Chapter 2

Geology

2 Geology

2.1 Adama town, Mt. Boseti and its surrounding areas

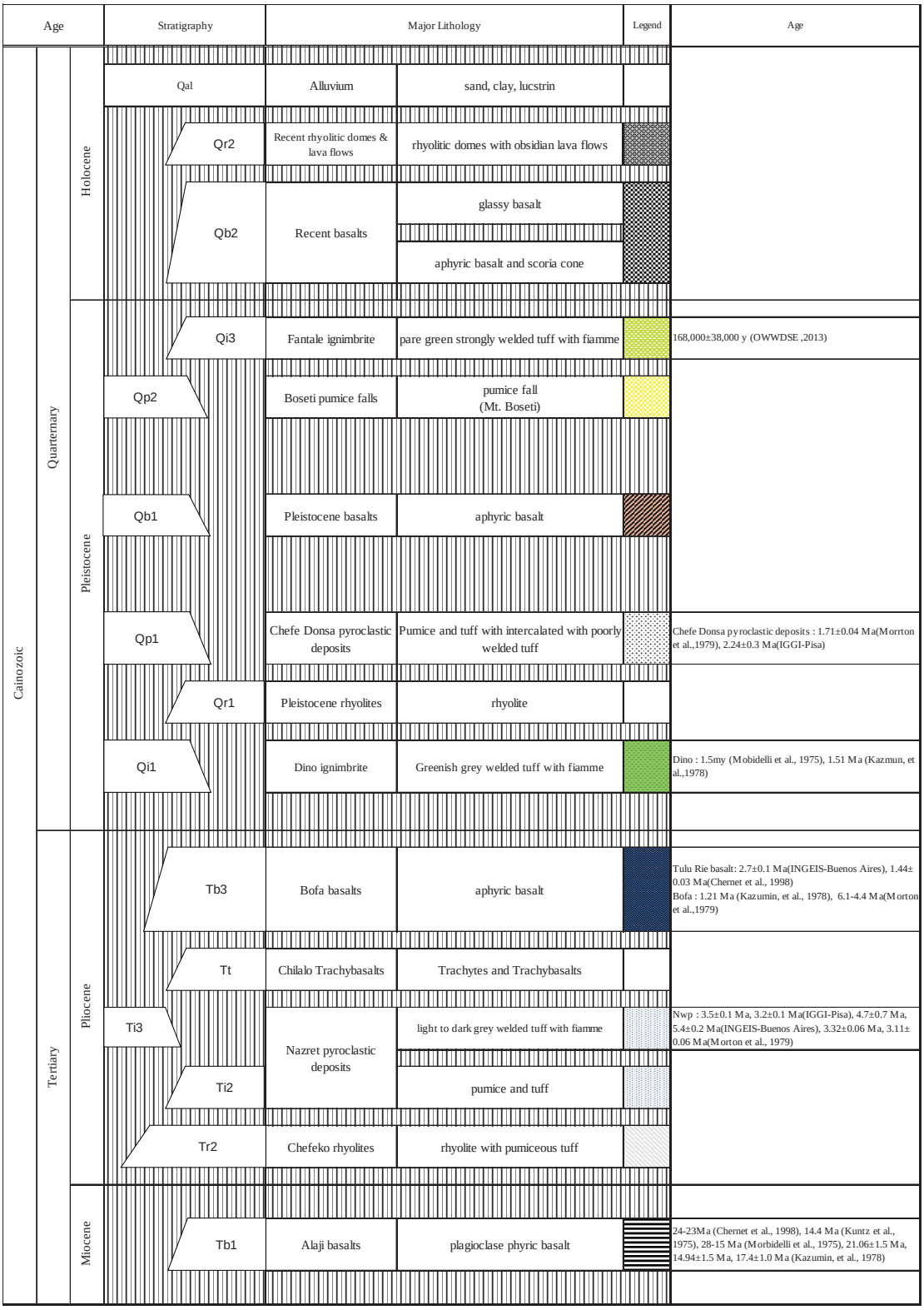
2.1.1 General

Adama town–Mt. Boseti and its surrounding areas are located in the central MER. The rift floor is widely covered by Pleistocene to Holocene volcanic deposits. The lowest unit, named Alaji basalts, is observed at the scarps of the eastern margin and the NE-SW trending faults. Alaji basalts is distributed widely in the survey area and has a chronological age of 24-23Ma according to Chernet et. al, 1998, 14.4Ma according to Kuntz et al., 1975, 28-15Ma according to Morbideli et al., 1975, and 21.06±1.5Ma, 14.94±1.5Ma, 17.4±1.-0Ma according to Kazumin, et al., 1978. Chefeco rhyolites and Pliocene rhyolites overlie Alaji basalts and have formed hilly topography. Nazret pyroclastic deposits are mainly observed at the scarps of the rift margin. Chilalo trachybasalts is observed at the northern foot of Mt. Chilalo. Bofa basalts from Late Pliocene to Pleistocene is well observed at the area, and has a chronological age of 1.21Ma by Kazmin et.al, 1978, and 6.1-4.4 Ma by Morton et al., 1979. Pleistocene, Dino ignimbrite, Quaternary rhyolites, Chefe Donsa pyroclastic deposits and Pleistocene basalts are widely observed on the rift floor. In the Late Pleistocene period, pumice fall from Mt. Boseti, and Fentale ignimbrite are widely distributed on the rift floor and fault scarps. In Holocene, rift floor basalts from volcanic activities in the eastern side of Mt. Boseti.

Table 2.1.1 shows the stratigraphy in Adama town-Mt. Boseti.

In addition, location map of each outcrop number mentioned in this chapter is shown in Figure 2.1.1.

Table 2.1.1: Stratigraphy in Adama Town-Mt. Boseti



Source: the Project Team, Data: Result of geological survey in this Project

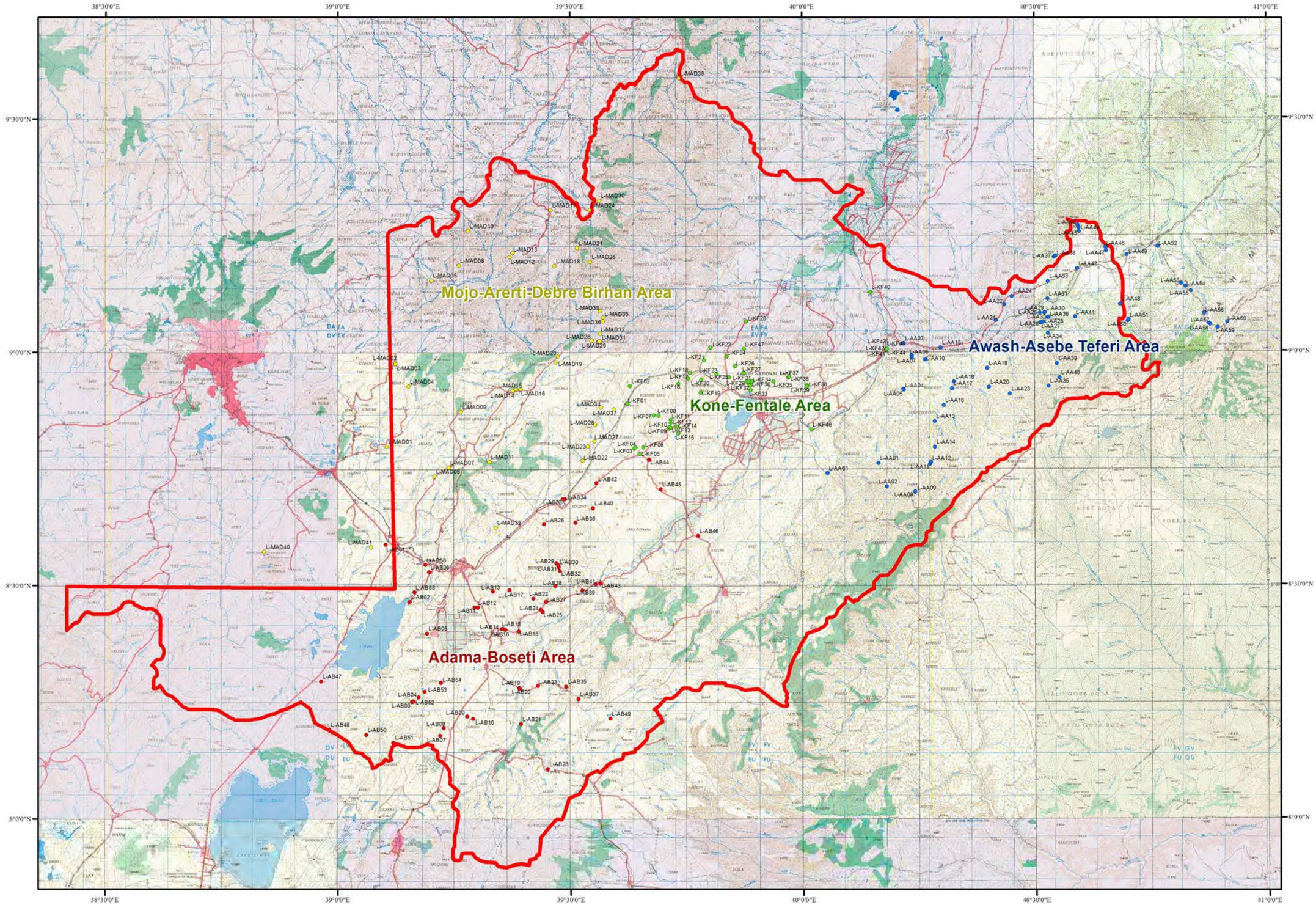


Figure 2.1.1: Location map of outcrops

2.1.2 Geological unit

a. Miocene-Pliocene

a.1 Alaji basalts: porphyritic to plagioclase phyric basalt lavas: Tb1

Lithology: Consists of porphyritic to plagioclase phyric basalt lavas. At the type locality, the unit is overlain by Nazret pyroclastic deposits (L-AB21).

Distribution: Western cliff of Sire town, Hula near Arboye town, and Kelefa river near Huruta town

Thickness: More than 30 m at the type locality.

Type locality: The Kelefa river (L-AB21)

Correlation: The unit is classified as N1a: Alaji basalts in GSE (1978).

Dark grey porphyritic to plagioclase phyric basalt
Source: the Project Team, Data: Result of geological survey in this Project

Figure 2.1.2: Kelefa River (L-AB21)

b. Pliocene

b.1 Chefeko rhyolites: Rhyolite, rhyolitic tuff, pumice tuff: Tr2

Lithology: Consists mainly of white to bluish grey rhyolite lava flows and tuff, white pumice and hard tuff including obsidians. This unit is unconformably overlain by Dino ignimbrite at Tulu near Itaya town (L-AB07). In the type locality the rhyolite lava is observed to have developed platy joints and obsidians forming along chilled margin.

Distribution: Mt. Debeso, Chefeko, Lugo, forms a hill at Dera, Sodere, and Sara, and NE-SW distribution at Korkada Ridge.

Thickness: Around 150 m in the type locality

Type locality: Chefeko, 5km northwest of Iteya town (L-AB08)

Correlation: The area is classified as N2r: Older alkaline and peralkaline rhyolite domes and flows in GSE (1978).

This unit is overlain unconformably by Dino ignimbrite

Hard tuff including obsidians at type locality

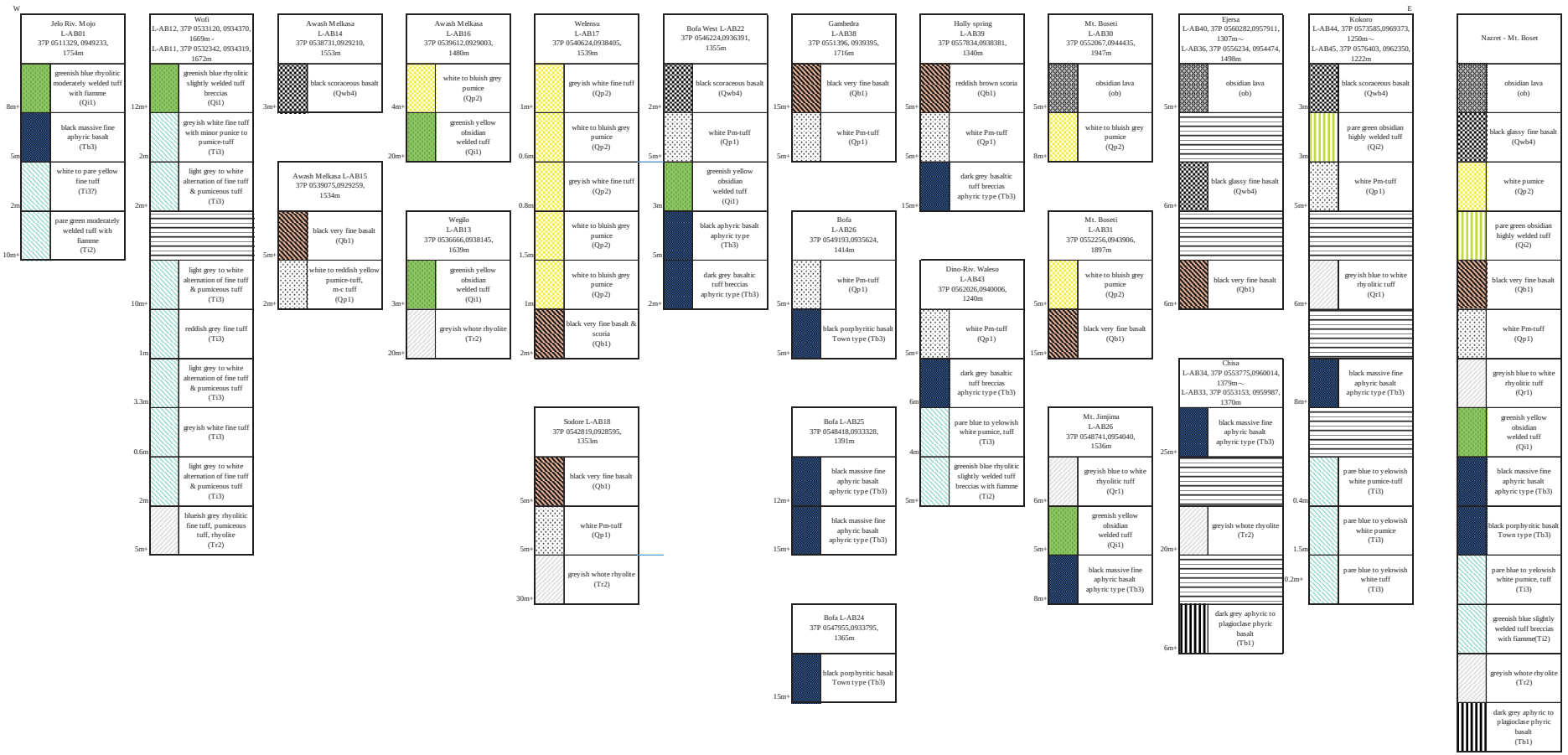
Rhyolitic tuff, obsidian distributed at Mt. Debeso outcrop

Source: the Project Team, Data: Result of geological survey in this Project

Figure 2.1.3: Tulu (L-AB07) (top left), Chefeko (L-AB08)(top light), Mt.Debeso (L-AB09)(bottom)

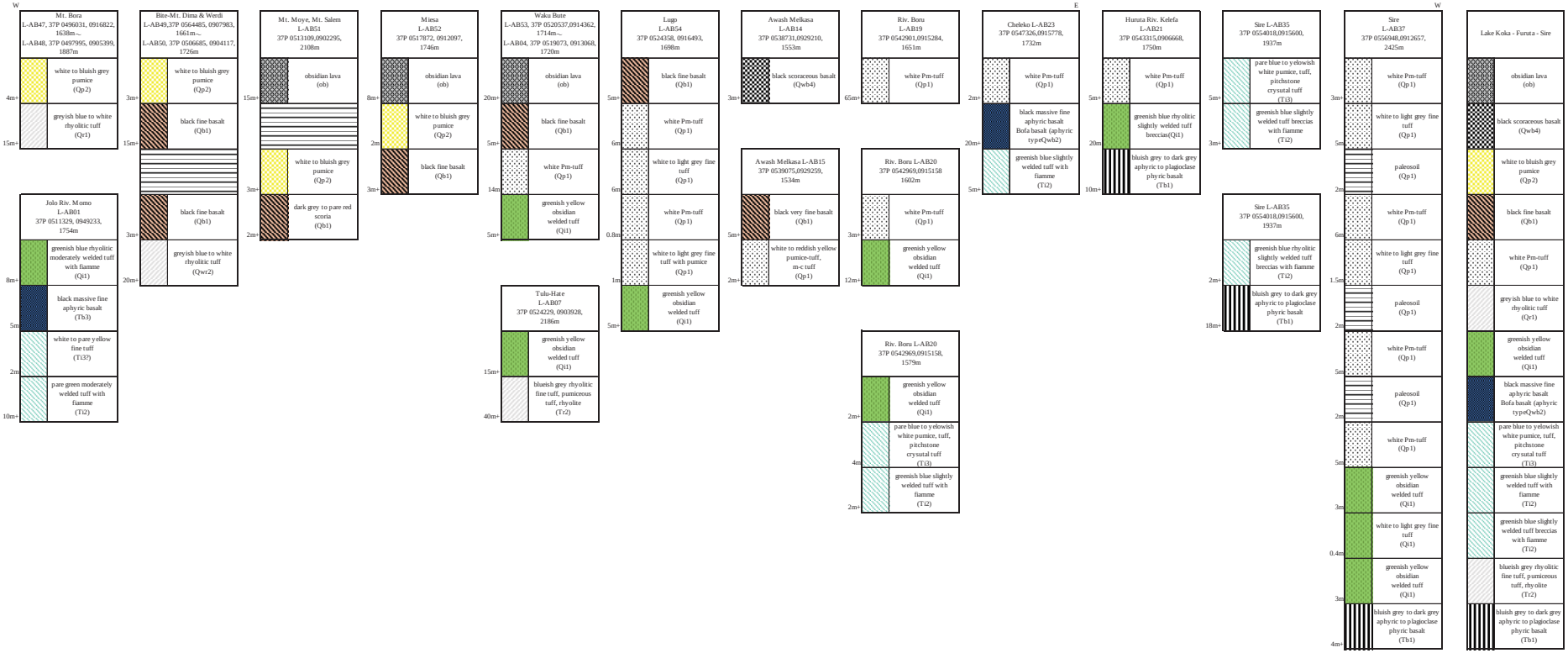
Table 2.1.2 describes the geological succession along Nazret town-Mt. Boseti and Table 2.1.3 is Lake Koka – Huruta town – Sire town.

Table 2.1.2: Geological Succession along Adama Town-Mt. Boseti



Source: the Project Team, Data: Result of geological survey in this Project

Table 2.1.3: Geological Succession along Lake Koka – Hurita Town – Sire Town



Source: the Project Team, Data: Result of geological survey in this Project

b.2 Nazret pyroclastic deposits: Welded tuff, Rhyolitic slightly welded tuff and tuff breccia, pumice, tuff, and crystal tuff:

This unit is divided by two lithological facies; the lower part consists of yellowish white pumice fall deposits, tuff, crystal tuff, alternation of fine volcanic sands and pumiceous tuff (Ti2), and the upper part consists of white to bluish-gray rhyolitic consolidated tuff and tuff breccia which contain white pumice, rhyolitic lava fragments, crushed and/or slightly weathered obsidian fragments and rare reddish-brown basaltic lava fragments (Ti3).

b.2.1 Lower Nazret pyroclastic deposits: Ti2

Lithology: Consists of yellowish white pumice fall deposits, tuff, crystal tuff, alternation of fine volcanic sands and pumiceous tuff. At the type locality, alternation of dark grey medium tuff, reddish-brown fine tuff, white pumiceous tuff, dark grey lapilli tuff and bluish-grey fine tuff are observed. The strike is N150W and the dip is 22 0W. This unit is overlain unconformably by Bofa basalts at the Wakleso river in Doni town (L-AB43).

Distribution: Boru river, Sire, Huruta town, Ufura Ridge,

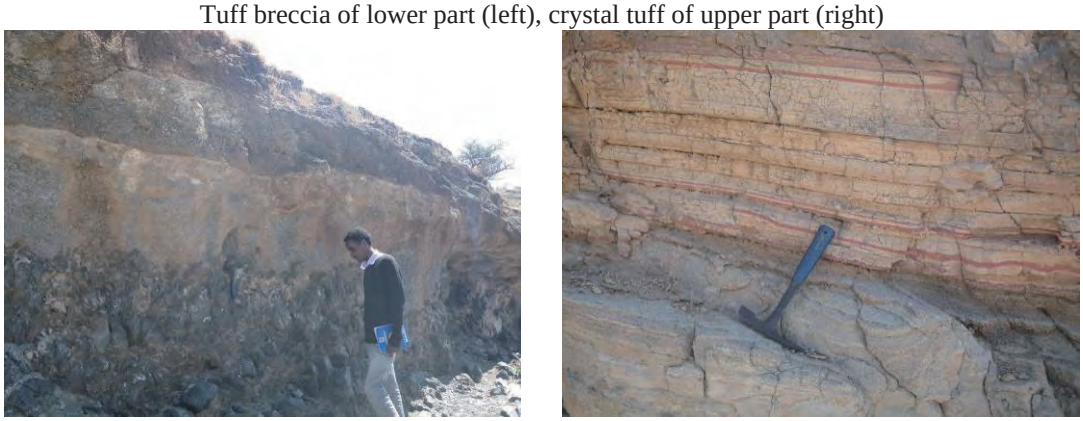
Thickness: More than 15 m in the type locality

Type locality: Boko, northeast of Wanji Sugar Farm (L-AB11)

Correlation: The area is classified as Nn: Nazret Group in GSE (1978).

Chronology: 5.5-3.5 Ma K-Ar age by Mohr, (1974), Morbidelli et al. (1975).

Tuff breccia of lower part (left), crystal tuff of upper part (right)



The unit consists of pumice tuff and alternated tuff.

Source: the Project Team, Data: Result of geological survey in this Project

Figure 2.1.4: Sire (L-AB35) (top), Boko (L-AB11) (bottom)

b.2.2 Upper Nazret pyroclastic deposits: Ti3

Lithology: Consists of white to bluish-gray rhyolitic compacted tuff, grayish green welded tuff with fiamme and tuff breccia which contain white pumice, rhyolitic lava fragments, crushed and/or slightly weathered obsidian fragments and rare reddish brown basaltic lava fragments. At the type locality, this unit unconformably overlies the lower part.

Distribution: Boru river, Huruta town, and the northeastern shore of Lake Koka

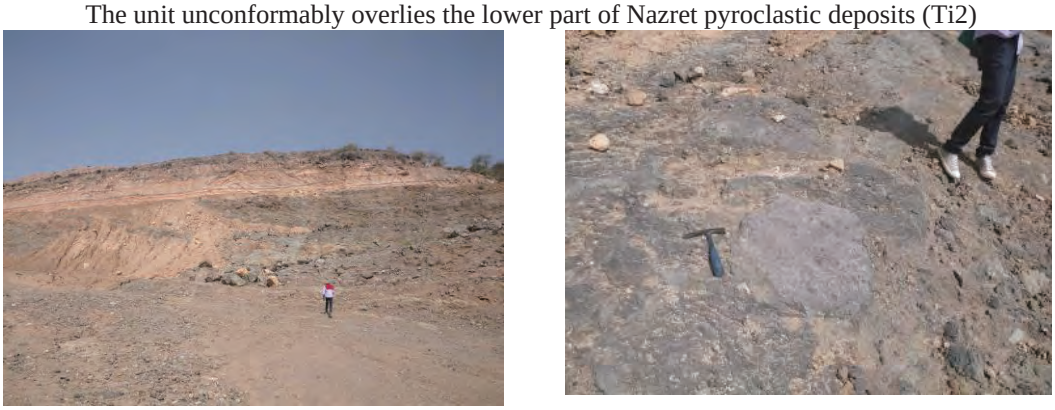
Thickness: More than 2 m in the type locality, more than 30m at Rukecha (L-MAD40)

Type locality: Koka Dam (L-AB02)

Correlation: The area is classified as Nn: Nazret Group in GSE (1978).

Chronology: 5.5-3.5 Ma K-Ar age by Mohr, (1974), Morbidelli et al. (1975).

The unit unconformably overlies the lower part of Nazret pyroclastic deposits (Ti2)



The unit consists of welded tuff and pumice tuff.

Source: the Project Team, Data: Result of geological survey in this Project

Figure 2.1.5: Koka Dam (L-AB02) (top), Rukecha (L-MAD40) (bottom)

b.3 Chilalo trachybasalts: Tt

Lithology: Consists of dark grey to black massive trachybasalt lavas and basaltic tuff breccia. At the type locality, this unit is unconformably overlain by Chefe Donsa pyroclastic deposits.

Distribution: Widely distributed in the northern mountain foot of Mt. Chilalo

Thickness: More than 30 m in the type locality.

Type locality: River Robi, north of Hamda Disks town (L-AB28)

Correlation: The unit is classified as N2c: Chilalo and Badda trachytes and trachybasalts in GSE (1978).

The unit is unconformably overlain by Chefe Donsa pyroclastic deposits.
Source: the Project Team, Data: Result of geological survey in this Project

Figure 2.1.6: River Robi（L-AB28)

b.4 Bofa basalts : massive aphyric basalt lava and tuff breccia: Tb3

Lithology: Consists of dark grey to black massive aphyric basalt lavas and basaltic tuff breccia. At the type locality, the unit forms NE-SW ridge (30 m high cliff) and is divided into two flow units. At the Awash river in Doni town, an approximately 20 m high waterfall is formed by basaltic lava (L-AB41). At Holly spring in Doni town, southeastern foot of Mt. Boseti Guda (L-AB39), and the Wakleso river in Doni town (L-AB43), dark grey to black basaltic tuff breccia which contains fine to medium volcanic sand, black basaltic breccia, and rare hyaloclastites is observed. This unit is unconformably overlain by Dino ignimbrite west of Bofa town (L-AB22).

Distribution: Widely distributed in the plains surrounding the southern part of Mt. Boseti Guda, Bofa town, and Cheleko near Sire town,

Thickness: More than 30 m in the type locality, around 700 m at the center of Mt. Aluto (from borehole data by GSE, 1986)

Type locality: Bofa (L-AB25)

Correlation: The unit is classified as Bofa basalts in GSE (1978).

Chronology: 6.1-4.4 Ma K-Ar age by Morton et al. (1979)

The unit forms NE-SW ridge (30m high cliff)

The unit shows basaltic tuff breccia

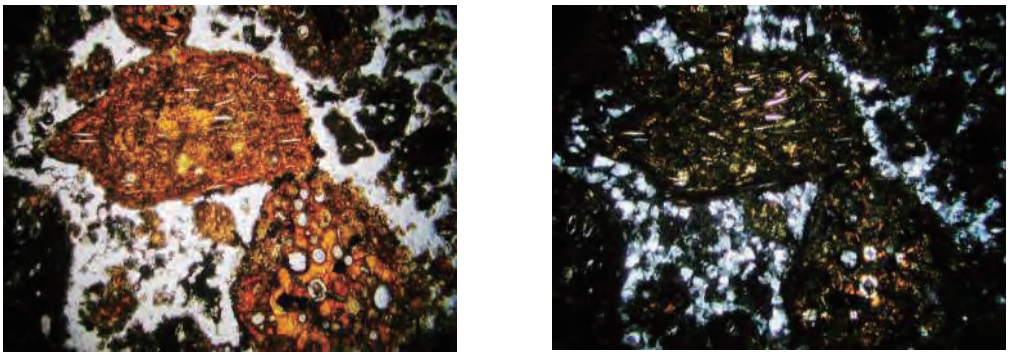
The unit shows hyaloclastites that unconformably overlies the lower part of Nazret pyroclastic deposits

Source: the Project Team, Data: Result of geological survey in this Project

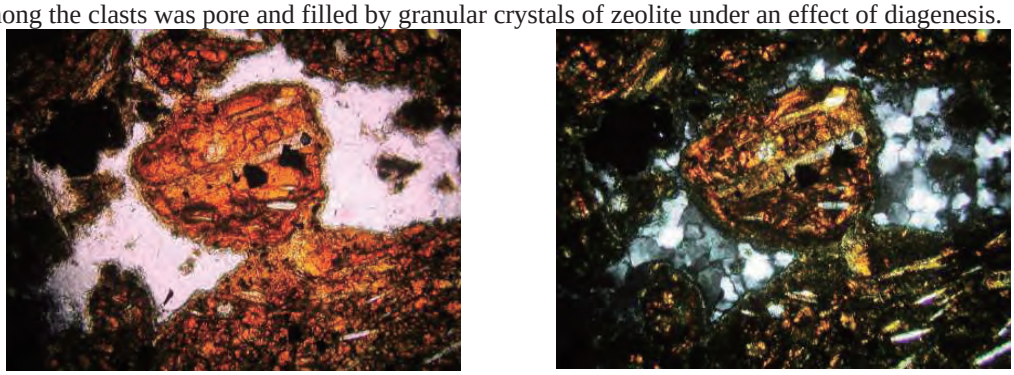
Figure 2.1.7: Bofa (L-AB25) (top left), Holly Spring (L-AB39) (top right), Weleso River (L-AB43) (bottom)

Observation of thin section

Sample number:	140419-1
Location:	About 2km NE of Dam of Lake Koka, foot of a cliff along the road to Dam of Lake Koka (L-AB55).
Stratigraphic horizon:	Bofa basalts
Rock type:	Basic volcanic sandstone.
Texture:	Parallel layered moderately sorted sandstone.
Clasts:	Mainly composed of basic rock fragments (basalt to vitrophyric basalt and scoria) associated with glass shards, plagioclase and alkali feldspar.
Matrix:	Pore which is mainly filled by zeolite.



Base of photo 1.6mm: Sand grains are composed of fragments of basalt, scoria and volcanic glass. Among the clasts was pore and filled by granular crystals of zeolite under an effect of diagenesis.



Base of photo 0.8mm: Basaltic rock fragments and cement of zeolite have outer limb of the clasts were coated by thin layer of clay mineral of saponite.

Figure 2.1.8: Photos of Thin Sections of Sample Number140419-1

c. Pleistocene

c.1 Dino ignimbrite: rhyolitic to andesitic welded tuff: Qi1

Lithology: Consists of greenish-yellow to light gray rhyolitic to andesitic welded tuff which typically contains elongated obsidian lenses (fiamme). Generally, most fiamme is horizontal and concordant with the unit, but some fiamme shows irregular and/or ripple structure. At the type locality, the unit unconformably overlies Bofa basalts, and is overlain by Chefe Donsa pyroclastic deposits and Pleistocene basalts. The unit is highly to moderately welded medium tuff with maximum 30 cm-long fiamme, rhyolite, pumice and rarely basaltic fragments.

Distribution: Around Megacha, west of Bofa town, east of Awash Melkasa town, east of Sire town , around Mojo town, and Jogo, Koka Dam

Thickness: More than 8 m at the type locality

Type locality: West of Bofa town (L-AB22)

Correlation: The area is classified as Nn: Nazret Group in GSE (1978).

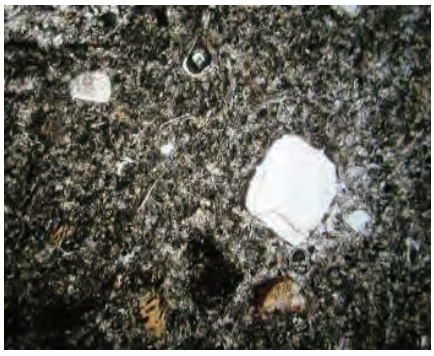

Fiamme shows irregular and/or ripple structure.


The unit unconformably overlies Bofa basalts
Source: the Project Team, Data: Result of geological survey in this Project

Figure 2.1.9: Jogo (L-AB06) (top), West of Bofa Town (L-AB22) (bottom)

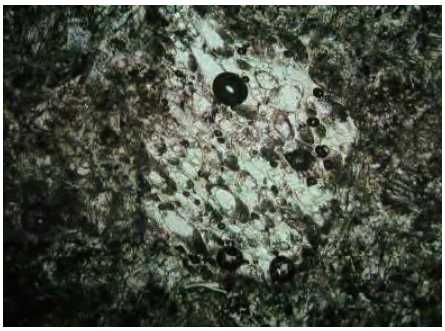
Observation of thin sections

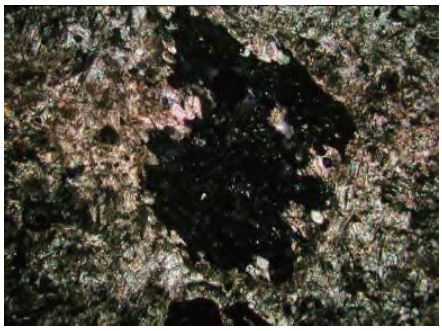
Sample number:	140414-1
Location:	Between Dera to Sire, about 500m west from Keleta river Bridge, base of single pyroclastic flow unit (L-AB19).
Stratigraphic horizon:	Dino ignimbrite
Rock type:	Glassy unwelded tuff
Texture:	Mainly composed of volcanic glass and minor crystal of phenocryst fragments.
Clasts:	Rich in alkali feldspar, fragments of pumice, rhyolite and andesite are common, minor plagioclase, green hornblende and quartz.
Matrix:	Volcanic glass fragment; pores are filled by secondary calcite.



Plane-polarized light; base of photo 1.4mm; Fragments of alkali feldspar and rhyolite and matrix of glass shards.

Plane-polarized light; base of photo 1.5mm: Fragments of pumice, Alkali feldspar and rhyolitic rock and matrix composed of glass shards

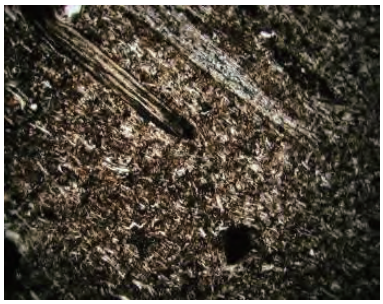




Base of photo 0.7mm: A pumice fragment is surrounded by matrix of glass shards. Pores of matrix are filled by secondary calcite. It might be caused by an effect of poor underground water circulation.

Figure 2.1.10: Photos of Thin Sections of Sample Number 140414-1

Sample number:	140414-2
Location:	Between Dera to Sire, at the Keleta river Bridge, Solid black layer of obsidian like ignimbrite (L-AB20).
Stratigraphic horizon:	Dino ignimbrite.
Rock type:	Glassy welded ignimbritic tuff.
Texture:	Mainly composed of welded volcanic glass.
Clasts :	Coarse-grained flattened pumice and fine-grained essential vitrophyric rhyolitic rock fragments are common. Fragments of alkali feldspar are observed.
Matrix:	Welded volcanic glass fragments.



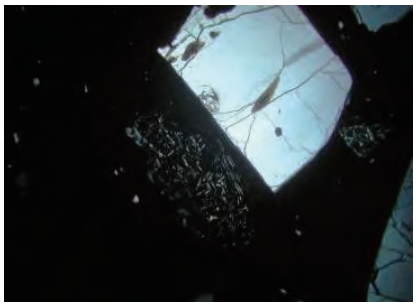
Plane-polarized light; base of photo 1.4mm; Flattened pumice and matrix of welded glass shards.

Plane-polarized light; base of photo 1.4mm: Fragments of alkali feldspar and fine-grained vitrophyric rhyolitic rock, and matrix composed of welded glass shards.

Base of photo 0.7mm: Matrix of welded glass shards and fragments of alkali feldspar and rhyolite. Grasses are dark in crossed polars indicates optical isotropism.

Figure 2.1.11: Photos of Thin Sections of Sample Number 140414-2

Sample number:	140414-5
Location:	At high terrace about 3 km SE of Sire (L-AB37).
Stratigraphic horizon:	Dino ignimbrite
Rock type:	Welded ignimbritic tuff, Black ignimbrite with large euhedral alkali feldspar
Texture:	Welded volcanic glass with crystals of phenocryst fragments and rock fragments.
Clasts:	Coarse-grained euhedral alkali feldspars are characteristically included. Flattened pumice, andesitic and rhyolitic rock fragments are common, fragments of green hornblende and quartz are observed.
Matrix:	Welded volcanic glass fragments. Clay mineral and limonite are formed in the matrix. It indicates that this rock is as old as the time needed for these minerals to be formed.

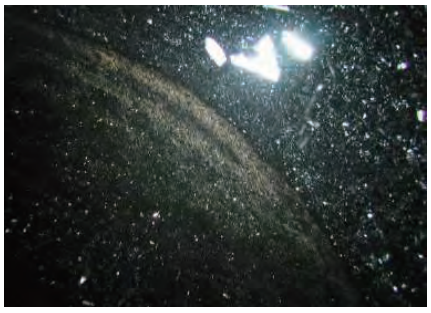



Base of photo 1.6mm: Coarse-grained euhedral alkali feldspars are characteristic. Andesitic rock fragment is at the center of the photo. A pumice is flattened and glass shards are welded.

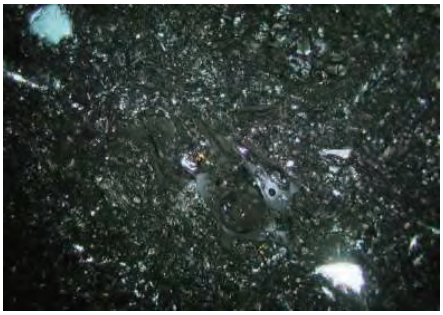

Base of photo 0.8mm: Clay minerals are formed in welded glass shards. The micaceous clay mineral is thought to be formed not so quickly like calcite. This rock is considered to be a member of older complex.

Figure 2.1.12: Photos of Thin Sections of Sample Number 140414-5

Sample number:	140414-6
Location:	At high terrace about 3km SE of Sire White tuff with accretionary lapilli which covers 140414-5 (L-AB37).
Stratigraphic horizon:	Dino ignimbrite
Rock type:	Vitric rhyolite tuff with accretionary lapilli.
Texture:	Volcanic glass with crystal and rock fragments.
Clasts:	Fine-grained fragment of alkali feldspars and pumices are common. Nepheline, albite and quartz are observed. Accretioary lapillis are associated.
Matrix:	Unwelded volcanic glass shards.

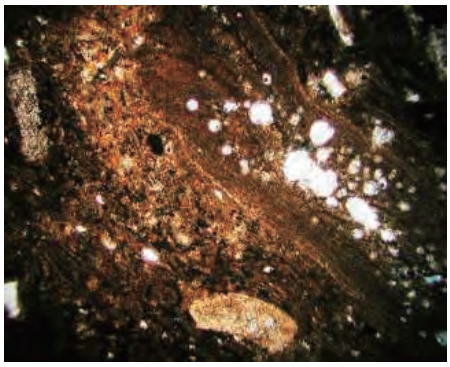
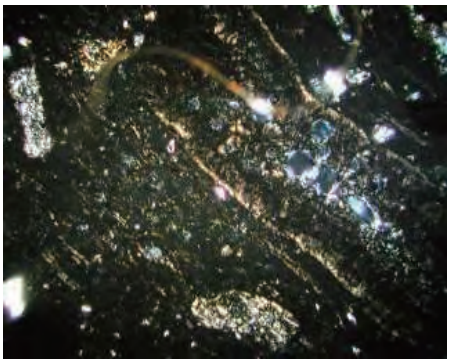
Base of photo 1.6mm: Accretionary lapilli (pisolite) are coated by very fine-grained volcanic ash. Matrix is also composed of very fine-grained glasses with small amount of crystal fragment. Clasts of nepheline are found.

Base of photo 0.8mm: Matrix of glass shards and fragments of pumices are not welded.

Figure 2.1.13: Photos of Thin Sections of Sample Number 140414-6

Sample number:	140419-3
Location:	About 2km NE of Dam of Lake Koka, top of a cliff along the road to Dam of Lake Koka (L-AB55).
Stratigraphic horizon:	Dino ignimbrite
Rock type:	Welded rhyolite tuff
Texture:	Welded volcanic glass with crystal of phenocryst fragments and rock fragments.
Clasts:	Fragments of alkali feldspars are common. Flattened pumices and acidic volcanic rock fragments (with variety of texture) are abundant. Fragments of green amphibole, opaque minerals and a few plagioclase and pyroxene are observed: fragments of trachyte are also found.
Matrix:	Welded volcanic glass fragments. Clay minerals are formed in matrix and flattened pumice.

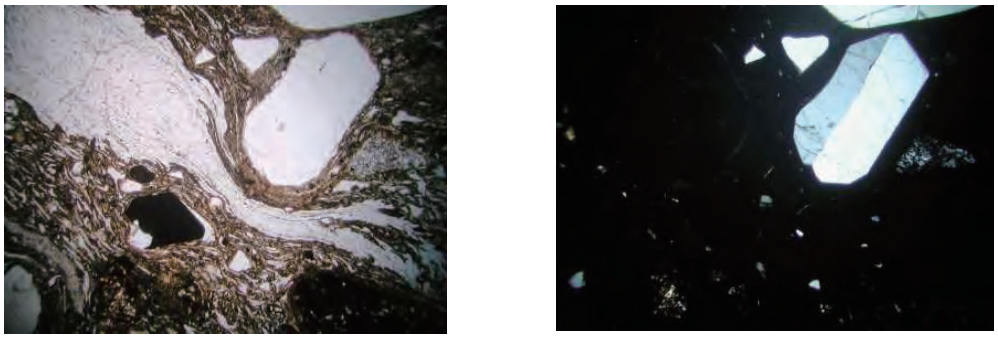



Base of photo 1.5m: Fragments of pumices and acidic volcanic rocks are dominant. Glass shards of matrix are welded. Clay minerals are formed in welded glass.


Base of photo 0.7mm: Some glass shards are changed into clay minerals. Microcrystalline acidic rock fragment of right side bottom is not essential.

Figure 2.1.14: Photos of Thin Sections of Sample Number140419-3

Sample number:	140419-5
Location:	Along road about 8km west of Nazret (L-AB56).
Stratigraphic horizon:	Dino ignimbrite
Rock type:	Welded ignimbritic tuff, black ignimbrite with large euhedral alkali feldspar.
Texture:	Welded volcanic glass and lenticuler obsidian with crystal of phenocryst fragments and rock fragments.
Clasts	Coarse-grained euhedral alkali feldspars are characteristic: Flattened pumice and obsidian lenses, acidic to basic rock fragments are common, fragments of green hornblende, opaque mineral, K-feldspar and chrome spinel are observed.
Matrix:	Welded volcanic glass fragments.



Base of photo 1.6mm: Coarse-grained euhedral alkali feldspars are characteristic. Lens of obsidian is upper left to the center of the photo. Glass shards are welded.

Base of photo 0.8mm. Fragments of alkali feldspar and amphibole. Welded glass shards of matrix are dark in crossed polars which indicates little effect of diagenesis.

Figure 2.1.15: Photos of Thin Sections of Sample Number140419-5

c.2 Pleistocene rhyolites: Rhyolite, rhyolitic tuff, pumice tuff: Qr1

Lithology: Consists mainly of white to bluish-gray rhyolite lava flows and tuff, white pumice, pitchstone and hard tuff including obsidians. At the northeastern part of the Gademsa caldera wall, the unit is observed more than 100m from the bottom.

Distribution: Caldera wall of Gademsa.

Thickness: More than 100 m at the type locality

Type locality: Northeastern cliff of Gademsa caldera (L-AB05)

Correlation: The area is classified as Nn: Nazret Group in GSE (1978).

The unit consists of rhyolitic tuff, obsidian

Source: the Project Team, Data: Result of geological survey in this Project

Figure 2.1.16: Northeastern Cliff of Gademsa Caldera (L-AB05)

c.3 Chefe Donsa pyroclastic deposits: pumice flow, pumice tuff: Qp1

Lithology: Consists mainly of pumice flow, white pumice tuff, bluish white pumice and white tuff. At the type locality, the unit consists of at least three layers with a paleosoil unconformity. The lower part contains a lot of lapilli and the upper part contains a lot of pumice, indicating normal grading in the unit. The unit, which consists of pumice tuff, tuff and paleosoil, unconformably overlies Dino ignimbrite east of Sire town (L-AB37).

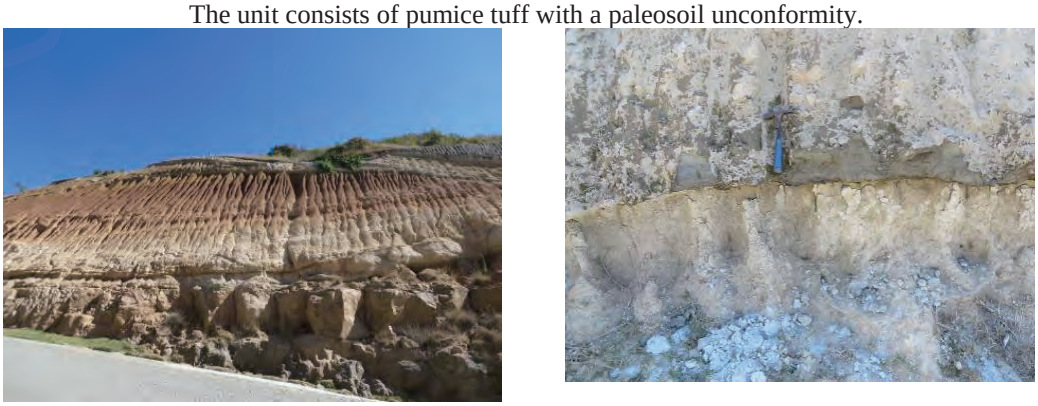
Distribution: Around Mojo town, Dire town, Sire town and northeast of Adama town.

Thickness: More than 70 m at the type locality.

Type locality: Boru river about 10 km east of Dera town (L-AB19)

Correlation: The area is classified as Nn: Nazret Group in GSE (1978).

The unit consists of pumice tuff with a paleosoil unconformity.



The unit unconformably overlies Dino ignimbrite.

Source: the Project Team, Data: Result of geological survey in this Project

Figure 2.1.17: Boru River (L-AB19) (top), Sire (L-AB37) (bottom)

c.4 Pleistocene basalts: basaltic lava: Qb1

Lithology: Consists of grayish-black aphyric basalt, dark grey to dark bluish-grey olivine basalt lavas, plagioclase basalt lavas and scoria cones. At the type locality, the units unconformably overlie Chefe Donsa pyroclastic deposits.

Distribution: Southeastern shore of Lake Koka, around Awash Melkasa town to Bofa town and the Mt. Boseti surroundings.

Thickness: More than 15 m at the type locality.

Type locality: Gambedra, northeast of Bofa town (L-AB38)

Correlation: The unit is classified as Qwb1: Pleistocene-sub-recent basalt and N2Qb: Bofa basalt in GSE (1978).

The unit unconformably overlies Chefe Donsa pyroclastic deposits.

Source: the Project Team, Data: Result of geological survey in this Project

Figure 2.1.18: Gambedra (L-AB38)

c.5 Boseti-Kone pumice fall deposits: pumice fall deposits, pumice tuff and tuff: Qp2

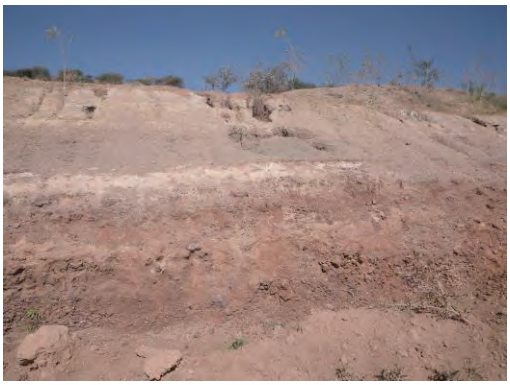
Lithology: Consists mainly of pale grey pumice fall deposits, light grey fine ash, white pumice tuff, bluish-white pumice and white tuff. The unit unconformably overlies Pleistocene basalts at the type locality.

Distribution: Southwest of Mt. Boseti, Lake Koka and Adama town surroundings.

Thickness: More than 8 m at Mt. Boseti (L-AB30).

Type locality: Welensu (L-AB17).

Correlation: The area is classified as Nn: Nazret Group, Qwb3: Recent basalt and N2Qb: Bofa basalt in GSE (1978).



The unit unconformably overlies Pleistocene basalts.

The unit consists of pumice fall deposits and ash

Source: the Project Team, Data: Result of geological survey in this Project

Figure 2.1.19: Welensu (L-AB17) (left), Mt.Boseti (L-AB29) (right)

c.6 Fentale ignimbrite: rhyolitic to andesitic welded tuff: Qi3

Lithology: Consists of greenish-blue to light yellow rhyolitic to andesitic welded tuff which typically contains elongated obsidian lenses (fiamme). Generally, fiamme is horizontal and concordant with the unit. The unit consists of highly to moderately welded medium tuff with maximum 20cm-long fiamme, rhyolite, pumice and strongly welded tuff fragments.

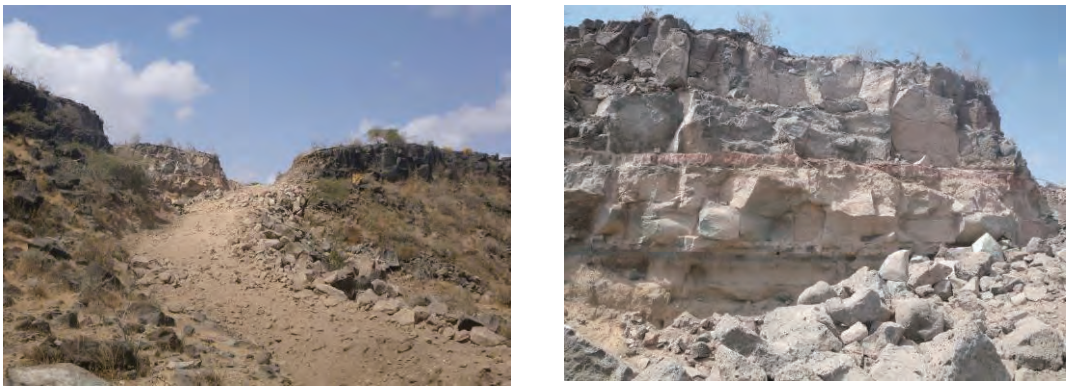
Distribution: Northern rim of Gademsa Caldera and west of Melka Jiro town

Thickness: More than 10 m at Koka Dam (L-AB46)

Type locality: Madiga, west of Melka Jiro town (L-AB46)

Correlation: The area is classified as Qwi2: Young ignimbrites of Fentale in GSE (1978), and as Fentale ignimbrite in OWWDSE (2013)

Chronology: 168,000±38,000 years fission track age by Williams et al. (2004) and 0.12-0.18Ma by Bigazzi et al. (1981).



The unit overlies a Mt. Boseti pumice fall deposit unconformity

The unit consists of rhyolitic to andesitic welded tuff.

Source: the Project Team, Data: Result of geological survey in this Project

Figure 2.1.20: Madiga, (L-MAD37) (top), Lake Koka (L-AB10) (bottom)

d. Holocene

d.1 Holocene basalts: Vesicular basalt, scoria falls and scoria cones: Qb2

Lithology: Consists of dark gray to dark bluish-gray vesicular basalt lava and dark brown to reddish-brown scoria falls and scoria cones. Scoria cones of this unit are observed around Mt. Boseti and the southwestern Lake Koka area.

The unit unconformably overlies Chefeko rhyolites (Tr2) at Haribona (L-AB42)

Distribution: Around Mt. Boseti and southwestern shore of Lake Koka

Thickness: More than 12 m at the type locality.

Type locality: Harorecha, southern foot of Mt. Boseti (L-AB32)

Correlation: The unit is classified as Qwb3: Recent aphyric basalts in GSE (1978).

Dark gray to dark bluish-gray vesicular basalt.

The unit unconformably overlies Chefeko rhyolites (Tr2).

Source: the Project Team, Data: Result of geological survey in this Project

Figure 2.1.21: Harorecha (L-AB32) (left), Haribona (L-AB42) (right)

d.2 Recent rhyolitic domes & lava flows: obsidian lavas and domes: Qr2

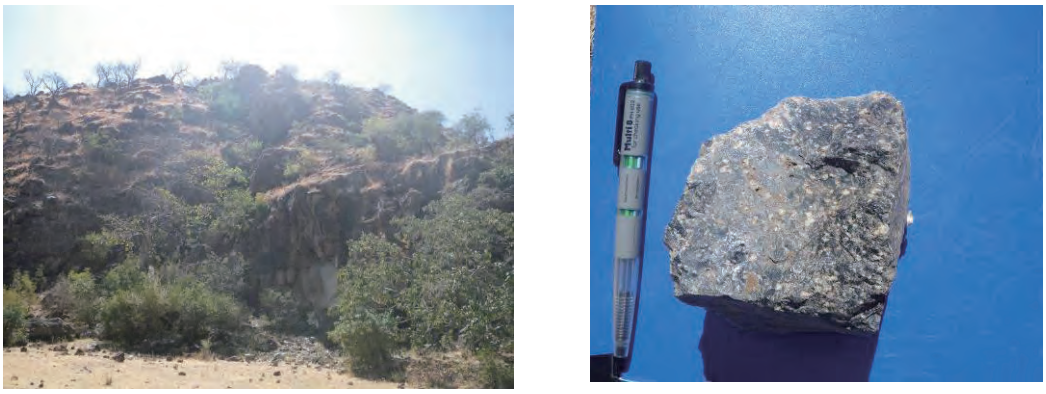
Lithology: Consists of obsidian lavas, pumice fall deposits with obsidian and obsidian domes. At the type locality, the unit unconformably overlies Dino ignimbrite.

Distribution: Obsidian lava is observed at southeastern foot of Mt. Boseti and obsidian domes are situated at the southeastern Lake Koka area

Thickness: More than 20 m at the type locality.

Type locality: Waka Bute southeastern Lake Koka area (L-AB04)

Correlation: The area is classified as Qwo: Recent pantelleric and comenditic obsidian flows and domes in GSE (1978).



The unit overlies unconformably Dino ignimbrite.

The unit unconformably overlies Holocene basalts.
Source: the Project Team, Data: Result of geological survey in this Project

Figure 2.1.22: Waka Bute (L-AB04) (top), Miesa (L-AB03) (bottom)

d.3 Alluvium: Qal

Lithology: Fine sand and mud
Distribution: Awash river
Thickness: 1 to 5 m

2.2 Kone – Mt. Fentale and its surrounding areas

2.2.1 General

Kone-Mt. Fentale and its surrounding areas are located in the central MER. The basin floor is widely covered by volcanic deposits from the Pleistocene to Holocene periods. WFB is well developed on the floor and margin of the MER in the area. Therefore, Pliocene – Pleistocene strata are generally observed at the scarps of these faults. The lowest unit, named Birenti-Hada rhyolites, is observed at the foot of Mount Bosena. Bofa basalts overlies Birenti-Hada rhyolites at the southern foot of Mount Bosena, and is widely observed at a gentle slope at the lava plateau. Dino ignimbrite is observed at the northern foot of Kone caldera, the western foot of Mt. Fentale, and is widely distributed at the flat plain of the southeastern plateau. Dino ignimbrite has a chronological age of 1.5Ma according to Mobidelli et. al, 1975, and 1.51 Ma according to Kazmin, et al, 1978. Tuff ring, Pleistocene basalts, Kone ignimbrite, Kone pumice fall, Fentale volcanic rocks and Fentale ignimbrite are

observed in the surroundings of Kone caldera and Mt. Fentale. In Holocene, rift floor basalts and Recent rhyolitic domes & lava flows from volcanic activity are observed in the southwest of Lake Besaka.

A more detailed geological survey was carried out around Lake Besaka. The details are described in Chapter 3.3 Topography, geology and geological structure.

Table 2.2.1 shows the stratigraphy in Kone-Mt. Fentale and its surrounding area.

Table 2.2.1: Stratigraphy in Kone-Mt. Fentale and its Surrounding Areas

Age			Stratigraphy	Major Lithology		Legend	Age
Cainozoic	Quarternary	Holocene	Qal	Alluvium	sand, clay, lucstrin		
			Qr2	Recent rhyolitic dome & lava flows	rhyolitic domes with obsidian lava flows		
			Qb2	Holocene basalts	aphyric basalt and scoria cone		
		Pleistocene	Qi3	Fantale ignimbrite	pare green strongly welded tuff with fiamme		168,000±38,000 y (OWWDSE ,2013)
			Qf	Fanrale volcanic rocks	greenish grey welded tuff, tuff, trachyte		
			Qp2	Kone pumice falls	pumice fall , tuff		
			Qi2	Kone ignimbrite	greenish consolidated to welded fine tuff		
			Qb1	Pleistocene basalts	aphyric basalt		
			Qs	Sobebor volcanic sand beds	sand, tuff, alternation		
			Qi1	Dino ignimbrite	Greenish grey welded tuff with fiamme		Dino : 1.5my (Mobidelli et al., 1975), 1.51 Ma (Kazmun, et al.,1978)
	Tertiary	Pliocene	Tb3	Bofa basalts	aphyric basalt		Tulu Rie basalt: 2.7±0.1 Ma(INGEIS-Buenos Aires), 1.44±0.03 Ma(Chernet et al., 1998) Bofa : 1.21 Ma (Kazumin, et al., 1978), 6.1-4.4 Ma(Morton et al.,1979)
			Tr2	Birenti-Hada rhyolites	rhyolite with pumiceous tuff		

Source: the Project Team, Data: Result of geological survey in this Project

2.2.2 Geological unit

a. Pliocene

a.1 Birenti-Hada rhyolites: Rhyolite, rhyolitic tuff, pumice tuff: Tr2

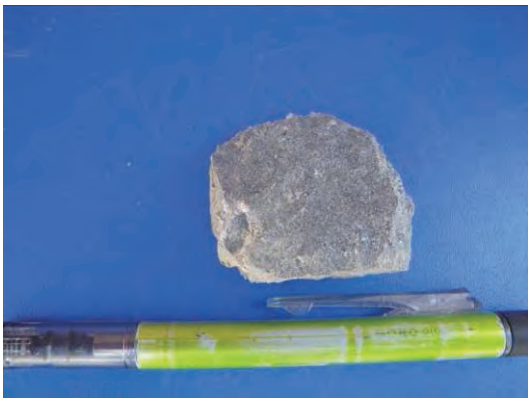
Lithology: Consists mainly of white to bluish gray rhyolite lava flows and tuff, white pumice, pitchstone and hard tuff including obsidians. At Mt. Birenti (L-KF15), the unit is divided by six lithological facies; from the lowest, bluish-white rhyolitic fine tuff (more than 20m in thickness), bluish-grey pumice fall deposits (more than 5m in thickness), bluish-white rhyolitic pumice-tuff (more than 25m in thickness), white pumice-tuff (3m in thickness), pitchstone (5m in thickness), and bluish- white rhyolitic tuff (more than 10m in thickness). At the southwestern part and northeastern part of the Kone caldera wall, the unit is observed more than 200 m from the bottom.

Distribution: Forms a NE-SW distribution hill at Bosena, Abadir Shero at Abadir Farm, Mt. Birenti and Dimtu Ridge south of Metehara Sugar Plantation.

Thickness: More than 80 m at the type locality.

Type locality: Bosena, northwest of Melka Jiro town (L-KF02)

Correlation: The area is classified as Qwr: Recent to sub-recent rhyolite domes and flows at the type locality, N2 Qb: Bofa basalts at Abadir and Dimitu Ridge in GSE (1978).



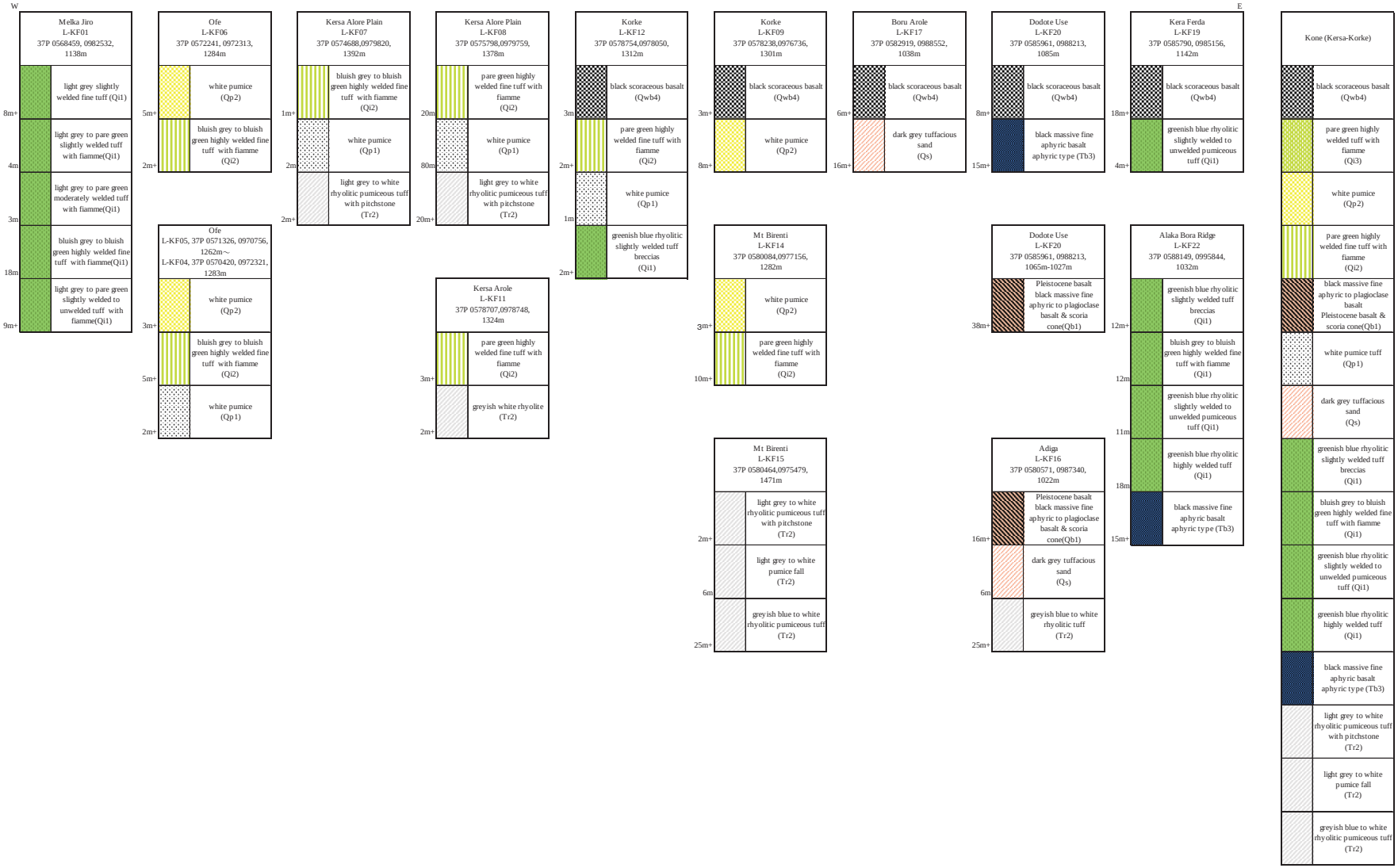
Rhyolitic tuff

Source: the Project Team, Data: Result of geological survey in this Project

Figure 2.2.1: Bosena (L-KF02) Bokan

Table 2.2.2 and Table 2.2.3 are described the geological succession along Kone-Mt. Fentale-Awash town.

Table 2.2.2: Geological Succession along Kone-Mt. Fentale



Source: the Project Team, Data: Result of geological survey in this Project

Table 2.2.3: Geological Succession along Mt. Fentale – Awash Town

Source: the Project Team, Data: Result of geological survey in this Project

a.2 Bofa basalts: massive aphyric basalt lava and tuff breccia: Tb3

Lithology: The unit is mainly aphyric basalts distributed around the southern foot of Mt. Birenti. It also includes olivine basalt at some places.

Distribution: Surrounding the southern foot of Mt. Birenti

Thickness: More than 15 m in the type locality

Type locality: North of Nura-Hira farm.

Correlation: The unit is classified as Bofa basalts in GSE (1978).

Chronology: 6.1-4.4 Ma K-Ar age by Morton et al. (1979)

Observation of thin section

Sample number: 140415-4

Location: Awash fall in Awash national park (L-KF46).

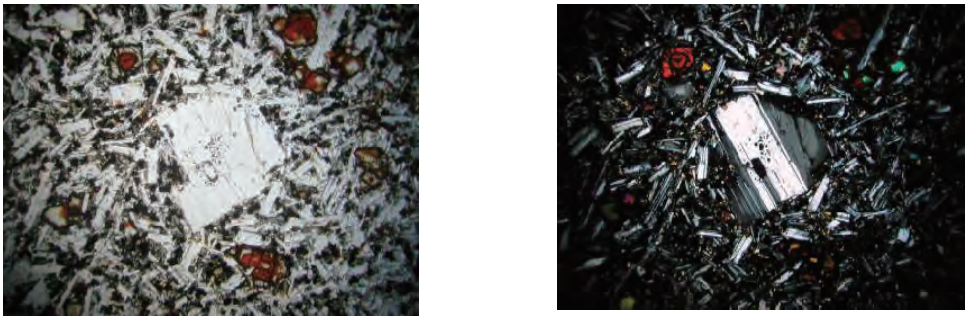
Stratigraphic horizon: Bofa basalts

Rock type: Basalt, Black amygdaloidal rock of aa-type basalt flow.

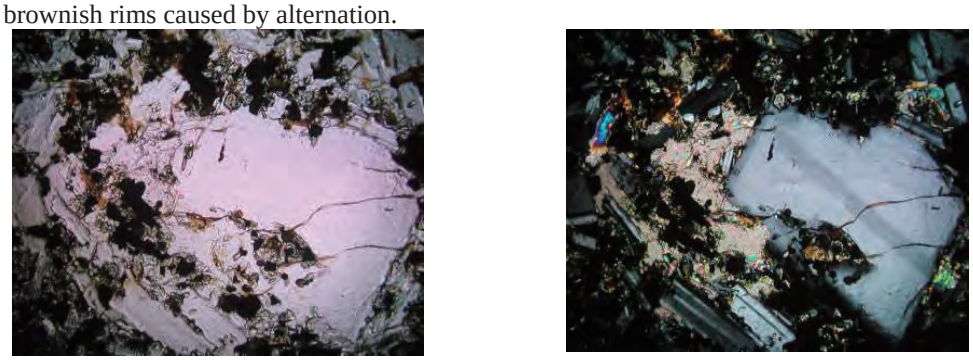
Texture: Porphiloclasts and groundmass

Phenocryst: Plagioclase, olivine and monor alkali feldspar.

Groundmass: Very fine-grained lath of plagioclase with very fine-grained pyroxene, olivine and opaque mineral.



Base of photo 1.5mm: Phenocrysts of plagioclase with multiple twinning. Plenocrysts of olivine have brownish rims caused by alternation.



Base of photo 0.7mm: Groundmass is composed of very fine-grained feldspar, opaque mineral and pyroxene. At the left side of phenocryst of alkali feldspar, there was a pore occupied by calcite. The calcite is considered to be formed by an effect of underground water. It leads this rock is relatively old.

Figure 2.2.2: Photos of Thin Sections of Sample Number 140415-4

b. Pleistocene

b.1 Dino ignimbrite : rhyolitic to andesitic welded tuff : Qi1

Lithology: Consists of greenish-yellow to light gray rhyolitic to andesitic welded tuff which typically contains elongated obsidian lenses (fiamme). Generally, most of fiamme is horizontal and concordant with the unit, but some fiamme shows irregular and/or ripple structure. At the type locality, the unit is classified into four layers from the grade of welding.

Distribution: Forms a flat plain surrounding Dodose Kelo at the northern foot of Kone caldera and the southeastern foot of Mt. Fentale.

Thickness: More than 39 m at the type locality.

Type locality: Southeastern foot of Fentale (L-KF39)

Correlation: The area is classified as Nn: Nazret Group, and as Qwi: Dino ignimbrites in GSE (1978).

Chronology: 1.51My K-Ar age from Awash rive near Karayu by Mobidelli et al. (1975)

Rhyolitic to andesitic Welded Tuff

Source: the Project Team, Data: Result of geological survey in this Project

Figure 2.2.3: Southeastern Foot of Mt. Fentale (L-KF39)

b.2 Sobebor volcanic sand beds: volcanic sand and tuff alteration beds: Qs

Lithology: The unit consists of yellowish brown-basaltic lapilli tuff to tuff breccia, containing basaltic sub-angular fragments. Boru Alore and Sobebor form craters and have relatively steep rims which dip equally both inwards and outwards. At Dinbiba, the southern foot of Mt. Fentale (L-KF30), the unit is around 250 dipping to the northeast, and is unconformably overlain by Fentale welded tuff.

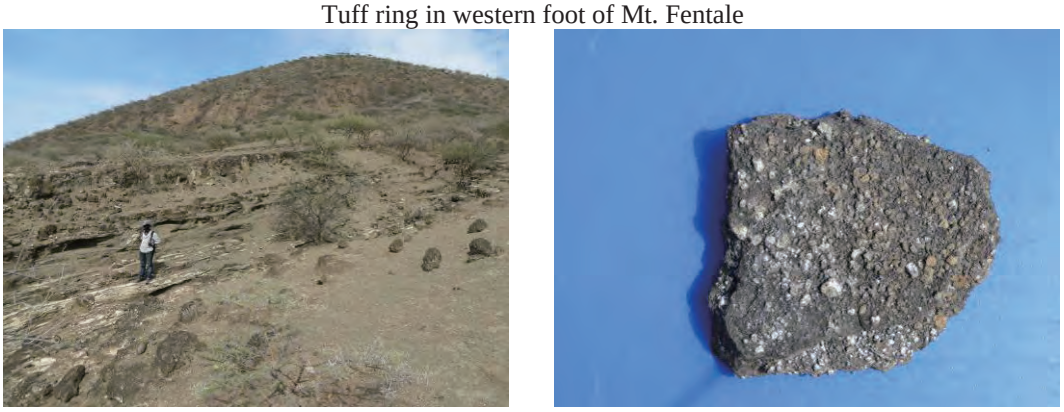
Distribution: A volcanic crater is formed. Boru Alore, the northeastern foot of Kone caldera, Sobebor, the western foot of Mt. Fentale, and Dinbiba, the southern foot of Mt. Fentale

Thickness: More than 15 m at Dinbiba, more than 240 m at Boru Alore, and more than 82 m at Sobebor.

Type locality: Sobebor (L-KF23)

Correlation: The unit is classified as Qwh: Basaltic hyaloclastites in GSE (1978).

Tuff ring in western foot of Mt. Fentale



Basaltic tuff distributed in northeastern foot of Kone caldera

Approximately 25°dipping toward mountain (northeast) and unconformably overlaid by Fentale ignimbrite

Source: the Project Team, Data: Result of geological survey in this Project

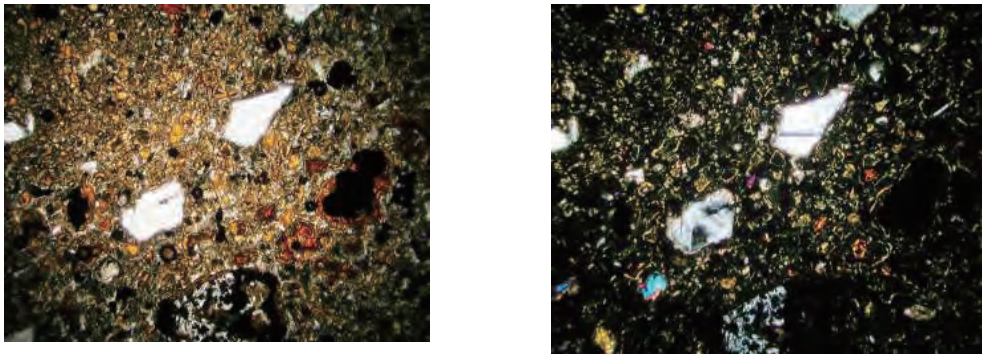
Figure 2.2.4: Sobebor (L-KF23) (top), Boru Alore (L-KF18) (middle) and Dinbiba (L-KF30) (bottom)

Observation of thin section

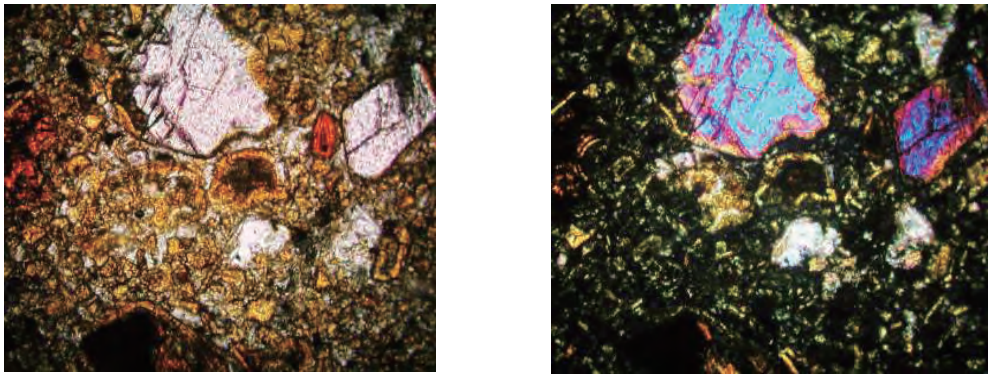
Sample number:	140417-5
Location:	About 5km SW of the caldera of Mt. Fentale, crop out on cliff slope at a foot of Mt. Fentale (L-KF30).
Stratigraphic horizon:	Sobebor volcanic sand beds
Rock type:	Basic volcanic sandstone.
Texture:	Parallel layered moderately sorted sandstone.

Clasts: Rich in fragments of glass shards associated with plagioclase, alkali feldspar and minor pyroxene and basic rock fragments.

Matrix: Pore which is partly filled by zeolite.



Base of photo 1.5mm: Sand grains are composed of volcanic glass, plagioclase, alkali feldspar and pyroxene.



Base of photo 0.7mm: Glass fragments have greenish color of saponite indicating basic composition. Clasts are cemented by fine-grained zeolite. Clasts of pyroxene supports that the volcanic materials of the sandstone were derived from basic volcanic ash.

Figure 2.2.5: Photos of Thin Sections of Sample Number140417-5

b.3 Pleistocene basalts: basaltic lava: Qb1

Lithology: Consists of dark grey to dark bluish-grey olivine basalt lavas, plagioclase basalt lavas and scoria cones. At Bogda, the southwestern foot of Mt. Fentale, the unit is unconformably overlain by Fentale ignimbrite.

Distribution: Kone caldera, the northern to western foot of Kone caldera, the southwestern and southeastern foot of Mt. Fentale.

Thickness: More than 38 m at Dodose Use (L-KF20)

Type locality: Dodose Use (L-KF20)

Correlation: The unit is classified as Qwb1: Pleistocene-sub-recent basalt and N2Qb: Bofa basalt in GSE (1978).

Northeastern foot of Kone caldera

Southwestern foot of Mt. Fentale. The unit is overlain by a Fentale ignimbrite unconformity
Source: the Project Team, Data: Result of geological survey in this Project

Figure 2.2.6: Dodose Use (L-KF20) (top) and Bogda (L-KF25) (bottom)

b.4 Kone ignimbrite: greenish consolidated to welded fine tuff: Qi2

Lithology: Consists of greenish-blue to light green rhyolitic to andesitic consolidated to welded tuff. At the type locality, the unit is unconformably overlain by Kone pumice fall deposits.

Distribution: Kone caldera and the caldera wall of Korke surroundings

Thickness: More than 20 m at the Kersa Alore plain (L-KF08)

Type locality: Kone (L-KF13)

Correlation: The area is classified as Qwpu: Unwelded rhyolitic pumice and unwelded tuff in GSE (1978)


At the type locality (L-KF13), the unite is unconformably overlain by Kone pumice fall deposits

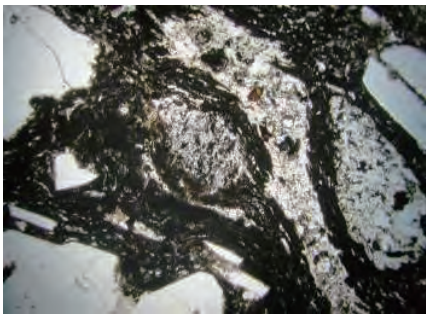
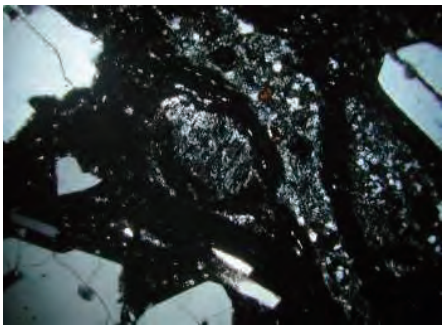

Ofe (20150116-04), southwestern foot of Kone caldera

Source: the Project Team, Data: Result of geological survey in this Project

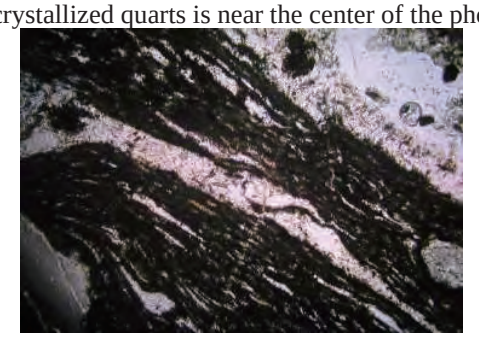
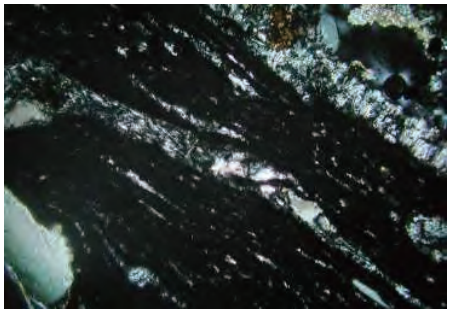
Figure 2.2.7: Kone (L-KF13) (top) and Ofe, Southwestern Foot of Kone Caldera (L-KF03) (bottom)

Observation of thin section

Sample number:	140415-2
Location:	Base of the Korke caldera, Greenish welded tuff covered by pumice layer (L-KF13).
Stratigraphic horizon:	Kone ignimbrite
Rock type:	Welded rhyolite tuff
Texture:	Welded volcanic glass with crystal of phenocryst fragments and rock fragments.
Clasts:	Fragments of alkali feldspars are dominant: Flattened pumice, basic and acidic rock fragments are common, fragments of nepheline, green hornblende, augite, clino-pyroxene and quartz are observed.
Matrix:	Welded volcanic glass fragments. Quartz is formed in matrix and flattened pumice. It indicate that this rock is affected by a diagenesis to form quartz which need long times.

Base of photo 1.6mm: Fragments of alkali feldspars are dominant. A flattened pumice with recrystallized quarts is near the center of the photo. Glass shards of matrix are welded.

Base of photo 0.8mm: Welded glass shards and flattened pumice. Cystallization of zeolite as fibrous aggregates from the edges towards the centers of lenses could be caused by diagenesis. This rock is considered to be a member of older complex.

Figure 2.2.8: Photos of Thin Sections of Sample Number 140415-2

b.5 Boseti-Kone pumice fall deposits: pumice fall deposits, pumice tuff and tuff: Qp2

Lithology: Consists mainly of pale grey pumice fall deposits, light grey fine ash, white pumice tuff, bluish white pumice and white tuff. The unit unconformably overlies Kone ignimbrite at Kone (L-KF13).

Distribution: Kone caldera surroundings, and Mt. Fentale.

Thickness: More than 10m at the type locality.

Type locality: Korke (L-KF10).

Correlation: The area is classified as Qwpu: Unwelded rhyolitic pumice and unwelded tuff in GSE (1978)

pumice fall deposits and ash
Source: the Project Team, Data: Result of geological survey in this Project

Figure 2.2.9: Korke (L-KF10)

b.6 Fentale ignimbrite: rhyolitic to andesitic welded tuff: Qi3

Lithology: Consists of greenish-blue to light yellow rhyolitic to andesitic welded tuff which typically contains elongated obsidian lenses (fiamme). Generally, fiamme is horizontal and concordant with the unit. At the type locality, the unit is divided by three lithological facies; from lowest, greenish-blue highly welded tuff with fiamme, pumice fall deposits, and light yellow highly welded tuff with fiamme. At the southern foot of Mt. Fentale (L-KF30), the unit unconformably overlies Sobebor volcanic sand beds (Qs) and is overlain by Holocene basalts. The unit is highly to moderately welded medium tuff with maximum 20cm-long fiamme, rhyolite, pumice and strongly welded tuff fragments.

Distribution: Foot of Mt. Fentale

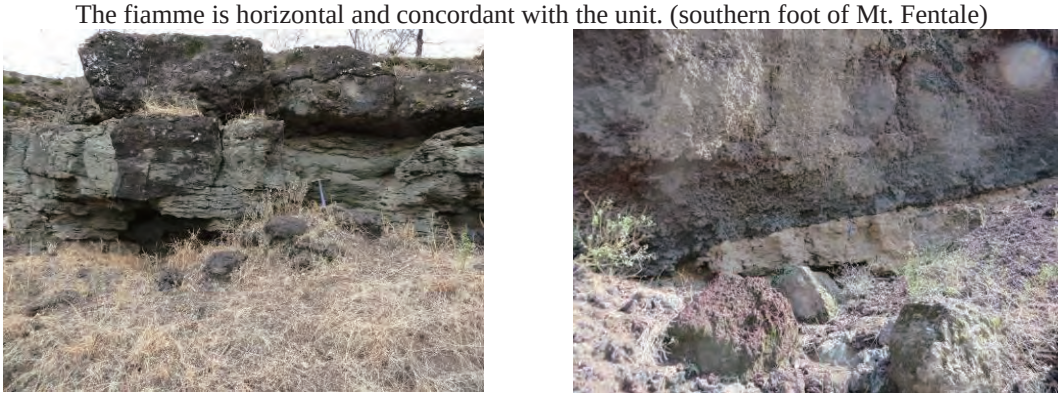
Thickness: More than 12 m at Bogda, western foot of Mt. Fentale (L-KF24)

Type locality: Dinbiba, southern foot of Mt. Fentale (L-KF31)

Correlation: The area is classified as Qwi2: Young ignimbrites of Fentale in GSE (1978), and as Fentale ignimbrite in OWWDSE (2013)

Chronology: 168,000±38,000 years fission track age by Williams et al. (2004).

The fiamme is horizontal and concordant with the unit. (southern foot of Mt. Fentale)



The unit unconformably overlies tuff ring.

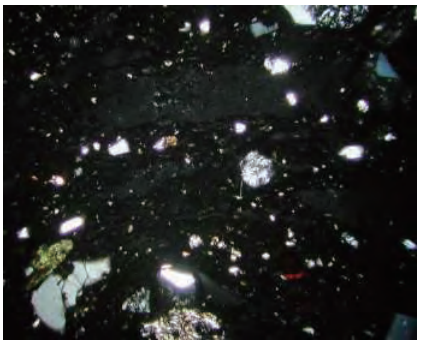
The unit is unconformably overlain by Holocene basalts.

Source: the Project Team, Data: Result of geological survey in this Project

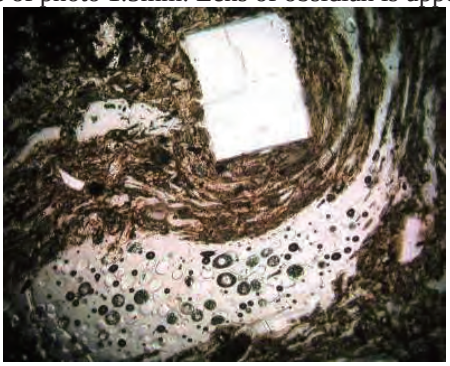
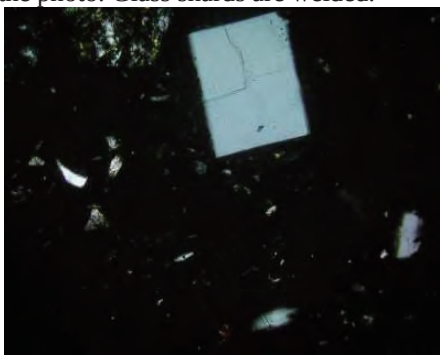
Figure 2.2.10: Dinbiba (L-KF31) (top), Southern Foot of Mt. Fentale (L-KF30) (bottom left) and Southern Foot of Mt. Fentale (L-KF34) (bottom right)

Observation of thin sections

Sample number:	140415-3
Location:	Along the new road about 5km NW of Metehara (L-KF33).
Stratigraphic horizon:	Fentale ignimbrite
Rock type:	Welded ignimbritic tuff, greenish ignimbrite with black obsidian lenses.
Texture:	Welded volcanic glass and lenticuler obsidian with crystal of phenocryst fragments and rock fragments.
Clasts:	Euhedral alkali feldspars and flattened obsidian lenses are characteristic. Basic volcanic rock and trachyte fragments are common. Fragments of nepherine, opaque mineral, amphibole and biotite are observed.
Matrix:	Welded volcanic glass fragments.

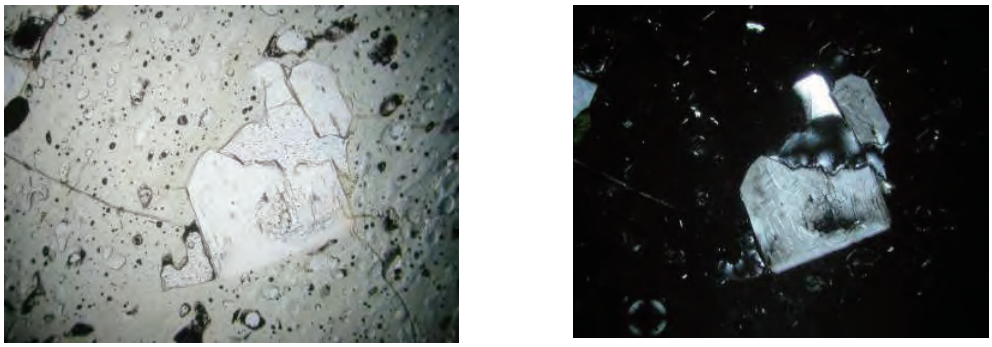
Base of photo 1.5mm: Lens of obsidian is upper part of the photo. Glass shards are welded.

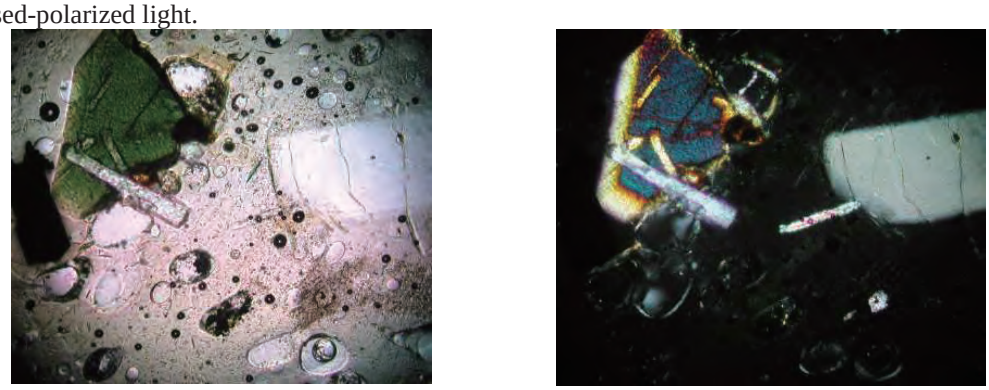
Base of photo 0.7mm: Euhedral alkali feldspar without twinning. Obsidian contains many small bubbles of inclusion. Welded glass shards of matrix is dark in crossed polars which indicates little effect of diagenesis.

Figure 2.2.11: Photos of Thin Sections of Sample Number 140415-3

Sample number:	140417-1
Location:	About 5km NW of the caldera of Mt. Fentale (L-KF47).
Stratigraphic horizon:	Fentale ignimbrite
Rock type:	Obsidian, black obsidian on a surface of pyroclastic flow unit as a small stock like body.
Texture:	Groundmass of volcanic glass with phenocrysts.
Phenocryst:	Alkali feldspars are dominant. Amphibole, opaque mineral and minor biotite are associated. Clast of trachyte is found.
Groundmass:	Massive glass with very small bubble.



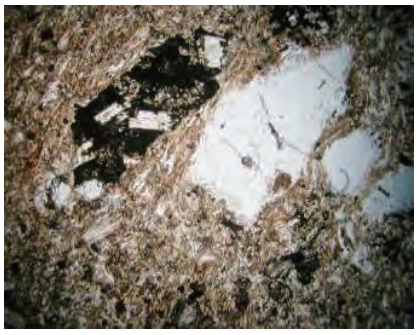
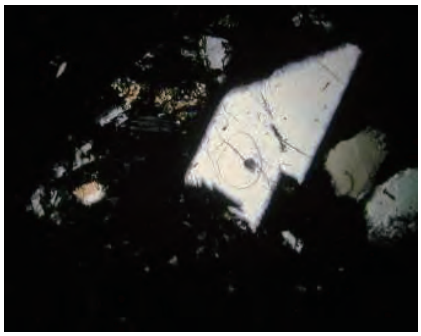
Base of photo 1.5mm: Phenocryst of alkali feldspars. Glass of groundmass is completely dark under crossed-polarized light.



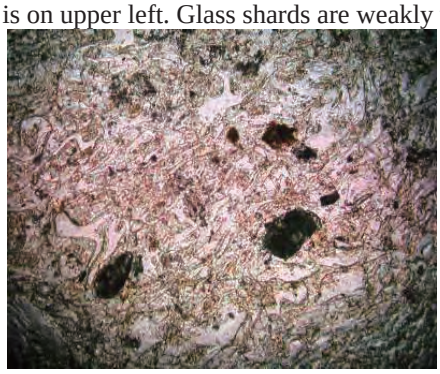
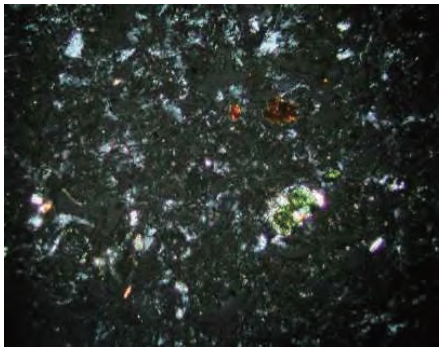
Base of photo 0.7mm: Small phenocrysts of amphibole and alkali feldspar. Glass of groundmass has babbles.

Figure 2.2.12: Photos of Thin Sections of Sample Number140417-1

Sample number:	140417-2
Location:	About 5 km NW of the caldera of Mt. Fentale (L-KF47).
Stratigraphic horizon:	Fentale ignimbrite
Rock type:	Glassy weakly welded tuff, tuff on a surface of pyroclastic flow.
Texture:	Mainly composed of volcanic glass and pumice associated with minor crystal of phenocryst fragments.
Clasts:	Rich in alkali feldspar and fragments of pumice. Amphibole, opaque mineral and acidic tuff, basic lava, syenite, trachyte are observed.
Matrix:	Volcanic glass fragments.

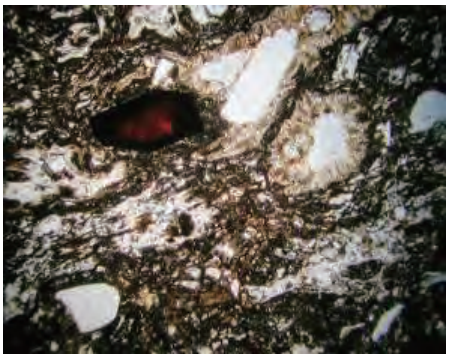
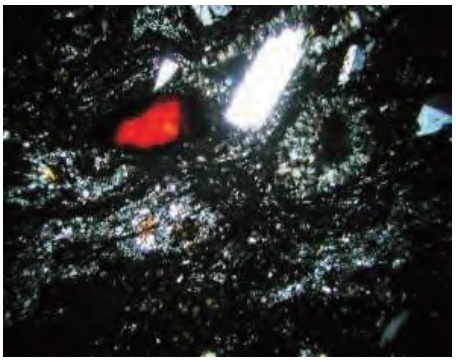
Base of photo 1.5mm: Fragments of alkali feldspar and matrix of glass shards; a fragment of basic lava is on upper left. Glass shards are weakly welded.

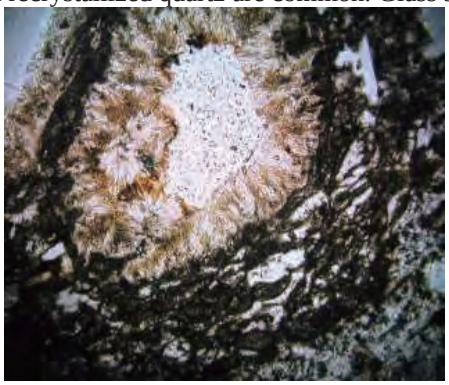
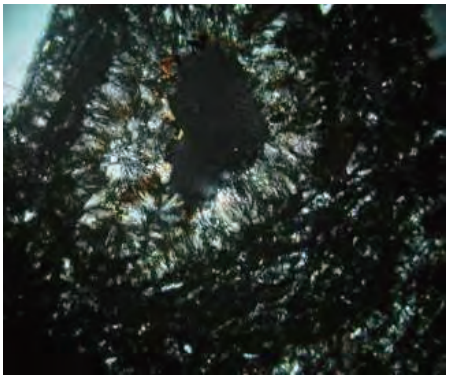
Base of photo 0.7mm: Matrix of glass shards. Y-shapes glass shards reflecting former vesicles in pumice. A very fine-grained amphibole is associated.

Figure 2.2.13: Photos of Thin Sections of Sample Number140417-2

Sample number:	140417-4
Location:	About 5km NW of the caldera of Mt. Fentale (L-KF47).
Stratigraphic horizon:	Fentale ignimbrite
Rock type:	Welded rhyolite tuff, greenish welded tuff of about several meters deep of pyroclastic flow unit which is cut and appeared by stream.
Texture:	Welded volcanic glass with crystal of phenocryst fragments and rock fragments.
Clasts:	Fragments of alkali feldspars are dominant. Flattened pumices are abundant. A few fragments of scyanite are found, fragments of green amphibole and opaque mineral are observed.
Matrix:	Welded volcanic glass fragments. Fine-grained quartz is formed in matrix and flattened pumice. Zeolite occupied in pore. The formation of quartz and zeolite is considered to be caused by diagenesis in a deeper (hotter) part of pyroclastic unit.

Base of photo 1.5m: Fragments of alkali feldspars and pumices are dominant. Flattened pumices with recrystallized quartz are common. Glass shards of matrix are welded.

Base of photo 0.7mm: Zeolite occupied a rounded pore. Very fine-grained quartz is formed in welded glass shards. These mineralization is considered to be formed under diagenesis caused by a heat and vapor in the hot pyroclastic flow unit.

Figure 2.2.14: Photos of Thin Sections of Sample Number140417-4

c. Holocene

c.1 Holocene basalts: Vesicular basalt, scoria falls and scoria cones: Qb2

Lithology: Consists of dark gray to dark bluish-gray vesicular basalt lava and dark brown to reddish-brown scoria falls and scoria cones. Scoria cones of this unit are observed around Kone caldera and the western foot of Mt. Fentale.

Distribution: Widely distributed in the southwestern to northeastern foot of Kone caldera and Mt. Fentale surroundings

Thickness: 18 m at Kera Feda, western foot of Kone caldera (L-KF19)

Type locality: Boru Alore (L-KF21) and the northeastern foot of Kone caldera

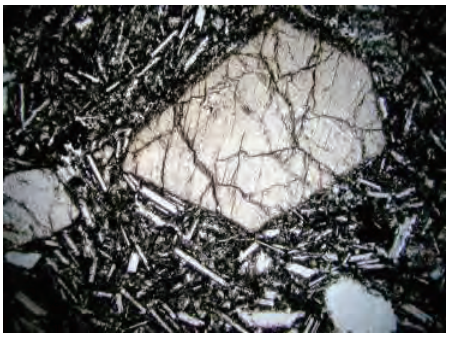
Correlation: The unit is classified as Qwb3: Recent aphyric basalts in GSE (1978).

Northeastern foot of Kone caldera. The unit unconformably overlies a tuff ring.
Source: the Project Team, Data: Result of geological survey in this Project

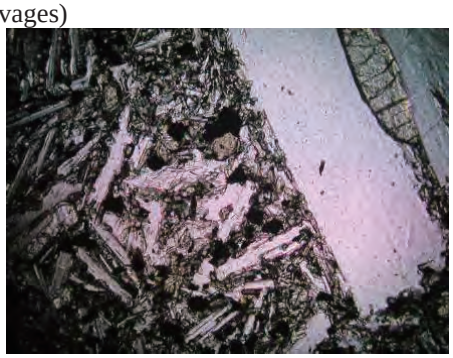
Figure 2.2.15: Boru Alore (L-KF21)

Observation of thin section

Sample number:	140415-1
Location:	Along the road which cut the rim of the Korke Caldera (KF-09).
Stratigraphic horizon:	Holocene basalts
Rock type:	Basalt, black amygdaloidal rock of aa type basalt flow.
Texture:	Porphiloclasts and groundmass with amygdules
Phenocryst:	Clino-pyroxene, plagioclase and minor olivine.
Groundmass:	Very fine-grained lath of feldspar (plagioclase and minor alkali feldspar) with very fine-grained pyroxene and opaque mineral.




Base of photo 1.5 mm: Phenocrysts of plagioclase of clino pyroxene (center: pale green in plane-polarized light with cleavage) and olivine (left side: colorless in plane-polarized light without cleavages)




Base of photo 0.7 mm: Groundmass is composed of very fine-grained feldspar, opaque mineral and pyroxene. Phenocryst of plagioclase with multiple twinning.

Figure 2.2.16: Photos of Thin Sections of Sample Number 140415-1

c.2 Recent rhyolitic domes & lava flows: obsidian flows: Qr2

Lithology: Consists of obsidian lava flows of Mt. Fentale.

Distribution: Bogda, and Dinbiba the western foot of Mt. Fentale and Sodido the southeastern foot of Mt. Fentale

Thickness: About 8 m at Bogda

Type locality: Dinbiba (L-KF29)

Correlation: The area is classified as Nn: Nazret Group in GSE (1978).


The unit unconformably overlies Fentale ignimbrite

Source: the Project Team, Data: Result of geological survey in this Project

Figure 2.2.17: Dinbiba (L-KF29)

c.3 Alluvium: Qal

Lithology: Fine sand and mud
Distribution: Awash river
Thickness: 1 to 5 m

2.3 Mojo town – Arerti town – Debre Birhan town and its surrounding areas

2.3.1 General

Mojo town-Arerti town, Debre Birhan town and its surrounding areas are located in the central Ethiopian plateau and the central MER. The plateau area is mainly covered by Miocene volcanic deposits and the basin floor is widely covered by Pleistocene deposits. The lowest unit, named Kesem basalts, is observed at the Kesem River. In Debre Birhan, ignimbrite, which consists of ignimbrite and conglomerated stone that is cemented by white ash, overlies Kesem basalts and is widely observed at the northern plateau of the Kesem River. Tarmaber-Megezeze basalts forms a high mountain range, and has a chronological age of 13Ma according to Zanettin, et al, 1974, and 10.4Ma according to Chernet et al, 1998. In Pliocene, Bokan rhyolites, Nazret pyroclastic deposits, and Tulu Rie basalts are observed on the basin floor. Nazret pyroclastic deposits are widely observed at the southern flat plain of the Kesem River. Tulu Rie basalts, contrasted as a part of the Bofa Basalt, is observed at the surrounding Mojo area, and has a chronological age of 2.7±0.1Ma according to INGEIS-Buenos Aires, and 1.44±0.03Ma according to Chernet et. al, 1998. In Pleistocene, Dino ignimbrite, Chefe Donsa pyroclastic deposits, Zkikala trachyte, Maar deposits, Boseti Pumice Fall, and Fentale ignimbrite are observed at the basin floor.

Table 2.3.1 shows the stratigraphy in Mojo town-Arerti town-Debre Birhan town and surrounding areas.

Table 2.3.1: Stratigraphy in Mojo Town-Arerti Town-Debre Birhan Town and Surrounding Areas

Age			Stratigraphy	Major Lithology		Legend	Age
Cainozoic	Quaternary	Holocene	Qal	Alluvium	sand, clay, lucstrin		
		Pleistocene	Qi3	Fantale ignimbrite	pare green strongly welded tuff with fiamme		168,000±38,000 y (OWWDSE ,2013)
			Qp2	Boseti pumice falls	pumice fall and ash		
			Qb1	Pleistocene basalts	aphyric basalt		Zikwala olivine basalt : 0.61±0.03Ma (Morton et.al.,1979)
			Qs	Maar deposits	sand, tuff, alternation		
			Qt	Zikwala Trachytes	dark gray, porphyritic trachytes with intercalation of pyroclastic material		0.85±0.05Ma, 0.92±0.04Ma, 1.28±0.15Ma (Morton et al.,1979)
			Qp1	Chefe Donsa pyroclastic deposits	Pumice and tuff with intercalated with poorly welded tuff		Chefe Donsa pyroclastic deposits : 1.71±0.04 Ma(Morrton et al.,1979), 2.24±0.3 Ma(IGGI-Pisa)
			Qi1	Dino ignimbrite	Greenish grey welded tuff with fiamme		Dino : 1.5my (Mobidelli et al., 1975), 1.51 Ma (Kazmun, et al.,1978)
	Tertiary	Pliocene	Tb3	Tulu Rie basalts	aphyric basalt		Tulu Rie basalt: 2.7±0.1 Ma(INGEIS-Buenos Aires), 1.44±0.03 Ma(Chernet et al., 1998) Bofa : 1.21 Ma (Kazumin, et al., 1978), 6.1-4.4 Ma(Morton et al.,1979)
			Ti2, Ti3	Nazret pyroclastic deposits	light to dark grey welded tuff with fiamme		Nwp : 3.5±0.1 Ma, 3.2±0.1 Ma(IGGI-Pisa), 4.7±0.7 Ma, 5.4±0.2 Ma(INGEIS-Buenos Aires), 3.32±0.06 Ma, 3.11±0.06 Ma(Morton et al., 1979)
					pumice and tuff		
			Tr2	Bokan rhyolites	rhyolite with pumiceous tuff		
		Miocene	Tb2	Tamaber-Megezeze basalts	aphyric basalt		Anchar : 12.4 Ma (Kazumin et.al., 1978) Mt. Megezeze: 13Ma, (Zanettin et al., 1974), 10.4Ma, (Chernet et al., 1998)
			Ti1	Debre Birhan ignimbrite	Upper Conglomerate(inc. greenish welded tuff fragments, cemented by white ash), tuff. Sand, alternation		
					greenish consolidated to welded fine tuff		
					Lower Conglomerate(inc. basalt fragments, cemented by white ash)		
			Tb1	Kesem basalts	plagioclase phyric basalt		24-23Ma (Chernet et al., 1998), 14.4 Ma (Kuntz et al., 1975), 28-15 Ma (Morbidelli et al., 1975), 21.06±1.5 Ma, 14.94±1.5 Ma, 17.4±1.0 Ma (Kazumin, et al., 1978)
					rhyolite with pumiceous tuff (Balchi rhyolite)		

Source: the Project Team, Data: Result of geological survey in this Project

2.3.2 Geological unit

a. Miocene-Pliocene

a.1 Kesem basalts: plagioclase phyric basalt, rhyolite: Tb1

Lithology: Consists of porphyritic to plagioclase phyric basalt lavas and rhyolite. At the type locality, the unit is divided by three lithological facies; from the lowest, pale blue to light grey rhyolite (more than 40m in thickness, Balchi rhyolite), light gray to pale blue tuff containing white pumice (2m in thickness), and bluish-grey porphyritic plagioclase basalt lava (more than 20m in thickness). At Tigre Ridge in northeast Welenchiti town (L-MAD22), the unit is divided by three lithological facies; from the lowest, reddish-brown tuff breccia (more than 2m in thickness), black fine plagioclase-basalt lava with columnar joint (17m in thickness), and black massive fine basalt (17m in thickness).This unit is overlain by the lower conglomerate of Debre Birhan ignimbrite along the Arerti town – Kesen river route (L-MAD29).

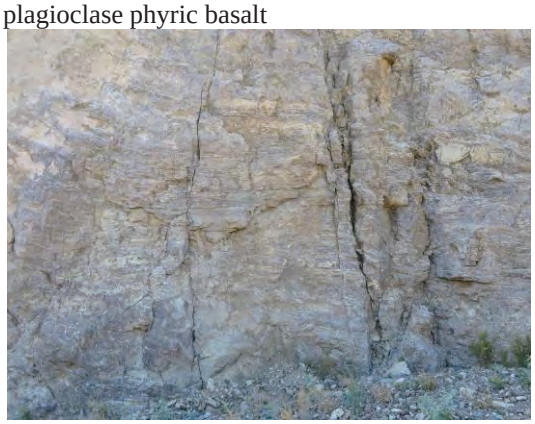
Distribution: Widely distributed in the Kesem river basin, around Balchi town, NE-SW direction cliff of western Melka Jiro town

Thickness: More than 62 m at the type locality, more than 200m along the Kesen valley.

Type locality: Balchi (L-MAD14)

Correlation: The unit is classified as N1a: Alaji basalts in GSE (1978), and as Tkb: Kesem basalt in GSE (2010).

Bluish-grey porphyritic to plagioclase phyric basalt



Balchi rhyolite which is distributed at the lowest part

Source: the Project Team, Data: Result of geological survey in this Project

Figure 2.3.1: Balchi (L-MAD14) (top), Balchi (L-MAD15) (bottom)

a.2 Debre Birhan ignimbrite: ignimbrite, conglomerates, and tuff: Ti1

This unit is divided by three lithological facies; the lower part consists of conglomerate, alternation of sands, tuff and minor pumice (lower conglomerate), the widely distributed middle part consists of consolidated to highly welded finer to medium tuff and unwelded to slightly welded pumiceous tuff (Debre Birhan ignimbrite) and the upper part consists of conglomerate included pebble of Debre Birhan ignimbrite, alternation of sands, tuff and minor pumices (upper conglomerate). However, the lower conglomerate is distributed only in the Arerti town – Kesem river route.

a.2.1 Conglomerates, tuff, and pumice

Lithology: Consists of conglomerate which was typically cemented by white ash, alternation of sandstone, tuff and minor pumice. This unit is divided by two facies, intercalated by Debre Birhan ignimbrite. The lower part consists of conglomerate cemented by white ash, alternation of sandstone, tuff and minor pumice. The upper part consists of conglomerate cemented by white ash which typically included pale green pebbles of lower Debre Birhan ignimbrite, alternation of sandstone, tuff and minor pumice. At the type locality, the unit is intercalated by Debre Birhan ignimbrite, and is unconformably overlain by welded tuff with fiamme of upper Nazret pyroclastic deposits.

Distribution: Widely distributed in the Kesem river basin

Thickness: More than 8m of the lower conglomerate, and more than 7.5m of the upper conglomerate at the type locality (L-MAD29)

Type locality: Aroge Minjar, along the Arerti town – Kesem river route (L-MAD29).

Correlation: The area is classified as N1a: Alaji basalts in GSE (1978), and as Tkb: Kesem basalt and Tdig: Sela Dengay-Debre Birhan-Gorgo ignimbrite in GSE (2010).

The unit is intercalated by Debre Birhan ignimbrite

The unit is unconformably overlain by Nazret pyroclastic deposits

The unit consists of alternations of conglomerate and tuff.

Source: the Project Team, Data: Result of geological survey in this Project

Figure 2.3.2: Aroge Minjar (L-MAD29) (top and middle), Chifey (L-MAD12) (bottom left), Gina Ager (L-MAD30) (bottom right)

a.2.2 Debre Birhan ignimbrite: consolidated to welded tuff

Lithology: Consists of greenish-blue to light green consolidated to welded fine to medium tuff. At the type locality, the unit is unconformably overlain by Nazret pyroclastic deposits, and is unconformably overlain by Tarmaber-Megezeze basalts at Balchi (L-MAD14).

Distribution: Widely distributed in the plains surrounding the Kesem river and the Kebena river, form the flat plain along Sendefa town to Seno town route.

Thickness: More than 25 m at Kosfe (L-MAD33, L-MAD35)

Type locality: Aroge Minjar, along the Arerti town – Kesem river route (L-MAD29).

Correlation: The area is classified as N1a: Alaji basalts in GSE (1978), and as Tkb:

Kesem basalt and Tdig: Sela Dengay-Debre Birhan-Gorgo ignimbrite in GSE (2010).

The unit unconformably overlies Kesem basalts (Tb1)

The unit is unconformably overlain by Tarmaber-Megezez basalt.

Greenish blue to light green consolidated to welded fine tuff

The unit is unconformably overlain by Tarmaber-Megezez basalt.

Source: the Project Team, Data: Result of geological survey in this Project

Figure 2.3.3: Aroge Minjar (L-MAD29) (top), Balchi (L-MAD14) (middle left), Zengo (L-MAD10) (middle right), Gobemsa (L-MAD25) (bottom)

a.3 Tarmaber-Megezeze basalts: aphyric basalt: Tb2

Lithology: Consists of massive aphyric basalt lavas and tuff breccia. At the type locality, the unit unconformably overlies Debre Birhan ignimbrite. At Balchi (L-MAD14), the unit unconformably overlies Debre Birhan ignimbrite and is unconformably overlain by Nazret pyroclastic deposits .

Distribution: Widely distributed in the Kesem river basin

Thickness: More than 20 m at the type locality.

Type locality: Gidm Asfa (L-MAD29)

Correlation: The unit is classified as N1n: Anchar basalts in GSE (1978), and as Ttb: Tarmaber-Megezeze basalts in GSE (2010).

Chronology: 13Ma K-Ar age by Zanettin et al., (1974), and 10.4Ma by Chernet et al., (1998).

The unit unconformably overlies Debre Birhan ignimbrite.

The unit unconformably overlies Debre Birhan ignimbrite.

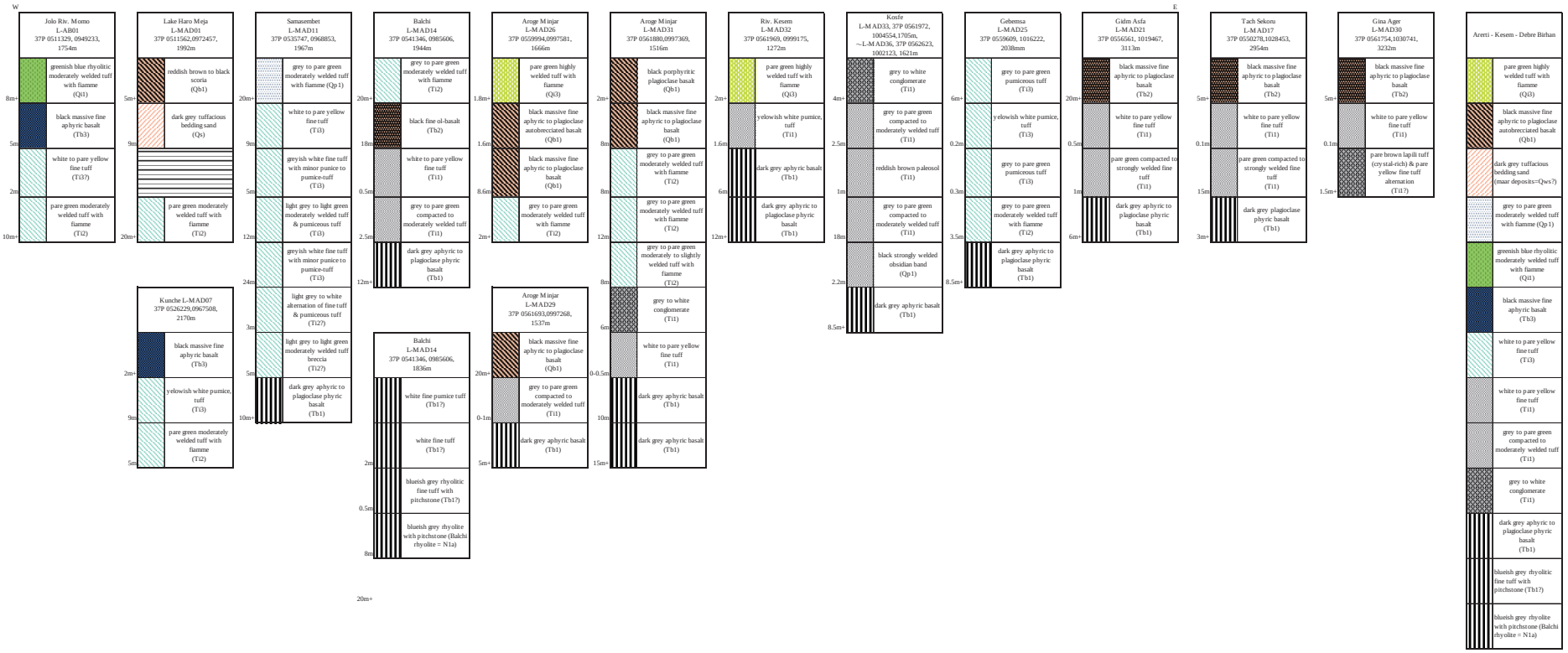
Mt. Megezeze (EL.3595m)

Source: the Project Team, Data: Result of geological survey in this Project

Figure 2.3.4: Gidm Asfa (L-MAD21) (top), Zongo (L-MAD10) (bottom left), Megezeze (L-MAD24) (bottom right)

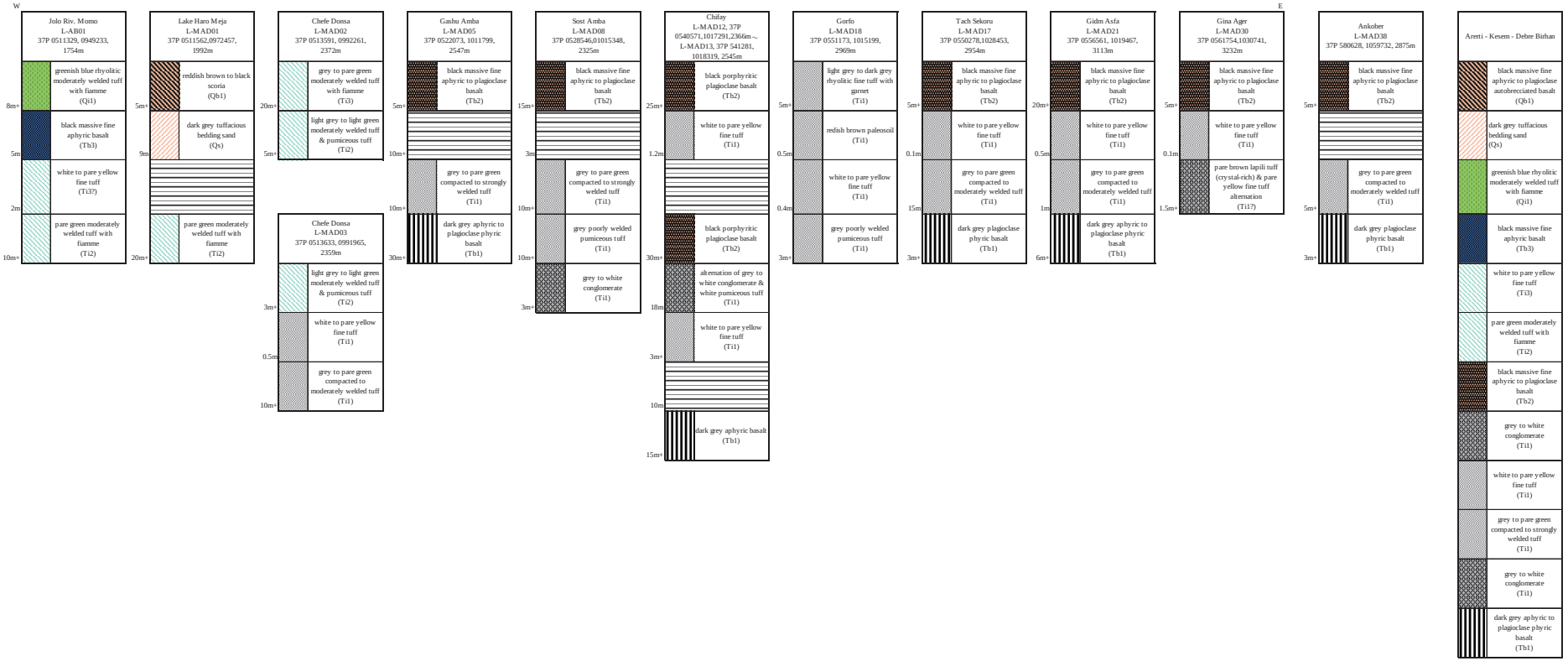
Table 2.3.2 describes the geological succession along the Mojo town-Arerti town- Debre Birhan town route, and Table 2.3.3 describes the Mojo town – Chefe Donsa town – Debre Birhan town route.

Table 2.3.2: Mojo Town-Arerti Town -Debre Birhan Town



Source: the Project Team, Data: Result of geological survey in this Project

Table 2.3.3: Mojo Town – Chefe Donsa Town – Debre Birhan Town



Source: the Project Team, Data: Result of geological survey in this Project

b. Pliocene

b.1 Bokan rhyolites: rhyolite with pumiceous tuff: Tr2

Lithology: Consists mainly of white to bluish-gray rhyolite lava flows, tuff, white pumice, pitchstone and hard tuff including obsidians.

Distribution: Forms a hill at Mt. Bokan west of Balchi town, Mt. Gebre Arada east of Arerti town, NE-SW distribution at Adadi Ridge and Dikub, Yilas Ager.

Thickness: More than 100 m at the type locality

Type locality: Mt. Bokan, west of Balchi town (L-MAD09)

Correlation: The area is classified as N2r: Older alkaline and peralkaline rhyolite domes and flows in GSE (1978).

Rhyolitic tuff, with obsidian distributed
Source: the Project Team, Data: Result of geological survey in this Project

Figure 2.3.5: Mt. Bokan (L-MAD09)

b.2 Nazret pyroclastic deposits: Rhyolitic slightly welded tuff and tuff breccia, pumice, tuff, crystal tuff

This unit is divided by two lithological facies; the lower part consists of yellowish- white pumice fall deposits, tuff, crystal tuff, alternation of fine volcanic sands and pumiceous tuff (Ti2), and the upper part consists of white to bluish-gray rhyolitic compacted tuff and tuff breccia which contain white pumice, rhyolitic lava fragments, crushed and/or slightly weathered obsidian fragments and rare reddish-brown basaltic lava fragments (Ti3).

b.2.1 Nazret pyroclastic deposits Lower: Ti2

Lithology: Consists of yellowish-white pumice fall deposits, tuff, crystal tuff, alternation of fine volcanic sands and pumiceous tuff. At the type locality, the unit consists of alternations of greyish-white fine tuff with minor pumice to pumice-tuff, light grey to white fine tuff & pumiceous tuff. It is unconformably overlain by Chefe Donsa pyroclastic deposits.

Distribution: Samasembet in eastern Ejere town, NE-SW directional cliff of western Melka Jiro town

Thickness: More than 85 m in the type locality

Type locality: Samasembet (L-MAD11)

Correlation: The area is classified as Nn: Nazret Group in GSE (1978).

Chronology: 5.5-3.5 Ma K-Ar age by Mohr, (1974), Morbidelli et al. (1975).


The unit consists of pumice tuff and alternated tuff.
Source: the Project Team, Data: Result of geological survey in this Project

Figure 2.3.6: Samasembet (L-MAD11)

b.2.2 Upper Nazret pyroclastic deposits: Ti3

Lithology: Consists of white to bluish-gray rhyolitic consolidated tuff, grayish-green welded tuff with fiamme and tuff breccia which contain white pumice, rhyolitic lava fragments, crushed and/or slightly weathered obsidian fragments and rare reddish -brown basaltic lava fragments. At the type locality, this unit unconformably overlies conglomerate of Debre Birhan ignimbrite.

Distribution: Widely distributed in the plains surrounding Ejere town to Arerti town forms a gentle slope along the Kesem river basin.

Thickness: More than 28 m in the type locality

Type locality: Aroge Minjar, along the Arerti town – Kesem river route (L-MAD29)

Correlation: The area is classified as Nn: Nazret Group in GSE (1978) and as Tkb: Kesen basalt and Tdig: Sela Dengay-Debre Birhan-Gorgo ignimbrite in GSE (2010).

Chronology: 5.5-3.5 Ma K-Ar age by Mohr, (1974), Morbidelli et al. (1975).


The unit unconformably overlies conglomerate of Debre Birhan ignimbrite.
Source: the Project Team, Data: Result of geological survey in this Project

Figure 2.3.7: Aroge Minjar (L-MAD29)

b.3 Tulu Rie basalts: aphyric basalt : Tb3

Lithology: Consists of black aphyric basalt lavas. At the type locality, the unit unconformably overlies Nazret pyroclastic deposits.

Distribution: NE-SW distribution hill north of Mojo town to Ejere town.

Thickness: More than 15 m in the type locality

Type locality: Kunche (L-MAD06)

Correlation: The unit is classified as Bofa basalts in GSE (1978), and as Tulu Rie Basalts unit in F. Mazzarini, et al. (1999).

Chronology: 1.21 Ma by Kazumin, et al.'1978), 6.1-4.4 Ma K-Ar age by Morton et al. (1979), 2.7±0.1 Ma by INGEIS-Buenos Aires, and 1.44±0.03 Ma by Chernet et al. (1998).

The unit unconformably overlies Nazret pyroclastic deposits.
Source: the Project Team, Data: Result of geological survey in this Project

Figure 2.3.8: Kunche (L-MAD06)

Table 2.3.4 describes the geological succession of Arerri town- Melka Jiro town.

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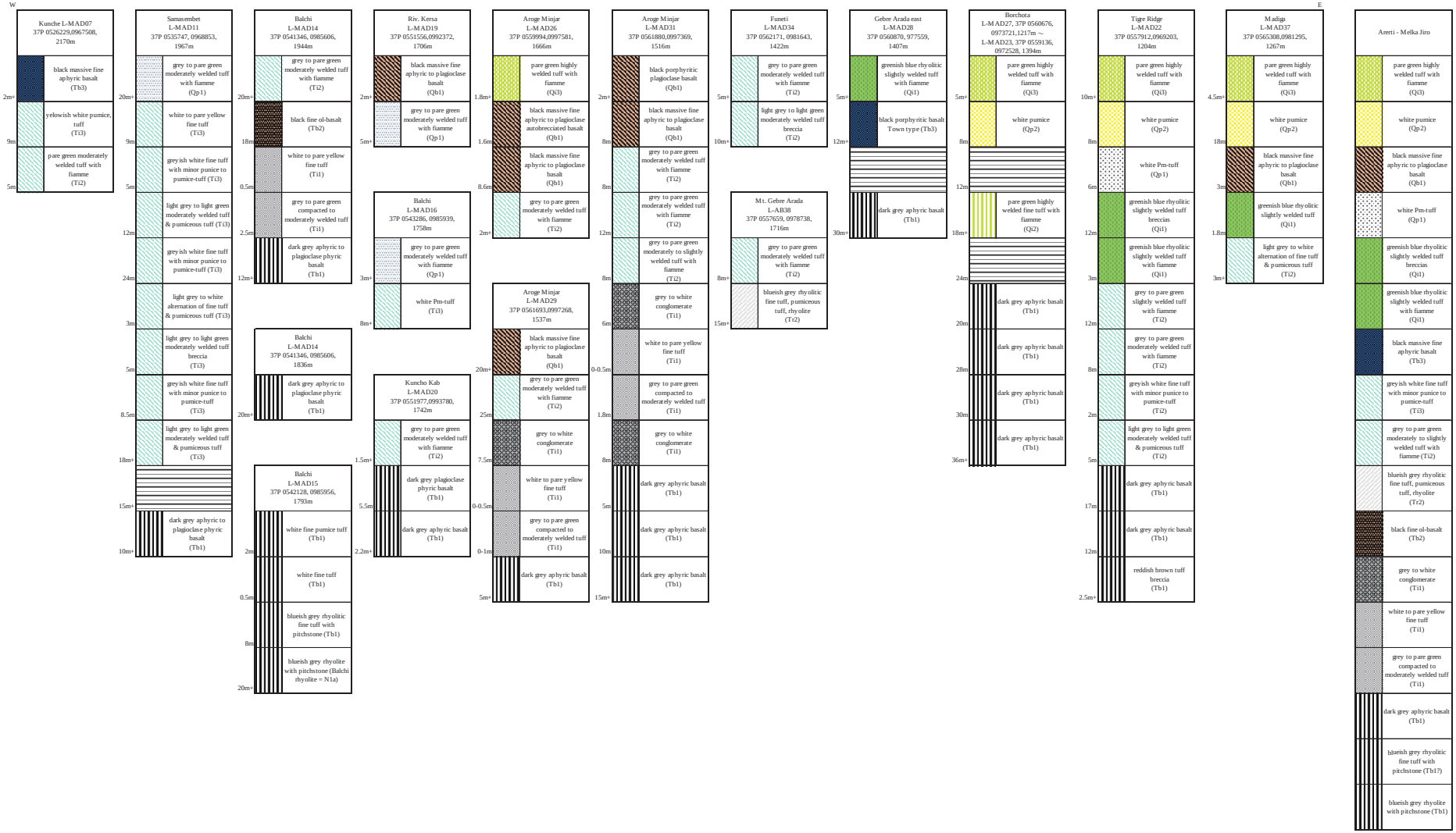
Table 2.3.4: Arerti Town – Melka Jiro Town



Source: the Project Team, Data: Result of geological survey in this Project

c. Pleistocene

c.1 Dino ignimbrite: rhyolitic to andesitic welded tuff: Qi1

Lithology: Consists of greenish-yellow to light gray rhyolitic to andesitic welded tuff which typically contains elongated obsidian lenses (fiamme). Generally, most fiamme is horizontal and concordant with the unit, but some fiamme shows irregular and/or ripple structure. At the type locality, the unit unconformably overlies Tulu Rie basalts.

Distribution: Along the Momo river, southwest of Mojo town

Thickness: More than 8 m at the type locality

Type locality: Joro (L-AB47)

Correlation: The area is classified as Nn: Nazret Group in GSE (1978).

The unit unconformably overlies Tulu Rie basalts
Source: the Project Team, Data: Result of geological survey in this Project

Figure 2.3.9: Jolo (L-MAD41)

c.2 Chefe Donsa pyroclastic deposits: pumice flow, pumice tuff: Qp1

Lithology: Consists mainly of pumice flow, white pumice tuff, bluish white pumice and white tuff. At the type locality, the unit unconformably overlies Nazret pyroclastic deposits (Ti3).

Distribution: Around Mojo town to Debra Zeyt town, Chefe Donsa town.

Thickness: More than 20 m at the type locality.

Type locality: Chefe Donsa town (L-MAD02)

Correlation: The area is classified as Nn: Nazret Group in GSE (1978), and as Ncp: Chefe Donsa pyroclastic deposits in GSE (2010).

Chronology: 1.71±0.04 Ma by Morrton et al. (1979), and 2.24±0.3 Ma by IGGI-Pisa.


The unit unconformably overlies Nazret pyroclastic deposits.
Source: the Project Team, Data: Result of geological survey in this Project

Figure 2.3.10: Chefe Donsa (L-MAD02)

c.3 Zikwala trachytes: Trachytes: Qt

Lithology: The unit consists of dark gray, porphyritic trachytes with intercalation of pyroclastic material.

Distribution: Around Mt. Zikwala.

Thickness: More than 130 m.

Type locality: Mt. Zikwala (L-MAD41)

Correlation: The unit is classified as Qtz: Zikwala tracytes in GSE (2010).

Chronology: 0.85±0.05Ma, 0.92±0.04Ma, and 1.28±0.15Ma by Morton et al, (1979).


The unit consists of dark gray, porphyritic trachytes
Source: the Project Team, Data: Result of geological survey in this Project

Figure 2.3.11: Mt. Zikwala (L-MAD41)

c.4 Maar deposits: sand, tuff, alternation: Qs

Lithology: The unit consists of alteration of yellowish brown tuff and white tuff. The unit unconformably overlies Nazret pyroclastic deposits (Ti3) at Lake Haro Kilole (L-MAD01).

Distribution: Around Argoba, Lake Haro Kilole, Lake Haro Meja, Bebeli.

Thickness: More than 10 m at the type locality.

Type locality: Argoba (L-MAD04)

Correlation: The unit is classified as Qwe: Bedded explosion tuff in GSE (1978), and as Qup: Phreatomagmatic Deposits in GSE (2010).

The unit consists of alteration of yellowish-brown tuff and white tuff.

Source: the Project Team, Data: Result of geological survey in this Project

Figure 2.3.12: Argoba (L-MAD04) (top), Lake Haro Meja (L-MAD01) (bottom left), Lake Haro Kilole (L-MAD39) (bottom right)

c.5 Pleistocene basalts: aphyric basalt and scoeia: Qb1

Lithology: Consists of dark bluish-grey olivine basalt and scoria cones. At the type locality, the unit unconformably overlies Nazret pyroclastic deposits.

Distribution: Around Mojo town, Debra Zeyt town, along the Kersa river northeast of Arerti town.

Thickness: More than 5 m at the type locality.

Type locality: Wubit Ager, Kersa river (L-MAD19)

Correlation: The unit is classified as Qwb1: Pleistocene-sub-recent basalt in GSE (1978).

Chronology: 0.61±0.03Ma by Morton et. al. (1979) at olivine basalt near Mt. Zikwala.

The unit unconformably overlies Nazret pyroclastic deposits.
Source: the Project Team, Data: Result of geological survey in this Project

Figure 2.3.13: Wubit Ager, Kersa River (L-MAD19)

c.6 Boseti-Kone pumice fall deposits: pumice fall deposits, pumice tuff and tuff : Qp2

Lithology: Consists mainly of pale grey pumice fall deposits, light grey fine ash, white pumice tuff, bluish white pumice and white tuff. The unit unconformably overlies Chefe Donsa pyroclastic deposits at Tigre Ridge (L-MAD22).

Distribution: NE-SW trending cliff of western Melka Jiro town.

Thickness: More than 8m at the type locality.

Type locality: Borchota (L-MAD23).

Correlation: The area is classified as Nn: Nazret Group in GSE (1978).

The unit consists of pumice fall deposits and ash
Source: the Project Team, Data: Result of geological survey in this Project

Figure 2.3.14: Borchota (L-MAD23)

c.7 Fentale ignimbrite: rhyolitic to andesitic welded tuff: Qi3

Lithology: Consists of greenish-blue to light yellow rhyolitic to andesitic welded tuff which typically contains elongated obsidian lenses (fiamme). Generally, fiamme is horizontal and concordant with the unit. At the type locality, the unit unconformably overlies Mt. Boseti pumice fall deposit.

Distribution: NE-SW directional cliff of western Melka Jiro town.
Thickness: More than 5 m at the type locality.
Type locality: Borchota (L-MAD23).
Correlation: The area is classified as Na: Nazret Group in GSE (1978).
Chronology: 168,000±38,000 years fission track age by Williams et al. (2004).

The unit unconformably overlies Mt. Boseti pumice fall deposits
Source: the Project Team, Data: Result of geological survey in this Project

Figure 2.3.15: Borchota (L-MAD23)

d. Holocene

d.1 Alluvium: Qal

Lithology: Fine sand and mud
Distribution: Mojo river
Thickness: 1 to 5 m

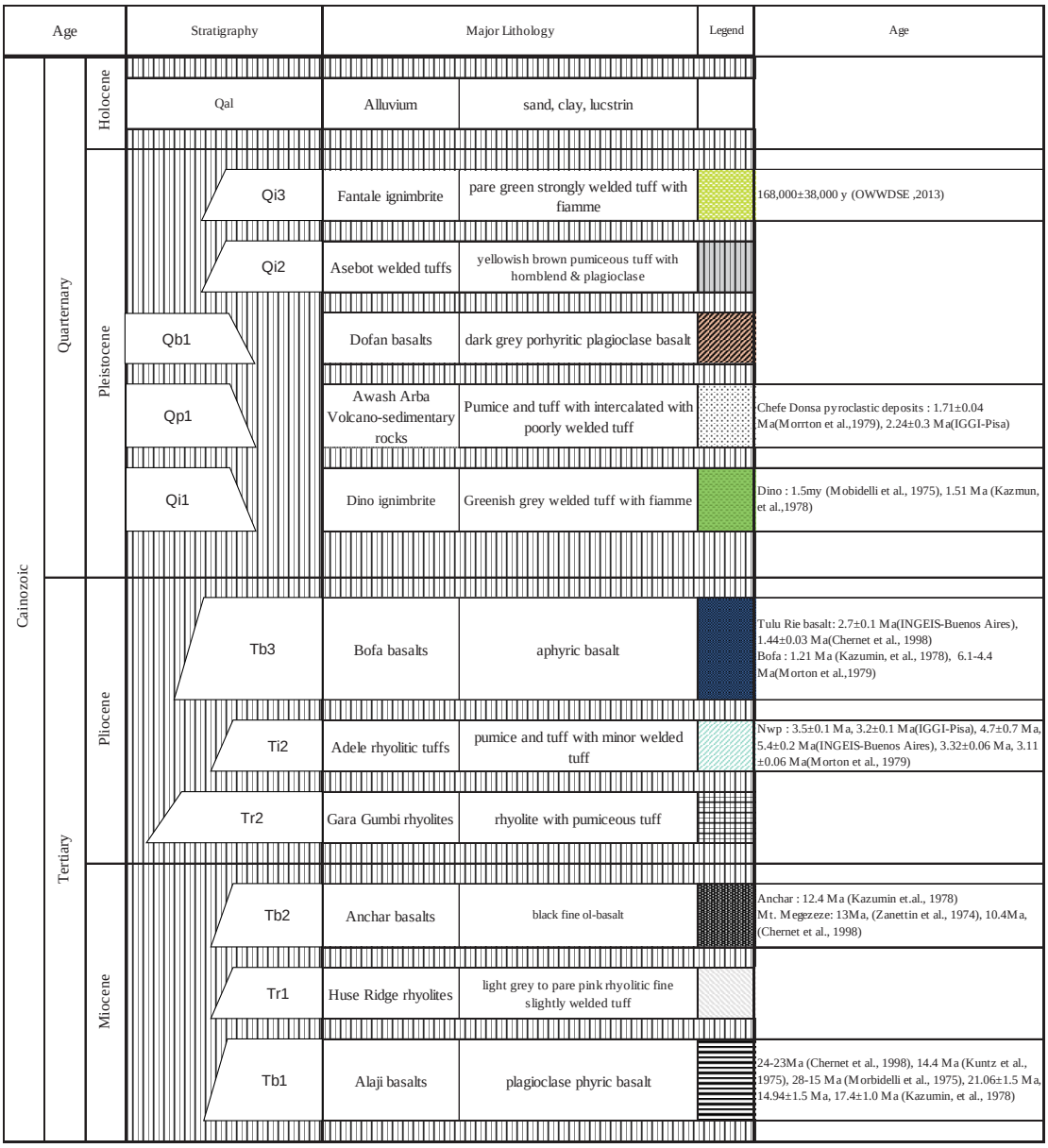
2.4 Awash town – Asebe Teferi town and its surrounding areas

2.4.1 General

Awash town-Asebe Teferi town and its surrounding areas are located in the central MER. The basin floor is widely covered by Holocene deposits. WFB is well developed on the floor and margin of the MER in the area. Therefore Pliocene – Pleistocene strata are generally observed at the scarps of these faults. The lowest unit, named Alaji basalts, is observed at the southern mountain chain. Huse Ridge rhyolites and Anchar basalts overlie Alaji basalts, and are observed at the southern mountain chain with a NE-SW trend. Anchar basalts has a chronological age of 12.4 Ma, according to Kazmin et.al, 1978. Gara Gumbi rhyolites is observed on the basin floor of the remaining hills. Also, Adele rhyolitic tuffs and Bofa basalts are widely observed at the basin floor. In Pleistocene, Dino ignimbrite, Dofan basalts, Asebot welded tuff, Awash acidic volcano-sedimentary rocks and Fentale ignimbrite are widely distributed on the basin floor

Table 2.4.1 shows the stratigraphy in Awash town-Asebe Teferi town and its surrounding areas.

Table 2.4.1: Stratigraphy in Awash Town-Asebe Teferi Town



Source: the Project Team, Data: Result of geological survey in this Project

2.4.2 Geological unit

a. Miocene-Pliocene

a.1 Alaji basalts: porphyritic basalt lavas: Tb1

Lithology: Consists of porphyritic basalt lavas with large plagioclase. At the type locality, the unit is divided by two flow units: from the lowest, dark grey porphyritic basalt lava (more than 10 m in thickness), light gray to dark grey porphyritic plagioclase basalt lava with columnar joints (more than 10 m in thickness). At Komena (L-AA35), the unit is divided in lower porphyritic plagioclase-basalt and upper aphyric basalt. This unit is unconformably

overlain by Huse ridge rhyolites (Tr1) at Huse ridge, 10 km northwest of Asebe Teferi town (L-AA53).

Distribution: Around Arba Rekete town, Huse ridge in northwest of Asebe Teferi town, and around Cheleleka town.

Thickness: More than 20 m at the type locality.

Type locality: Arba Rekete, 5 km southwest of Asebe Teferi town (L-AA59)

Relationship with lower unit: Considered as the lowest unit in the area.

Correlation: The unit is classified as PNa1: Alajae formation, mainly transitional basalt with minor trachyte and rhyolite in AGRAP (2009), as N1a: Alaji basalt in GSE (1978) and as P3N1a: Alaji basalts in GSE (1985).

The unit is divided by two flow units: from the lowest, dark grey porphyritic basalt lava (more than 10m in thickness), light gray to dark grey porphyritic plagioclase basalt lava with columnar joints (more than10m in thickness).

Plagioclase-basalt Plagioclase-basalt

Source: the Project Team, Data: Result of geological survey in this Project

Figure 2.4.1: Arba Rekete (L-AA59) (top), Komena (L-AA35) (bottom left) and Cheleleka (L-AA09) (bottom right)

a.2 Huse Ridge rhyolites: Rhyolite, rhyolitic tuff, trachyte, Tr1

Lithology: Consists mainly of white to bluish-grey, rarely pale pink rhyolite, tuff and trachyte. The unit is unconformably overlain by Anchar basalts at the query of Asebe Teferi town (L-AA55). At the type locality, the unit forms NE-SW ridge (more than 50 m high).

Distribution: Beka Town to NE-SW distribution at Huse Ridge in 10 km southeast of

Mieso Town

Thickness: More than 50 m at the type locality

Type locality: Huse Ridge in 10 km southeast of Mieso town (L-AA53)

Correlation: The area is classified as N1r: Arba Guracha silicics, rhyolitic lavasa and ignimbrites in AGRAP (2009) and GSE (1985).

Rhyolitic Tuff in The type locality

Source: the Project Team, Data: Result of geological survey in this Project

Figure 2.4.2: Huse Ridge (L-AA53)

Observation of thin section

Sample number: 140416-1

Location: Near the top surface of high terrace like a plain in Gericha, gray intrusion about 5m in width (L-AA61).

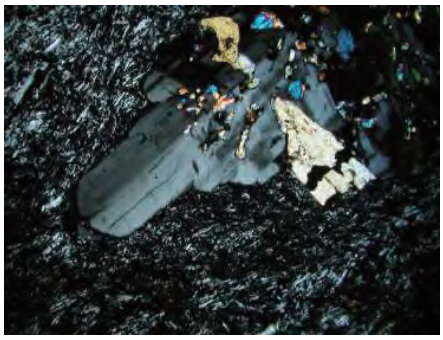
Stratigraphic horizon: Pliocene rhyolites

Rock type: Trachyte

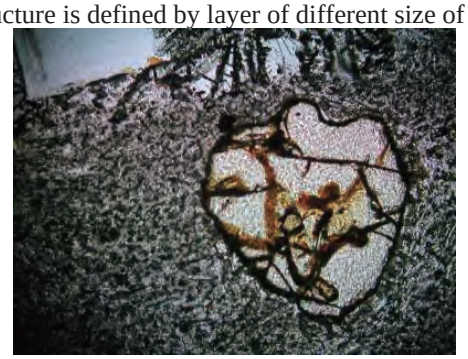
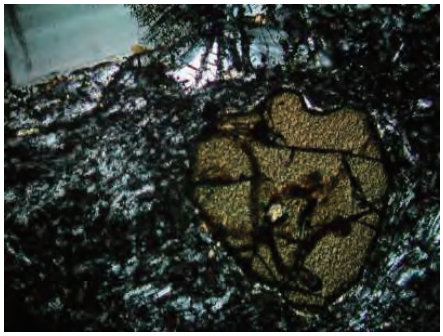
Texture: Porphyritic texture with flow structure.

Phenocryst: Alkali feldspar (sanidine to anorthoclase) is abundant. Small clino-pyroxene is formed in feldspar. Small olivine is observed.

Groundmass: Preferred oriented very fine-grained lath of feldspar with very fine-grained pyroxene and opaque mineral.

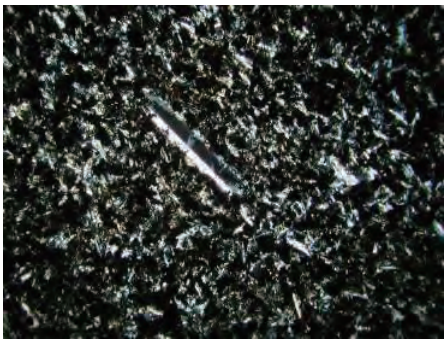
Base of photo 1.5mm: Phenocryst of alkali feldspar including pyroxenes.In groundmass, flow structure is defined by layer of different size of crystal.

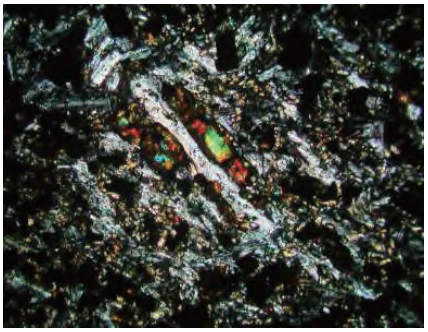
Base of photo 0.7 mm: Flow alignment of euhedral groundmass crystal of feldspar. Small phenocryst of olivine is observed.

Figure 2.4.3: Photos of Thin Sections of Sample Number140416-1

Sample number:	140416-2
Location:	Along the road of the valley of Arba river in Gericha (L-AA61).
Stratigraphic horizon:	Pliocene rhyolite (A block included in the rhyolite dome)
Rock type:	Basalt, gray colored fine-grained rock with sheeted Joint.
Texture:	Very fine-grained massive texture with minor fine-grained porphiloclasts.
Phenocryst:	Fine-grained plagioclase.
Groundmass:	Very fine-grained lath of feldspar (plagioclase and alkali feldspar) with very fine-grained pyroxene, olivine and opaque mineral. Opaque mineral is abundant.

Base of photo 1.5mm: Small number of fine-grained phenocrysts of plagioclase are observed. Opaque minerals are very rich in groundmass.

Base of photo 0.7mm: Groundmass is composed of very fine-grained feldspar, opaque mineral, olivine and pyroxene of much smaller size (pale green in PPL and high refrigence color in CPL).

Figure 2.4.4: Photos of Thin Sections of Sample Number140416-2

a.3 Anchar basalts: massive basalt lavas and tuff breccia: Tb2

Lithology: Consists of massive aphyric basalt lavas and tuff breccia. At the type locality, the unit is divided by three lithological facies; from the lowest, dark grey to black olivine-basalt with columnar joint (more than 40 m in thickness), reddish-brown auto-brecciated olivine-basalt (6 m in thickness), reddish brown to grey auto-brecciated basalt (6 m in thickness), and reddish-brown basaltic tuff breccia (6 m in thickness). At the Awash river (L-KF45), the unit is overlain by a Bofa basalt unconformity.

Distribution: NE-SW distribution at the southern mountain chain, around Awash town, Asebot town, Debala town and Chelelka town.

Thickness: More than 58 m at the type locality.

Type locality: Asebe Teferi town (L-AA59)

Correlation: The unit is classified as N1n: Anchar basalts in AGRAP (2009) and GSE (1985).

The unit unconformably overlies Huse ridge rhyolites.

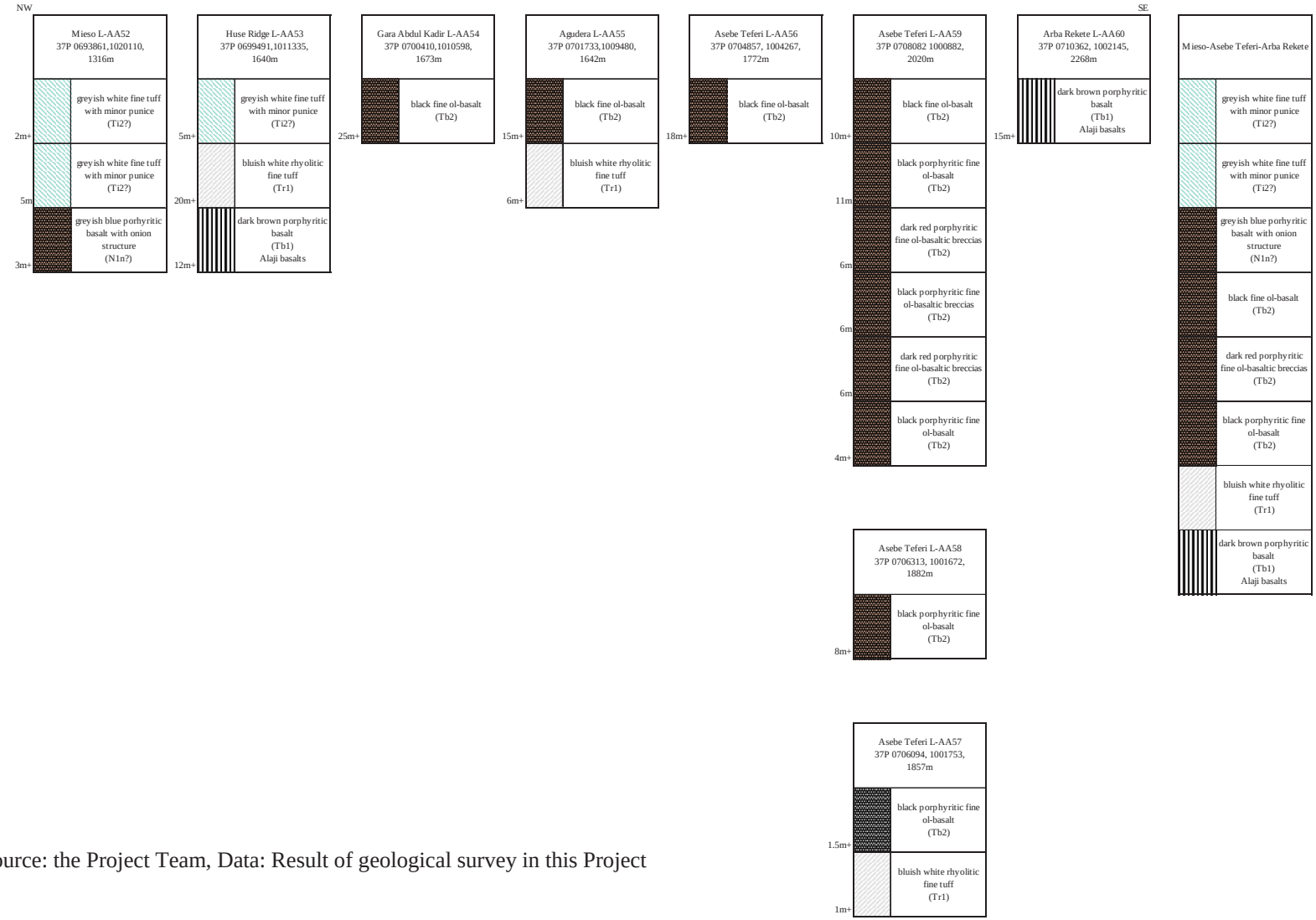
Outcrop of dark grey aphyric basalt

Source: the Project Team, Data: Result of geological survey in this Project

Figure 2.4.5: Asebe Teferi (L-AA57) (top), Agemti (L-AA20) (bottom)

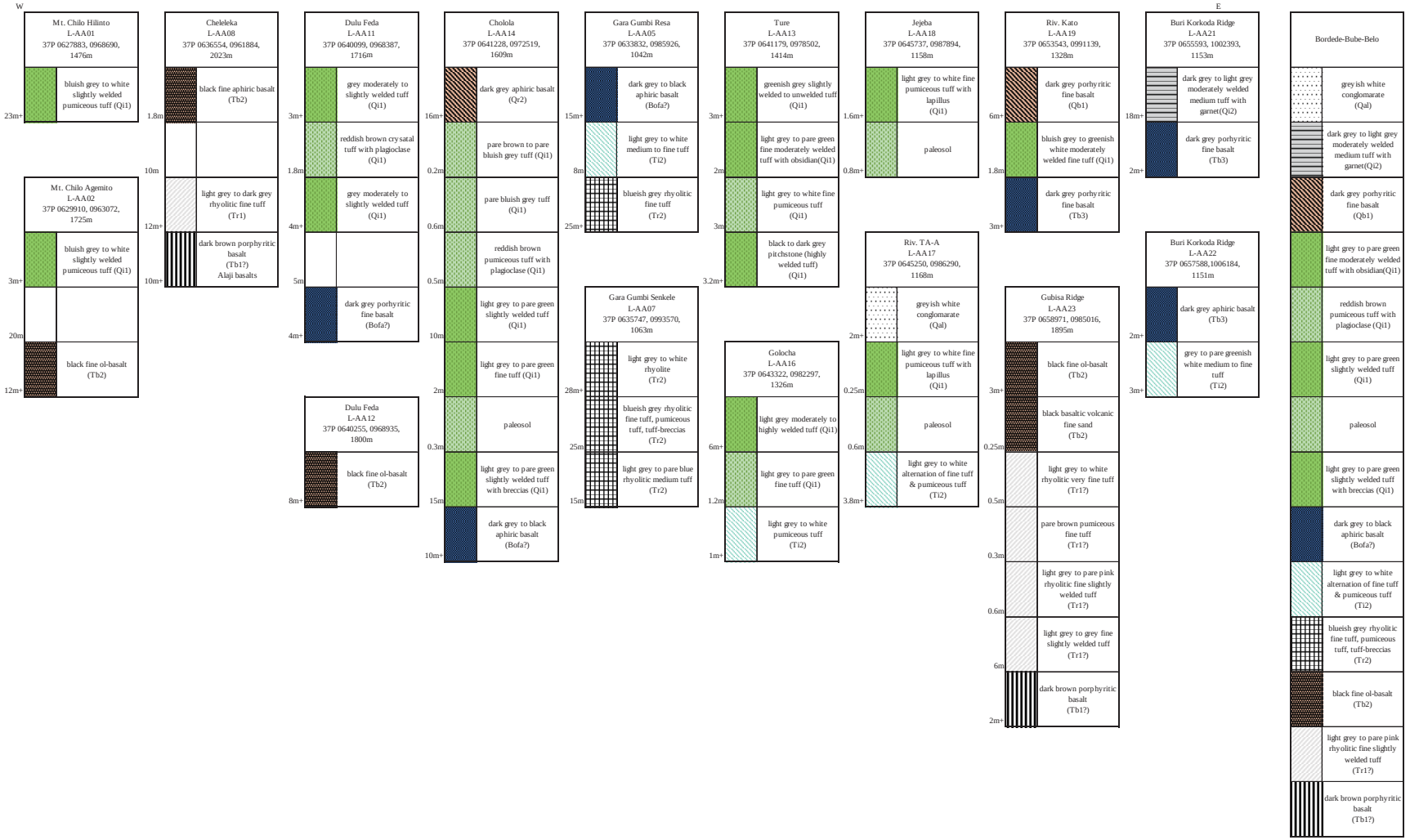
Table 2.4.2 describes the geological succession of Mieso-Asebe Teferi town route, and Table 2.4.3 is for the Bordede – Bube – Belo town route.

Table 2.4.2: Geological Succession of Mieso Town-Asebe Teferi Town-Arba Bekete Town



Source: the Project Team, Data: Result of geological survey in this Project

Table 2.4.3: Geological Succession of Bordede Town – Bube Town – Belo Town



Source: the Project Team, Data: Result of geological survey in this Project

b. Pliocene

b.1 Gara Gumbi rhyolites: Rhyolite, rhyolitic tuff, pumice tuff

Lithology: Consists mainly of white to bluish-gray rhyolite, welded tuff, tuff, white pumice, pitchstone and hard tuff including obsidians. At the type locality, the unit is bluish-grey rhyolite interbedded with white rhyolitic tuff and pumiceous tuff. At Dalecha (L-AA46), the unit is divided by five lithological facies; from the lowest, bluish-grey to white rhyolitic fine tuff (more than 10m in thickness), bluish-grey to greenish-grey welded tuff (5m in thickness), grayish-brown to white rhyolitic pumice-tuff (3m in thickness), grayish-white to dark grey rhyolite with pitchstone (10m in thickness), and bluish-white to grey rhyolitic tuff (more than 20m in thickness).

Distribution: Gara Gumbi, Dalecha Mountain Asebot town, forms a hill at northern part of Mieso town.

Thickness: More than 65 m at the type locality, more than 50 m at Dalecha (L-AA46)

Type locality: Gara Gumbi Shinshit (L-AA06)

Correlation: The area is classified as Nry: Rhyolitic volcanic centers. Intercalation of rhyolite with andesite, trachyte, obsidian, minor pyrodasitic flow deposits and lahars; Gumbi, Asebot, Meiso and Afdem Mountains in AGRAP (2009), and as N1-2gg: Stratoid silicics, peralkaline rhyolitic ignimbrites, unwelded tuff, ash-flows and lava flows in GSE (1985).

Rhyolitic tuff and pumiceous tuff in the type locality.

Rhyolitic Tuff including Obsidians

Source: the Project Team, Data: Result of geological survey in this Project

Figure 2.4.6: Gara Gumbi (L-AA06) (top) and Dalecha (L-AA46) (bottom)

b.2 Adele rhyolitic tuff: Rhyolitic slightly welded tuff and tuff breccia, pumice, tuff, crystal tuff: Ti2

Lithology: Consists of pumice tuff, tuff, and hard tuff. At the type locality, the unit is divided into five lithologies:, from lower, light brown to grey pumice tuff (more than 10 m in thickness), white to light grey fine tuff (2.5 m in thickness), alternation of dark grey medium tuff and bluish-grey fine tuff (3 m in thickness), pale blue fine to very fine tuff (0.6 m in thickness), and white very fine tuff (more than 1.5 m in thickness). This unit is overlain and intercalated by Adele basalt at Adele, and basaltic the dyke is encounters this unit near the type locality (L-AA29).

Distribution: Around Adele, Kora town, Jejeba to Wangeyu southeastern foot of Gara Gumbi, northern part of Debala town

Thickness: More than 20 m in the type locality

Type locality: Adele near Kora town (L-AA30)

Correlation: The area is classified as Nrig: Rhyolotic ignimbrite and N1ab: Afar stratoid basalt lower in AGRAP (2009), and as Nch: Chorora formation, tuff, diatomite, sediments, and N1-2n: Stratoid silicics, peralkaline rhyolitic ignimbrites, unwelded tuff, ash-flows and lava flows in GSE (1985).

The unit consists of pumice tuff and alternated tuff.

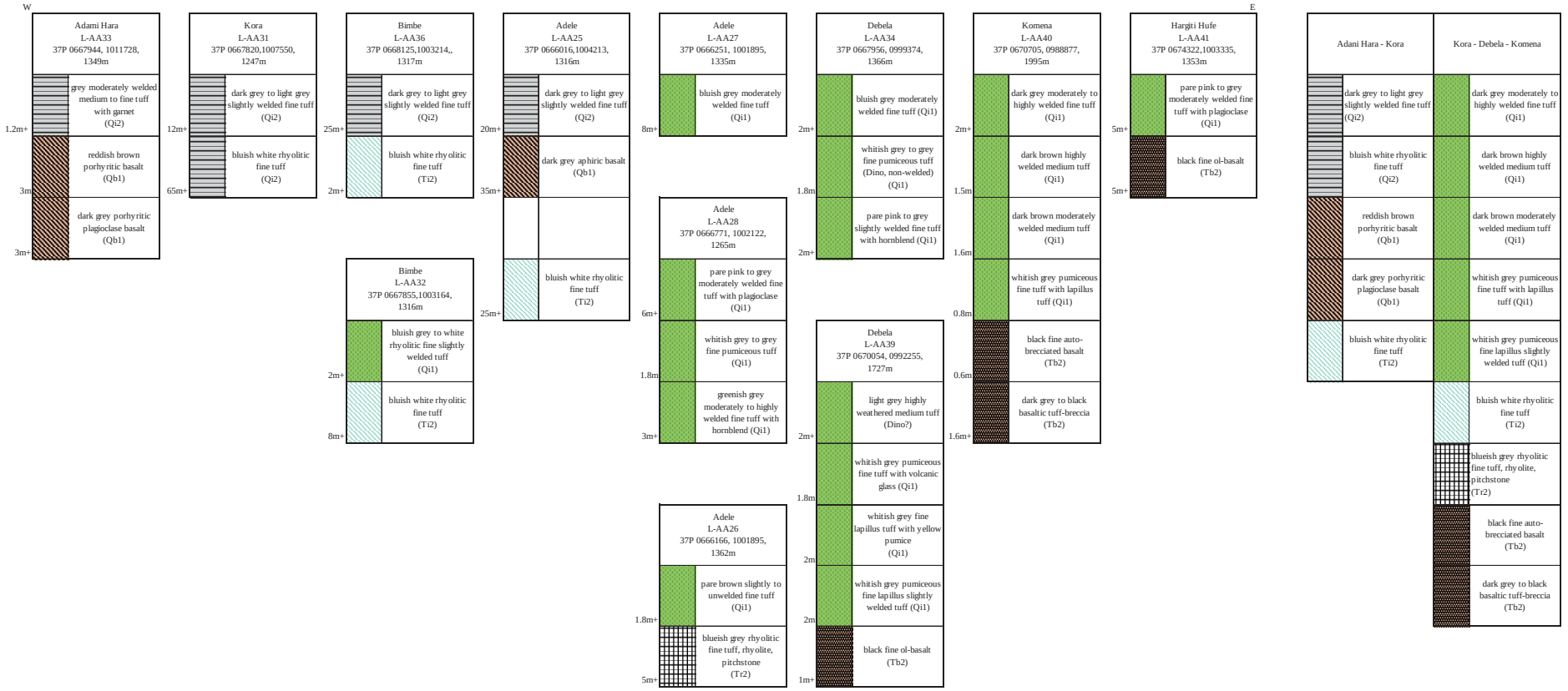
The basaltic dyke is encountered in this unit.

Source: the Project Team, Data: Result of geological survey in this Project

Figure 2.4.7: Type Locality (L-AA30) (top) and its Vicinity (L-AA29) (bottom)

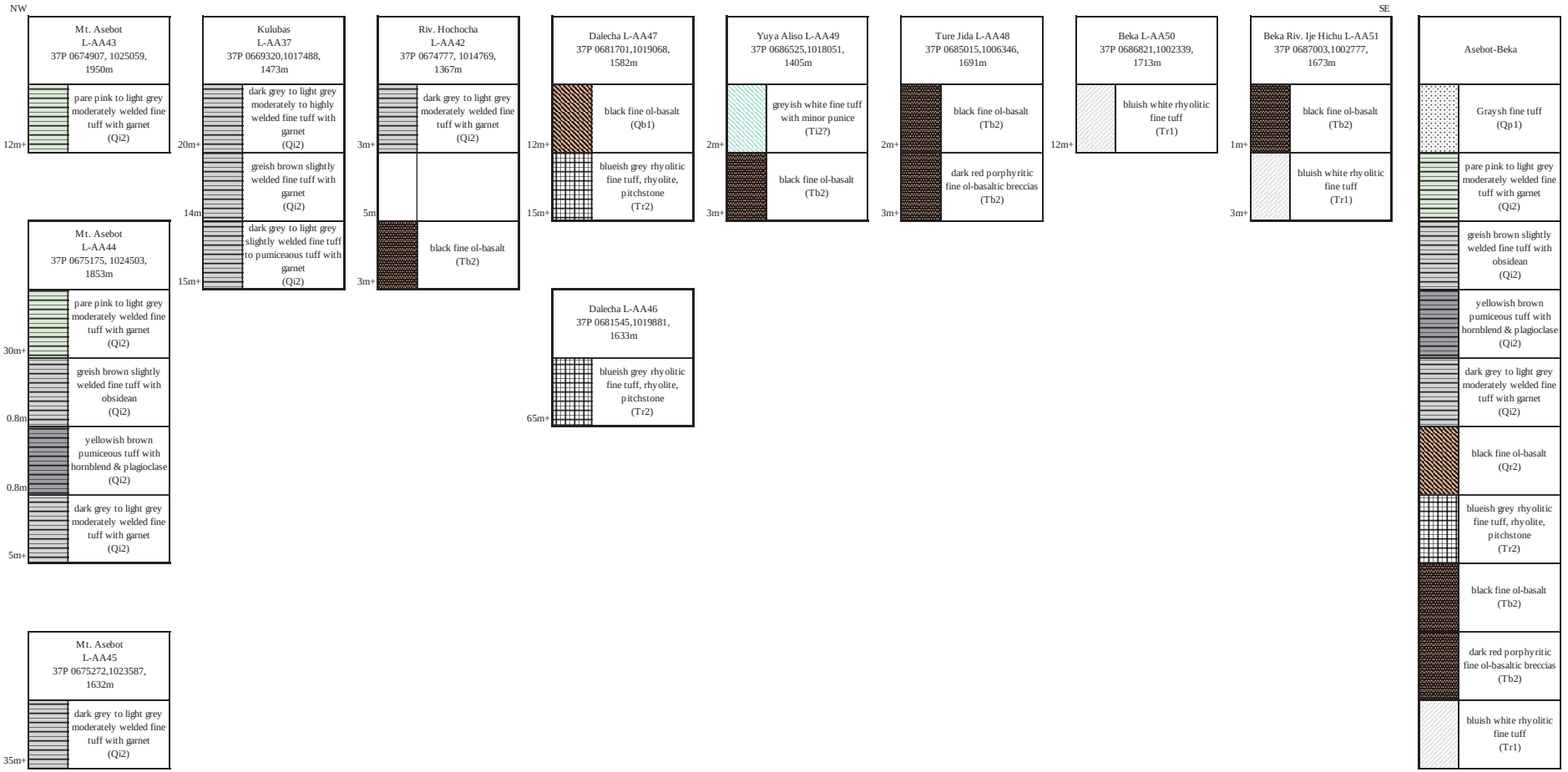
Table 2.4.4 describes the geological succession of the Adami Hara –Kora town -Debala town route, and Table 2.4.5 is for Asebot town – Beka town route.

Table 2.4.4: Geological Succession of Adami Hara –Kora Town -Debala Town



Source: the Project Team, Data: Result of geological survey in this Project

Table 2.4.5: Geological Succession of Asebot Town – Beka Town.



Source: the Project Team, Data: Result of geological survey in this Project

b.3 Bofa basalts: massive aphyric basaltic lava and tuff breccia: Tb3

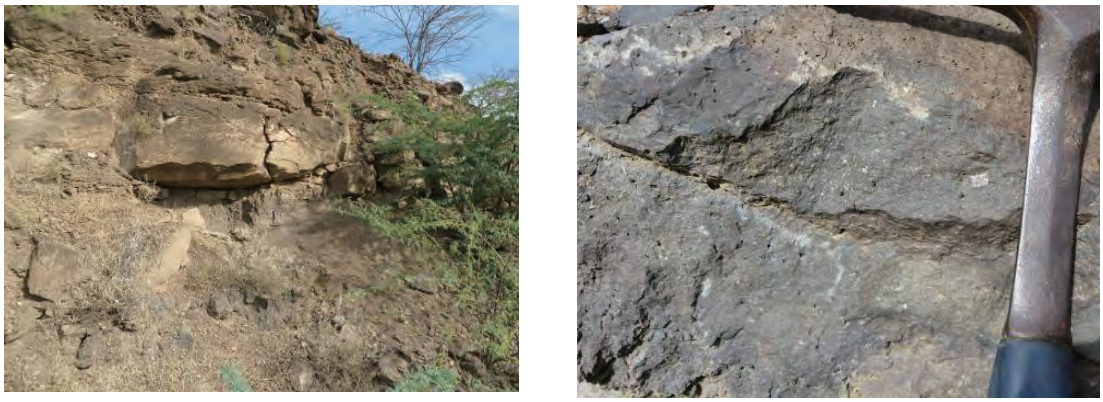
Lithology: Consists of dark grey to black massive aphyric basalt lavas and basaltic tuff breccia. At the type locality, the unit is divided into two lithological facies: from the lower, black basaltic breccia (6m in thickness), and black massive fine basalt (14m in thickness), and is unconformably overlain by Dino ignimbrite.

Distribution: Awash river, Gara Gumbi Rasa

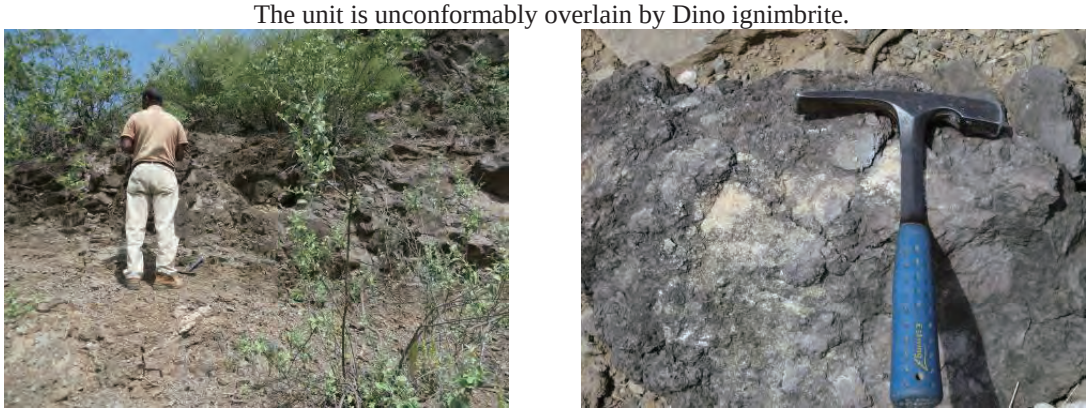
Thickness: Around 20 m in the type locality

Type locality: Awash river (L-KF43)

Correlation: The unit is classified as Bofa basalts in GSE (1978), and as Qfig: Fentale-Alay Dege ignimbrite in GSE (2010).



The unit is unconformably overlain by Dino ignimbrite.



Basaltic tuff breccia

Source: the Project Team, Data: Result of geological survey in this Project

Figure 2.4.8: Type Locality (L-KF43) (top) and Gara Gumbi Rasa (L-AA10) (bottom)

Table 2.4.6 describes the geological succession of Awash town – Mieso town route.

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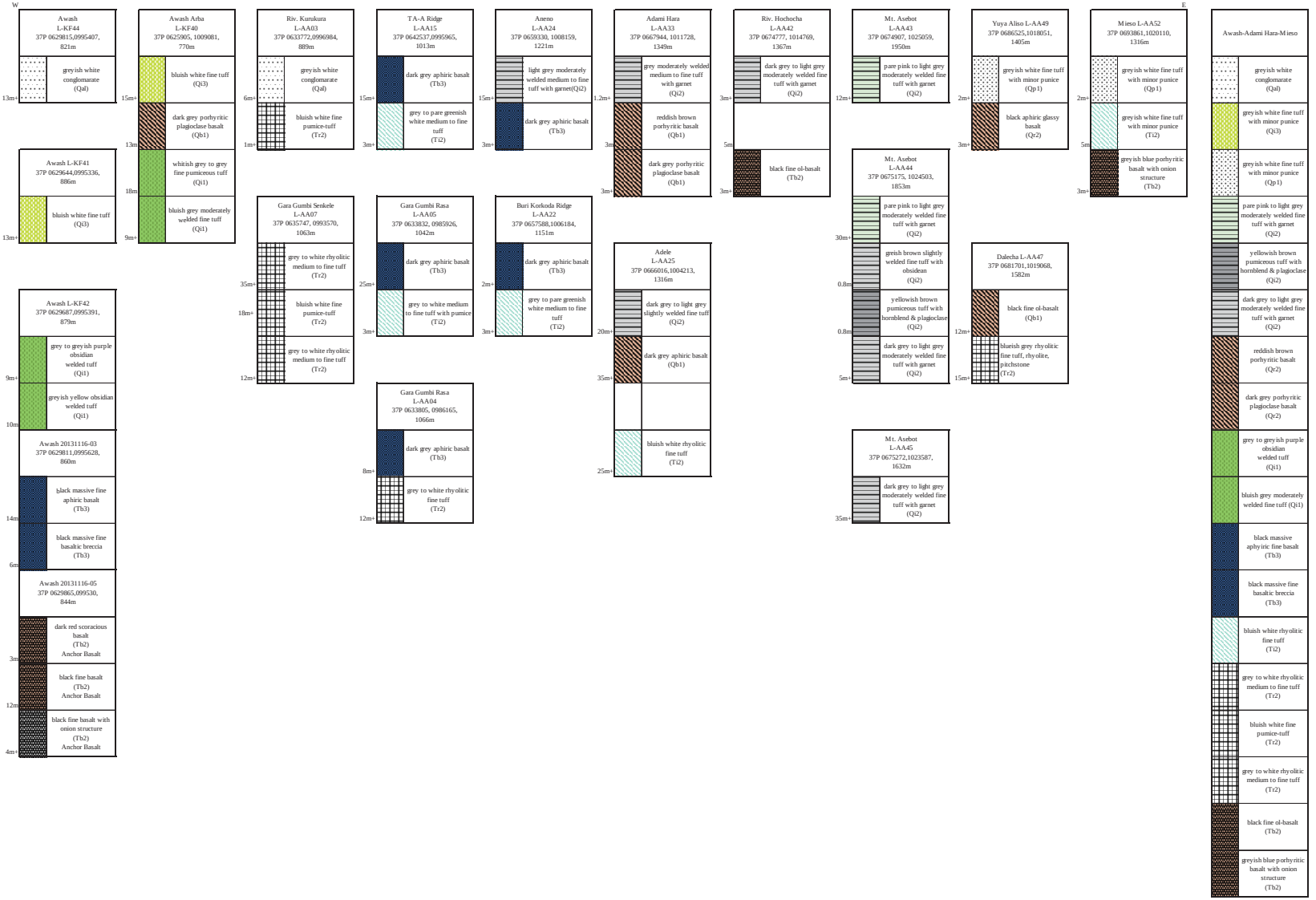
Table 2.4.6: Geological Succession of Awash Town – Mieso Town



Source: the Project Team, Data: Result of geological survey in this Project

c. Pleistocene

c.1 Dino ignimbrite: Qi1

Lithology: Consists of greenish-blue to light gray rhyolitic to andesitic welded tuff which typically contains elongated obsidian lenses (fiamme). Generally, most fiamme is horizontal and concordant with the unit, but some fiamme shows irregular and/or ripple structure. At the type locality, the unit is divided into two flow units. The lower unit appears grayish-yellow in color, medium to coarse grained welded tuff with maximum 40cm-long fiamme, accompanied by 50 cm-thick unwelded part at the bottom and contains rhyolite, green welded tuff, and white pumice. Rarely basaltic fragments and reverse grading of lithic fragments are observed. The upper part indicates normal grading of fiamme (large elongated obsidian clasta), and reverse grading of large litic clasts (rhyolite, white pumice, and rare green welded tuff) is observed. At Debela town (L-AA39), and Komena town (L-AA40), south of Bordede town, the perpendicular layer phases change of welding was observed.

Distribution: Awash river, Adele town, Kora town, Jejeba to Wangeyu southeastern foot of Gara Gumbi, Debala town and Komena town surroundings

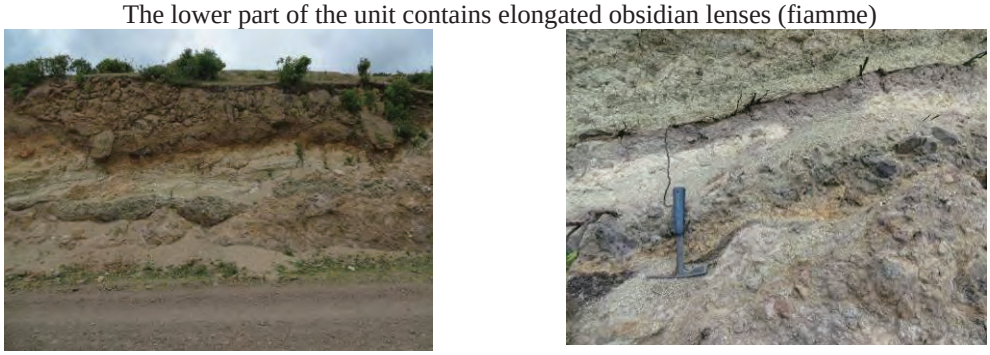
Thickness: Around 20 m in the type locality

Type locality: Awash river (L-KF42)

Correlation: The area is classified as Qwi: Dino ignimbrites in GSE (1978), and as Qfig: Fentale-Alay Dege ignimbrite in GSE (2010).

Chronology: 1.51My K-Ar age from the Awash river near Karayu by Mobidelli et al. (1975)

The lower part of the unit contains elongated obsidian lenses (fiamme)



Layer phases change of welding

Source: the Project Team, Data: Result of geological survey in this Project

Figure 2.4.9: Type Locality, Awash River (L-KF42) (top) and Komena (L-AA40) (bottom)

Observation of thin section

Sample number: 140416-4

Location: Valley bottom of the Arba river in Gericha (L-AA61).

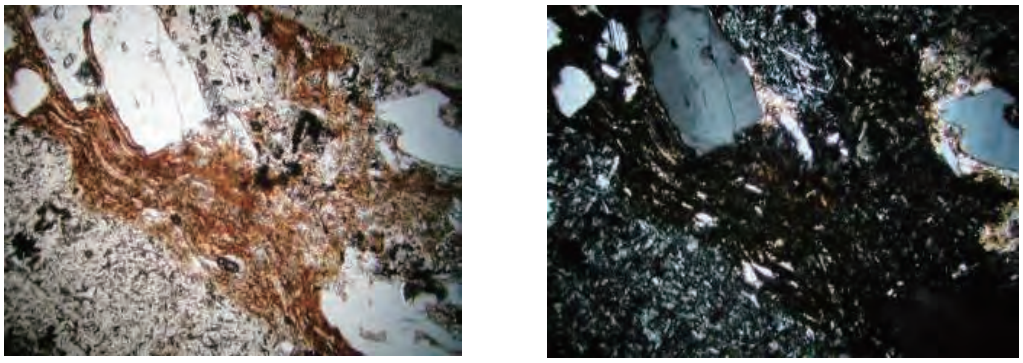
Stratigraphic horizon: Dino ignimbrite

Rock type: Welded rhyolite tuff, welded tuff with lapilli.

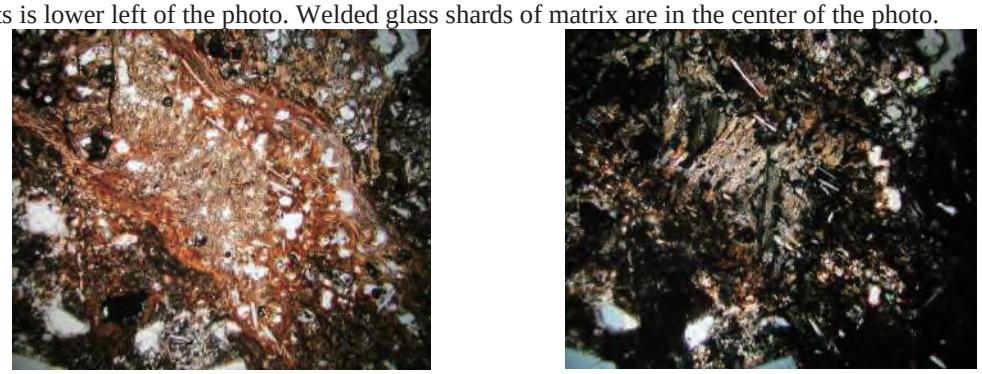
Texture: Welded volcanic glass with crystal of phenocryst fragments and rock fragments.

Clasts: Fragments of alkali feldspars are dominant. Flattened pumice is common. Fragments of basic to acidic volcanic rocks (including trachyte) are observed. Fragments of biotite, albite and microcline are observed.

Matrix: Welded volcanic glass fragments. Quartz and large zeolite are formed in matrix and flattened pumice. It indicate that this rock is affected by a diagenesis to form quartz and zeolite which need long times.



Base of photo 1.5mm: Fragments of alkali feldspars are dominant. A pumice with recrystallized quarts is lower left of the photo. Welded glass shards of matrix are in the center of the photo.



Base of photo 0.7mm: A flattened pumice with welded outer parts. Inside of the pumice is occupied by neocrystallized zeolite. Pores are filled by quartz.

Figure 2.4.10: Photos of Thin Sections of Sample Number 140416-4

c.2 Awash Arba acidic volcano-sedimentary rocks: Qp1

Lithology: Consists mainly of white pumice tuff, tuff and their alternations deposited by pumice flows and lake-land environment.

Distribution: Widely distributed, forms a flat plain which is located around Awash Arba town

Thickness: More than 6 m at the type locality.

Type locality: Jejeba, west of Bordede town (L-AA03)

Correlation: The area is classified as Qwi2: Young ignimbrites of Fentale in GSE (1978), and as Qfig: Fentale-Alay Dege ignimbrite, and Qal: Alluvium with minor agglomerate in GSE (2010).

Pumiceous tuff

Source: the Project Team, Data: Result of geological survey in this Project

Figure 2.4.11: Type Locality, Riv. Jejeba (L-AA03)

c.3 Dofan basalts: plagioclase basalt : Dofan

Lithology: Consists of dark grey basalt with large plagioclase, black basalt with rectangular plagioclase, and black fine olivine basalt. Plagioclase-basalt is widely distributed from Awash Arba town to Adami Hara town, and black fine olivine basalt is distributed from Deka Duku to Asebot town. At the type locality, the unit is unconformably overlain by Asebot welded tuff.

Distribution: Around Awash Arba town, Buri Arba to Aneno town, Adami Hara town and Asebot town.

Thickness: About 12 to 16m in the type locality

Type locality: Adami Hara town (L-AA33)

Correlation: The unit is classified as N1-2ab: Stratoid basalts of Afar (lower part), in GSE (1985), and as Qdb : Dofan basalts, vesicular basalt, aphanitic basalt, olivine phyric basalt and recent scoria cones in GSE (2010).as N2ab: Afar stratoid basalt upper. Mostly vesiculated and rubby surfaced transitional basalt, covers the rift floor in AGRAP (2009).

The unit is unconformably overlain by Asebot welded tuff.

The unit unconformably overlies Adele rhyolitic tuff.

Plagioclase basalt, classified as Dofan basalts in GSE (2010)

Source: the Project Team, Data: Result of geological survey in this Project

Figure 2.4.12: Type Locality, Adami Hara (L-AA33) (top), Buri Korkoda Ridge (L-AA22) (bottom left) and Awash Arba (L-KF40) (bottom right)

c.4 Asebot welded tuff: Qi2

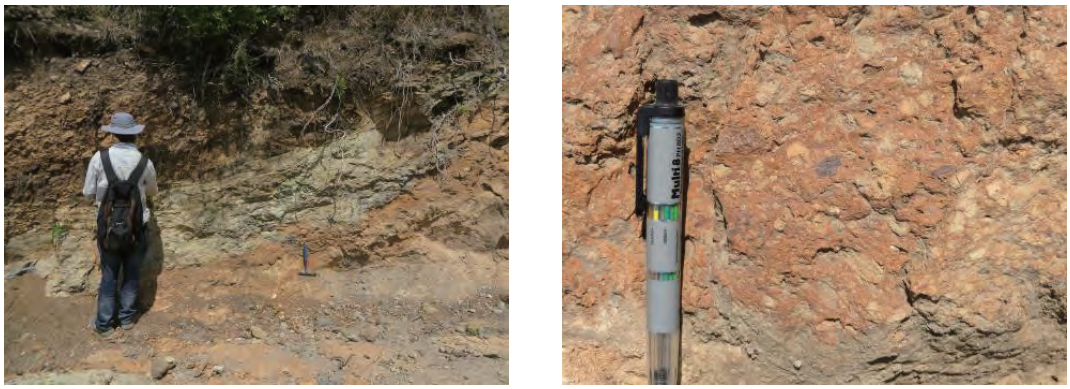
Lithology: Consists of light grey to dark gray rhyolitic welded tuff, and pumiceous tuff which contains square to rectangle shaped minerals with garnet color characteristics. At the type locality, the unit is divided into four lithological phases; from lower, dark grey to light grey moderately welded tuff (6 m in thickness), yellowish-brown pumiceous tuff (0.8 m in thickness), grayish-brown slightly welded tuff with elongated obsidian lenses (fiamme, 0.8m in thickness), and grayish-purple moderately welded tuff (more than 5 m in thickness). At Kulbas, southwestern foot of Mt. Asebot (L-AA38), dark grey to light grey moderately welded tuff of this unit is observed to increase with higher altitudes in the northeast (Mt. Asebot).

Distribution: Widely distributed in the plains surrounding Buri Arba town to Aneno town, Adami Hara, and Asebot town.

Thickness: More than 36 m in the type locality, more than 60 m at Kulbas (L-AA37).

Type locality: Mt. Asebot (L-AA44)

Correlation: The area is classified as N1_2ab: stratoid basalt of Afar (lower part) in GSE (1985), as Qdb: Dofan basalts in GSE (2010), and as N2ab: Afar stratoid basalt upper in AGRAP (2009).



Yellowish brown pumiceous tuff

Pumiceous tuff　　Dark grey welded tuff

Source: the Project Team, Data: Result of geological survey in this Project

Figure 2.4.13: Type Locality, Mt. Asebot (L-AA44) (top), Kulbas (L-AA38) (bottom left) and Aneno (L-AA21) (bottom right)

c.5 Fentale ignimbrite: Qi3

Lithology: Consists of bluish-grey pumiceous tuff, welded tuff, and pale green tuff. At the type locality, the unit unconformably overlies Dofan basalts.

Distribution: Widely distributed, forms a flat plain which is located around Awash town and Awash Arba town

Thickness: More than 15 m at the type locality.

Type locality: Awash Arba (L-KF40)

Relationship with lower unit: The unit unconformably overlies Dofan basalts at the type locality.

Correlation: The area is classified as Nn: Nazret Group, and Qwi2: Young ignimbrites of Fentale in GSE (1978), and as Qfig: Fentale-Alay Dege ignimbrite in GSE (2010)

Chronology: 168,000±38,000 years fission track age by Williams et al. (2004).


Pumiceous Tuff

Source: the Project Team, Data: Result of geological survey in this Project

Figure 2.4.14: Awash River (L-KF41)

d. Holocene

d.1 Alluvium: Qal

Lithology: Fine sand and mud
Distribution: Awash river
Thickness: 1-5m

2.5 Correlation of stratigraphy of each part of the study area

The correlation of the stratigraphy of the above mentioned four areas, namely, Nazret-Mt.Boseti, Kone-Mt.Fentale, Mojo-Arerti-Debre Birhan and Awash-Asebe Teferi and in addition the stratigraphy around the Lake Beseka area where a detailed geological study was conducted is shown in Table 2.5.1.

Table 2.5.1: Correlation of stratigraphy in the study area

Age			Areas					Stratigraphy of the whole study area	Age
			Nazret-Mt.Boseti	Kone-Mt.Fantale	Mojo-Arerti-Debre Birhan	Awash-Asebe Teferi	Lake Besaka (1:100,000)		
Cainozoic	Quarternary	Holocene	Alluvium	Alluvium	Alluvium	Alluvium	Alluvium (Qa)	**Alluvium (Qal)**	
			Recent rhyolitic domes & lava flows	Recent rhyolitic domes & lava flows				**Recent rhyolitic domes & lava flows (Qr2)**	
			Holocene basalts	Holocene basalts			Holocene basalts (Qb2)	**Holocene basalts (Qb2)**	
		Pleistocene basalt	Fantale ignimbrite	Fantale ignimbrite	Fantale ignimbrite	Fantale ignimbrite	Fentale ignimbrite (Qi3)	**Fentale ignimbrite (Qi3)**	168,000±38,000 y (OWWDSE ,2013)
				Fantale volcanic rocks			Fentale volcanic rocks (Qf)	**Fentale volcanic rocks (Qf)**	
			Boseti pumice falls	Kone pumice falls	Boseti pumice falls			**Boseti-Kone pumice fall deposits (Qp2)**	
				Kone ignimbrite		Asebot welded tuffs	Kone ignimbrite (Qi2)	**Kone ignimbrite (Qi2)**	
			Pleistocene basalts	Pleistocene basalts	Pleistocene basalt	Dofan basalt	Pleistocene basalts (Qb1)	**Pleistocene basalts (Qb1)**	Zikwala olivine basalt : 0.61±0.03Ma (Morton et.al.,1979)
				Tuff ring deposits	Maar deposits		Sobebor volcanic sand beds (Qs)	**Sobebor volcanic sand beds (Qs)**	
					Zikwala Trachytes			**Zikwala Trachytes (Qt)**	0.85±0.05Ma, 0.92±0.04Ma, 1.28±0.15Ma (Morton et al.,1979)
			Chefe Donsa pyroclastic deposits		Chefe Donsa pyroclastic deposits	Awash Arba Volcano-sedimentary rocks		**Chefe Donsa pyroclastic deposits (Qp1)**	Chefe Donsa pyroclastic deposits : 1.71±0.04 Ma(Morrton et al.,1979), 2.24±0.3 Ma(IGGI-Pisa)
			Pleistocene rhyolites					**Pleistocene rhyolites (Qr1)**	
			Dino ignimbrite	Dino ignimbrite	Dino ignimbrite	Dino ignimbrite	Dino ignimbrite (Qi1)	**Dino ignimbrite (Qi1)**	Dino ignimbrite: 1.5my (Mobidelli et al., 1975), 1.51 Ma (Kazmun, et al.,1978)
	Tertiary	Pliocene	Bofa basalt	Bofa basalts	Tulu Rie basalts	Bofa basalt	Nura Hira basalts (Tb)	**Bofa basalts (Tb3)**	Tulu Rie basalt: 2.7±0.1 Ma(INGEIS-Buenos Aires), 1.44±0.03 Ma(Chernet et al., 1998) Bofa : 1.21 Ma (Kazumin, et al., 1978), 6.1-4.4 Ma(Morton et al.,1979)
			Chilalo Trachybasalts					**Chilalo Trachybasalts (Tt)**	
			Nazret pyroclastic deposits – Upper		Nazret pyroclastic deposits – Upper		Old ignimbrite (Ti)	**Upper Nazret pyroclastic deposit (Ti3)**	Nwp : 3.5±0.1 Ma, 3.2±0.1 Ma(IGGI-Pisa), 4.7±0.7 Ma, 5.4±0.2 Ma(INGEIS-Buenos Aires), 3.32±0.06 Ma, 3.11±0.06 Ma(Morton et al., 1979)
			Nazret pyroclastic deposits – Lower		Nazret pyroclastic deposits – Lower	Adele rhyolitic tuffs		**Lower Nazret pyroclastic deposits (Ti2)**	
			Chefeko rhyolites	Birenti-Hada rhyolites	Mt. Bokan rhyolites	Gara Gumbi rhyolites	Birenti-Hada rhyolites (Tr)	**Pliocene rhyolites (Tr2)**	
		Miocene			Tarmaber-Megezeze basalts	Anchar basalts		**Anchar basalts (Tb2)**	Anchar : 12.4 Ma (Kazumin et.al., 1978) Mt. Megezeze: 13Ma, (Zanettin et al., 1974), 10.4Ma, (Chernet et al., 1998)
					Debre Birhan ignimbrite			**Debre Birhan ignimbrite (Ti1)**	
						Huse Ridge rhyolites		**Huse Ridge rhyolites (Tr1)**	
			Alaji basalts		Kesem basalts	Alaji basalts		**Alaji basalts (Tb1)**	24-23Ma (Chernet et al., 1998), 14.4 Ma (Kuntz et al., 1975), 28-15 Ma (Morbidelli et al., 1975), 21.06±1.5 Ma, 14.94±1.5 Ma, 17.4±1.0 Ma (Kazumin, et al., 1978)

2.6 Correlation of stratigraphy with previous studies

Results of correlation of stratigraphy established in this study and the previous documents listed below which cover the same area are shown in Table 2.6.1.

Documents and maps	Study area
Kazmin & Berhe (1978)	Nazret area
Alidge Groundwater Resources Assessment Project (2009)	Alidge, Awash area
Oromia Water Works Design & Supervision Enterprise (2013)	Beseka area
GSE (1985)	Dire Dawa area
GSE (2010)	Debre Birhan area
GSE (2010)	Akaki-Beseka area
F. Mazzarini et al (1999)	Debre Zeyt area
JICA (2012)	Rift valley lake zone

Table 2.6.1: Correlation of stratigraphy with existing documents and maps

Age			This study	Kazmin et al.(1978), GSE (1978) Nazret area	AGRAP (2009) Alidge-Awash area	OWWDSE (2013) Beseka area	GSE (1985) Dire-Dawa area	GSE (2010) Debre Birhan area	GSE (2010) Akaki-Beseka area	F. Mazzarini, et al.(1999) Debre Zeyt area	JICA (2012) Rift Valley lake zone	Geological Age
Cainozoic	Quarternary	Holocene	Alluvium (Qal)		Qed, Elluvial deposit Qsd, Slope deposits Qaf, Alluvial fan Qgf, Gravel outwash		Qtr, Travertine	Qal, Alluvial with minor agglomerate Qel, Eluvial	Qus, Alluvium	Alluvium Cover	Al, Alluvium Q, Unclassified fluvial deposits	
			Recent rhyolitic domes & lava flows (Qr2)	Qwra, Alkali and paralkali rhyolites, trachytes, domes and flows of Boset Weldoyi and Hada mountains (Wanji group) Qwpu, Unwelded rhyolitic pumice and unwelded tuffs (Wanji group)								
			Holocene basalts (Qb2)	Qwb3, Recent aphyric basalt (Wanji group)	Qb2, Aa lava	Holocene basalt Scoria cone	Qwbh, Recent and subrecent basaltic flows and caves		Qub, Basaltic lava flows Quc, Scoria cones and fall out deposits		rb, Butajira recent basalt	
		Pleistocene basalt	Fantale ignimbrite (Qi3)	Qwi2, Young ignimbrites of Fantale (Wanji group) Nn, Ash flow tuffs, pantelleritic ignimbrites and unwelded tuffs (Nazret group)	Qed, Elluvial deposit	Fantale ignimbrite	Fantale ignimbrite	Qfig, Fentale-Alay dege ignimbrite			G, Gonde strongly green welded tuff ob, Kulmusa highly welded tuff	168,000±38,000 y (OWWDSE ,2013)
			Fantale volcanic rocks (Qf)	Qwt, Trachytic flows and domes associated with Fantale, Tinish Fantale and Kone (Wanji group) Qwp, Pitchstone flows and domes (Wanji group) Qwpo, Pantelleritic volcanics of Fantale rhyolites, trachytes, tuffs and agglomerates (Wanji group)		diverse Fantale volcanics		Qft, Fentale trachyte				
			Boseti & Kone pumice falls (Qp2)	Qwpu, Unwelded rhyolitic pumice and unwelded tuffs (Wanji group) Nn, Ash flow tuffs, pantelleritic ignimbrites and unwelded tuffs (Nazret group) Qwb3, Recent aphyric basalt (Wanji group)							Y, Langano poorly welded pumiceous pyroclastics	
			Kone ignimbrite (Qi2)	Nn, Ash flow tuffs, pantelleritic ignimbrites and unwelded tuffs (Nazret group)	N2ab, Afar stratoid basalt upper		N1_2n, Stratoid silicics	Qdb, Dofan basalt			G, Gonde strongly green welded tuff	
			Pleistocene basalts (Qb1)	Qwb1, Pleistocene-subrecent basalts (Wanji group) Qwb2, Porphyritic feldspar basalts of Tulu Moye (Wanji group)	Qb1, Basic lava flow and caves	Pleistocene Basalt		Qdb, Dofan basalt		Bishoftu Volcanic unit	ba, Ogolche pleistocene basalt	Zikwala olivine basalt : 0.61±0.03Ma (Morton et.al.,1979)
			Sobebor volcanic sand beds (Qs)	Qwh, Basaltic hyaloclastites (Wanji group) Qwe, Bedded explosion tuffs (Wanji group)		Tuff Cone			Qup, Phreatomagmatic deposits			
			Zikwala Trachytes (Qt)						Qtz, Zikwala trachytes	Zikwala Volcanic unit		0.85±0.05Ma, 0.92±0.04Ma, 1.28±0.15Ma (Morton et al.,1979)
			Chefe Donsa pyroclastic deposits (Qp1)	Qwpu, Unwelded rhyolitic pumice and unwelded tuffs (Wanji group) Nn, Ash flow tuffs, pantelleritic ignimbrites and unwelded tuffs (Nazret group) Qwb3, Recent aphyric basalt (Wanji group)	N2ab, Afar stratoid basalt upper	older ignimbrite of the Fantale area	N1_2n, Stratoid silicics		Ncp, Chefe donsa pyroclastic deposits	Chefe Donsa unit	W, Ketar river acidic volcanic sedimentary rocks	Chefe Donsa pyroclastic deposits : 1.71±0.04 Ma(Morrton et al.,1979), 2.24±0.3 Ma(IGGI-Pisa)
			Pleistocene rhyolites (Qr1)	Nn, Ash flow tuffs, pantelleritic ignimbrites and unwelded tuffs (Nazret group) Qwp, Pitchstone flows and domes (Wanji group)							rh, Gademotta rhyolite	
			Dino ignimbrite (Qi1)	Qwi, Dino ignimbrites (Wanji group) Nn, Ash flow tuffs, pantelleritic ignimbrites and unwelded tuffs (Nazret group)	Nig, Dino ignimbrite	Dino Tuff					G, Gonde strongly green welded tuff	Dino ignimbrite: 1.5my (Mobidelli et al., 1975), 1.51 Ma (Kazmun, et al.,1978)
	Tertiary	Pliocene	Bofa basalts (Tb3)	N2Qb, Bofa basalts	N1ab, Afar stratoid basalt lower	Bofa basalt	N1_2ab, Stratoid basalts of Afar (lower part)			Tulu Rie Basalts unit	N2b, Basalt	Tulu Rie basalt: 2.7±0.1 Ma(INGEIS-Buenos Aires), 1.44±0.03 Ma(Chernet et al., 1998) Bofa : 1.21 Ma (Kazumin, et al., 1978), 6.1-4.4 Ma(Morton et al.,1979)
			Chilalo Trachybasalts (Tt)	N2c, Chilalo and Badda trachytes and trachybasalts								
			Upper Nazret pyroclastic deposit (Ti3)	Nn, Ash flow tuffs, pantelleritic ignimbrites and unwelded tuffs (Nazret group) Ql, Lacustrine sediments	N1ab, Afar stratoid basalt lower	older ignimbrite of the Fantale area			Nwp, Welded pyroclastic flows	Nazret unit	rht, Rhyolitic tuff Nqs, Rhyolite	Nwp : 3.5±0.1 Ma, 3.2±0.1 Ma(IGGI-Pisa), 4.7±0.7 Ma, 5.4±0.2 Ma(INGEIS-Buenos Aires), 3.32±0.06 Ma, 3.11±0.06 Ma(Morton et al., 1979)
			Lower Nazret pyroclastic deposits (Ti2)	Nn, Ash flow tuffs, pantelleritic ignimbrites and unwelded tuffs (Nazret group) Ql, Lacustrine sediments			N1_2ab, Stratoid basalts of Afar (lower part)		Npp, Welded to partially welded pyroclastic flows			
			Pliocene rhyolites (Tr2)	N2r, Older alkaline and paralkaline rhyolite domes and flows Qwt, Trachytic flows and domes associated with Fantale, Tinish Fantale and Kone (Wanji group) Qwra, Alkali and paralkali rhyolites, trachytes, domes and flows of Boset Weldoyi and Hada mountains (Wanji group)	Nry, Rhyolitic volcanic centres	rhyolite domes, flows and pumice N2r	N1_2gg, Peralkaline rhyolitic and trachytic domes and flows		Nrd, Rhyolitic and trachytic lava domes		N1_2n, Rhyolitic volcanics	
		Miocene	Anchar basalts (Tb2)	N1n, Anchar basalts	N1n, Anchor basalt		N1n, Anchar basalts	Ttb, Tarmaber-Megezeze basalt	E3tm, Tarmaber megezez formation Ega, Guraghe-Anchor basalts		Ngs, Sharenga rhyolite	Anchar : 12.4 Ma (Kazumin et.al., 1978) Mt. Megezeze: 13Ma, (Zanettin et al., 1974), 10.4Ma, (Chernet et al., 1998)
			Debre Birhan ignimbrite (Ti1)					Tdig, Sela dengay-Debre birhan-Gorgo ignimbrite			Ngu, Upper basalt	
			Huse Ridge rhyolites (Tr1)	N1r, Arba Guracha silicics	N1r, Arba guracha silicics		N1r, Arba guracha silicics				Ngu, Upper basalt	
			Alaji basalts (Tb1)	N1a, Alaji basalts	PNa1, Alajae formation		P3N1a, Alaji basalts	Tkb, Kesem basalt	E2aa, Aiba-Alaje basalts		Ngb, Beyana tuff, Ngm, Middle basalt	24-23Ma (Chernet et al., 1998), 14.4 Ma (Kuntz et al., 1975), 28-15 Ma (Morbidelli et al., 1975), 21.06±1.5 Ma, 14.94±1.5 Ma, 17.4±1.0 Ma (Kazumin, et al., 1978)

2.7 Geological structure

2.7.1 Fault system

The MER (Main Ethiopian Rift) is an area of graben showing intense tensional tectonism and the related emplacement of volcanic products. The study area is located in a very complex junction of three important rift structures, two oceanic, the Red Sea and the Gulf of Aden and one continental, the East African Rift (Elc Electroconsult and Geotermica Italiana, 1987).

Generally, there are two main hypotheses of kinematic evolution of the Ethiopian Rift (ER). Some authors believe that the ER evolution has been mostly dominated by nearly pure extension (Mohr, 1983; Ebinger et al., 1993) with also a dextral component of displacement along the rift structure (Chorowicz et al., 1994), while the other authors suggest the occurrence of a left-lateral component of displacement along the rift axis during Quaternary (Boccaletti et al., 1999).

Boccaletti et al. (1999) summarized the previous study of structural setting of the MER as follows. The occurrence of two distinct fault systems in the MER is recognized; i) a mainly NE to NNE-trending border fault system that defines the rift margins and ii) a N to NNE-trending fault system that is mainly composed of right-stepping en-echelon faults constituting the so-called “Wonji Fault Belt (WFB)” (Mohr, 1960).

2.7.2 Active structures

The Wonji Fault Belt (WFB) is formed by several segments of Quaternary volcano-tectonic activity and these segments are disposed en-echelon left laterally (Gibson and Tazieff, 1970). They most probably represent incipient spreading center (Kazmin and Barhe, 1978).

The general structural pattern of the whole MER suggests the occurrence of a recent sinistral component of displacement along the rift axis. Nearly NNE-trending right-stepping en-echelon segments of the WFB located within the rift zone are arranged obliquely to the Rift margins. This setting is interpreted as evidence of the occurrence of some left-lateral shearing along the Rift (Boccaletti et al., 1999).

These segments of high activity can be recognized as shown in Figure 2.7.1. Kazmin and Barhe (1978) describe the characteristics of the WFB in the study area as follows. The southernmost segment, about 10 kilometers wide, extends along the eastern shore of Lake Ziway up to Gedemsa Caldera. It consists of numerous faults and open fractures situated 500 to 1,000 m apart. This segment is marked by extensive eruptions of basalts, mainly from the Tulu Moye center and by the large silicic center of Gedemsa. There is no visible continuation of this axial segment in the north of Gademsa. It is substituted by the next segment, which is displaced about 10 kilometers to the east. This segment widens to 20 kilometers to the north and is marked by the two large silicic centers of Boseti and Kone as well as extensive fissure basalt eruptions. In the north of Kone Caldera, it is substituted by the third segment, which starts from the Fentale.

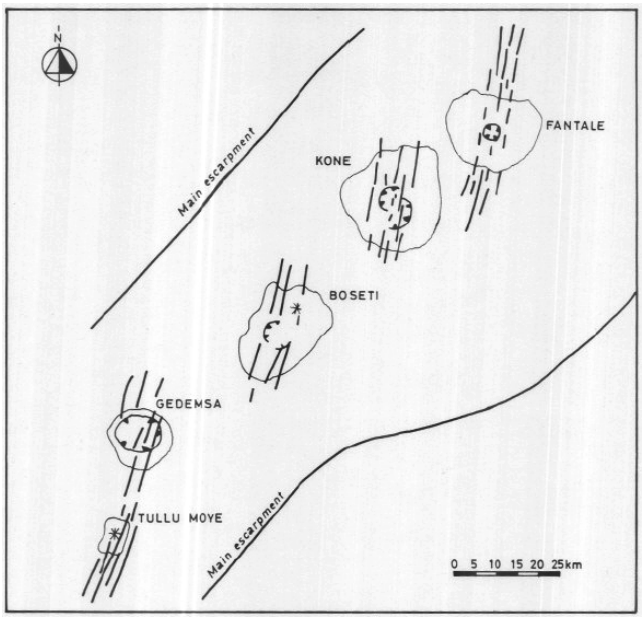


Figure 2.7.1: "En Echelon" arrangement of the active volcano-tectonic axis within the northern part of the Ethiopian rift (after Elc Electroconsult and Geotermica Italiana, 1987)

2.8 Volcanic activity

2.8.1 Characteristics of volcanic topography in the middle Awash River basin

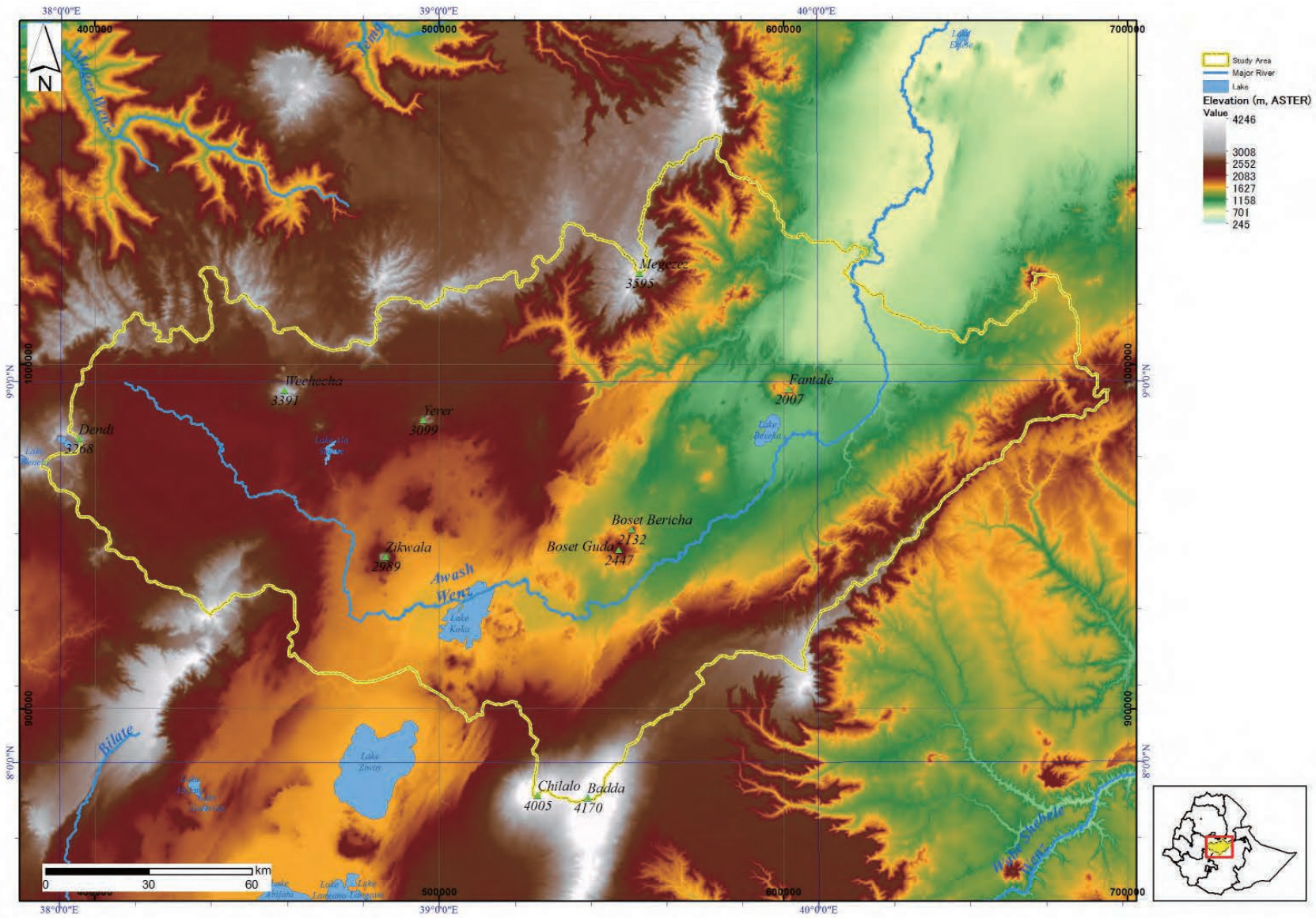
Within the middle of the Awash River basin, MER is situated in the center of the basin trending in the NE direction. The southeast edge of the Rift is bounded by the range of hills, at the altitude of 2,000 to 3,000 m where Miocene basalts are exposed. The thick basalts and pyroclastic deposits of the Miocene to Pliocene cover the northwest side of the Rift. This forms a plateau at the elevation of 2,000 to 3,000 m (Figure 2.8.1). Within the Rift, pyroclastic deposits and basaltic lavas of the Miocene to early Pleistocene show a relatively flat topography. Along the Rift floor, stratovolcanos, calderas and volcanic cones formed during the middle Pleistocene to Holocene are scattered and has formed new topographic surface. These new volcanic topographies are disconnected by the Quaternary normal faults of the Wonji Faults Belt (WFB) and the fault escarpments are extending NE and NNE direction with the height of a few meters to about 20 m, which have developed in the large area of the Rift. Dissection of the major fault escarpments has developed along the Rift shoulders.

The recent basalts of the late Pleistocene to Holocene observed along the Rift center generally show a'a type, which has a rough surface composed of broken lava blocks called clinker and pahoehoe type, which has ropy structures is also partly observed. Many volcanic cones related to recent basalt eruption are arranged in a NE trend along the Rift floor. Most volcanic cones are scoria cones with a diameter of 200 to 500 m. Larger ones are tuff rings (or tuff cones), which exceeds 1.5 km in diameter.

Calderas in the study area are considered to have formed during the late Pleistocene (Elc Electroconsult and Geotermica Italiana, 1987). These are arranged linearly along the Rift,

which are Gedemsa Caldera (8 km in diameter), Kone caldera (5 km in diameter) and Fentale caldera (4km in diameter) from the south.

There are stratovolcanos within the study area, which are Fentale volcano (2,007 m), Boseti volcano (2,447 m) and Zikwala volcano. These were formed during the late Pleistocene and are composed of rhyolitic to trachy lavas, showing the typical topography of stratovolcanos with beautiful conical shapes. In the western part of the rift shoulder within the study area there are stratovolcanos formed during the late Pleistocene such as Yerer volcano (3,099 m) and Wechecha volcano (3,391 m). Shield volcanos, Chilalo (4,005 m and 4,170 m) are located at the southernmost point of the study area, and the topography continues to the southeastern hills.



Source: the Project TeamData: ASTER (version 2), Resolution 30 m, vertical accuracy 20 m

Figure 2.8.1: Elevation Map of the Study Area

2.8.2 Volcanic history in the middle Awash River Basin

Kazmin and Berhe (1978) summarized the general volcanic activities of the northern Ethiopian Rift as follows.

Eruption of the Oligocene-Lower Miocene Alaji volcanics predates the opening of the northern part of the Ethiopian Rift and Afar. Development of these rifts can be traced back to 14 Ma, when the Anchar Basalts and the Arba Gracha Silicious (14-10 Ma) began accumulating within the areas bounded by rift escarpments. Initial sagging of the rift was accompanied by downwarping of older strata and development of radial fractures which were later altered to antithetic faults. Faulted rift escarpments were formed about 10 Ma, followed by the epoch of in-rift silicic volocanism of the Nazret Group between 9.5 and 4 Ma. This was followed by fissural eruption of the Bofa Basalts on the rift floor (3.5 – 2 Ma) and then by a major rifting episode during which an en echelon axial zone, the Wonji Fault Belt, was formed. The oldest ignimbrite belonging to the Wonji Group, the volcanic assemblage related to the axial zone, are dated at 1.5 Ma. Four major stages of rifting at 14, 10, 4-5 and 1.6-1.8 Ma are estimated. Each stage of sinking of the rift floor was accompanied by the formation of shield volcanoes on its shoulders.

The geological history of the northern part of Ethiopian rift is shown in Figure 2.8.2.

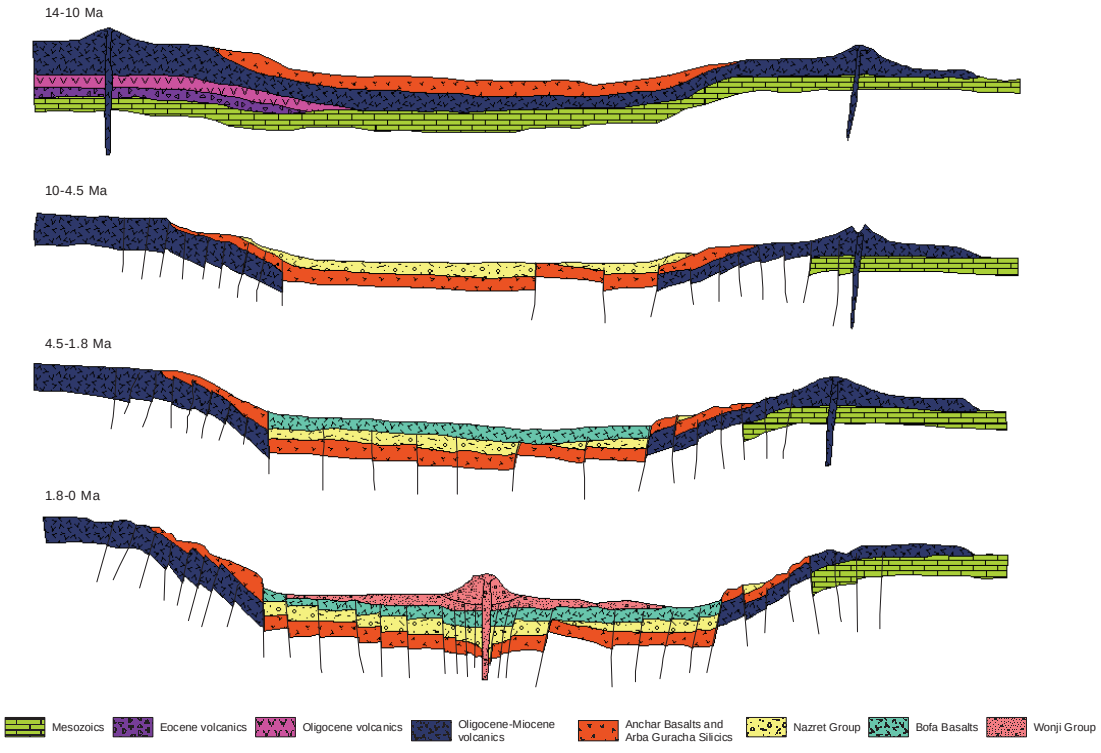


Figure 2.8.2: Stages in the Development of the Ethiopian Rift (after Kazmin and Berhe, 1978)