agate gravel all over the unit, especially the upper part, because of conglomeration (Photo 3.4.1 (4)). The unit has gradational contact with overlying siltstone and shale.

The strike of the bedding plane has NW trend on Goha Tsiyon side; on the other hand, it has almost N to NE trend in Dejen side. The difference on both sides is probably an undulation of these formations. The unit has two well developed joint sets besides bedding plane. The bedding plane is almost horizontal, and the strikes of two other joint sets are NW-NNE and NE-NEE in trend (Figure 3.4.4). The two joint sets are almost over 80 degree dip.

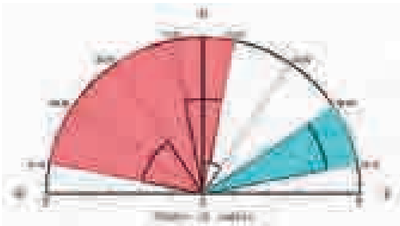
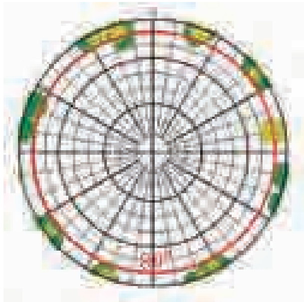



Figure 3.4.4 The tendency of the sandstone joint set

b. Abay Formation: Middle Jurassic

According to Tefera et al (1996), this formation is composed of Jurassic limestone, siltstone, shale and gypsum. The formation thickness is 320 m on the Goha Tsiyon side, and about 270 m on the Dejen side. The details about each unit are explained as follows.

b.1 Siltstone and Shale

The siltstone and the shale layers are intercalated with underlying sandstone (Adigrat Formation) and overlying limestone and gypsum (Abay Formation). The thickness of the main unit is about 120 m on the Goha Tsiyon side and about 40 m on the Dejen side, and is also observed as an alternating layer in limestone and gypsum units.

The siltstone unite is composed as well as of silt and clay particles. It is found intercalated with shale, mudstone and sandstone with calcite and/or gypsum veins

The shale is argillaceous clastic sedimentary rock which contains a lot of clay minerals (Photo 3.4.2 (1)). The shale between underlying sandstone (Adigrat Formation) and overlying gypsum is often called “the lower shale unit.” The shale between underlying siltstone and overlying limestone (Antalo Formation) is called “the upper shale unit.” However, “the upper shale unit” is not observed along the road due to weathering and erosion.

On the Dejen side at up stream of 22kp, the shale directly covers the underlying sandstone (Photo 3.4.2 (2)). In this area a gentle slope is formed by removed soil and has lots of landslide forms.

The shale is susceptible to weathering and erosion locally, which is totally changed to clay by weathering. The lower part of the shale is not exposed due to weathering and erosion, therefore the silt and shale area show almost flat plane and/or gentle slope (Photo 3.4.2 (3)).

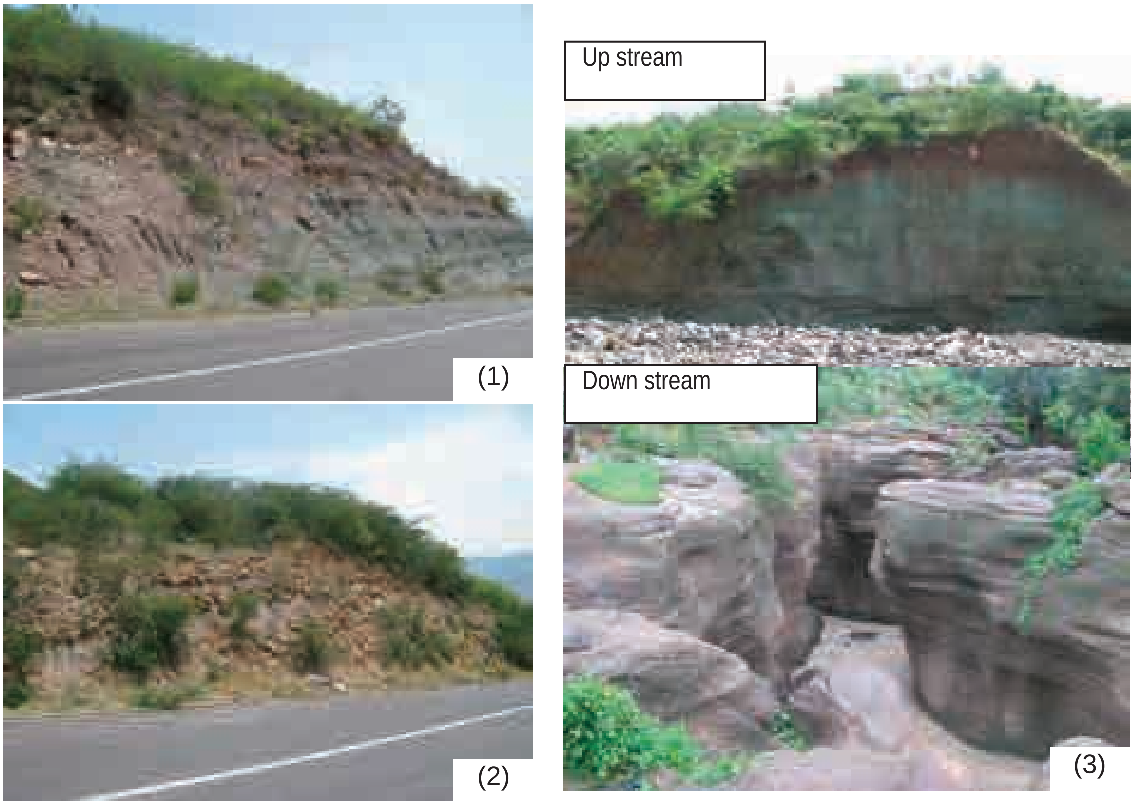


Photo 3.4.2 View of the siltstone and shale on Abay Formation

b.2 Limestone

This unit is found in between the underlying massive shale and overlying gypsum unit (Photo 3.4.3 (1)). It is about 70 m thick on both sides of the gorge and contains alternated limestone, siltstone and shale. Each layer of limestone is under 50 cm thick, although this varies from place to place. The siltstone and shale layer thickness also locally varies; however it is basically less than the thickness of the limestone. The upper part of the limestone has well cemented siliceous siltstone (Photo 3.4.3 (2)), which contains lots of fossils. It may indicate depositional environment change.

Upper stream of Sta. 22kpt: limestone and gypsum out crop (height is totally over 50m

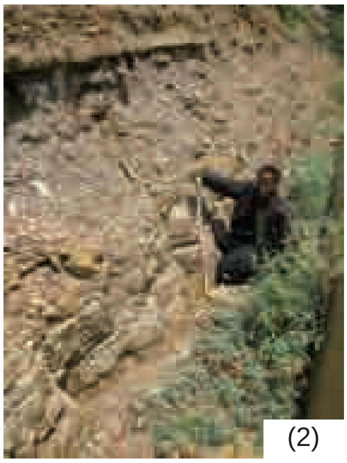


Photo 3.4.3 View of the limestone on Abay Formation

The limestone basically belongs to “the lower shale unit.” However geographically, the limestone area is completely different from the siltstone and shale area. The former forms relatively steep slope and is alternated, and the latter forms gentle slope or almost flat plane and are massive. The limestone should be independent unit from "the lower shale unit."

b.3 Gypsum

The thickness of this unit is about 130 m on the Goha Tsiyon side and about 160 m on the Dejen side. It is found between "the lower shale unit" and overlying "the upper shale unit" (not observed along the road). On the other hand, intercalated layers are affected by deep weathering (Photo 3.4.4 (1)). This phenomenon will cause slope unstability.

The lower part, the unit contains a massive gypsum bed (up to 3.6 m), has various color and layered (up to 2.5m) with limestone alternation (up to 1.5 m), and thinly bedded shale, siltstone and sandstone. The lower part is intercalated with several biogenesis limestone beds (up to 1.0 m) (Photo 3.4.4 (2)) and thinly bedded reddish siltstone - limestone alternation (unit thickness up to 3.2 m: each bed thickness around up to 4 cm).

The middle part, the unit contains a massive gypsum bed (up to around 3.0 m) (Photo 3.4.4 (3)), of various color and layered with thin limestone beds (up to around 1 m), gypsum with limestone alternations (up to around 0.5 m), and gypsum limestone alternation with thinly bedded shale (up to around 1 m).

The upper part is mainly gypsum, which is composed of massive (up to 5 m) (Photo 3.4.4 (4)) and layered, and has slightly thin limestone and shale beds intercalation.

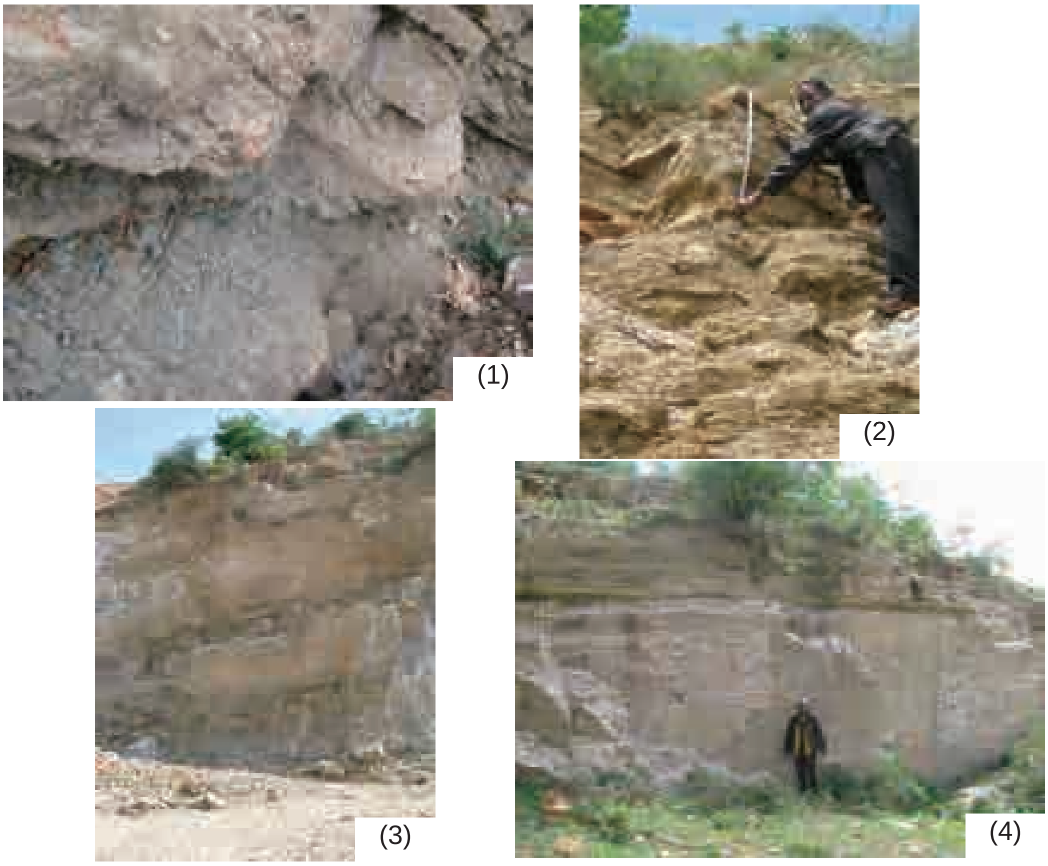


Photo 3.4.4 View of the gypsum on Abay Formation

c. Antalo Formation: Late Jurassic

The limestone layers form fitful steep slopes and escarpments. The bedding plane is generally horizontal (Figure 3.4.5). The upper part is thickly bedded (Photo 3.4.5 (1)) whereas the middle part is thinly bedded. The lower part is relatively less compacted.

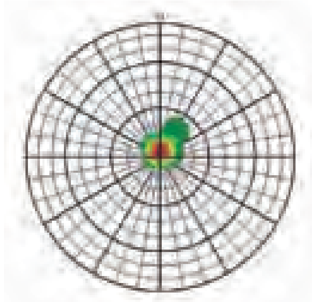
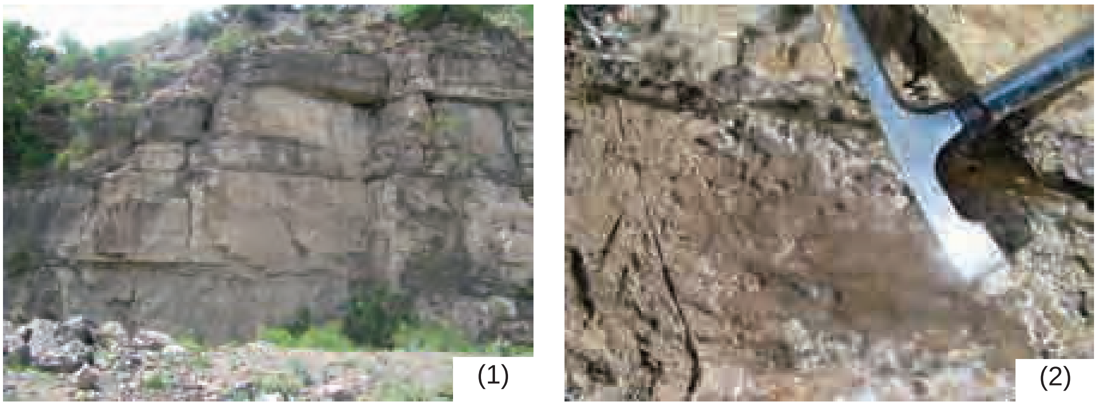


Figure 3.4.5 The tendency of Limestone bedding.

The transition form lower to middle part is relatively thickly bedded, and coarse grained and less compacted. Sometimes it contains quartz veins, calcite vein and/or zeolite as a result of crystallization (Photo 3.4.5 (2)). The rock is basically yellowish grey and contains lots of fossils. The limestone is susceptible to weathering and erosion.



(1) (2)

Photo 3.4.5 View of the limestone on Antalo Formation

The middle part is basically thinly bedded limestone which is white or pale grey and sometimes yellowish grey. Although the bed is well compacted, it is relatively susceptible to weathering and erosion, due to closely spaced minor vertical joints.

The upper part is characterized by thick limestone beds and minor intercalation of silt and marl. The color of the limestone is white to pale grey and sometime yellowish. The unit has both hard and weak layers.

The bedding plane of the limestone is horizontal, and the strikes of the two joint sets are NW and NE in trend (Figure 3.4.6). The joints are filled with either calcite or marl fragments.

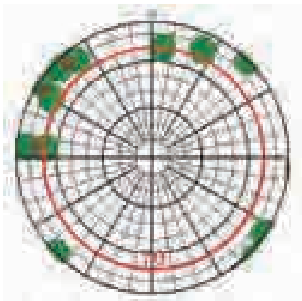


Figure 3.4.6 The tendency of Limestone joint.

d. Ashangi Formation

The thickness of the formation is over 380 m on both the Goha Tsiyon side and Dejen side. It also includes some brittle pyroclastic layers which would be one triggering factor for landslides in the area.

In Goha Tsiyon side, the lower part is characterized by a massive basaltic lava flow associated with colluvial deposit (Photo 3.4.6 (1)). The unit is almost 70 m thick and is reddish grey to grey. The joints of the layer are opened because of weathering and by the exerted load of the overlying huge colluvial deposit.

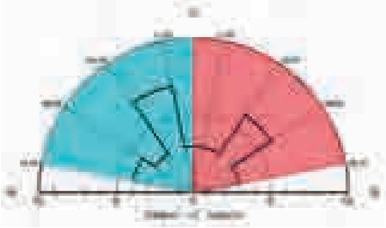
The middle part is composed of basaltic lava and pyroclastic rocks. The lava is over 70 m thick, and is observed only in the upper part. The pyroclastic rock has 50 m thickness and is not observed along the road cut. The basalt is mainly grey and sometimes brownish grey. It has clearly developed columnar joints (10-20 cm) of different orientation.

The upper part is constituted by basaltic lava and pyroclastic rocks. The basalt is over 80 m thick, whereas the pyroclastic is up to 40 m thick. The basalt is mainly black to dark grey and has clearly developed columnar joints (30-50 cm). A flow breccia is observed in the lowest part (Photo 3.4.6 (2)).

Pyroclastic rocks are observed under this lava unit (Photo 3.4.6 (3)). The pyroclastic rocks unit contains lapili tuff, tuff breccia, tuffaceous sandstone and mudstone, which are susceptible to slaking erosion. The slaking erosion means that rock collapse by alternate wetting and drying. The characteristic that the pyroclastic change to a soil by the slaking would be one of the triggering factor of landslides in this area. The pyroclastic unit basically forms gentle slopes, however sometimes makes a steep slope (Photo 3.4.6 (4)). The color is varied depending on the materials and weathering oxidation reaction.

Photo 3.4.6 View of the basalt on Ashangi Formation

The Ashangi Formation has clearly developed columnar joints (20-50cm). The strike of the joints is trending NW and NE with over 70 degree dip (Figure 3.4.7). The two joint sets with both closely and widely spaced cracks would result in huge rock failures especially at these intersections.



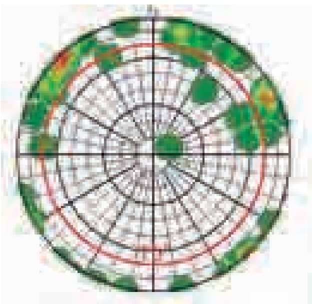


Figure 3.4.7 The tendency of the basaltic lava joint set

e. Surface soils

In the study area, there are huge amounts of surface soil covering the bed rocks. These are colluvial deposits, alluvial fans, terrace deposits and others.

The location of the deposit depends on their source and geography. Basalt, limestone, gypsum and sandstone layers generally form steep cliffs, and pyroclastic rock, siltstone and shale form gentle slopes due to the susceptibility to weathering and erosion in the area. The pyroclastic unit and the shale unit are covered by huge amount of surface soils, has a lot of landslide forms.

Photo 3.4.7 Thick colluvial deposit, along the road in Filiklik,

3.4.2 Surface anomalies of the landslides

a. Surface anomalies of the landslide in L/S00 (ST.0+200 to 1+100)

In this area, several small landslide blocks can be classified as shown in following figure. The crack near the toe of the L/S00-1 block is conspicuous. From the fact that the lower part of the L/S00-1 is upthrusting and the surface is oppositely dipping as well as the inclination of the large rock block at the lower part, it can be estimated that the direction on the landslide is skewed to the southwest from the strike of the slope.

Relatively new cracks were observed in the two landslide blocks on the upper side of the road. Therefore several minor deformations seem to be still continuing.

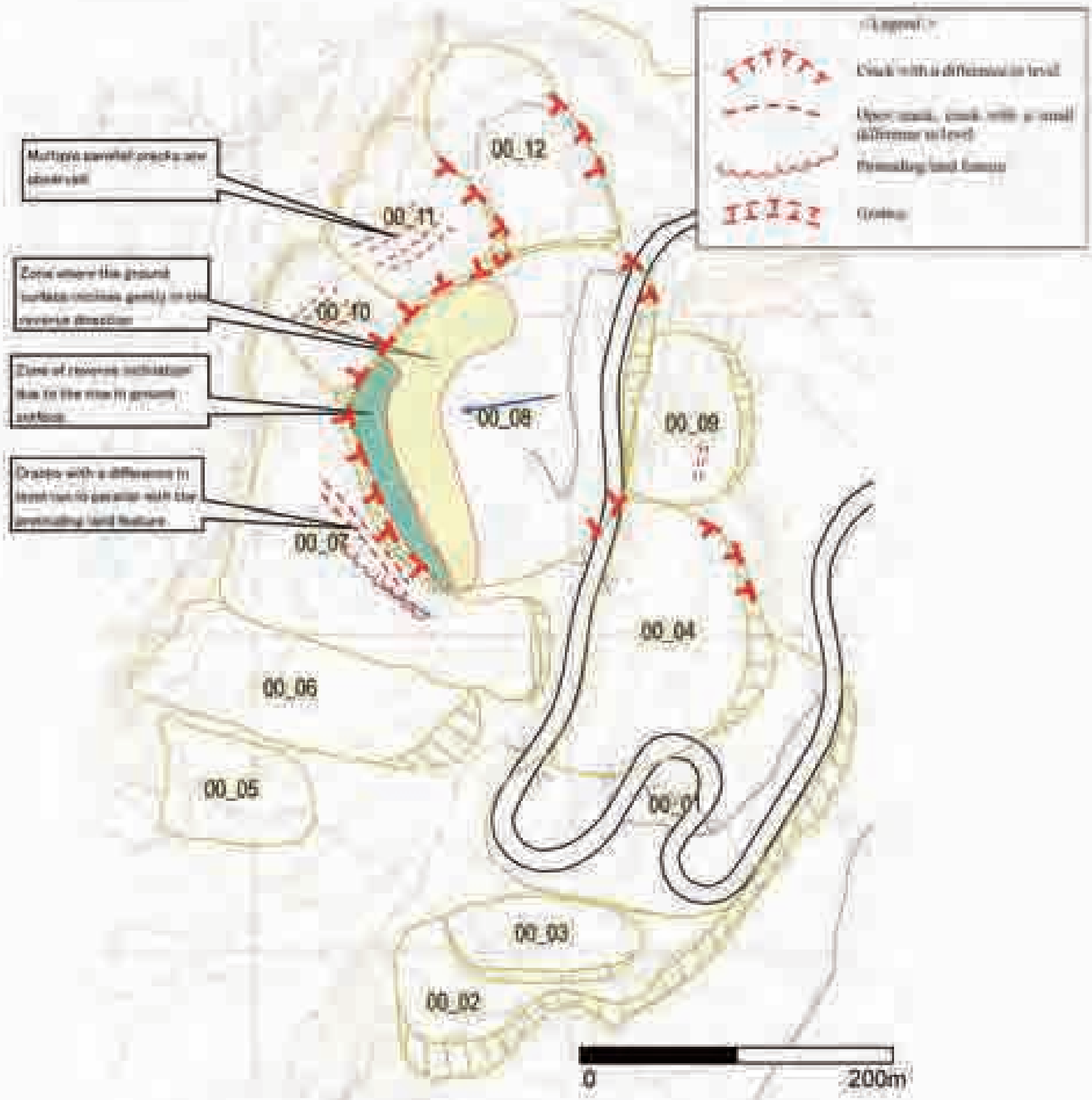


Figure 3.4.8 Surface anomalies in L/S00 (ST.0+200 to 1+100)

Photo (1)
Distant view near the boundary of the lower part of L/S00-1 and L/S00-5
Wrinkle-like irregular land features running in parallel.
Deformation seems to be occurring in L/S00-5 due to movement of L/S00-1.

Photo (2)
Lateral cracks on the L/S00-2 block
Multiple small cracks are opening on the right flank of L/S00-2.

Photo (3)
Cracks near the boundary of the toe of L/S00-1 and L/S00-3.
The maximum difference in level of the cracks is about 2m. The transported land mass could also be seen to have taken on a toppling style.

Photo (4)
Inclination of the surface near the lower part of L/S00-1.
The surface is upthrusting at the lower part; it is dipping in the reverse direction.

Photo (5)
Parallel cracks with a difference in level at the lower part of the L/S00-1 block.
Land features with a difference in level oriented toward the valley run in parallel near the boundary of the L/S00-1 and the L/S00-5.

Photo (6)
Crack and a fallen rock at the toe of the L/S00-1.
A 1 to 2m deep crack with a difference in level is continuing at the lower part of the L/S00-1.
Near the center, a large rock had fallen, with the previously buried portion appearing.
The strike of the rocks seems to be similar with the one of the L/S00-1.

Photo 3.4.8 Situation of L/S00

b. Surface anomalies of the landslide in L/S05 (ST.4+800 to 5+600)

In this area, soil and sand which have been collapsed from the crown of the L/S05-1 block have been piling up on the upper part of L/S05-1. The L/S05-2 on the valley side is made of the debris from the L/S05-1.

From new cracks along the old channel that crosses the upper part of L/S05-1 and small collapses on the lower part, it is considered that micro-displacements are still occurring in the L/S05-1.

New cracks at the top of the L/S05-2 on the valley side of the road indicate a continuing series of small collapses; therefore it is considered that small displacement is also occurring in this block.

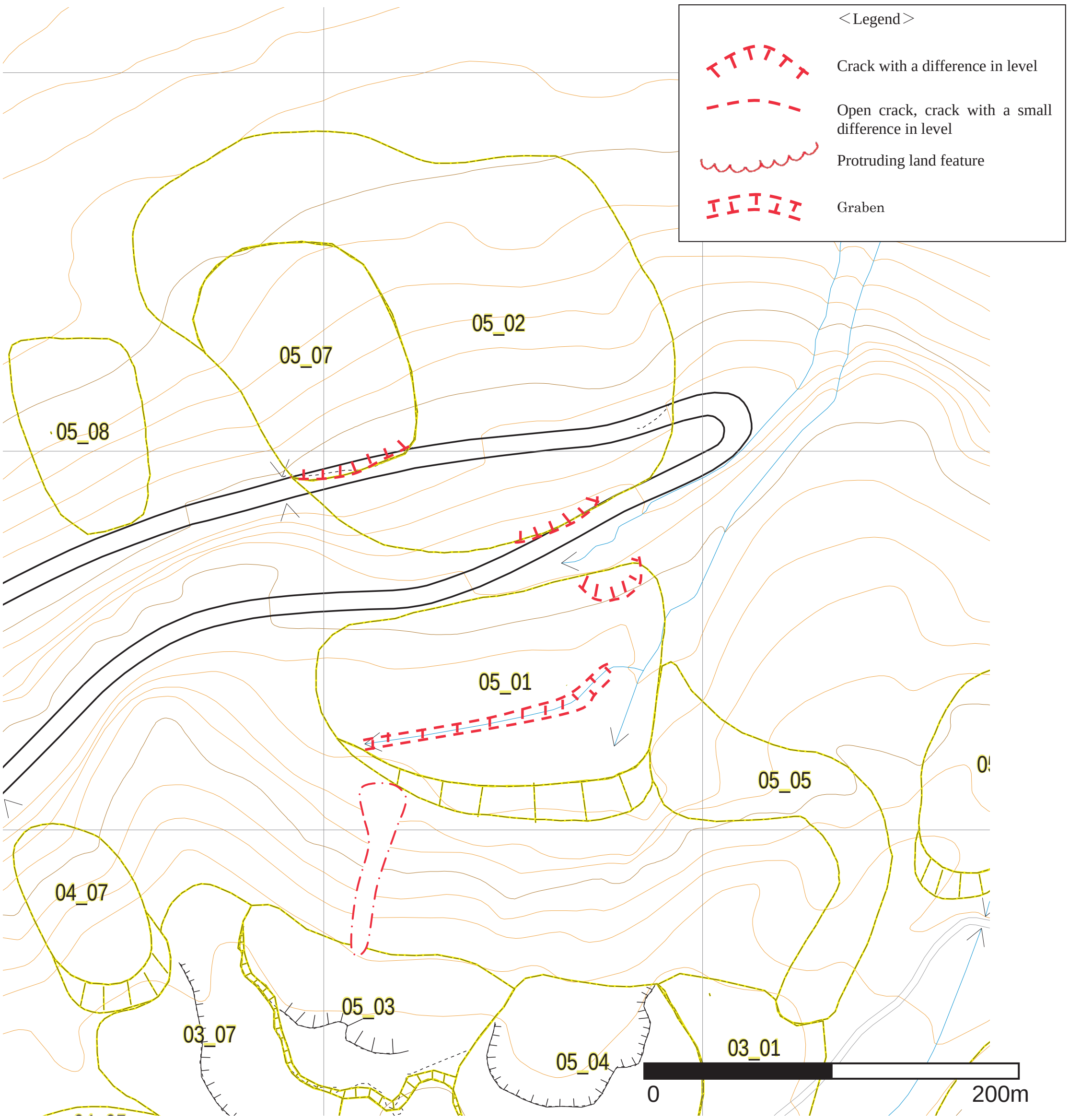


Figure 3.4.9 Surface anomalies in L/S05 (ST.4+800 to 5+600)

Photo (1)
L/S05-1 block as viewed from the top
An old channel crosses the L/S05-1, and debris from the upper part is piled up on the block. The debris is a load on the L/S05-1 block.

Photo (2)
Expansion of the cracks along the channel in the L/S05-1.
The blue vinyl sheet that was covering the old channel has been torn, so it can be considered that cracks are expanding along the old channel.

Photo (3)
A continuous crack along the channel in the L/S05-1
The crack continues along the old channel.

Photo (4)
Small collapses on the mountain side of the toe of the L/S05-1 (1)
Multiple small collapses are occurring on the slope.

Photo (5)
Small collapses on the mountain side of the toe of the L/S05-1 (2)
Small collapses as viewed from inside the block.

Photo (6)
Top of the L/S05-2
The debris area from the L/S05-01 block is considered to be the L/S05-02 block. Cracks indicating a small collapse are occurring at the top of the block.

Photo 3.4.9 Situation of L/S05

c. Surface anomalies of the landslide in L/S22 (ST.21+600 to 22+300)

In this area, there are two blocks that are believed to have been active in recent years; a predominant displacement is the L/S22-1. This block could have resulted from events that occurred when the toe of the block has been eroded by surface water.

The main scarp and cracks 1 to 2 m in height on the valley side are quite close to the new road.

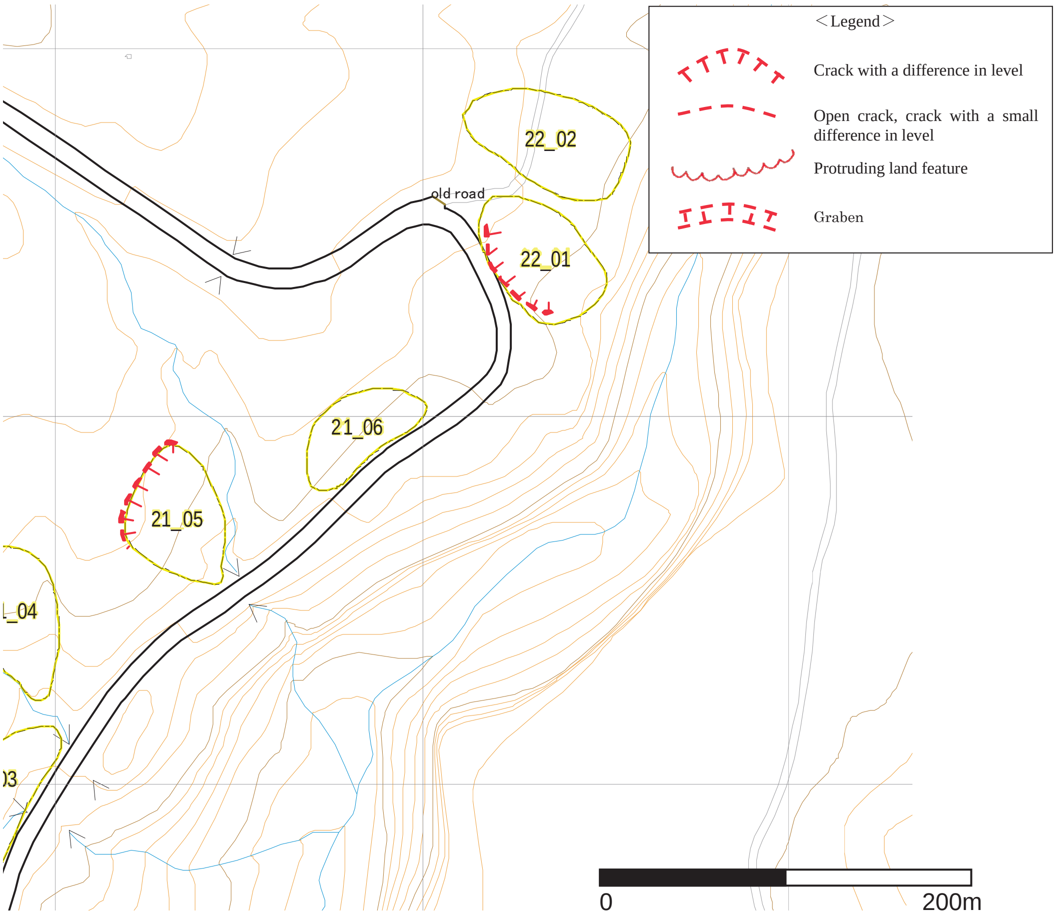


Figure 3.4.10 Surface anomalies in L/S22 (ST.21+600 to 22+300)

Photo 3.4.10 Main scarp of the L/S22-1

The main scarp and cracks with a difference in level are close to a new road that has been relocated.

d. Surface anomalies of the landslide in L/S27 (ST.27+200 to 28+400)

In this area, multiple landslide blocks overlap. As indicated by the significant subsidence of the road in recent years, the activities in the L/S27-2 are most conspicuous in this area. It is possible that the L/S27-2 and the L/S27-3 are a continuous block from the viewpoint of the deformation on the road as of April 2009; however, because it was unable to find the reasonable factors through satellite image interpretation or reconnaissance, it is assumed here that they are separate blocks.

In the L/S27-1, where there is a broken church and a new church under construction, multiple displacements consisting of cracks by landslide activities are developing; however, the cracks are not new or clear.

In contrast, a new continuous crack, as well as the main scarp and graben, can be observed in the L/S28-1; a subsidence on the road can also be an extension of the deformation direction.

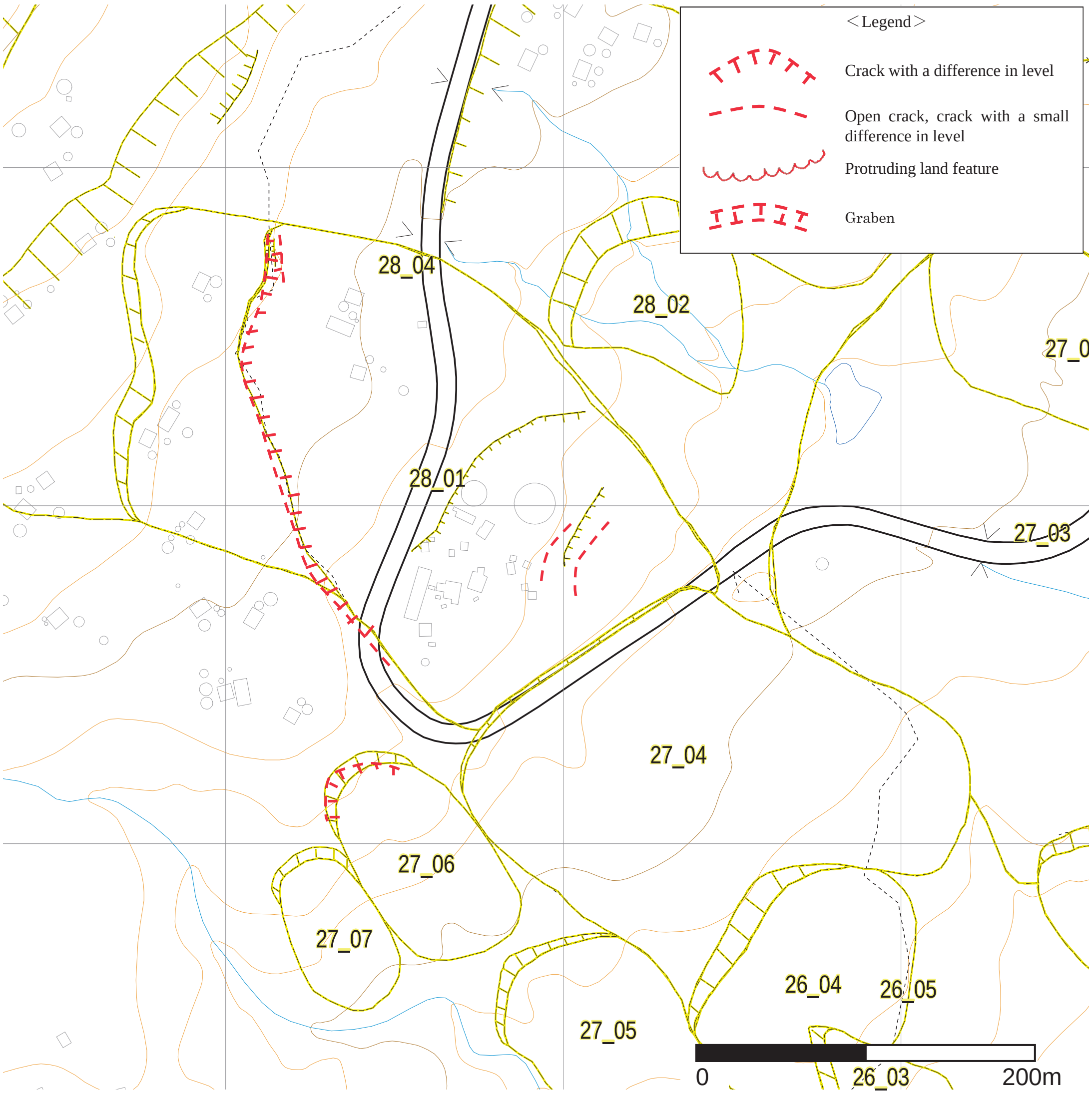


Figure 3.4.11 Surface anomalies in L/S27 (ST.27+200 to 28+400)

Photo (1)
Displacement on the L/S208-1
There are continuous displacements on the slope above the broken church, and there is a new and clear crack on a line extending from it (Photo 2).

Photo (2)
Crack at the head of the L/S28-1 block (1).
There is a new crack extending from the displacement seen in Photo 1.

Photo (3)
Crack at the head of the L/S28-1 (2).
The cracks in the slope in Photo 2are continued to new cracks in the next wood.

Photo (4)
Main scarp in the L/S28-1
There is a main scarp with a height of 2m, which is continuing from the crack in Photo 3. A 5m-wide graben formed around there.

Photo (5)
Subsidence on the head of the L/S28-1.
There is a subsidence at the head of the L/S28-1 that crossed the national road. The road has also a subsidence on an extension of the deformation.

Photo (6)
The top of the L/S27-2
The area from the L/S27-3 to the top of the L/S27-2 devastated due to erosion and small collapses.

Photo (7)
Gully erosion on the L/S27-2.
A channel with developed gullies appears on the slope.

Photo (8)
Channel on the L/S27-2.
There is a series of small channel.

Photo (9)
Top of the L/S27-2.
The road surface is sinking at the top of the block, causing a maximum difference in altitude of 1m from the former roadside channel. It can be seen that the top of the block has sunken due to the landslide.

Photo 3.4.11 Situation of L/S27

e. Surface anomalies of the landslide in L/S28 (ST.28+400 to 28+800)

This area is positioned at the head of a large landslide covering the whole region. There are continuous clear main scarps, and cracks, whose mountain side is sinking, that runs roughly in parallel with the main scarps. L/S28-2 is one of the multiple landslide blocks in the area.

However, as to whether the current L/S28-3 block is a part of the huge landslide or is independent from the big one, it is difficult to judge only through satellite image interpretation and reconnaissance. Considering the size of the subsidence, however, it can be estimated that a moving block is at least 300 m wide.

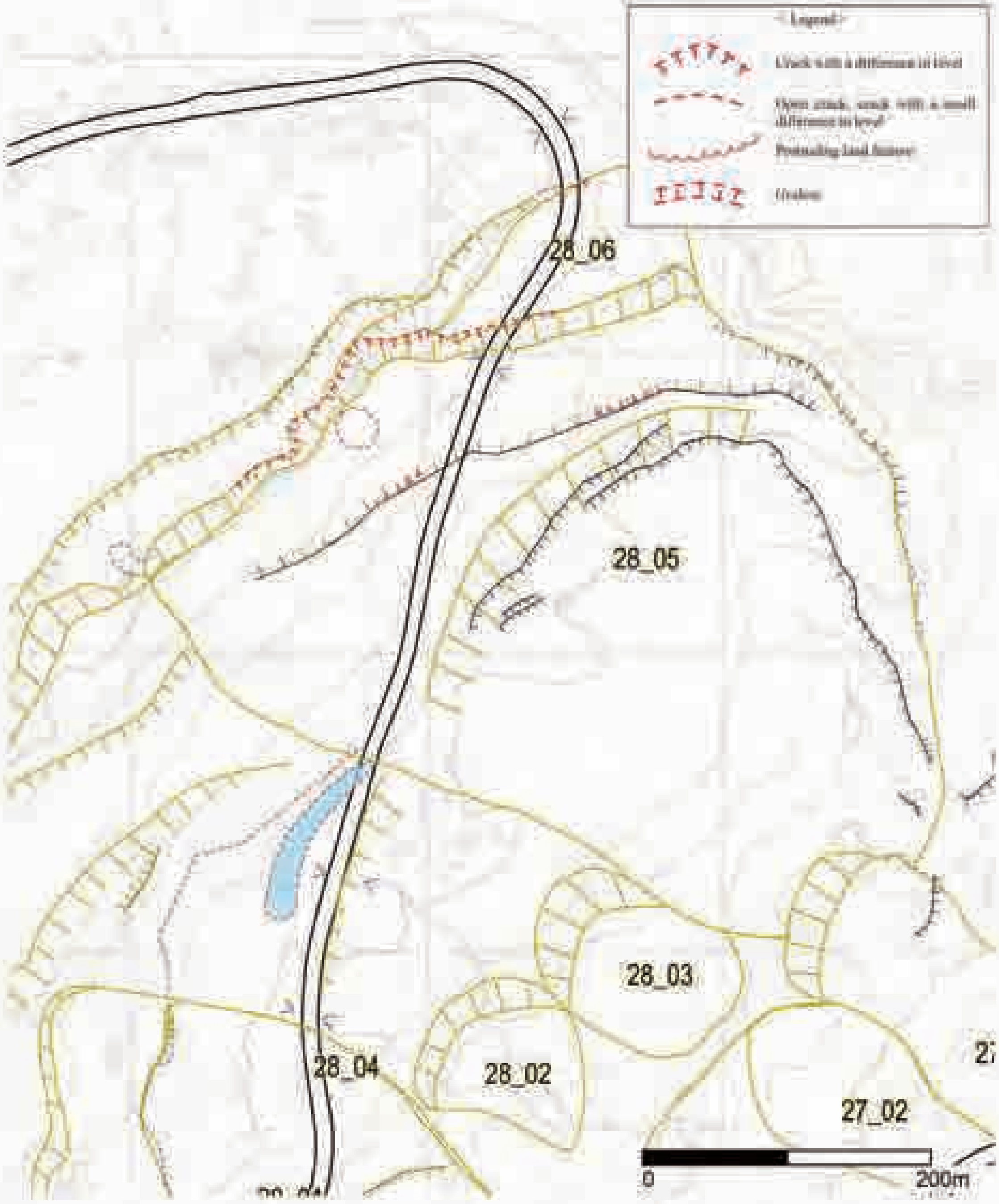


Figure 3.4.12 Surface anomalies in L/S28 (ST.28+400 to 28+800)

Photo (1)
<u>Main scarps and subsidence in the L/S28-3 (1).</u>
A new and clear main scarp with about 10 m difference is continuing, and the displacement is also occurring on the road. On the valley side, cracks, whose mountain side is sinking, that runs roughly in parallel with the main scarps.

Photo (2)
<u>Main scarp and subsidence in the L/S28-3 (2).</u>
Cracks whose mountain side is sinking can be seen on the head of the slope. New cracks are continuing from this crack.

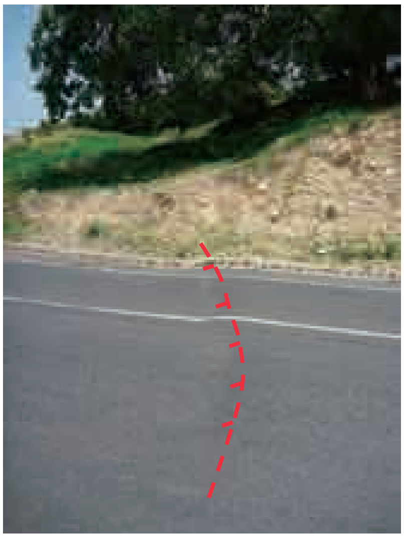


Photo (3)
<u>Cracks on the main scarp of the L/S28-2.</u>
The displacement that occurred on the national road continues toward the old main scarp.

Photo 3.4.12 Situation of L/S28