## Contents

1 Background .................................................. 1  
1.1 Scientific Drilling—A New Field of Earth Science .................. 1  
1.2 A Brief Introduction of China Continental Scientific Drilling Project  1  
1.3 Site Selection and Scientific and Technological Objectives .......... 2  
1.4 Developing History of CCSD Engineering  .................... 3  
1.4.1 Early Stage of Understanding (Before 1991) ................. 3  
1.4.2 Project Argumentation and Demonstration Stage  (1991–September 1999) ..... 4  
1.4.3 Project Preparation Stage (September 1999–June 2001) .......... 5  
1.4.4 Project Implementation Stage (June 2001–April 2005) .......... 6  
1.5 Technical Preparation .................................. 7  
1.5.1 Technical Training .................................. 8  
1.5.2 Pre-pilot Hole Construction .......................... 9  
1.5.3 Pre-research on Key Technologies ..................... 10  

2 Drilling Engineering Design .................................. 15  
2.1 Assignment of Drilling ................................... 15  
2.2 Basic Situation of the Well Site .......................... 15  
2.2.1 Forecast of Lithological Profile of the Formation  
Encountered .................................................. 16  
2.3 Lithological Characteristic of the Rock Formations  
to be Encountered by Drilling ........................... 17  
2.4 Drilling Technical Program ................................ 18  
2.4.1 Combined Drilling Techniques ......................... 18  
2.4.2 Flexible Double Hole Program ........................ 19  
2.4.3 Feel Ahead Open Hole Drilling Techniques ............. 19  
2.5 Borehole Structure and Casing Program .................. 20  
2.5.1 Designed Borehole Structure and Casing Program  
for the Pilot Hole ........................................... 20  
2.5.2 Designed Borehole Structure and Casing Program  
for the Main Hole ........................................... 20  
2.6 Drilling Equipment Program ................................ 20  
2.6.1 Main Drilling Equipment ................................ 20  
2.6.2 Equipment and Instruments Should Be Added .......... 22  
2.7 Drilling String Program .................................... 22  
2.8 Core Drilling Program .................................... 23  
2.8.1 Wireline Core Drilling ................................ 23  
2.8.2 Hydro-hammer Wireline Core Drilling Tool ............. 25  
2.8.3 PDM Wireline Core Drilling Tool ........................ 25  
2.8.4 Turbomotor Wireline Core Drilling Tool ................. 25  
2.8.5 Conventional Core Drilling Tool ........................ 26  
2.8.6 Hydro-hammer Core Drilling Tool ..................... 26  

Bibliografische Informationen  
http://d-nb.info/1066472238
2.8.7 PDM Core Drilling Tool .............................................. 28
2.8.8 Design Program of Diamond Core Drill Bit 
and Reaming Shell ...................................................... 28
2.9 Hole Deviation Control Program .................................. 29
2.9.1 Deviation Prevention for Cored Hole Section 
and Monitor Measures .................................................. 31
2.9.2 Deviation Control Measure for Cored Hole Section .... 31
2.9.3 Deviation Control Measure for the Upper Section 
of the Main Hole Where Non-core Drilling Was Conducted ... 31
2.10 Non-core Drilling and Reaming Drilling Program .......... 31
  2.10.1 Design of Drilling Tool Assembly For Non-core Drilling. . 31
  2.10.2 Design of Drilling Tool Assembly for Reaming Drilling . 32
  2.10.3 Selection of Non-core Drill Bit .................................. 32
  2.10.4 Design of Reaming Drill Bit .................................... 33
2.11 Drilling Fluid Technique and Solid Control Program ...... 33
  2.11.1 The Main Technical Problems Should Be Considered .... 33
  2.11.2 Design of Drilling Fluid Type .................................. 34
  2.11.3 Solid Control ...................................................... 34
2.12 Well Cementation and Completion Program ................ 34
  2.12.1 Well Cementation Program ...................................... 34
  2.12.2 Principle in Design of Casing String Strength .......... 35
  2.12.3 Well Completion Operation .................................... 36
2.13 Design of Moving Casing ........................................... 36
  2.13.1 Necessity of Adopting Moving Casing Design ............ 36
  2.13.2 Fixing of Moving Casing ........................................ 37
  2.13.3 Safety Management of Moving Casing ......................... 37
2.14 Time and Cost Estimation .......................................... 38
  2.14.1 Designed Construction Progress ............................. 38
  2.14.2 Budgetary Estimation of Cost ................................. 38
2.15 Change and Modification of Design ............................ 38

3 Well Site and Drilling Equipment ................................ 47
  3.1 Well Site .......................................................... 47
  3.2 Drilling Equipment ................................................ 49
    3.2.1 ZJ70D Drill Rig ................................................. 50
    3.2.2 Drill Rig Reconstruction ..................................... 53
    3.2.3 The Power System ............................................. 56
    3.2.4 Corollary Equipment .......................................... 57
    3.2.5 Application Evaluation on ZJ70D Drill Rig ............... 60

4 Construction Situation .............................................. 63
  4.1 Basic Situation of the Construction of CCSD-1 Well ...... 63
    4.1.1 The Basic Data ................................................ 63
    4.1.2 Drill Hole Trajectory ......................................... 67
    4.1.3 Well Temperature Curve ....................................... 68
  4.2 Simple Situation of the Construction at Different Periods 69
    4.2.1 Hole Opening and Non-core Drilling (the First Opening) 69
    4.2.2 Pilot Hole (Section CCSD-PHI) Core Drilling 
    (the Second Opening) .................................................. 71
    4.2.3 The First Expanding Drilling of the Main Hole 
    (Hole Section CCSD-MH-1K) ...................................... 74
    4.2.4 The First Core Drilling of the Main Hole (Hole Section 
    CCSD-MH, the Third Hole Opening) ............................. 77
    4.2.5 The First Sidetracking (Deviation Correction) Drilling 
    of the Main Hole ...................................................... 82
4.2.6 The Second Core Drilling of the Main Hole (Hole Section CCSD-MH-1C) ........................................ 89
4.2.7 The Second Expanding Drilling of the Main Hole (Hole Section CCSD-MH-2K) ................................. 91
4.2.8 The Second Sidetracking (Obstacle Avoidance) Drilling and Running Casing and Well Cementation in the Main Hole .......................................................... 97
4.2.9 The Third Core Drilling of the Main Hole (Section CCSD-MH-2C, the Fourth Opening) ....................... 99
4.2.10 Testing Drilling Tools .......................................... 102
4.2.11 Well Completion .................................................. 105

5 Hard Rock Deep Well Core Drilling Techniques .......................................................... 107
5.1 Current Status of Core Drilling Techniques ........................................................................... 107
5.2 Experiment on Core Drilling Methods for CCSD-1 Well ...................................................... 108
5.2.1 Rotary Table Drive Double Tube Core Drilling ................................................................. 108
5.2.2 Rotary Table Hydro-hammer Drive Double Tube Core Drilling ........................................... 109
5.2.3 Top Drive Double Tube Core Drilling .............................................................................. 109
5.2.4 Top Drive Wireline Core Drilling .................................................................................... 110
5.2.5 Top Drive Hydro-hammer Wireline Core Drilling .......................................................... 111
5.2.6 PDM Drive Single Tube Core Drilling ............................................................................ 111
5.2.7 PDM Drive Double Tube Core Drilling .......................................................................... 113
5.2.8 PDM Drive Wireline Core Drilling ................................................................................ 114
5.2.9 PDM Hydro-hammer Drive Double Tube Core Drilling .................................................... 116
5.2.10 PDM Hydro-hammer Drive Wireline Core Drilling ......................................................... 116
5.2.11 Summary of the Tests for Core Drilling Methods .............................................................. 118
5.3 Down Hole Power Percussive Rotary Core Drilling System .................................................... 119
5.3.1 Constituent of the System ................................................................................................. 119
5.3.2 Technical Data of the System .......................................................................................... 121
5.3.3 Down Hole Rotary Drive Drilling Tool—PDM .................................................................. 127
5.3.4 Down Hole Percussive Drilling Tool—Hydro-hammer ..................................................... 128
5.3.5 Core Drilling Tool ......................................................................................................... 155
5.3.6 Core Drilling Technologies .............................................................................................. 166
5.3.7 The Application Results of Hard Rock Deep Well Core Drilling Techniques ..................... 172

6 Diamond Core Drill Bit ........................................................................................................... 183
6.1 The Physical and Mechanical Properties of the Rocks to Be Drilled ...................................... 183
6.1.1 The Properties of the Rocks to Be Drilled ...................................................................... 183
6.1.2 The Physical and Mechanical Properties of the Rocks .................................................. 183
6.2 Selection of Diamond Core Drill Bit Types ............................................................................ 185
6.2.1 Core Drilling Technologies ............................................................................................. 185
6.2.2 Types of Diamond Core Drill Bits .................................................................................. 186
6.3 Design and Manufacture of Impregnated Diamond Core Drill Bits ........................................ 187
6.3.1 Segment Inserted Drill Bit by Twice Forming ................................................................ 187
6.3.2 Sintered Diamond Drill Bit ............................................................................................. 189
6.3.3 Electro-plated Diamond Drill Bit by Twice Forming ......................................................... 190
6.4 Application of Diamond Core Drill Bits ................................................................................ 191
6.4.1 Brief Introduction .......................................................................................................... 191
6.4.2 Application Results of Three Main Core Drill Bits .......................................................... 200
6.4.3 Application Results of Other Type Core Drill Bits .......................................................... 205
7 Reaming Drilling Techniques of Hard Crystalline Rock

7.1 Development of Pilot Reaming Bits
7.1.1 KZ157/311.1 Type Reaming Bit
7.1.2 KHAT 157/311.1 Reaming Bit
7.1.3 Development and Improvement of KZ157/244.5 Reaming Bit

7.2 Design of Drilling Tool
7.2.1 Strength Check of Drilling String
7.2.2 Selection of Drilling Tools
7.2.3 Design of Drilling Tool Assembly

7.3 Optimization of Drilling Parameters
7.3.1 WOB
7.3.2 Rotary Speed
7.3.3 Pump Displacement

7.4 Effect of Reaming Drilling
7.4.1 General Drilling Conditions
7.4.2 Application of Pilot Reaming Bits

8 Well-Deviation Control Techniques for Strong Dipping Strata

8.1 Summary
8.1.1 The Formation Conditions
8.1.2 The Well Deviation Control Technology
8.1.3 The Basic Conditions of Well Deviation Control in CCSD-1 Well

8.2 Deviation Prevention Drilling Technology
8.2.1 The Well Deviation Control in Core Drilling
8.2.2 Well Deviation Control in Non-core Drilling and Reaming Drilling

8.3 Drilling Techniques for Deviation Correction
8.3.1 Side-Tracking Deviation-Correction Techniques
8.3.2 Situation on Side-Tracking Drilling for Deviation-Correction
8.3.3 Deviaton Correction at the Well Bottom of MH-1C Well Section

8.4 Side-Tracking Drilling for Bypassing Obstacles
8.4.1 Selection of Side-Tracking Drilling Tool
8.4.2 Drilling Conditions of Side-Tracking Drilling to Bypass Obstacles

8.5 Development of PDM Drive Continuous Deflector
8.5.1 Working Principle of the Drilling Tool
8.5.2 Practical Drilling Test at Drill Site
8.5.3 Test Result Commentary

8.6 The Analysis on Well Deviation Control Effect

9 Drilling Fluids and Solids Control Technology

9.1 Requirements of Scientific Drilling for Drilling Fluid
9.1.1 Strata Encountered and Requirements of Well Structure
9.1.2 Requirements of Core Drilling
9.1.3 Requirements of Non-core Drilling and Expanding Drilling
9.1.4 Requirements of Borehole Log
9.1.5 Requirements of Environmental Protection
9.1.6 Requirements of Drilling Fluid Design

9.2 Drilling Fluid System
9.2.1 Selection of Drilling Fluid System
9.2.2 LBM-SD Composite Drilling Fluid Material
9.2.3 Drilling Fluid Mechanism and Composition of LPA Polymer
9.2.4 Manufacture Technology of LBM-SD .................................................. 280
9.2.5 Evaluation Procedure of Drilling Fluid ............................................. 281
9.2.6 Performance of LBM-SD Drilling Fluid System .................................... 281

9.3 Drilling Fluid for Core Drilling .......................................................... 285
9.3.1 Properties .......................................................... 285
9.3.2 Circulating Pressure Drop ......................................................... 288
9.3.3 Lubrication Effect of Drilling Fluid ................................................ 292

9.4 Solid Control Technique of Drilling Fluid ............................................ 293
9.4.1 Cuttings Size Analysis ............................................................. 294
9.4.2 Requirement of Solids Control Equipment to Drilling Fluid ................. 295
9.4.3 Analysis of Solids Control Effect .................................................. 295

9.5 Site Application of Drilling Fluid ..................................................... 297
9.5.1 Application of Drilling Fluid in Non-core Drilling in the First Opening (Spudding-in) ......................................................... 297
9.5.2 Application of Drilling Fluid in Pilot Hole Core Drilling .................... 297
9.5.3 Application of Drilling Fluid in the First Expanding Drilling in the Main Hole ......................................................... 298
9.5.4 Application of Drilling Fluid in the First Core Drilling in the Main Hole ......................................................... 298
9.5.5 Application of Drilling Fluid in the First Sidetrack Straightening Drilling in the Main Hole ......................................................... 299
9.5.6 Application of Drilling Fluid in the Second Core Drilling in the Main Hole ......................................................... 299
9.5.7 Application of Drilling Fluid in the Second Expanding Drilling in the Main Hole ......................................................... 300
9.5.8 Application of Drilling Fluid in the Second Sidetrack Drilling-Around in the Main Hole ......................................................... 301
9.5.9 Application of Drilling Fluid in the Third Core Drilling in the Main Hole ......................................................... 301
9.5.10 Application Characteristics of LBM Drilling Fluid ............................. 302

10 Casing and Well Cementation ............................................................... 303
10.1 Borehole Structure and Casing Program .............................................. 303
10.1.1 Borehole Structure and Casing Program for the Pilot Hole .................. 303
10.1.2 Borehole Structure and Casing Program for the Main Hole ................. 303
10.1.3 Casing Design ............................................................. 303

10.2 Well Head Assembly ................................................................. 306
10.2.1 Well Head Assembly for the First Opening (Spud-in) ......................... 306
10.2.2 Well Head Assembly for the Second Opening (Spud-in) ...................... 307
10.2.3 Well Head Assembly for the Third and the Fourth Opening (Spud-in) .......... 308
10.2.4 Well Head Assembly for Well Completion ...................................... 308

10.3 Casing Running and Well Cementing Operation .................................... 308
10.3.1 508.0 mm Well Head Conductor ................................................. 308
10.3.2 339.7 mm Surface Casing ......................................................... 309
10.3.3 273.0 mm Intermediate Casing .................................................. 311
10.3.4 193.7 mm Intermediate Casing .................................................. 317
10.3.5 127.0 mm Tail Pipe ............................................................. 320

10.4 Moving Casing Techniques .............................................................. 322
10.4.1 Overall Programme ............................................................... 323
10.4.2 Design of Fixing Moving Casing .................................................. 323
10.4.3 Moving Casing Strength Check .................................................... 325
10.4.4 Design of Casing Shoe and Retaining Sub ...................................... 325
10.4.5 Design of Thread Back-off Proof for Moving Casing ......................... 327
10.4.6 Design of Centralizer .............................................................. 327
10.4.7 Operating Technology of Moving Casing .......................... 329
10.4.8 Application of Moving Casing Techniques ..................... 329

11 Drilling Data Acquisition ............................................. 333
11.1 General Situation .................................................. 333
11.2 Analysis of Data Acquisition and Processing Requirements .... 336
  11.2.1 Data Acquisition System Requirements ..................... 336
  11.2.2 Data Processing System Requirements ...................... 336
11.3 Drilling Data Acquisition System ................................ 337
  11.3.1 Surface Drilling Data Acquisition System .................. 338
  11.3.2 Down-Hole Drilling Data Acquisition System .............. 341
11.4 Drilling Data Processing System .................................. 343
  11.4.1 Single Parameter Monitoring ................................. 343
  11.4.2 Comprehensive Monitoring .................................. 344
  11.4.3 Case History ................................................ 345

12 Technical Economical Analysis ....................................... 349
12.1 Construction Time and Cost Analysis ........................... 349
  12.1.1 Construction Time Analysis ................................ 349
  12.1.2 Construction Cost Analysis ................................. 349
12.2 Economic Evaluation of Core Drilling Techniques ............... 352
  12.2.1 Evaluation Method ......................................... 352
  12.2.2 Index System of Technical Economic Evaluation
     for Core Drilling Construction ............................... 353
  12.2.3 Calculation of Drilling Construction Time and Cost ....... 353
  12.2.4 Technical Economical Indexes of Different Core
     Drilling Methods .............................................. 355
  12.2.5 Economic Evaluation ....................................... 355
  12.2.6 Technical Risk Evaluation ................................ 355
  12.2.7 Comprehensive Evaluation ................................. 358

References ............................................................. 361