

Content

Acknowledgment 11

PART I.

THE REGIONAL GEOLOGY OF ETHIOPIA 13

Preface 15

1. Introduction 16

1.1. Previous Geological Mapping and Map Outputs 17

1.2. Data Sources 19

2. Remote Sensing Analysis 21

2.1. Digital Elevation Model (DEM) 21

2.2. Optical Satellite Data 21

3. Regional Gravity Field of Ethiopia 25

4. Geodynamic Evolution and Paleogeography 31

5. Precambrian to Lower Paleozoic Basement Rocks 43

5.1. The Northern Ethiopian Shield (NES) 45

5.2. The Western Ethiopian Shield (WES) 52

5.3. The Southern Ethiopian Shield (SES) 56

5.4. The Eastern Ethiopian Shield (EES) 60

5.5. Petrology and Geochemistry of Igneous Rocks 61

5.6. Geodynamic Evolution 65

6. Sedimentary Formations 67

6.1. Evolution of the Sedimentary Basins 68

6.2. Stratigraphy 72

6.2.1. Lower Paleozoic 72

6.2.2. Upper Paleozoic – Triassic 74

6.2.3. Triassic–Jurassic 75

6.2.4. Jurassic 76

6.2.5. Jurassic–Cretaceous 80

6.2.6. Cretaceous 83

6.2.7. Cenozoic 84

7. Cenozoic Volcano-Sedimentary Sequences 86

7.1. Pre-Rift Volcanic and Associated Sedimentary Units of the Ethiopian Plateau 93

7.2. Rift Structure and Subdivision 107

7.2.1. The Main Ethiopian Rift (MER) 107

7.2.2. The Afar Depression 112

7.3. Rift Volcanic and Associated Sedimentary Units	114
7.3.1. Early-Rift Volcanic Deposits	114
7.3.2. Late-Rift Volcanic Deposits	130
7.4. Geochemical Characteristics of the Cenozoic Volcanic Sequences	143
7.4.1. Ethiopian Plateau	144
7.4.2. The Main Ethiopian Rift	146
7.4.3. The Afar Depression	146
7.4.4. Petrogenesis of the Cenozoic Volcanic Rocks	147
7.5. Fabric Pattern in the Cenozoic Volcanic Sequences	150
7.6. Geodynamic Evolution	153
8. Quaternary Sediments	158
8.1. Pleistocene Sediments	160
8.2. Pleistocene-Holocene Sediments	161
8.3. Holocene Sediments	165

PART II.

THE REGIONAL HYDROGEOLOGY OF ETHIOPIA. 169

9. Introduction	171
9.1. Brief History of Hydrogeology in Ethiopia	172
9.2. Data Sources	173
10. Morphological, Climatic and Hydrological Characteristics	175
10.1. Morphological Characteristics	175
10.2. Climatic Characteristics	176
10.2.1. Trends in Temperature and Rainfall Variability and Climatic Hazards	179
10.2.2. Droughts	181
10.2.3. Flood Hazards	183
10.3. Hydrological Characteristics	185
11. Role of Geological Features on Groundwater Occurrence	189
12. Methodology for Compiling the Hydrogeological Map	191
12.1. Legend to the Lithology and Hydrogeology	192
12.2. Layout of the Hydrogeological Map	193
13. Hydrogeological System of Ethiopia – Aquifers – Aquitards – Aquicludes	194
13.1. Units with Intergranular Permeability	194
13.2. Units with Fissured/Karst Permeability	201
13.2.1. Volcanic Rocks	201
13.2.2. Sedimentary Rocks	212
13.2.3. Marbles and Dolomites of the Basement of Western and Northern Ethiopia	219
13.3. Units with Alternating Layers of Fissured and Intergranular Permeability (Mixed Aquifers)	220
13.4. Extensive and Low Productive Fissured Aquifers	225
13.5. Impermeable Units – Aquitards and Aquicludes	229

14. Hydrogeological Conceptual Models	235
15. Groundwater Chemistry and Quality.	241
15.1. Groundwater Chemistry	241
15.2. Groundwater Quality	243
15.3. Isotopic Signature	246
16. Groundwater Resources and Hydrogeological Zones	248
16.1. Groundwater Resource Assessment Based on Baseflow Calculations	248
16.2. Thermal Groundwater Resources	249
16.3. Hydrogeological Zones and their Groundwater Resources	251
16.4. Integrated Water Resources Management	252
17. Transboundary Aquifers in Ethiopia	257
17.1. AF061 The Gedaref-Adigrat Sandstone	259
17.2. AF046 Alwero Sandstone (Sudd Basin)	259
17.3. AF043 Dawa	260
17.4. AF044 Jubba	261
17.5. AF045 Shebelle	262
17.6. AF059 Afar Triangle/Main Ethiopian Rift/Hanle Graben	263
17.7. AF073 Mareb (Mareb River Basin)	264
18. Conclusions and Recommendations	265
 List of References	 269
 Annexes	 321
Annex 1	323
List of references (geological maps)	323
List of references (hydrogeological and hydrochemical maps)	328
Annex 2	333
Annex 3	345
Annex 4	351