BSC	**Design Calculation or Analysis Cover Sheet** **Complete only applicable items.**	1. QA: QA 2. Page ~~87~~ 1 JC 9/4/2008

3. System	4. Document Identifier
Subsurface Facility	800-K0C-SSD0-00500-000-00A

5. Title
Input Parameters for Ground Support Design

6. Group
Subsurface/Mining/Geotechnical

7. Document Status Designation
☐ Preliminary ☒ Committed ☐ Confirmed ☐ Cancelled ☐ Superseded

8. Notes/Comments
This revision is prepared based on the current qualified data from *Subsurface Geotechnical Parameters Report* and TDMS. This revision is extensive and supersedes previous version, 800-K0C-TEG0-00500-000-00B. The screening for potential LA effects was performed and found that this revision has no impact to LA.

Attachments	Total Number of Pages
I. In-situ Rock Thermal Gradient Estimates	15

RECORD OF REVISIONS

9. No.	10. Reason For Revision	11. Total # of Pgs.	12. Last Pg. #	13. Originator (Print/Sign/Date)	14. Checker (Print/Sign/Date)	15. EGS (Print/Sign/Date)	16. Approved/Accepted (Print/Sign/Date)
00A	See Notes/Comments (Block 8)	67	67	Jay Cho 9/4/08	Marek Mrugala 9/04/2008	Fei Duan 9/4/08	Robert Boutin 9/4/08

DISCLAIMER

The parameters contained in this calculation were developed by Bechtel SAIC Company, LLC (BSC) and are intended solely for the use of BSC in its work for the Yucca Mountain Project.

CONTENTS

Page

1 PURPOSE 9
2 REFERENCES 10
2.1 PROCEDURES /DIRECTIVES 10
2.2 DESIGN INPUTS 10
2.3 DESIGN CONSTRAINTS 15
2.4 DESIGN OUTPUTS 15
3 ASSUMPTIONS 16
3.1 ASSUMPTIONS REQUIRING VERIFICATION 16
3.2 ASSUMPTIONS NOT REQUIRING VERIFICATION 16
3.2.1 Base Case Testing Conditions 16
4 METHODOLOGY 17
4.1 QUALITY ASSURANCE 17
4.2 USE OF SOFTWARE 17
4.2.1 Level 1 Software Usage 17
4.2.2 Level 2 Software Usage 17
4.3 CALCULATION METHODOLOGY 17
5 LIST OF ATTACHMENTS 18
6 BODY OF CALCULATION 19
6.1 LITHOSTRATIGRAPHY OF YUCCA MOUNTAIN 19
6.2 REPOSITORY LAYOUT 22
6.3 GROUND SUPPORT SYSTEM 25
6.4 FIELD STRESS 26
6.5 INTACT ROCK 26
6.5.1 Physical Properties 26
6.5.2 Mechanical Properties 26
6.5.3 Thermal Properties 28
6.6 ROCK MASS 36
6.6.1 Mechanical Properties at RHH 36
6.6.2 Mechanical Properties at Non RHH 38
6.6.3 Thermal Properties 40
6.7 ROCK JOINTS/FRACTURES 44
6.8 TIME HISTORIES OF ROCK TEMPERATURES 46
6.9 AVERAGE SURFACE TEMPERATURE AND IN-SITU ROCK THERMAL GRADIENT 46
6.10 THERMAL AND MECHANICAL PROPERTIES OF GROUND SUPPORT MATERIALS 47
6.10.1 Stainless Steel 47
6.10.2 Carbon Steel 47
6.10.3 Cement Grouts 48
6.10.4 Shotcrete 49
6.10.5 Concrete 49
6.11 SEISMIC INPUTS 50
7 RESULTS AND CONCLUSIONS 52

FIGURES

Page

Figure 6-1 Typical Fractures Pattern in the Tptpmn Zone 24
Figure 6-2 Typical Lithophysae and Fracturing in the Tptpll Zone 24
Figure 6-3 Time Histories of Velocity Components of Seismic Motion for Mean APE of 5×10^{-4} 50
Figure 6-4 Time Histories of Velocity Components of Seismic Motion for Mean APE of 1×10^{-4} 51
Figure I- 1 Temperature at Borehole USW NRG 7-A 54
Figure I- 2 Temperature at Borehole USW NRG-6 55
Figure I- 3 Temperature at Borehole USW UZ-7a 56
Figure I- 4 Temperature at Borehole UE-25 WT #18 57
Figure I- 5 Temperature at Borehole USW WT-2 58
Figure I- 6 Temperature at Borehole USW H-1 59
Figure I- 7 Temperature at Borehole USW H-3 60
Figure I- 8 Temperature at Borehole USW H-4 60
Figure I- 9 Temperature at Borehole USW H-5 60
Figure I- 10 Temperature at Borehole USW UZ-1 60
Figure I- 11 Temperature at Borehole USW G-1 60
Figure I- 12 Temperature at Borehole USW G-4 60
Figure I- 13 Temperature at Borehole USW SD-12 60

TABLES

Page

Table 5-1 Borehole Temperature Data and In-situ Rock Thermal Gradient Estimates 18
Table 6-1 Yucca Mountain Stratigraphy 20
Table 6-2 Summary of Ground Support System 25
Table 6-3 Bulk Densities and Porosities for RHH Lithostratigraphic Zones.....26
Table 6-4 Intact Rock Mechanical Properties by Stratigraphic Unit 27
Table 6-5 Intact Rock Thermal Conductivity of Oven Dried Specimens 29
Table 6-6 Intact Rock Thermal Conductivity of Saturated Specimens.....30
Table 6-7 Intact Rock Coefficient of Thermal Expansion of Air-Dried Specimens.....32
Table 6-8 Intact Rock CTE Measurements of Tptpmn Specimens from SHT 34
Table 6-9 Intact Rock CTE Measurements of Tptpmn Specimens from DST Area.....35
Table 6-10 Intact Rock Heat Capacity 36
Table 6-11 Rock Mass Mechanical Properties for Nonlithophysal Rock at Tptpmn 37
Table 6-12 Rock Mass Mechanical Properties for Nonlithophysal Rock at Tptpln 37
Table 6-13 Rock Mass Mechanical Properties for Lithophysal Rock at RHH 38
Table 6-14 Rock Mass Mechanical Properties at Non-RHH Lithostratigraphic Zone 39
Table 6-15 In Situ Rock Mass Thermal Conductivity from DST During the Heating Phase (Tptpmn) 40
Table 6-16 Rock Mass Thermal Conductivity from ECRB Cross-Drift Thermal K Tests (Tptpll) 40
Table 6-17 Rock Mass Thermal Conductivity for RHH Lithostratigraphic Zones.....41
Table 6-18 Rock Mass Thermal Conductivity for Non-RHH Lithostratigraphic Zones 41
Table 6-19 Rock Mass Thermal Expansion Coefficients from DST 42
Table 6-20 Summary of Volumetric Heat Capacity from ECRB Cross Drift Thermal K Tests (Tptpll) 42
Table 6-21 Average Rock Grain Heat Capacities for Lithostratigraphic Zones 43
Table 6-22 Average Rock Mass Heat Capacities for Lithostratigraphic Zones.....44
Table 6-23 Summary Statistics of Fracture Strength from Rotary Shear Tests 44
Table 6-24 Summary Statistics of Peak Dilation Angle from Rotary Shear Test.....45
Table 6-25 Summary Statistics of the Fracture Normal Stiffness from Rotary Shear Tests....45
Table 6-26 Summary Statistics of the RHH Fracture Shear Stiffness from Rotary Shear Test45
Table 6-27 Time Histories of Rock Temperatures.....46

TABLES (continued)

Page

Table 6-28 In-Situ Rock Thermal Gradient 46
Table 6-29 Stainless Steel Properties 47
Table 6-30 Carbon Steel Properties.....47
Table 6-31 Physical, Thermal and Mechanical Properties for Cement Grout 48
Table 6-32 Shotcrete Properties 49
Table 6-33 Thermal and Mechanical Properties for Concrete 49
Table I-1 Summary of In-Situ Rock Thermal Gradient (deg C/km) 60

ACRONYMS AND ABBREVIATIONS

ACI	American Concrete Institute
APE	annual probability exceedance
ASM	American Society for Metals
ASTM	American Society for Testing and Materials
BSC	Bechtel SAIC Company, LLC
c/c	center to center
CIP	cast in place
CRWMS M&O	Civilian Radioactive Waste Management System Management and Operating Contractor
CTE	coefficient of thermal expansion
DIRS	Document Input Reference System
DST	Drift Scale Test
DTN	data tracking number
ESF	Exploratory Studies Facility
ECRB	Enhanced Characterization of the Repository Block
GFM	Geologic Framework Model
GSI	geologic strength index
IED	information exchange document
ITS	important to safety
ITWI	important to waste isolation
LA	License Application
L/D	length to diameter
MPBX	multi-point borehole extensometer
Q	Quality
QA	quality assurance
RHH	repository host horizon
RMR	rock mass rating
RQD	rock quality designation
SD	standard deviation
SGPR	Subsurface Geotechnical Parameters Report
SHT	Single Heater Test
SR	Site Recommendation
STN	software tracking number

ACRONYMS AND ABBREVIATIONS (continued)

TBM	tunnel boring machine
TDMS	Technical Data Management System
TM	thermal mechanical
UCS	unconfined or uniaxial compressive strength
USGS	U.S. Geological Survey
WWF	welded wire fabric
YMP	Yucca Mountain Project

1 PURPOSE

The purpose of this calculation is to provide the input parameters to be used in ground support design for post-License Application (LA) activities. These input parameters are primarily related to physical, mechanical and thermal properties of rock, which include the intact rock, jointed rock, and rock mass. Other inputs such as seismic parameters and ground support components and materials are also included in this calculation. It should be noted that only the Q parameters are presented in this calculation and parameters not listed in this calculation should be justified by the user for its use.

The scope of work includes the identification of input parameters to be used in ground support design based on existing project documents, vendor information, and data from the Technical Data Management System (TDMS).

Unless otherwise indicated, the term "ground support system" or "ground support control system" used in this calculation is referred to as the final ground support system.

2 REFERENCES

2.1 PROCEDURES /DIRECTIVES

2.1.1 EG-PRO-3DP-G04B-00037, Rev: 012, ICN 0. *Calculations and Analyses*. Las Vegas, Nevada: Bechtel SAIC Company. ACC: ENG.20080519.0005.

2.1.2 IT-PRO-011, Rev. 009. *Software Management*. Las Vegas, Nevada: Bechtel SAIC Company. ACC: DOC.20080416.0010.

2.2 DESIGN INPUTS

2.2.1 ACI 318-02/318R-02. 2002. *Building Code Requirements for Structural Concrete (ACI 318-02) and Commentary (ACI 318R-02).* Farmington Hills, Michigan: American Concrete Institute. TIC: 252731. ISBN 0-087031-065-8.

2.2.2 ACI 506R-05. 2005. *Guide to Shotcrete.* Farmington Hills, Michigan: American Concrete Institute. TIC: 258596. ISBN: 0-87031-198-0.

2.2.3 AISC (American Institute of Steel Construction) 1997. *Manual of Steel Construction, Allowable Stress Design.* 9th Edition, 2nd Revision, 2nd Impression. Chicago, Illinois: American Institute of Steel Construction. TIC: 240772. ISBN: 1-56424-000-2.

2.2.4 ASM (American Society for Metals) 1978. *Properties and Selection: Irons and Steels.* Volume 1 of Metals Handbook. 9th Edition. Bardes, B.P., ed. Metals Park, Ohio: American Society for Metals. TIC: 209799. ISBN: 0-87170007-7.

2.2.5 ASM International 1990. *Properties and Selection: Irons, Steels, and High-Performance Alloys.* Volume 1 of Metals Handbook. 10th Edition. Materials Park, Ohio: ASM International. TIC: 245666. ISBN: 0-87170-377-7.

2.2.6 ASTM A 276-06. 2006. *Standard Specification for Stainless Steel Bars and Shapes.* West Conshohocken, Pennsylvania: American Society for Testing and Materials. TIC: 258258.

2.2.7 ASTM A 36/A 36M-05. 2005. *Standard Specification for Carbon Structural Steel.* West Conshohocken, Pennsylvania: American Society for Testing and Materials. TIC: 258055.

2.2.8 ASTM A 588/A 588M-05. 2005. *Standard Specification for High-Strength Low-Alloy Structural Steel, up to 50 ksi [345 MPa] Minimum Yield Point, with Atmospheric Corrosion Resistance.* West Conshohocken, Pennsylvania: American Society for Testing and Materials. TIC: 258058.

2.2.9 Board, M. 2003. *Resolution Strategy for Geomechanically-Related Repository Design and Thermal-Mechanical Effects (RDTME).* REV 00. Las Vegas, Nevada: Bechtel SAIC Company. ACC: MOL.20030708.0153. [DIRS 165036].

2.2.10 Brodsky, N.S.; Riggins, M.; Connolly, J.; and Ricci, P. 1997. *Thermal Expansion, Thermal Conductivity, and Heat Capacity Measurements for Boreholes UE25 NRG-4,*

UE25 NRG-5, USW NRG-6, and USW NRG-7/7A. SAND95-1955. Albuquerque, New Mexico: Sandia National Laboratories. ACC: MOL.19980311.0316. [DIRS 100653].

2.2.11 BSC 2003. *Underground Layout Configuration.* 800-P0C-MGR0-00100-000-00E. Las Vegas, Nevada: Bechtel SAIC Company. ACC: ENG.20031002.0007; ENG.20050817.0005; ENG.20080310.0024.

2.2.12 BSC 2004. *Geologic Framework Model (GFM2000).* MDL-NBS-GS-000002 REV 02. Las Vegas, Nevada: Bechtel SAIC Company. ACC: DOC.20040827.0008. [DIRS 170029].

2.2.13 BSC 2004. *Lithophysal Rock Mass Mechanical Properties of the Repository Host Horizon.* 800-K0C-SS00-00200-000-00A. Las Vegas, Nevada: Bechtel SAIC Company. ACC: ENG.20041111.0001; ENG.20071220.0007.

2.2.14 BSC 2004. *Rock Mass Quality Ratings and Classifications of the Combined ESF, Heated Drift and ECRB Cross Drift.* 800-K0C-SS00-00700-000-00A. Las Vegas, Nevada: Bechtel SAIC Company. ACC: ENG.20040901.0031; ENG.20071106.0034.

2.2.15 BSC 2004. *Thermal Conductivity of the Potential Repository Horizon.* MDL-NBS-GS-000005 REV 01. Las Vegas, Nevada: Bechtel SAIC Company. ACC: DOC.20040928.0006 [DIRS 169854].

2.2.16 BSC 2005. *Intact Rock Mechanical Properties of Yucca Mountain Stratigraphic Units.* 800-K0C-SS00-00800-000-00A. Las Vegas, Nevada: Bechtel SAIC Company. ACC: ENG.20051108.0007.

2.2.17 BSC 2005. *Wet Process Shotcrete.* BABEE0000-01717-6300-03363 REV 02. Las Vegas, Nevada: Bechtel SAIC Company. ACC: SIT.20050613.0006. [DIRS 172362].

2.2.18 BSC 2007 *Repository Subsurface Turnout, Invert & Rails Concrete Sections.* 800-D00-SSD0-00703-000-00A. Las Vegas, Nevada: Bechtel SAIC Company. ACC: ENG.20070529.0027.

2.2.19 BSC 2007 *Repository Subsurface Turnout, Invert & Rails Plan and Elevation.* 800-D00-SSD0-00701-000-00A. Las Vegas, Nevada: Bechtel SAIC Company. ACC: ENG.20070529.0025.

2.2.20 BSC 2007 *Repository Subsurface Turnout, Invert & Rails Sections.* 800-D00-SSD0-00702-000-00A. Las Vegas, Nevada: Bechtel SAIC Company. ACC: ENG.20070529.0026.

2.2.21 BSC 2007. *Ground Control for Emplacement Drifts for LA.* 800-K0C-SSE0-00100-000-00C. Las Vegas, Nevada: Bechtel SAIC Company. ACC: ENG.20070925.0082; ENG.20080304.0028.

2.2.22 BSC 2007. *Ground Control for Non-Emplacement Drifts for LA*. 800-K0C-SSD0-00400-000-00A. Las Vegas, Nevada: Bechtel SAIC Company. ACC: ENG.20071001.0042; ENG.20071218.0001; ENG.20080304.0027.

2.2.23 BSC 2007. *Subsurface Geotechnical Parameters Report.* ANL-SSD-GE-000001 REV 00. Las Vegas, Nevada: Bechtel SAIC Company. ACC: ENG.20070115.0006.

2.2.24 BSC 2007. *Turnout Design and Configuration.* 800-KMC-SSD0-00900-000-00A. Las Vegas, Nevada: Bechtel SAIC Company. ACC: ENG.20070625.0041; ENG.20080304.0023.

2.2.25 BSC 2007. *Typical Ground Support for Emplacement Drifts*. 800-K00-SSE0-00101-000-00A. Las Vegas, Nevada: Bechtel SAIC Company. ACC: ENG.20070515.0002.

2.2.26 BSC 2007. *Typical Ground Support for Ventilation Shafts.* 800-K00-SSD0-00101-000-00A. Las Vegas, Nevada: Bechtel SAIC Company. ACC: ENG.20070515.0001.

2.2.27 BSC 2007. *Underground Layout Configuration for LA*. 800-KMC-SS00-00200-000-00B. Las Vegas, Nevada: Bechtel SAIC Company. ACC: ENG.20070727.0004; ENG.20071214.0002; ENG.20080304.0021.

2.2.28 BSC 2008. *Basis of Design for the TAD Canister-Based Repository Design Concept.* 000-3DR-MGR0-00300-000-002. Las Vegas, Nevada: Bechtel SAIC Company. ACC: ENG.20080229.0007; ENG.20080306.0007; ENG.20080307.0009; ENG.20080312.0011; ENG.20080312.0012; ENG.20080312.0013; ENG.20080312.0014; ENG.20080312.0021; ENG.20080317.0002; ENG.20080313.0003; ENG.20080406.0003; ENG.20080407.0001; ENG.20080508.0005; ENG.20080825.0002; ENG.20080828.0014.

2.2.29 BSC 2008. *FLUENT Thermal Calculation for 2.0 kW/m Thermal Load*. 800-KVC-VUE0-00800-000-00A Las Vegas, Nevada: Bechtel SAIC Company. ACC: ENG.20080124.0007.

2.2.30 BSC. 2008. *IED Geotechnical and Thermal Parameters.* 800-IED-MGR0-00401-000 REV 00I. Las Vegas, Nevada: Bechtel SAIC Company. ACC: ENG.20080723.0018.

2.2.31 BSC 2008. *IED Geotechnical and Thermal Parameters II.* 800-IED-MGR0-00402-000-00C. Las Vegas, Nevada: Bechtel SAIC Company. ACC: ENG.20080626.0001.

2.2.32 BSC 2008. *IED Geotechnical and Thermal Parameters III.* 800-IED-MGR0-00403-000 REV 00B. Las Vegas, Nevada: Bechtel SAIC Company. ACC: ENG.20080219.0008.

2.2.33 BSC 2008. *IED Seismic and Seismic Consequence Data.* 800-IED-MGR0-00701-000 REV 00C. Las Vegas, Nevada: Bechtel SAIC Company ACC: ENG.20080514.0003.

2.2.34 Buesch, D.C.; Spengler, R.W.; Moyer, T.C.; and Geslin, J.K. 1996. *Proposed Stratigraphic Nomenclature and Macroscopic Identification of Lithostratigraphic Units*

of the Paintbrush Group Exposed at Yucca Mountain, Nevada. Open-File Report 94-469. Denver, Colorado: U.S. Geological Survey. ACC: MOL.19970205.0061. [DIRS 100106].

2.2.35 CRWMS M&O 1997. *Data Transmittal Package (DTP) for "Hydraulic Fracturing Stress Measurements in Test Hole: ESF-AOD-HDFR#1, Thermal Test Facility, Exploratory Studies Facility at Yucca Mountain.* DTN: SNF37100195002.001, TDIF 305878. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19970717.0005; MOL.19970717.0006; MOL.19970717.0007; MOL.19970717.0008. [DIRS 147458].

2.2.36 GS980608314221.002. *Revised Bedrock Geologic Map of the Yucca Mountain Area*, *Nye County, Nevada.* Submittal date: 06/09/1998. [DIRS 107024].

2.2.37 Holman, J.P. 1997. *Heat Transfer.* 8th Edition. New York, New York: McGraw-Hill. TIC: 239954. ISBN: 0-07-844785-2.

2.2.38 Hsu, C.T.; Cheng, P.; and Wong, K.W. 1995. "*A Lumped-Parameter Model for Stagnant Thermal Conductivity of Spatially Periodic Porous Media*." Journal of Heat Transfer, 117, (2), 264-269. New York, New York: American Society of Mechanical Engineers. TIC: 252402. [DIRS 158073].

2.2.39 Jaeger, J.C. and Cook, N.G.W. 1979. *Fundamentals of Rock Mechanics.* 3rd Edition. New York, New York: Chapman and Hall. TIC: 218325. ISBN: 0-41222010-5.

2.2.40 Kosmatka, S.H. and Panarese, W.C. 1994. *Design and Control of Concrete Mixtures.* 13th Edition. Skokie, Illinois: Portland Cement Association. TIC: 242269. ISBN: 0-89312-087-1.

2.2.41 LB0708WTTEMDAT.001. *Borehole Temperature Data and Qualification for Estimating Water-Table Temperature Condition*. Submittal date: 08/06/2007. [DIRS 185542].

2.2.42 Merritt, F.S., ed. 1983. *Standard Handbook for Civil Engineers.* 3rd Edition. New York, New York: McGraw-Hill. TIC: 206892. ISBN: 0-07041515-3.

2.2.43 MO0201THERMGRT.000. *Thermal Properties of Grout Samples*. Submittal date: 01/29/2002. [DIRS 160669].

2.2.44 MO0204EBSPYMPG.017. *Physical and Mechanical Properties of Grout*. Submittal date: 04/23/2002. [DIRS 159887].

2.2.45 MO0210THERMECG.000. *Linear Thermal Expansion of Cement Grouts*. Submittal date: 10/24/2002. [DIRS 160947].

2.2.46 MO0612MEANTHER.000. *Mean Thermal Conductivity of Yucca Mountain Repository Units*. Submittal date: 04/27/2007. [DIRS 180552].

2.2.47 MO0707THRB1E4A.000. *Time Histories for the Repository Block at 1E-4 APE*. Submittal date: 07/26/2007. [DIRS 183200].

2.2.48 MO0707THRB5E4A.000. *Time Histories for the Repository Block at 5E-4 APE.* Submittal date: 07/26/2007. [DIRS 183197].

2.2.49 MO0709REVTHERM.000. *Revised Thermal Properties - Heat Capacity*. Submittal date: 09/04/2007. [DIRS 184749].

2.2.50 MO9510RIB00002.004. RIB Item: *Stratigraphic Characteristics: Geologic/Lithologic Stratigraphy.* Submittal date: 06/26/1996. [DIRS 103801].

2.2.51 Mongano, G.S.; Singleton, W.L.; Moyer, T.C.; Beason, S.C.; Eatman, G.L.W.; Albin, A.L.; and Lung, R.C. 1999. *Geology of the ECRB Cross Drift - Exploratory Studies Facility, Yucca Mountain Project, Yucca Mountain, Nevada.* [Deliverable SPG42GM3]. Denver, Colorado: U.S. Geological Survey. ACC: MOL.20000324.0614. [DIRS 149850].

2.2.52 SN0203L2210196.007. *Thermal Expansion and Thermal Conductivity of Test Specimens from the Drift Scale Test Area of the Exploratory Studies Facility at Yucca Mountain, Nevada*. VA Supporting Data. Submittal date: 03/06/2002. [DIRS 158322].

2.2.53 SN0206F3504502.011. *Revised Data for Changes in Temperature at Each Thermocouple Location for ECRB Thermal K Test 1 (Two-Hole Test).* Submittal date: 06/07/2002. [DIRS 165270].

2.2.54 SN0206F3504502.012. *Revised Thermal Conductivity, Volumetric Heat Capacity and Thermal Diffusivity Data for ECRB Thermal K Test 1 (Two-Hole Test).* Submittal date: 06/07/2002. [DIRS 159145].

2.2.55 SN0206F3504502.013. *Revised Thermal Conductivity, Volumetric Heat Capacity and Thermal Diffusivity Data for ECRB Thermal K Test 3 (Three-Hole Test, with Results from 1/22/2002 through 4/9/2002).* Submittal date: 06/07/2002. [DIRS 159146]

2.2.56 SN0208F3504502.019. *Thermal Conductivity, Volumetric Heat Capacity and Thermal Diffusivity Data for ECRB Thermal K Test 2 (Six-Hole Test).* Submittal date: 08/30/2002. [DIRS 161883].

2.2.57 SN0303T0503102.008. *Revised Thermal Conductivity of the Non-Repository Layers of Yucca Mountain.* Submittal date: 03/19/2003. [DIRS 162401].

2.2.58 SN0307T0510902.003. *Updated Heat Capacity of Yucca Mountain Stratigraphic Units.* Submittal date: 07/15/2003. [DIRS 164196].

2.2.59 SN0404T0503102.011. *Thermal Conductivity of the Potential Repository Horizon Rev 3.* Submittal date: 04/27/2004. [DIRS 169129].

2.2.60 SN0407F3912298.060. *Rock Mass Thermal Expansion Coefficients from the Drift Scale Test (DST) Compared with In Situ Measurements*. Submittal date: 07/13/2004. [DIRS 170627].

2.2.61 SNF37100195002.001. *Hydraulic Fracturing Stress Measurements in Test Hole: ESF-AOD-HDFR1, Thermal Test Facility, Exploratory Studies Facility at Yucca Mountain*. Submittal date: 12/18/1996. [DIRS 131356].

2.2.62 SNL01C12159302.002. *Laboratory Measurements of Heat Capacity/Thermal Capacitance, for Boreholes UE25 NRG-4 and NRG-5*. Submittal date: 02/07/1996. [DIRS 148289].

2.2.63 SNL22080196001.003. *Posttest Laboratory Thermal and Mechanical Characterization for Single Heater Test (SHT) Block*. Submittal date: 08/26/1998. [DIRS 119042].

2.2.64 Torquato, S. 1987. "*Thermal Conductivity of Disordered Heterogeneous Media from the Microstructure*." Reviews in Chemical Engineering, *4,* (3-4), 151-204. [London, England]: Freund Publishing House. TIC: 249565. [DIRS 165105].

It should be noted that the direct use of data tracking numbers (DTNs) that contain scientific data is suitable since these data are qualified and use of these has been approved (References 2.2.30, 2.2.31, 2.2.32, and 2.2.33). Other DTNs (References 2.2.43, 2.2.44, and 2.2.45) used directly are suitable since these data are qualified and the use of preclosure data does not require an information exchange document (IED). References 2.2.9, 2.2.18, 2.2.19, 2.2.20, 2.2.25, and 2.2.26 are QA: N/A documents; however, these documents are cited for information purposes only, and the latter five documents are drawings for items classified as not important to safety (ITS) and not important to waste isolation (ITWI).

2.3 DESIGN CONSTRAINTS

There are no design constraints that were used in this calculation.

2.4 DESIGN OUTPUTS

The outputs of this calculation are the various input parameters to be used in the design of ground support systems for the subsurface openings during the post-LA activities. The outputs consist of physical, mechanical and thermal properties of rocks which include intact rock, jointed rock, and rock mass, and various ground support materials, i.e., stainless steel, carbon steel, cement grout, shotcrete, and concrete.

3 ASSUMPTIONS

3.1 ASSUMPTIONS REQUIRING VERIFICATION

Not used.

3.2 ASSUMPTIONS NOT REQUIRING VERIFICATION

3.2.1 Base Case Testing Conditions

Assumption: Intact rock mechanical properties data presented in this calculation are those obtained under the base case testing conditions. The base case test conditions for all rock units are as follows:

- Specimen size (diameter): 38 to 70 mm
- Length to diameter (L/D) ratio: approximately 2 to 1
- Specimen saturation: saturated
- Testing temperature: ambient
- Strain rate: 0.5E-05 to 5.0E-05 per second
- Confining pressure and pore pressure: none

Rationale: Over the course of the Yucca Mountain Project (YMP), several hundred laboratory tests have been conducted on the rock samples obtained from the boreholes in the vicinity of YMP site, surface outcrops, and underground tunnels, i.e., Exploratory Studies Facility (ESF) and Enhanced Characterization of the Repository Block (ECRB) Cross-Drift. The laboratory tests were conducted on various specimen sizes ranging from 25 mm to about 275 mm and under different test conditions, i.e., saturation, temperature, strain rate, and confining pressure. The laboratory testing under different test conditions with varying specimen sizes yield wide ranges of intact rock mechanical data as indicated in Reference 2.2.16 (Tables 6-4, 6-11, and 6-14). The base case conditions are standard practice in rock testing. Therefore, the above assumption is considered adequate for the purpose of this calculation does not require verification.

4 METHODOLOGY

4.1 QUALITY ASSURANCE

This calculation has been prepared in accordance with EG-PRO-3DP-G04B-00037, *Calculations and Analyses* (Reference 2.1.1). Although the ground support system is classified as non-ITS and non-ITWI, emplacement drifts are classified as ITWI (Reference 2.2.28, Section 8.1.2). Therefore, the approved version is designated as QA: QA.

4.2 USE OF SOFTWARE

All software documented in this section is appropriate for applications used in this calculation. The software is managed under IT-PRO-0011 (Reference 2.1.2), *Software Management*, and was obtained from Software Configuration Management in accordance with IT-PRO-0011 (Reference 2.1.2).

4.2.1 Level 1 Software Usage

No level 1 software was used in this calculation.

4.2.2 Level 2 Software Usage

Microsoft® Office Excel 2003 SP-3 (STN: 610236-2003-00) was used to perform arithmetic calculation and simple statistic analysis. The arithmetic calculations and simple statistic analyses were verified by hand calculation.

Microsoft® Office Excel is a Level 2 controlled software that is commercially available and is not required to be qualified per IT-PRO-0011, *Software Management* (Reference 2.1.2, Attachment 12).

Microsoft® Office Excel 2003 calculations were performed on personal computers with a Pentium® microprocessor and Microsoft® Windows XP Professional operating system.

4.3 CALCULATION METHODOLOGY

Methods used in this calculation include review of project documents, data, vendor information, literature, consultation with experts, and compiling existing data.

5 LIST OF ATTACHMENTS

Listed in Table 5-1 is borehole temperature data and in-situ rock thermal gradient estimates.

Table 5-1 Borehole Temperature Data and In-situ Rock Thermal Gradient Estimates

Attachment	Description	Page No.
I	In-situ Rock Thermal Gradient Estimates	15

6 BODY OF CALCULATION

This section presents the various input parameters to be used in the ground support design analysis. The majority of these input parameters are obtained from SGPR Rev. 00 (Reference 2.2.23) and TDMS database. Where appropriate, discussion is presented describing a process of parameters selection. It should be noted that this calculation is considered a living document and will be updated, as new information on input parameters are available.

6.1 LITHOSTRATIGRAPHY OF YUCCA MOUNTAIN

Table 6-1 lists the lithostratigraphic sequence at Yucca Mountain as used in Geologic Framework Model (GFM) (Reference 2.2.12). The correlation between thermal mechanical (TM) unit and lithostratigraphic zones used in this calculation is based on U.S. Geological Survey (USGS) Open-File Report (Reference 2.2.34, Table 4). It should be noted that the stratigraphic units below Calico Hill Formation are not included in this table since the analysis of ground support design does not involve these units.

Table 6-1 Yucca Mountain Stratigraphy

Stratigraphic Unit[a]						Lithostratigraphic Unit, Abbreviation[a]	Thermal Mechanical Unit	Geologic Framework Model Unit
Group	Formation	Member	Zone	Subzone				
	Alluvium and Colluvium					Qal, Qc	UO	Alluvium
Timber Mountain Group						**Tm**		
	Rainier Mesa Tuff					Tmr		
Paintbrush Group						**Tp**		
		Post-tuff unit "x" bedded tuff				Tpbt6		
		Tuff unit "x"[b]				Tpki (informal)		Crystal-Rich Tiva and Post-Tiva
		Pre-tuff unit "x" bedded tuff				Tpbt5		
	Tiva Canyon Tuff					Tpc	TCw	
		Crystal-Rich Member				Tpcr		
			Vitric zone			Tpcrv		
				Nonwelded subzone		Tpcrv3		
				Moderately welded subzone		Tpcrv2		
				Densely welded subzone		Tpcrv1		
			Nonlithophysal subzone			Tpcrn		
				Subvitrophyre transition subzone		Tpcrn4		
				Pumice-poor subzone		Tpcrn3		
				Mixed pumice subzone		Tpcrn2		
				Crystal transition subzone		Tpcrn1		
			Lithophysal zone			Tpcrl		
				Crystal transition subzone		Tpcrl1		
		Crystal-Poor Member				Tpcp		Tpcp
			Upper lithophysal zone			Tpcpul		
				Spherulite-rich subzone		Tpcpul1		
			Middle nonlithophysal zone			Tpcpmn		
				Upper subzone		Tpcpmn3		
				Lithophysal subzone		Tpcpmn2		
				Lower subzone		Tpcpmn1		
			Lower lithophysal zone			Tpcpll		
				Hackly fractured subzone		Tpcpllh		
			Lower nonlithophysal zone			Tpcpln		
				Hackly subzone		Tpcplnh		
				Columnar subzone		Tpcplnc		
								TpcLD
			Vitric zone			Tpcpv		
				Densely welded subzone		Tpcpv3		Tpcpv3
				Moderately welded subzone		Tpcpv2	PTn	Tpcpv2
				Nonwelded subzone		Tpcpv1		Tpcpv1
		Pre-Tiva Canyon bedded tuff				Tpbt4		Tpbt4
	Yucca Mountain Tuff					Tpy		Yucca

Table 6-1 Yucca Mountain Stratigraphy (continued)

Stratigraphic Unit[a]						Lithostratigraphic Unit, Abbreviation[a]	Thermal Mechanical Unit	Geologic Framework Model Unit
Group	Formation	Member	Zone	Subzone				
		Pre-Yucca Mountain bedded tuff				Tpbt3	PTn (continued)	Tpbt3_dc[c]
	Pah Canyon Tuff					Tpp		Pah
		Pre-Pah Canyon bedded tuff				Tpbt2		Tpbt2
	Topopah Spring Tuff					Tpt		
		Crystal-Rich Member				Tptr		
			Vitric zone			Tptrv		
				Nonwelded subzone		Tptrv3		Tptrv3
				Moderately welded subzone		Tptrv2		Tptrv2
				Densely welded subzone		Tptrv1	TSw1	Tptrv1
			Nonlithophysal zone			Tptrn		Tptrn
				Dense subzone		Tptrn3		
				Vapor-phase corroded subzone		Tptrn2		
				Crystal transition subzone		Tptrn1		
			Lithophysal zone			Tptrl		Tptrl
				Crystal transition subzone		Tptrl1		
		Crystal-Poor Member				Tptp	TSw1 (continued)	
			Lithic-rich zone			Tptpf or Tptrf		Tptf
			Upper lithophysal zone			Tptpul		Tptpul
								RHH top
			Middle nonlithophysal zone			Tptpmn	TSw2	Tptpmn
				Nonlithophysal subzone		Tptpmn3		
				Lithophysal bearing subzone		Tptpmn2		
				Nonlithophysal subzone		Tptpmn1		
			Lower lithophysal zone			Tptpll		Tptpll
			Lower nonlithophysal zone			Tptpln		Tptpln
			Vitric zone			Tptpv		
				Densely welded subzone		Tptpv3	TSw3	Tptpv3
				Moderately welded subzone		Tptpv2	CHn1	Tptpv2
				Nonwelded subzone		Tptpv1		Tptpv1
		Pre-Topopah Spring bedded tuff				Tpbt1		Tpbt1
	Calico Hills Formation					Ta		Calico
		Bedded tuff				Tacbt	CHn2	Calicobt

RHH = Repository Host Horizon and shaded in orange. N/A: Not available

Notes: Shaded in gray indicates not defined.

a. DTN: MO9510RIB00002.004 (Reference 2.2.50).

b. Correlated with the rhyolite of Comb Peak (Reference 2.2.34, Table 2).

c. Includes rhyolite of Delirium Canyon north of Yucca Wash (DTN: GS980608314221.002 (Reference 2.2.36).

6.2 REPOSITORY LAYOUT

According to the SGPR Rev. 00 (Reference 2.2.23, Section 6.1.3), the RHH will be located in the Topopah Spring Tuff and contains four lithostratigraphic zones: the upper lithophysal zone (Tptpul), the middle nonlithophysal zone (Tptpmn), the lower lithophysal zone (Tptpll), and the lower nonlithophysal zone (Tptpln). Based on the reports (Reference 2.2.51 and Reference 2.2.9, Section 3.4), the site-specific geotechnical characteristics of the repository horizon zones from tunnel mapping are summarized below. The rock quality designation (RQD), quality (Q) and rock mass rating (RMR) values are based on Reference 2.2.14 (Section 7).

Tptpul: The crystal-poor upper lithophysal zone is exposed in both the ESF tunnel and ECRB Cross-Drift. The ECRB Cross-Drift begins in the upper central portion of the zone and it exposes rocks of the central and lower portions of the zone from Station 0+00 to 10+15. The upper portion of the upper lithophysal zone is also exposed in the hanging wall of the eastern strand of the Solitario Canyon fault zone from Station 25+90 to 26+57.5. In both exposures, the zone is moderately to densely welded, devitrified, and vapor-phase altered. In general, the rock appears grayish red-purple and contains 10% to 40% vapor-phase spots, stringers, and partings. The central and lower parts of the zone (Station 0+00 to 10+15) are composed of 0% to 15% pumice, 1% to 3% phenocrysts, 0% to 5% lithic fragments, 10% to 60% lithophysae, and 40% to 90% matrix. The upper part of the zone (Station 25+90 to 26+57.5) is composed of 5% to 15% pumice, 2% to 5% phenocrysts, less than 1% lithic fragments, 3% to 20% lithophysae, and 60% to 90% matrix.

The Tptpul zone has a mean horizontal RQD rating of 44 (poor), a RMR value of 55 (fair) and a Q rating of 10.4 (good, based on Kirsten approach) all including lithophysae. Its lithophysae content ranges from 10 to 40 percent by volume. These cavities have an average diameter of 10 cm. Fractures are hard to distinguish, with an average of only one joint set. Keyblock-type failures are not likely to occur in this zone, though some horizontal cooling joints are observed.

Tptpmn: The ESF tunnel is excavated in the middle nonlithophysal zone from Stations 27+21 to 57+29, from 58+78 to 63+08, and from 70+58 to 71+68. The ECRB Cross-Drift exposes the middle nonlithophysal zone from Station 10+15 to 14+44. In general, the moderately to densely welded, devitrified and variably vapor-phase altered zone is composed of less than 5% to 10% pumice (locally 25% to 35%), 1% to 2% phenocrysts, 1% to 2% lithic fragments, 0% to 1% lithophysae, and 85% to 93% matrix. Vapor-phase spots, stringers, and partings comprise from 1% to 15% of the rock. Smooth, high-angle fractures are typical of the zone, but it also contains occasional low-angle, continuous shears and cooling joints. Another feature characteristic of the Tptpmn is the presence of low-angle concentrations of vapor-phase minerals. These features appear as continuous partings subparallel to the dip of the zone.

The Tptpmn zone has a mean horizontal RQD rating of 61 (fair), a RMR value of 60 (fair), and Q rating of 7.6 (fair, based on Kirsten approach) all including lithophysae. It is characterized by less than 3 percent lithophysae by volume. This zone has an average of three to three plus random joint sets, with predominately two vertical joint sets and one horizontal joint set. The horizontal joint set, or vapor-phase partings, is the primary cause of potential formation of keyblocks. A typical fracture pattern in the Tptpmn zone is shown in Figure 6-1.

Tptpll: The ESF tunnel exposes a small portion of the upper contact of the lower lithophysal zone from Station 57+29 to 58+78. The lower lithophysal zone is exposed along the ECRB Cross-Drift from Station 14+44 to 23+26. In general, the moderately to densely welded, devitrified, and vapor-phase altered zone is composed of 3% to 7% pumice (locally 10% to 35%), 1% to 2% phenocrysts, 1% to 5% lithic fragments (locally 12% to 15%), 5% to 30% lithophysae (locally 1% to 5%), and 56% to 90% matrix. Lithophysae vary in size from ten centimeters to greater than 1 m in diameter. Throughout most of the zone, vapor-phase spots, stringers, and wisps comprise between 3% and 12% of the rock. In several intervals, however, vapor-phase alteration products form 15% to 40% of the rock.

The Tptpll zone has a mean horizontal RQD rating of 40 (poor), a RMR value of 56 (fair) and a Q rating of 8.7 (fair, based on Kirsten approach) all including lithophysae. Its content of lithophysae varies from 5 to 30 percent by volume, with a size ranging from 5 to 130 cm. The larger lithophysal cavities tend to be irregular or ellipsoidal features that exhibit prismatic fracturing. The zone has an average of two plus random joint sets; however, no keyblock problems are expected. Typical lithophysae and fracturing in the Tptpll are shown in Figure 6-2.

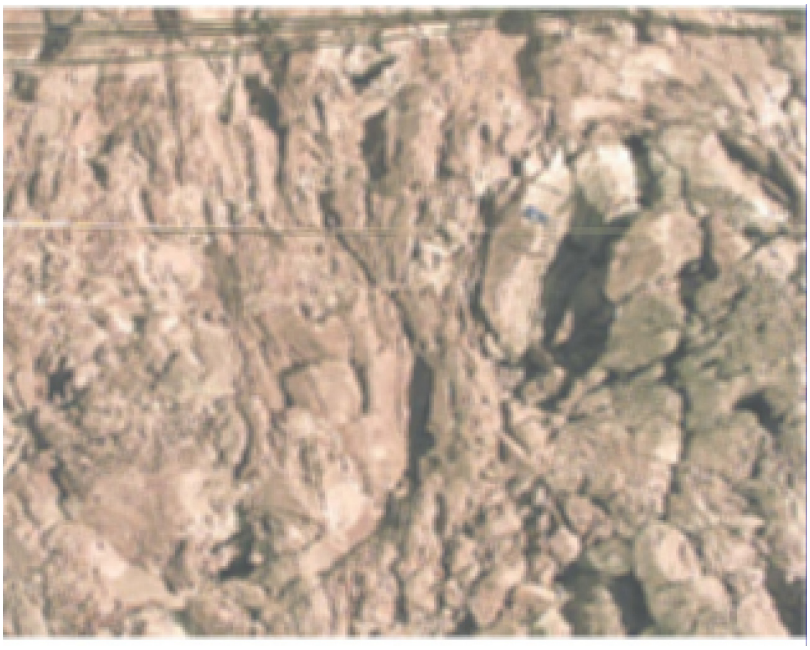
Tptpln: The Tptpln, exposed only in the ECRB Cross-Drift from Station 23+26 to 25+85, comprises moderately to densely welded, devitrified pyroclastic-flow material. It is generally composed of 3% to 20% pumice, 1% to 2% phenocrysts, 3% to 7% lithic fragments, 0% to 5% lithophysae, and 66% to 93% matrix. Vapor-phase alteration products form a minor component of the rock in some portions of the zone. Rocks of the lower nonlithophysal zone vary from a heterogeneous mix of grayish red and grayish orange pink to comparatively homogeneous pale red, light brown, pale brown, or grayish brown. Near the Solitario Canyon fault zone, this zone is brecciated and altered. In this area, the breccia matrix varies from moderate reddish brown to grayish orange pink to pale red; breccia clasts are locally bleached to very light gray adjacent to the fault plane.

The Tptpln zone has a RQD rating ranging from 62 (fair), a RMR value of 60 (fair), and a Q rating of 12.3 (good, based on Kirsten approach) all including lithophysae. This zone contains less than 3 percent lithophysal cavities by volume. It has an average of three joint sets, with no keyblock problems anticipated.

00266DC_007.ai

Source: Reference 2.2.9, Figure 8

Figure 6-1 Typical Fractures Pattern in the Tptpmn Zone



Source: Reference 2.2.9, Figure 10b

Figure 6-2 Typical Lithophysae and Fracturing in the Tptpll Zone

6.3 GROUND SUPPORT SYSTEM

Proposed LA ground support systems for the emplacement drifts and non-emplacement openings are summarized in Table 6-2.

Table 6-2 Summary of Ground Support System

Type	Ground Support System	Location	Notes
Initial	Friction-type rock bolts and wire mesh (W2 x W2)	Emplacement drifts, circular non-emplacement openings and shafts (8 m diameter) except in the north construction ramp, raises (5 m diameter or less), and existing ESF and ECRB cross drift	Rock bolts: 1.5 m long (25.4 mm diameter), spaced at 1.5 m c/c grid. Wire mesh: W2 x W2, 100 mm c/c opening size. All installed in the crown area (four bolts in each row) and around the opening in shaft. Initial rock bolts are considered committed. Wire mesh in all openings with the exception of the emplacement drifts, turnouts, and shafts is considered committed.
Final	Friction-type expandable rock bolts	Emplacement drifts and turnouts	3-m long stainless steel bolts (54 mm diameter and 3 mm thick) spaced at 1.25 m and cover a 240° arc in emplacement drifts and turnouts.
Final	Bernold-type perforated stainless steel sheets	Emplacement drifts	Dimension: 1080 mm (W) x 1200 mm (L) x 3 mm (T), covers a 240° arc around the drift with overlapping width of 120 mm in emplacement drifts.
Final	WWF (Stainless Steel)	Turnouts (only the circular portion)	Size: W4 x W4 with 75 mm c/c openings and covers 240° arc.
Final	Fully grouted rock bolts (3-m long)	Non-emplacement openings except in turnouts, intersections, shafts and raises	3-m long rock bolts (25.4 mm diameter) spaced at 1.25 m c/c grid to be installed in 38.1 mm boreholes and cover a 240° arc for circular openings and 2/3 of total surface area for non-circular openings.
Final	Fully grouted rock bolts (5-m long)	Intersections	5-m long rock bolts (25.4 mm diameter) spaced at 1.25 m c/c each way to be installed in 38.1 mm boreholes and are extended below springline.
Final	WWF (Carbon Steel)	Non-emplacement openings except in turnouts, intersections, ESF north ramp, shafts and raises	Size: W4 x W4 with 100 mm c/c openings and will be held by rock bolts, together with deformed plates (150 mm x 150 mm).
Final	Steel fiber-reinforced shotcrete	Intersections, ESF north ramp, and vent raise (3.7 m dia.)	Thickness of shotcrete: Intersections: 100 mm with additional 100 mm in Turnout bulkhead, Vent Raise in 3.7 m dia.: 75 mm, and ESF North Ramp: 100 mm. Shotcrete in ESF North Ramp will cover from invert to invert (~270° arc).
Final	Steel fiber-reinforced shotcrete (as-needed basis)	North construction ramp and ESF south ramps	100-mm thick steel fiber-reinforced shotcrete on as-needed basis.
Final	Lattice girders (as-needed basis)	Intersections	The lattice girders extend from invert to invert and are encapsulated in shotcrete to a depth of 38.1 mm.
Final	CIP concrete lining	Shafts/raises except in vent raise (3.7 m dia.)	300-mm thick CIP concrete lining for 8 m (diameter) shafts. For 5 m (diameter) exhaust raises: use 250 mm CIP concrete lining. Concrete lining is considered non-committed.

Sources: References 2.2.21, 2.2.22, 2.2.25, and 2.2.26

Note: The ground support system presented in this table may change as the design of ground support systems evolves and their details are specified and this calculation will be updated as new information is available.

6.4 FIELD STRESS

According to the five in situ stress measurements by hydraulic fracturing in a test hole located in the TSw2 unit at a depth of 244 m, the in situ stresses are (Reference 2.2.61):

$$\sigma_v = 4.7 \text{ MPa}$$

$$\sigma_h = 1.7\ (\pm 0.1) \text{ MPa acting in the N75°W } (\pm 14°)$$

$$\sigma_H = 2.9\ (\pm 0.4) \text{ MPa acting in the N15°E } (\pm 14°)$$

These stresses correspond to minimum and maximum horizontal to vertical in situ stress ratio (K_o) of 0.36 and 0.62, respectively. Details of hydraulic fracturing stress measurements are presented in Reference 2.2.35.

6.5 INTACT ROCK

6.5.1 Physical Properties

Table 6-3 presents the dry bulk densities and porosities for the RHH lithostratigraphic zones.

Table 6-3 Bulk Densities and Porosities for RHH Lithostratigraphic Zones

RHH Zones	Dry Bulk Density (g/cc)		Matrix Porosity		Lithophysal Porosity	
	Mean	SD	Mean	SD	Mean	SD
Tptpul	1.8344	0.1496	0.1667	0.0412	0.1228	0.0613
Tptpmn	2.1483	0.0932	0.1287	0.0323	0.0254	0.0225
Tptpll	1.9793	0.1381	0.1486	0.0340	0.0883	0.0540
Tptpln	2.2114	0.0857	0.1058	0.0264	0.0302	0.0253

Source: Reference 2.2.31, Table 1

Note: SD: Standard Deviation

The values presented in Table 6-3 are mean values and standard deviations of the product output parameters (Reference 2.2.15). These were derived from histograms of the expected value models, which were based on the input data consisting of laboratory core physical properties, petrophysical measurements, and matrix thermal conductivity measurements.

6.5.2 Mechanical Properties

Table 6-4 presents mean values of mechanical properties of intact rock, which was obtained under base case testing conditions. The base case testing conditions are (Assumption 3.2.1):

- Specimen size (diameter): 38 to 70 mm
- L/D ratio: approximately 2 to 1
- Specimen saturation: saturated
- Testing temperature: ambient
- Strain rate: 0.5E-05 to 5.0E-05 per second
- Confining pressure and pore pressure: none

Detailed statistical analysis of intact rock mechanical properties data are presented in calculation, *Intact Rock Mechanical Properties of Yucca Mountain Stratigraphic Units* (Reference 2.2.16, Section 6).

Table 6-4 Intact Rock Mechanical Properties by Stratigraphic Unit

TM Unit	Litho-stratigraphic Zone	UCS (MPa)	Static Young's Modulus (GPa)	Static Poisson's Ratio	Cohesion (MPa)	Friction Angle (Degrees)	Indirect Tensile Strength (MPa)
UO	Tmr	7.60	3.36	0.03	NA	NA	1.23
	Tpki	5.94	3.77	0.19	NA	NA	0.70
	Overall UO	6.63	3.60	0.12	NA	NA	NA
TCw	Tpcrn	36.02	15.16	0.20	NA	NA	7.14
	Tpcpul	62.14	23.72	0.19	15.1	42	9.99
	Tpcpmn	167.19	35.81	0.20	53.1	37	14.52
	Tpcpll	186.74	32.82	0.24	35.6	58	12.20
	Tpcpln	172.33	33.84	0.21	22.8	61	10.89
	Overall TCw	119.23	27.34	0.21	NA	NA	NA
PTn	Tpcpv2	28.18	7.63	0.10	NA	NA	3.18
	Tpcpv1	5.05	2.53	0.10	NA	NA	0.50
	Tpbt4	1.20	0.20	0.17	NA	NA	NA
	Tpy	19.30	5.24	0.16	NA	NA	3.00
	Tpbt3	1.80	1.30	0.28	NA	NA	0.30
	Tpp	3.19	0.98	0.26	NA	NA	0.16
	Tpbt2	2.92	0.67	0.21	NA	NA	0.33
	Tptrv3	4.25	0.99	0.23	NA	NA	NA
	Overall PTn	8.59	2.51	0.19	NA	NA	NA
TSw1	Tptrn	61.98	20.95	0.25	14.4	44	5.43
	Tptrl	26.73	9.13	0.30	NA	NA	4.81
	Tptf	157.00	54.70	0.34	NA	NA	NA
	Tptpul	65.21	20.41	0.25	12.6	45	5.57
	Overall TSw1	62.21	20.86	0.25	NA	NA	NA
TSw2	Tptpmn	164.58	32.53	0.19	50.7	34	10.88
	Tptpll	123.01	29.97	0.22	24	45	8.33
	Tptpln	155.51	37.78	0.22	15.8	63	7.92
	Overall TSw2	153.92	32.74	0.20	NA	NA	NA
TSw3	Tptpv3	16.40	25.20	0.39	5.5	36	3.97
CHn	Tpbt1	20.50	3.90	0.11	NA	NA	NA
	Tac	24.60	6.50	0.20	10.2	16	NA
	Overall CHn	23.23	5.63	0.17	NA	NA	NA

Sources: Reference 2.2.16, Tables 6-8, 6-19, and 6-20

Notes:

1. All values except of tensile strength in this table were based on base case testing conditions.
2. The length/diameter ratios of specimen for indirect tensile strength tests are less than 1.8.
3. All values presented in table represent mean values.
4. NA: Not Available.

6.5.3 Thermal Properties

Presented in this section are intact rock thermal properties which include thermal conductivity, coefficient of thermal expansion, and heat capacity.

6.5.3.1 Thermal Conductivity

Table 6-5 and Table 6-6 present a summary of the intact rock thermal conductivity measurements for the oven-dried and saturated specimens, respectively. The laboratory thermal conductivity was calculated using Equation 6-1 (Reference 2.2.37, Equation 1-1).

$$\frac{\Delta Q}{\Delta t} = -kA\frac{\Delta T}{\Delta x} \qquad \text{(Eq. 6-1)}$$

where,

$\Delta Q/\Delta t$: heat transfer rate
$\Delta T/\Delta x$: temperature gradient in the direction of the heat flow
A: cross-sectional area
k: thermal conductivity

Detailed descriptions of the intact rock thermal conductivity measurements and data are presented in Brodsky et al.1997 (Reference 2.2.10, Sections 3.1 and 4.1).

Table 6-5 Intact Rock Thermal Conductivity of Oven Dried Specimens

TM Unit	Litho-stratigraphic Zone	Descrip-tion	Intact Rock Thermal Conductivity (W/m-K), Oven-Dried Specimens at Temperature (°C)						
			30-50	50-70	~110	~150	~200	~250	~290
TCw	Tpcr	Mean+1 SD	1.14+0.35	1.22+0.38	1.50+0.18	1.54+0.19	1.53+0.18	1.53+0.17	1.55+0.14
		Minimum	0.73	0.81	1.16	1.18	1.18	1.19	1.21
		Maximum	1.70	1.73	1.79	1.82	1.81	1.8	1.69
PTn	Tpcpv2	Mean+1 SD	0.57+0.02	0.60+0.01	0.75+0.01	0.79+0.01	0.81+0.01	0.83+0.00	0.85+n/a
		Minimum	0.56	0.59	0.74	0.78	0.8	0.83	0.85
		Maximum	0.59	0.6	0.75	0.8	0.82	0.83	0.85
	Tpcpv1	Mean+1 SD	0.42+0.01	0.44+0.02	0.43+0.00	0.46+0.00	0.48+0.01	0.49+0.00	0.51+0.01
		Minimum	0.41	0.43	0.43	0.46	0.47	0.49	0.5
		Maximum	0.44	0.46	0.44	0.47	0.49	0.5	0.51
	Tpbt4	Mean+1 SD	0.34+0.00	0.35+0.01	0.32+0.00	0.33+0.00	0.35+0.00	0.36+0.00	0.37+n/a
		Minimum	0.34	0.35	0.32	0.33	0.35	0.36	0.37
		Maximum	0.34	0.36	0.32	0.33	0.35	0.36	0.37
	Tpy	Mean+1 SD	0.39+0.02	0.42+0.01	0.44+0.02	0.47+0.02	0.48+0.02	0.49+0.02	0.48+n/a
		Minimum	0.38	0.41	0.42	0.45	0.46	0.47	0.48
		Maximum	0.41	0.42	0.45	0.48	0.49	0.5	0.48
	Tpp	Mean+1 SD	0.34+0.04	0.32+0.08	0.33+0.02	0.35+0.02	0.37+0.02	0.38+0.02	0.38+0.02
		Minimum	0.23	0.18	0.31	0.33	0.34	0.35	0.36
		Maximum	0.37	0.38	0.36	0.39	0.39	0.4	0.4
	Tpbt2	Mean+1 SD	0.28+0.10	0.33+0.11	0.30+0.06	0.32+0.06	0.33+0.06	0.34+0.06	0.33+0.06
		Minimum	0.18	0.16	0.24	0.26	0.27	0.28	0.29
		Maximum	0.36	0.38	0.36	0.37	0.38	0.39	0.39
TSw1	Tptrn	Mean+1 SD	0.95+0.29	0.94+0.28	1.14+0.13	1.18+0.13	1.18+0.13	1.17+0.12	1.17+0.11
		Minimum	0.55	0.62	0.89	0.92	0.93	0.95	0.97
		Maximum	1.49	1.54	1.36	1.39	1.4	1.4	1.41
	Tptrl	Mean+1 SD	1.20+n/a	1.23+0.01	1.29+n/a	1.33+n/a	1.34+n/a	1.31+n/a	1.26+n/a
		Minimum	1.2	1.22	1.29	1.33	1.34	1.31	1.26
		Maximum	1.2	1.24	1.29	1.33	1.34	1.31	1.26
	Tptpul	Mean+1 SD	1.08+n/a	1.08+0.01	1.23+0.27	1.25+0.27	1.26+0.26	1.25+0.25	1.16+0.29
		Minimum	1.08	1.07	0.91	0.94	0.97	0.97	0.95
		Maximum	1.08	1.09	1.4	1.43	1.44	1.42	1.36
TSw2	Tptpmn	Mean+1 SD	1.49+0.37	1.59+0.33	1.57+0.26	1.60+0.25	1.60+0.25	1.52+0.25	1.52+0.22
		Minimum	0.14	0.18	0.23	0.29	0.37	0.83	0.85
		Maximum	2.2	2.25	1.91	1.85	1.82	1.81	1.76
	Tptpll	Mean+1 SD	1.71+0.27	1.73+0.26	1.71+0.24	1.71+0.21	1.69+0.21	1.54+0.03	1.49+0.05
		Minimum	0.9	0.9	0.9	1	1	1.5	1.44
		Maximum	2.1	2.1	2	1.9	1.9	1.57	1.54
CHn	Calico	Mean+1 SD	0.47+0.03	0.52+0.03	0.57+0.03	0.60+0.03	0.64+0.03	n/a	n/a
		Minimum	0.43	0.49	0.53	0.56	0.59	n/a	n/a
		Maximum	0.52	0.56	0.61	0.64	0.67	n/a	n/a

Source: Reference 2.2.23, Table 6-78

Note: n/a: Not Available.

Table 6-6 Intact Rock Thermal Conductivity of Saturated Specimens

TM Unit	Lithostratigraphic Zone	Description	Intact Rock Thermal Conductivity (W/m-K), Saturated Specimens at Temperature (°C)		
			~30	~50	~70
TCw	Tpcr	Mean+1 SD	1.79+0.08	1.96+0.09	1.92+0.12
		Minimum	1.66	1.81	1.71
		Maximum	1.89	2.04	2.04
PTn	Tpcpv2	Mean+1 SD	1.03+0.00	1.13+0.01	1.20+N/A
		Minimum	1.03	1.12	1.20
		Maximum	1.03	1.13	1.20
	Tpcpv1	Mean+1 SD	0.83+0.06	0.92+0.05	1.03+0.02
		Minimum	0.79	0.88	1.01
		Maximum	0.90	0.97	1.04
	Tpbt4	Mean+1 SD	0.79+0.02	0.87+0.01	0.95+N/A
		Minimum	0.77	0.86	0.95
		Maximum	0.80	0.88	0.95
	Tpy	Mean+1 SD	0.91+0.00	0.99+0.01	1.04+ N/A
		Minimum	0.91	0.98	1.04
		Maximum	0.91	0.99	1.04
	Tpp	Mean+1 SD	0.76+0.05	0.83+0.09	0.89+0.13
		Minimum	0.70	0.72	0.79
		Maximum	0.79	0.90	0.98
	Tpbt2	Mean+1 SD	0.80+0.25	0.80+0.18	0.86+0.18
		Minimum	0.62	0.67	0.73
		Maximum	0.97	0.92	0.98
	Tptrv2	Mean+1 SD	0.98+0.01	1.05+0.00	1.13+ N/A
		Minimum	0.97	1.05	1.13
		Maximum	0.98	1.05	1.13
TSw1	Tptrn	Mean+1 SD	1.55+0.15	1.63+0.10	1.66+0.10
		Minimum	1.34	1.45	1.49
		Maximum	1.76	1.80	1.82
	Tptrl	Mean+1 SD	1.64+n/a	1.69+n/a	1.7+ N/A
	Tptpul	Mean+1 SD	2.07+0.14	2.04+0.12	1.99+0.08
		Minimum	1.97	1.95	1.93
		Maximum	2.17	2.12	2.04
TSw2	Tptpmn	Mean+1 SD	2.20+0.35	2.19+0.32	2.14+0.31
		Minimum	1.56	1.65	1.66
		Maximum	3.57	3.36	3.09
	Tptpll	Mean+1 SD	2.14+0.17	2.13+0.15	2.11+0.14
		Minimum	1.80	1.80	1.80
		Maximum	2.50	2.40	2.40

Source: Reference 2.2.23, Table 6-79

Note: N/A: Not Available

6.5.3.2 Coefficient of Thermal Expansion

The laboratory thermal expansion tests were conducted at ambient pressure over a temperature range of 25 °C to 325 °C. Table 6-7 presents summary of the intact rock CTE measurements of air dried specimens. Also presented in Table 6-8 and Table 6-9 are the intact rock CTE measurements of Tptpmn specimens from SHT and DST, respectively. The CTE is defined as the ratio of the change to its length at a referenced temperature. The mean CTE is the linear thermal expansion per unit change in temperature and is calculated using Equation 6-2 (Reference 2.2.10, Equation 3-10a).

$$\alpha_m = \frac{L_2 - L_1}{L_0 (T_2 - T_1)} \qquad \text{(Eq. 6-2)}$$

where,

α_m: mean CTE between two temperatures, T_1 and T_2
L_0: specimen length at reference temperature
L_1 and L_2: specimen displacement at temperature T_1; and T_2, respectively

Temperatures and displacements of rock specimens were measured throughout a heating and cooling cycle during the SHT and DST.

Table 6-7 Intact Rock Coefficient of Thermal Expansion of Air-Dried Specimens

Stratigraphic Units	Description	Intact Rock Coefficient of Thermal Expansion (10^{-6}/°C), Air-Dried Specimens at Temperature (°C)											
		25-50	50-75	75-100	100-125	125-150	150-175	175-200	200-225	225-250	250-275	275-300	300-325
Crystal-Rich Tiva/Post-Tiva Canyon Tuff (Tpcr)	Mean+1 SD	6.96+1.78	7.67+1.17	9.50+1.11	10.15+0.87	12.03+1.24	13.83+1.49	16.14+1.95	18.92+1.85	21.75+1.38	37.55+13.85	48.84+18.34	NA
	Minimum	2.71	5.16	7.84	8.81	10.28	11.82	13.31	15.95	19.5	25.22	33.16	NA
	Maximum	9.1	8.81	11.55	11.31	13.94	15.62	18.4	21.11	23.79	62.82	81.37	NA
Tpcpv2	Mean+1 SD	6.90+0.32	6.06+0.92	4.91+0.89	7.45+n/a	8.94+0.57	6.60+1.29	1.57+2.06	NA	NA	NA	NA	NA
	Minimum	6.67	5.41	4.28	7.45	8.54	5.69	0.11	NA	NA	NA	NA	NA
	Maximum	7.12	6.71	5.54	7.45	9.34	7.51	3.03	NA	NA	NA	NA	NA
Tpcpv1	Mean+1 SD	4.72+0.58	3.43+1.03	3.12+1.89	4.39+1.31	6.27+0.58	5.80+0.22	5.75+0.23	5.66+0.23	5.10+0.79	3.82+0.74	1.71+n/a	NA
	Minimum	4.08	1.88	0.96	3.46	5.86	5.64	5.58	5.5	4.54	3.29	1.71	NA
	Maximum	5.48	4.01	4.46	5.31	6.68	5.95	5.91	5.82	5.66	4.34	1.71	NA
Tpbt4	Mean+1 SD	4.20+0.35	2.11+0.78	NA	5.31+n/a	5.53+0.06	4.67+0.25	5.80+0.60	6.30+0.13	6.70+0.18	5.82+0.35	3.03+1.75	NA
	Minimum	3.95	1.56	NA	5.31	5.49	4.49	5.37	6.2	6.57	5.57	1.79	NA
	Maximum	4.45	2.66	NA	5.31	5.57	4.85	6.22	6.39	6.82	6.07	4.26	NA
Tpy	Mean+1 SD	4.73+0.56	4.87+0.30	5.33+0.34	4.77+2.48	6.41+0.29	5.88+0.46	4.09+2.24	5.97+0.25	5.47+0.54	3.92+0.70	1.24+0.93	NA
	Minimum	4.12	4.52	4.94	1.11	6.11	5.46	1.2	5.79	5.08	3.42	0.58	NA
	Maximum	5.39	5.18	5.77	6.49	6.72	6.38	6.28	6.15	5.85	4.41	1.9	NA
Tpp	Mean+1 SD	4.22+0.75	2.84+0.59	3.14+0.56	6.32+0.49	5.72+0.90	3.72+1.00	3.73+0.59	4.46+0.10	4.10+0.51	3.31+1.20	1.02+1.00	NA
	Minimum	2.82	2	2.45	5.84	4.03	2.62	3.31	4.39	3.74	2.46	0.31	NA
	Maximum	5.56	3.71	3.99	6.81	6.52	4.95	4.15	4.53	4.46	4.15	1.72	NA
Tptrv2	Mean+1 SD	5.76+0.94	6.11+0.18	6.56+0.10	4.22+3.62	8.07+0.35	8.05+0.30	5.67+1.35	2.65+n/a	NA	NA	NA	NA
	Minimum	5.09	5.98	6.49	1.66	7.82	7.84	4.71	2.65	NA	NA	NA	NA
	Maximum	6.42	6.23	6.63	6.78	8.31	8.26	6.62	2.65	NA	NA	NA	NA
Tptrn	Mean+1 SD	6.52+1.05	7.02+0.87	7.90+0.91	8.30+1.01	9.90+1.78	16.30+5.97	20.83+10.26	25.04+14.75	27.58+12.50	30.80+10.09	33.22+9.43	NA
	Minimum	4.13	5.26	6.26	6.73	7.05	10.19	12.32	13.59	14.84	16.92	16.88	NA
	Maximum	8.47	8.44	9.68	10.78	14.44	29.96	43.22	62.11	56.39	49.02	44.23	NA
Tptrl	Mean+1 SD	7.76+1.07	8.21+1.05	9.13+0.94	10.31+1.35	11.89+1.98	23.82+6.33	33.69+11.21	39.90+11.50	37.59+7.42	38.82+7.95	39.95+4.13	NA
	Minimum	6.6	7.28	8.08	8.91	9.92	16.61	23.67	28.82	31.22	31.52	35.57	NA
	Maximum	9.16	9.17	10.03	11.97	14.33	31.92	46.6	50.78	45.75	46.78	45.09	NA
Tptpul	Mean+1 SD	7.78+0.62	8.21+0.48	9.00+0.68	9.62+0.53	10.81+0.83	14.94+4.44	23.36+7.77	31.07+10.97	33.71+9.76	42.41+20.22	45.98+16.80	NA
	Minimum	6.7	7.26	7.78	8.58	9.45	10.7	11.97	13.42	15.51	18.41	25.17	NA
	Maximum	8.74	8.72	10.07	10.35	12.73	25.83	35.88	49.03	50.46	84.01	75.58	NA
Tptpmn	Mean+1 SD	8.06+0.73	9.00+0.82	9.11+0.56	9.77+0.57	10.46+0.74	11.42+0.89	12.94+1.68	16.55+3.43	21.87+4.80	33.56+9.28	49.17+11.24	43.34+13.29
	Minimum	6.03	6.47	7.4	8.66	8.99	9.16	10.74	10.93	12.58	11.97	29.53	27.2
	Maximum	9.58	11	10.63	11.2	12.3	13.3	20.5	28.1	35	57.9	81.4	73
Tptpll	Mean+1 SD	7.71+0.69	8.51+0.38	8.84+0.56	9.09+0.51	9.88+0.57	10.82+0.87	12.96+2.57	15.06+3.06	17.77+3.16	21.77+3.41	28.51+4.58	NA
	Minimum	6.9	7.89	8.11	8.35	9.15	9.83	10.7	12.13	14.42	17.59	22.76	NA
	Maximum	9.02	9.06	9.65	9.86	10.75	11.92	17.5	19.62	22.1	27.04	35.63	NA

Table 6-7 Intact Rock Coefficient of Thermal Expansion of Air-Dried Specimens (continued)

Stratigraphic Units	Description	Intact Rock Coefficient of Thermal Expansion (10^{-6}/°C), Air-Dried Specimens at Temperature (°C)											
		25-50	50-75	75-100	100-125	125-150	150-175	175-200	200-225	225-250	250-275	275-300	300-325
Tptpln	Mean+1 SD	7.18+1.31	8.19+0.68	8.97+0.79	9.74+1.26	10.69+2.19	11.33+2.62	12.22+2.07	12.95+1.56	14.27+1.46	15.48+2.51	18.62+4.91	NA
	Minimum	4.32	7.38	8.01	8.85	9.05	9.17	10.47	11.51	12.45	12.13	11.5	NA
	Maximum	8.97	9.48	10.53	12.57	15.06	16.45	16.06	16.01	17.15	19.74	26.16	NA
Calico	Mean+1 SD	5.75+1.20	6.36+1.11	5.14+1.47	3.64+1.76	4.53+1.51	4.50+2.27	4.78+1.91	4.53+2.40	5.12+2.84	5.26+2.34	5.13+2.42	2.50+2.48
	Minimum	4	4.6	2.5	1.1	2.4	0.3	1.8	1.9	0.2	2	3	1
	Maximum	7.8	8	6.9	6	6.8	7.4	7.5	8.3	8.6	8.3	8.6	6.2

Source: Reference 2.2.23, Table 6-84

Note: NA: Not Available

Table 6-8 Intact Rock CTE Measurements of Tptpmn Specimens from SHT

Mean CTE on the First Heating Cycle ($10^{-6}/^{o}C$)												
Temperature	**25~50 °C**	**50~75 °C**	**75~100 °C**	**100~125 °C**	**125~150 °C**	**150~175 °C**	**175~200 °C**	**200~225 °C**	**225~250 °C**	**250~275 °C**	**275~300 °C**	**300~325 °C**
No. of Tests, N	14	14	14	14	14	14	14	14	14	14	14	14
Mean	8.63	9.87	8.95	9.64	10.62	11.77	12.34	15.37	21.89	33.56	57.06	54.88
SD	0.46	0.65	0.55	0.60	0.62	0.72	0.97	1.66	5.47	8.58	12.03	8.49
Mean CTE on the First Cooling Cycle ($10^{-6}/^{o}C$)												
Temperature	**300~325 °C**	**275~300 °C**	**250~275 °C**	**225~250 °C**	**200~225 °C**	**175~200 °C**	**150~175 °C**	**125~150 °C**	**100~125 °C**	**75~100 °C**	**50~75 °C**	**30~50 °C**
N	14	14	14	14	14	14	14	14	14	14	14	14
Mean	16.55	28.52	38.83	36.47	28.54	21.19	15.57	12.92	11.95	10.95	10.11	10.43
SD	2.55	3.86	5.32	8.94	11.86	5.86	2.28	0.99	0.68	1.30	0.54	2.87
Mean CTE on the Second Heating Cycle ($10^{-6}/^{o}C$)												
Temperature	**25~50 °C**	**50~75 °C**	**75~100 °C**	**100~125 °C**	**125~150 °C**	**150~175 °C**	**175~200 °C**	**200~225 °C**	**225~250 °C**	**250~275 °C**	**275~300 °C**	**300~325 °C**
N	14	14	14	14	14	14	14	14	14	14	14	14
Mean	8.53	9.67	9.01	10.21	11.13	12.23	14.10	19.08	25.17	43.56	49.64	31.80
SD	0.41	0.56	0.55	0.34	0.39	0.61	2.09	3.25	4.17	9.33	8.15	2.83
Mean CTE on the Second Cooling Cycle ($10^{-6}/^{o}C$)												
Temperature	**300~325 °C**	**275~300 °C**	**250~275 °C**	**225~250 °C**	**200~225 °C**	**175~200 °C**	**150~175 °C**	**125~150 °C**	**100~125 °C**	**75~100 °C**	**50~75 °C**	**30~50 °C**
N	14	14	14	14	14	14	14	14	14	14	14	14
Mean	17.38	28.64	39.99	38.36	26.02	20.00	15.16	13.69	11.81	11.13	10.13	10.84
SD	2.57	3.65	4.63	7.23	3.36	3.89	2.10	5.42	1.49	2.87	1.42	5.42

Source: SNL22080196001.003 (Reference 2.2.63)

Note: Air dried.

Table 6-9 Intact Rock CTE Measurements of Tptpmn Specimens from DST Area

Mean CTE on the First Heating Cycle (10^{-6}/°C)												
Temperature	**25~50 °C**	**50~75 °C**	**75~100 °C**	**100~125 °C**	**125~150 °C**	**150~175 °C**	**175~200 °C**	**200~225 °C**	**225~250 °C**	**250~275 °C**	**275~300 °C**	**300~325 °C**
N, No. of Tests	17	17	17	17	17	17	17	17	17	17	17	13
Mean	7.34	8.99	9.73	10.22	10.91	12.20	14.74	22.31	27.34	33.88	54.13	52.28
SD	0.57	0.47	0.54	0.58	0.79	1.04	4.79	18.09	15.70	6.94	12.18	13.42
Mean CTE on the First Cooling Cycle (10^{-6}/°C)												
Temperature	**300~325 °C**	**275~300 °C**	**250~275 °C**	**225~250 °C**	**200~225 °C**	**175~200 °C**	**150~175 °C**	**125~150 °C**	**100~125 °C**	**75~100 °C**	**50~75 °C**	**30~50 °C**
N	13	17	17	17	17	17	17	17	17	17	16	15
Mean	15.74	24.07	35.63	36.01	26.50	24.19	18.30	14.14	12.36	11.05	10.24	9.67
SD	1.88	5.70	8.39	8.32	4.69	9.82	7.37	2.61	1.76	0.84	1.24	0.66
Mean CTE on the Second Heating Cycle (10^{-6}/°C)												
Temperature	**25~50 °C**	**50~75 °C**	**75~100 °C**	**100~125 °C**	**125~150 °C**	**150~175 °C**	**175~200 °C**	**200~225 °C**	**225~250 °C**	**250~275 °C**	**275~300 °C**	**300~325 °C**
N	17	17	17	17	17	17	17	17	17	17	17	17
Mean	7.22	8.87	9.63	10.24	11.28	13.22	19.37	22.66	24.82	37.84	46.78	34.46
SD	0.76	0.59	0.54	0.61	0.98	2.98	14.97	10.66	5.47	9.52	11.63	10.17
Mean CTE on the Second Cooling Cycle (10^{-6}/°C)												
Temperature	**300~325 °C**	**275~300 °C**	**250~275 °C**	**225~250 °C**	**200~225 °C**	**175~200 °C**	**150~175 °C**	**125~150 °C**	**100~125 °C**	**75~100 °C**	**50~75 °C**	**30~50 °C**
N	17	17	17	17	17	17	17	17	17	17	17	17
Mean	16.50	26.48	37.06	36.39	26.44	23.64	17.46	13.75	12.01	11.36	10.16	9.81
SD	1.06	2.32	4.00	3.77	2.14	4.50	2.92	0.99	0.56	0.87	0.31	0.33

Source: SN0203L2210196.007 (Reference 2.2.52)

Notes: Air dried.
Lithostratigraphic zone is Tptpmn except for HDFR1-97.9, which may be from Tptpll.

6.5.3.3 Heat Capacity

Laboratory measured heat capacities are summarized in Table 6-10. The specimens were obtained from borehole UE25 NRG-4 for the Tptrn zone and borehole UE25 NRG-5 for Tptpmn zone.

Table 6-10 Intact Rock Heat Capacity

TM Unit	Lithostratigraphic Zone	Heat Capacity (J/kg·K)		
		25-94 °C	95-114 °C	115-325 °C
TSw1	Tptrn	815	913	982
TSw2	Tptpmn	854	968	1,066

Source: Reference 2.2.62

6.6 ROCK MASS

Some methods of analyzing ground support do not consider joints as discrete items but include them as part of the overall rock mass characteristics. Therefore, parameters are needed that reflect the overall behavior of the rock mass rather than discrete blocks of rock.

6.6.1 Mechanical Properties at RHH

The difference in the characteristics of lithophysal and nonlithophysal rock warrants that separate characteristics are determined for each.

6.6.1.1 Nonlithophysal Rock

Rock mass mechanical properties for nonlithophysal rock (Tptpmn and Tptpln) in the RHH are listed in Table 6-11 and Table 6-12. All data with the exception of bulk modulus and shear modulus are obtained from SGPR Rev. 00 (Reference 2.2.23, Table 6-76). Bulk modulus (K) and shear modulus (G) are calculated based on values of modulus of elasticity (E) and Poisson's ratio (ν) using the Equations 6-3 and 6-4 (Reference 2.2.39, Equations 13 and 14, p. 111).

$$K = \frac{E}{3(1-2\nu)} \qquad \text{(Eq. 6-3)}$$

$$G = \frac{E}{2(1+\nu)} \qquad \text{(Eq. 6-4)}$$

Table 6-11 Rock Mass Mechanical Properties for Nonlithophysal Rock at Tptpmn

Parameter	Nonlithophysal Rock (Tptpmn)				
Rock Mass Category	1	2	3	4	5
Geologic Strength Index (GSI)	51	59	62	68	72
Poisson's Ratio	0.19	0.19	0.19	0.19	0.19
Modulus of Elasticity (GPa)	10.59	16.79	19.95	28.18	35.48
Bulk Modulus (GPa)	5.69	9.03	10.73	15.15	19.08
Shear Modulus (GPa)	4.45	7.05	8.38	11.84	14.91
UCS (MPa)	26.90	32.02	34.28	39.57	43.90
Cohesion (MPa)	7.36	8.33	8.75	9.73	10.52
Friction Angle (degrees)	32.64	35.02	35.91	37.65	38.79
Tensile Strength (MPa)	0.27	0.50	0.63	0.99	1.33

Source: Reference 2.2.23, Table 6-76

Note: Rock mass properties of UCS, cohesion, friction angle, and tensile strength are based RocLab® analysis.

Table 6-12 Rock Mass Mechanical Properties for Nonlithophysal Rock at Tptpln

Parameter	Nonlithophysal Rock (Tptpln)				
Rock Mass Category	1	2	3	4	5
GSI	57	61	64	69	72
Poisson's Ratio	0.22	0.22	0.22	0.22	0.22
Modulus of Elasticity (GPa)	14.96	18.84	22.39	29.85	35.48
Bulk Modulus (GPa)	8.90	11.21	13.33	17.77	21.12
Shear Modulus (GPa)	6.13	7.72	9.18	12.23	14.54
UCS (MPa)	47.53	51.66	55.07	61.49	65.92
Cohesion (MPa)	11.34	12.00	12.53	13.52	14.20
Friction Angle (degrees)	38.98	40.17	41.06	42.53	43.39
Tensile Strength (MPa)	0.31	0.42	0.53	0.77	0.96

Source: Reference 2.2.23, Table 6-76

Note: Rock mass properties of UCS, cohesion, friction angle, and tensile strength are based RocLab® analysis.

6.6.1.2 Lithophysal Rock

Rock mass mechanical properties for lithophysal rock are listed in Table 6-13, which are primarily obtained from SGPR Rev. 00 (Reference 2.2.23, Tables 6-75 and 6-76). The values of bulk modulus and shear modulus are calculated based on values of modulus of elasticity (E) and Poisson's ratio (ν) using the Equations 6-3 and 6-4 (Reference 2.2.39, Equations 13 and 14, p. 111). Cohesion (c) can be estimated using an Equation 6-5 (Reference 2.2.39, Eq. 8.15):

$$c = \frac{q_u(1-\sin\phi)}{2\cos\phi} \qquad \text{(Eq. 6-5)}$$

where,

q_u: unconfined compressive strength in MPa

ϕ: friction angle

Table 6-13 Rock Mass Mechanical Properties for Lithophysal Rock at RHH

Parameter	Lithophysal Rock				
Rock Mass Category	1	2	3	4	5
Lithophysal Porosity (%) [a]	>30	25-30	15-25	10-15	<10
Poisson's Ratio [b]	0.22	0.22	0.22	0.22	0.22
Modulus of Elasticity (GPa) [a, c]	1.90	6.40	10.80	15.30	19.70
Bulk Modulus (GPa)	1.13	3.81	6.43	9.11	11.73
Shear Modulus (GPa)	0.78	2.62	4.43	6.27	8.07
UCS (MPa) [a, c]	10	15	20	25	30

Sources: Reference 2.2.23, [a] Table 6-75, [b] Table 6-76, and [c] Table 6-77

6.6.2 Mechanical Properties at Non RHH

Rock mass mechanical properties at non-RHH zones are listed in Table 6-14. These values are obtained from SGPR Rev. 00 (Reference 2.2.23, Table 6-76).

Table 6-14 Rock Mass Mechanical Properties at Non-RHH Lithostratigraphic Zone

Lithostratigraphic Zone	GSI	Poisson's Ratio	Modulus of Elasticity (GPa)	Bulk Modulus (GPa)	Shear Modulus (GPa)	UCS[1] (MPa)	Cohesion (MPa)	Friction Angle (degrees)	Tensile Strength (MPa)
Tmr	65	0.03	6.54	2.32	3.17	1.54	0.44	30.43	0.09
Tpki	65	0.19	5.78	3.11	2.43	1.36	0.37	33.32	0.05
Tpcrn	68	0.20	16.92	9.40	7.05	7.43	2.17	29.32	0.67
Tpcpul	59	0.19	13.32	7.16	5.60	10.70	3.16	28.86	0.47
Tpcpmn	64	0.20	22.39	12.44	9.33	58.18	14.28	37.72	0.97
Tpcpll	68	0.24	28.18	18.06	11.36	33.53	8.57	35.86	1.11
Tpcpln	69	0.21	29.85	17.16	12.33	69.59	15.73	41.34	1.05
Tpcpv2	62	0.10	10.91	4.55	4.96	6.63	1.79	33.39	0.18
Tpcpv1	68	0.10	6.33	2.64	2.88	1.34	0.34	35.75	0.05
Tpp	71	0.26	4.34	3.01	1.72	0.35	0.11	26.07	0.06
Tpbt2	70	0.21	5.40	3.10	2.23	0.78	0.20	35.10	0.03
Tptrn	64	0.24	17.82	11.42	7.19	16.22	4.14	35.90	0.36
Tptrl	54	0.30	7.77	6.48	2.99	6.48	1.89	29.60	0.15

Source: Reference 2.2.23, Table 6-76

Note: 1. UCS equal to the Global Strength (σ'_{cm}).

6.6.3 Thermal Properties

Presented in this section are field measurements and analytical estimates of various rock mass thermal properties which include thermal conductivity, coefficient of thermal expansion, and heat capacity.

6.6.3.1 Thermal Conductivity

Two major field tests of the rock mass thermal conductivity include the DST and the in situ measurements in the ECRB Cross-Drift. The DST measurements are made within the Tptpmn zone, while the ECRB Cross-Drift measurements are made within the Tptpll zone. Table 6-15 and Table 6-16 summarize the results of thermal conductivities measured from Tptpmn and Tptpll zones, respectively.

Table 6-15 In Situ Rock Mass Thermal Conductivity from DST During the Heating Phase (Tptpmn)

Field Rock Thermal Conductivity (W/m-K)						
Temperature	**20~35 °C**	**35~50 °C**	**50~70 °C**	**70~90 °C**	**90~100 °C**	**120~180 °C**
Count	14	21	33	55	9	76
Mean+1 SD	2.28+0.23	1.65+0.26	2.05+0.31	2.44+0.21	3.98+1.63	1.92+0.14
Minimum	1.58	0.90	1.30	1.89	2.02	1.38
Maximum	2.57	2.02	2.57	3.10	7.20	2.45

Source: Reference 2.2.23, Table 6-88

Table 6-16 Rock Mass Thermal Conductivity from ECRB Cross-Drift Thermal K Tests (Tptpll)

ECRB Cross-Drift Thermal K Test 1 (Two-Hole Test)	**ECRB Cross Drift Thermal K Test 2 (Six-Hole Test)**		**ECRB Cross Drift Thermal K Test 3 (Three-Hole Test)**	
Thermal conductivity (W/m-K)	**Borehole**	**Thermal conductivity (W/m-K)**	**Borehole**	**Thermal conductivity (W/m-K)**
1.75[a] or 1.74[b]	TMK6	2.18	TMK10	1.73
	TMK7	2.09	TMK11	1.76
	TMK8	2.03		
Average: 1.92 W/m-K				

Sources: References 2.2.54, 2.2.55, and 2.2.56

Notes: [a] A single value of each thermal property was calculated using all the temperature data shown in DTN: SN0206F3504502.011 (Reference 2.2.53).

[b] A single value of each thermal property was calculated using the temperature data shown in DTN: SN0206F3504502.011 (Reference 2.2.53) from an elapsed time of 2.665 days through 28.63 days.

Table 6-17 and Table 6-18 present analytical estimations of thermal conductivity for the RHH and non-RHH lithostratigraphic zones, respectively. A comprehensive study of the rock mass thermal conductivity based on the three-dimensional cubic simulation (Reference 2.2.38) and the parallel simulation (Reference 2.2.64) is presented in *Thermal Conductivity of the Potential Repository Horizon* (Reference 2.2.15, Section 6.1.7).

Table 6-17 Rock Mass Thermal Conductivity for RHH Lithostratigraphic Zones

Litho-stratigraphic Zone	Dry Bulk Thermal Conductivity (W/m-K)		Wet Bulk Thermal Conductivity (W/m-K)		Dry Matrix Thermal Conductivity (W/m-K)		Wet Matrix Thermal Conductivity (W/m-K)	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Tptpul	1.16	0.164	1.76	0.168	1.35	0.264	2.02	0.248
Tptpmn	1.39	0.184	2.06	0.177	1.46	0.269	2.13	0.252
Tptpll	1.24	0.134	1.87	0.142	1.4	0.264	2.07	0.246
Tptpln	1.44	0.126	2.11	0.126	1.54	0.291	2.2	0.276

Sources: Reference 2.2.23, Table 6-90 for matrix thermal conductivity and Reference 2.2.46 for bulk thermal conductivity

Notes: The bulk thermal conductivity values are based on harmonic analysis presented in DTN MO0612MEANTHER.000 (Reference 2.2.46).

Table 6-18 Rock Mass Thermal Conductivity for Non-RHH Lithostratigraphic Zones

Lithostratigraphic Zone	Dry Matrix Thermal Conductivity (W/m-K)		Wet Matrix Thermal Conductivity (W/m-K)	
	Mean	SD	Mean	SD
Crystal-Rich Tiva/Post-Tiva	1.3	0.231	1.81	0.195
Tpcp	1.3	0.231	1.81	0.195
TpcLD	1.3	0.231	1.81	0.195
Tpcpv3	0.688	0.229	0.796	0.251
Tpcpv2	0.49	0.158	1.06	0.146
Tpcpv1	0.49	0.158	1.06	0.146
Tpbt4	0.49	0.158	1.06	0.146
Yucca	0.49	0.158	1.06	0.146
Tpbt3_dc	0.49	0.158	1.06	0.146
Pah	0.49	0.158	1.06	0.146
Tpbt2	0.49	0.158	1.06	0.146
Tptrv3	0.49	0.158	1.06	0.146
Tptrv2	0.49	0.158	1.06	0.146
Tptrv1	0.688	0.229	0.796	0.251
Tptrn	1.3	0.231	1.81	0.195
Tptrl	1.3	0.231	1.81	0.195
Tptf	1.3	0.231	1.81	0.195
Tptpv3	0.688	0.229	0.796	0.251
Tptpv2	0.49	0.158	1.06	0.146
Tptpv1	0.49	0.158	1.06	0.146
Tpbt1	0.49	0.158	1.06	0.146
Calico	0.595	0.112	1.26	0.141

Source: SN0303T0503102.008 (Reference 2.2.57)

6.6.3.2 Coefficient of Thermal Expansion

The rock mass CTE was calculated from multi-point borehole extensometer (MPBX) data of the DST boreholes HD-81-MPBX1 and HD-82-MPBX2 and the results are summarized in Table 6-19.

Table 6-19 Rock Mass Thermal Expansion Coefficients from DST

Location	Coefficients of Thermal Expansion, 10^{-6}/°C						
	25-50	50-75	75-100	100-125	125-150	150-175	175-200
HD-81-MPBX1, Anchor 4- 5	1.94	3.27	4.61	3.98	7.02	9.47	12.55
HD-81-MPBX1, Anchor 5- 6	3.65	1.19	0.46	4.37	7.04	10.34	NA
HD-82-MPBX2, Anchor 2- 3	0.48	2.78	6.84	4.89	7.21	8.40	NA
HD-82-MPBX2, Anchor 3- 4	2.82	1.36	4.52	6.12	8.15	10.23	NA
HD-82-MPBX2, Anchor 4- 5	0.55	3.31	4.66	6.17	7.81	9.79	NA
HD-82-MPBX2, Anchor 5- 6	2.76	2.57	4.03	0.85	7.38	10.60	NA
Average	2.03	2.41	4.19	4.40	7.43	9.80	12.55
SD	1.29	0.93	2.07	1.95	0.46	0.80	NA
Average (no outliers)	2.03	2.41	4.45	5.11	7.43	9.80	12.55
SD (no outliers)	1.29	0.93	0.29	1.00	0.46	0.80	NA

Source: SN0407F3912298.060 (Reference 2.2.60)

Notes: DST MPBX data through 1/14/2002
NA: Not available

Below boiling, the rock mass CTE ranges from 2.0×10^{-6}/°C to 4.5×10^{-6}/°C and as the temperatures approach 200°C, the rock mass CTE values approach the in situ values, with a maximum rock mass CTE of 12.55×10^{-6}/°C in the highest temperature range.

6.6.3.3 Heat Capacity

The in situ tests for the rock mass heat capacity were performed in the ECRB Cross Drift for the Tptpll zone. The results of these tests are summarized in Table 6-20.

Table 6-20 Summary of Volumetric Heat Capacity from ECRB Cross Drift Thermal K Tests (Tptpll)

ECRB Cross-Drift Thermal K Test 1 (Two-Hole Test)	ECRB Cross-Drift Thermal K Test 2 (Six-Hole Test)		ECRB Cross-Drift Thermal K Test 3 (Three-Hole Test)	
Volumetric Heat Capacity (J/m^3K)	Borehole	Volumetric Heat Capacity (J/m^3K)	Borehole	Volumetric Heat Capacity (J/m^3K)
2.13E+06[a] or 2.15E+06[b]	TMK6	1.97E+06	TMK10	1.96E+06
	TMK7	1.95E+06	TMK11	2.01E+06
	TMK8	2.30E+06		
Average: 2.06E+06 J/m^3K.				

Sources: References 2.2.54, 2.2.55, and 2.2.56

Notes: [a] Single value of each thermal property was calculated using all the temperature data shown in DTN: SN0206F3504502.011 (Reference 2.2.53).

[b] A single value of each thermal property was calculated using the temperature data shown in DTN: SN0206F3504502.011 (Reference 2.2.53) from an elapsed time of 2.665 days through 28.63 days.

The mean values of rock mass volumetric heat capacity range from 1.95×10^6 to 2.30×10^6 $J/m^3 \cdot K$ and are averaged to 2.06×10^6 $J/m^3 \cdot K$. Using bulk density of the Tptpll rock as 1,979 kg/m^3 (Reference 2.2.59), the averaged rock mass heat capacity is 1,039 J/kg-K.

Table 6-21 and Table 6-22 present the summary of rock grain heat capacities and rock mass heat capacity from analytical estimation, respectively. The rock grain heat capacity may be intended to be used in simulations and analyses that explicitly account for the thermodynamic effects of water within the rock porosity, while rock mass heat capacity is intended to be used in the simulations and analyses that do not explicitly account for these thermodynamic effects, particularly boiling.

Table 6-21 Average Rock Grain Heat Capacities for Lithostratigraphic Zones

Lithostratigraphic Zone	Rock Grain Heat Capacity, J/kg K,			
	25-325 °C	25-94 °C	95-114 °C	115-325 °C
Tpc_un	930	790	870	990
Tpcpv3-Tpcpv2	950	830	900	1,000
PTn	960	840	900	1,000
Tptrv1	950	840	900	990
Tptrn-Tptrl-Tptf	930	780	870	990
Tptpul	930	780	870	990
Tptpmn	930	780	870	990
Tptpll	930	780	870	990
Tptpln	930	780	870	990
Tptpv3	980	860	930	1,020
Tptpv2	980	860	930	1,020
Tptpv1-Tpbt1	1,080	950	1,020	1,120
Tac4	1,070	930	1,010	1,120
Tac3	1,070	930	1,010	1,120
Tac2	1,070	940	1,010	1,120
Tac1	1,070	940	1,010	1,120
Tacbt	1,020	880	950	1,070

Source: DTN: SN0307T0510902.003 (Reference 2.2.58)

Note: Data below Tacbt1 zone are not presented.

Table 6-22 Average Rock Mass Heat Capacities for Lithostratigraphic Zones

Lithostratigraphic Zone	Rock Mass Heat Capacity, J/kg K		
	25-94 °C	95-114 °C	115-325 °C
Tpc_un	913	2,958	990
Tpcpv3-Tpcpv2	1,245	8,393	1,000
PTn	1,291	9,116	1,000
Tptrv1	894	1,815	990
Tptrn-Tptrl-Tptf	891	2,740	990
Tptpul	1,108	8,110	930
Tptpmn	1,080	6,322	930
Tptpll	1,108	7,840	930
Tptpln	1,079	6,340	930
Tptpv3	907	1,736	1,020
Tptpv2	1,095	5,082	1,020
Tptpv1-Tpbt1	1,245	6,438	1,120
Tac4	1,398	9,804	1,120
Tac3	1,398	9,804	1,120
Tac2	1,407	9,804	1,120
Tac1	1,407	9,804	1,120
Tacbt	1,247	7,622	1,070

Sources: Reference 2.2.58 for Non-RHH unit (Not shaded) and Reference 2.2.49 for RHH unit (Shaded)

6.7 ROCK JOINTS/FRACTURES

The fractured rock parameters are summarized in Table 6-23 to Table 6-26. These fractured rock parameters are based on the results of rotary shear tests and are obtained from the SGPR Rev. 00 (Reference 2.2.23).

Table 6-23 Summary Statistics of Fracture Strength from Rotary Shear Tests

Lithostratigraphic Zone	Temp.	Count	Peak Cohesion (MPa)	Peak Friction Angle (degrees)	Peak CC*
Tpcpll	Room	1	NA	46	NA
Tpcpln	Room	1	NA	46	NA
Tptrn	Room	13	1.75	37	0.84
Tptrl	Room	1	NA	55	NA
Tptpul	Room	1	NA	NA	NA
Tptpmn	Room	3	0[a]	51	0.97
Tptpmn	175 °C	6	1.87	40	1.0
Tptpll	Room	5	1.30	40	0.93
Tptpln	Room	5	1.61	35	0.87
Tptpln	175 °C	2	0.72	48	1.0
Tac	Room	4	1.69	38	0.83

Source: Reference 2.2.23, Table 6-48

Notes: NA: Not Available

* Refers to the correlation coefficient of a linear fit through the data.

[a] Value set to zero when the linear fit appears negative value.

Table 6-24 Summary Statistics of Peak Dilation Angle from Rotary Shear Test

Lithostratigraphic Zone	Temp.	Count	Mean (degrees)	SD	Median (degrees)	Minimum (degrees)	Maximum (degrees)
Tpcpll	Room	1	10.22	NA	10.22	10.22	10.22
Tpcpln	Room	1	7.35	NA	7.35	7.35	7.35
Tptrn	Room	12	7.21	5.27	6.38	1.19	16.02
Tptrl	Room	1	11.05	NA	11.05	11.05	11.05
Tptpul	Room	1	8.95	NA	8.95	8.95	8.95
Tptpmn	Room	3	11.00	8.74	14.20	1.11	17.7
Tptpmn	175 °C	6	13.68	9.29	15.65	0	24.5
Tptpll	Room	5	14.33	9.55	15.70	1.23	27.2
Tptpln	Room	5	17.82	9.42	15.10	8.48	33.4
Tptpln	175 °C	2	14.80	4.95	14.80	11.3	18.3
Tac	Room	4	14.04	8.54	13.50	4.44	24.7

Source: Reference 2.2.23, Table 6-49

Note: NA: Not Available

Table 6-25 Summary Statistics of the Fracture Normal Stiffness from Rotary Shear Tests

RHH Lithostratigraphic Zone	Rotary Rock Joint Tangent Normal Stiffness at 5 MPa (MPa/mm):						
	Temp.	Count	Mean	SD	Median	Minimum	Maximum
Tptpul/ll	Room	6	268	365	115	65	1,000
Tptpmn/ln	Room	4	94	22	98	65	115
Tptpmn/ln	175 °C	6	74	29	83	35	110

Source: Reference 2.2.23, Table 6-53

Table 6-26 Summary Statistics of the RHH Fracture Shear Stiffness from Rotary Shear Test

RHH Lithostratigraphic Zone	Rotary Rock Joint Maximum Tangent Shear Stiffness (MPa/mm):						
	Temp.	Count	Mean	SD	Median	Minimum	Maximum
Tptpul/ll	Room	6	168	132	160	30	400
Tptpmn/ln	Room	8	97	55	108	23	180
Tptpmn/ln	175 °C	8	56	39	38	18	115

Source: Reference 2.2.23, Table 6-54

6.8 TIME HISTORIES OF ROCK TEMPERATURES

Time histories of rock temperatures are listed in Table 6-27. These values reflect the effect of forced continuous ventilation at 15 m^3/s during the 50-year period and based on thermal load of 2.0 kW/m from the FLUENT output files associated with the ventilation model (Reference 2.2.29).

Table 6-27 Time Histories of Rock Temperatures

Time (years)	Temperatures (°C)		
	Drift Wall	50-m Above Drift Center	50-m Below Drift Center
0	24.5	24	26
0.08	87	24	26
1	98	24	26
2	101	24	26
5	103	24	26
10	97	25	26
30	78	29	30
50	66	31	33
70	58	33	34
100	50	34	36

Source: Reference 2.2.29, Figures 7 and 8

6.9 AVERAGE SURFACE TEMPERATURE AND IN-SITU ROCK THERMAL GRADIENT

The average surface temperature at six borehole locations (USW NRG-7A, USW NRG-6, UE-25 UZ-#4, UE-25 UZ-#5, UE-25 UZ-7a, and USW SD-12) is ranged from 11 to 28 °C with an average of about 19 °C (Reference 2.2.41). The in-situ rock thermal gradients are estimated based on the borehole temperature data from DTN: LB0708WTTEMDAT.001 (Reference 2.2.41) and are listed in Table 6-28. It should be noted that only the boreholes located in the vicinity of the proposed repository are used in the estimation of the rock thermal gradient, which include USW NRG-7A, USW NRG-6, USW UZ-7a, UE-25 WT #18, USW WT-2, USW H-1, USW H-3, USW H-4, USW H-5, USW UZ-1, USW G-1, USW G-4, and USW SD-12. Summary of in-situ rock thermal gradient estimates are presented in Attachment I (Table I-1).

Table 6-28 In-Situ Rock Thermal Gradient

Depth (m)	In Situ Thermal Gradient (°C/m)
0-150	0.020
150-400	0.018
400-600	0.030

Source: LB0708WTTEMDAT.001 (Reference 2.2.41)

Notes: There are 40 boreholes contained temperature data in the source DTN and only the 13 boreholes located in the vicinity of the proposed repository are used in the rock thermal gradient estimates. These boreholes include USW NRG-7A, USW NRG-6, USW UZ-7a, UE-25 WT #18, USW WT-2, USW H-1, USW H-3, USW H-4, USW H-5, USW UZ-1, USW G-1, USW G-4, and USW SD-12.

6.10 THERMAL AND MECHANICAL PROPERTIES OF GROUND SUPPORT MATERIALS

Ground support materials during LA design include stainless steels, carbon steel, cement grout, shotcrete, and concrete.

6.10.1 Stainless Steel

Stainless steels, such as 316L or equivalent, conforming to the requirements of ASTM A 276 (Reference 2.2.6) are considered as ground support material in emplacement drifts and emplacement drift turnouts (Reference 2.2.21). Table 6-29 lists thermal and mechanical properties for stainless steel.

Table 6-29 Stainless Steel Properties

Parameter	Value	Source
Density (kg/m^3)	8,000	Reference 2.2.5, Table 21, p. 871
Modulus of Elasticity (GPa)	193	Reference 2.2.5, Table 21, p. 871
Poisson's Ratio	0.3	Reference 2.2.42, p. 9-8.
Tensile Strength (MPa)	620	Reference 2.2.6, Table 2, p. 4
Coefficient of Thermal Expansion (1/°C)	15.9×10^{-6} (a) $16.2\text{x}10^{-6}$ (b)	Reference 2.2.5, Table 21, p. 871 for temperature ranges of (a) 0 to 100 °C and (b) 0 to 315 °C.
Thermal Conductivity (W/m-K)	16.2	Reference 2.2.5, p. 871, at a temperature 100 °C
Heat Capacity (J/kg·K)	500	Reference 2.2.5, p. 871

6.10.2 Carbon Steel

Carbon steel confirming to the requirements of ASTM A 36 (Reference 2.2.7) and ASTM A 588 (Reference 2.2.8) are considered as ground support material in most non-emplacement openings (Reference 2.2.22). Table 6-30 lists thermal and mechanical properties for carbon steel.

Table 6-30 Carbon Steel Properties

Parameter	Value	Source
Density (kg/m^3)	7,859	Reference 2.2.4, p. 145.
Modulus of Elasticity (GPa)	200	Reference 2.2.3, p. 1-117 (29,000 /145)
Poisson's Ratio	0.3	Reference 2.2.42, p. 9-8.
CTE (1/°C)	11.7×10^{-6}	For temperature range from 46 to 66 °C (Reference 2.2.42, Table 9.1)
Thermal Conductivity (W/m-K)	50.67	Reference 2.2.5, p. 197 (Average value for AISC-SAE grade 1025 for temperature range of 0 to 200 °C)
Heat Capacity (J/kg·K)	500	Reference 2.2.5, p. 871

6.10.3 Cement Grouts

Cement grout will be used in conjunction with rock bolts in non-emplacement openings. Cement grout mix design for rock bolts were developed during SR design which included 9 cement grout mix designs. The cement grout properties presented in Table 6-31 are based on the Mix Design # 3 which consists of 90 % (by weight) Type K cement, 10 % silica fume, 2 % superplasicizer, and water-cement ratio of 0.4.

Table 6-31 Physical, Thermal and Mechanical Properties for Cement Grout

Parameters	Value	Source
Density (kg/m^3)	1,545	MO0201THERMGRT.000 (Reference 2.2.43); Averaged over a range of temperature from 25 to 100 ºC.
Dry Bulk Density (kg/m^3)	1,500	MO0204EBSPYMPG.017 (Reference 2.2.44)
Thermal Conductivity (W/m-K)	0.67	MO0201THERMGRT.000 (Reference 2.2.43); Averaged over a range of temperature from 25 to 100 ºC.
Specific Heat (J/kg·K)	1,459.6	MO0201THERMGRT.000 (Reference 2.2.43); Averaged over a range of temperature from 25 to 100 ºC.
Mean Coefficient of Linear Thermal Expansion (10^{-6}/ºC)	9.37 at 25 ºC, 10.62 at 50 ºC, 12.22 at 75 ºC, and 13.47 at 100 ºC	MO0210THERMECG.000 (Reference 2.2.45)
Modulus of Elasticity (GPa) at 28 days	20.1	MO0204EBSPYMPG.017 (Reference 2.2.44); converted from 2.91x10^6 psi.
Poisson's Ratio at 28 days	0.12	MO0204EBSPYMPG.017 (Reference 2.2.44)
Cohesion (MPa) at 28 days	27.6	MO0204EBSPYMPG.017 (Reference 2.2.44); converted from 4,000 psi.
Angle of Internal Friction (degrees)	17.5	MO0204EBSPYMPG.017 (Reference 2.2.44)
UCS (MPa) at 28 days	75.7	MO0204EBSPYMPG.017 (Reference 2.2.44); converted from 10,980 psi.
Tensile Strength (MPa)	6.55	MO0204EBSPYMPG.017 (Reference 2.2.44); converted from 950 psi.

Note: The values presented in this table are based on Mix Design #3 which used in SR design and are considered appropriate for use in ground support design activities.

6.10.4 Shotcrete

Shotcrete will be used in intersections between access main and emplacement turnouts and emplacement drifts and exhaust mains (See Table 6-2). Properties of a shotcrete listed in Table 6-32.

Table 6-32 Shotcrete Properties

Parameter	Value	Source
Modulus of Elasticity (GPa)	29	Based on mean value in Section 1.7 of Reference 2.2.2.
Poisson's Ratio	0.25	Used same as concrete, Reference 2.2.42, p. 6-8.
UCS (MPa)	34.5	Reference 2.2.17, Section 2.02A

Note: The UCS value of 34.5 MPa is based on 5,000 psi.

6.10.5 Concrete

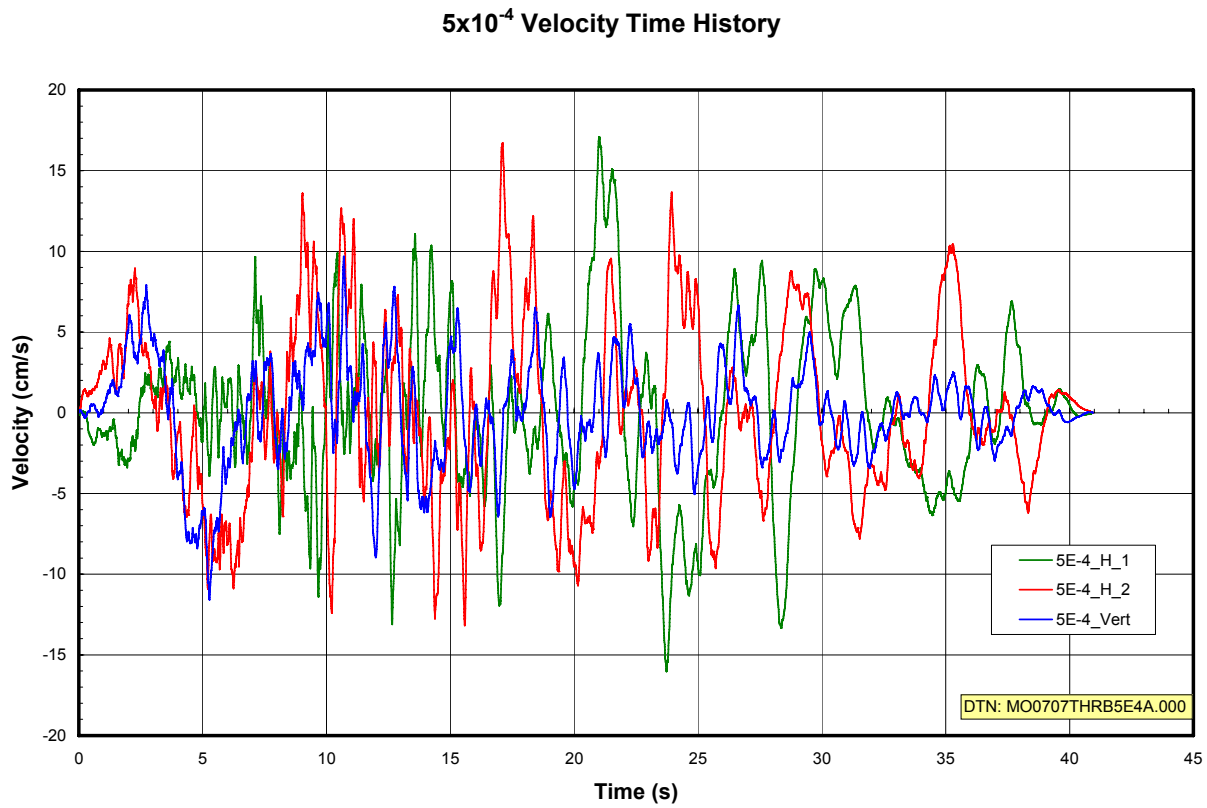
Concrete liner is considered in shaft ground support. Properties of concrete are listed in Table 6-33.

Table 6-33 Thermal and Mechanical Properties for Concrete

Parameter	Value	Source/Remark
Density (kg/m^3)	2,324	Converted from a typical unit weight for concrete 145 lb/ft^3 x 0.454 kg/lb x 35.315 ft^3/m^3 = 2324 kg/m^3 (Reference 2.2.40).
Modulus of Elasticity (GPa)	29	Based on mean value in Section 1.7 of ACI, 506R-05 (Reference 2.2.2).
Poisson's Ratio	0.25	Reference 2.2.42, p. 6-8
Compressive Strength (MPa)	40.0	Converted from concrete strength of 6,000 psi/(145 psi/MPa) = 40 MPa (approximately) (Reference 2.2.40, Chapter 1 page 5, Section "Unit Weight").
Tensile Strength (MPa)	4.0	10% of UCS or 0.1x40.0 MPa = 4.0 MPa
CTE (1/°C)	9.90E-06	Reference 2.2.42, p. 5-13
Allowable Stress (MPa)	26.0	Applied reduction factor (0.65 x 40 MPa = 26 MPa), based on ACI 318-02, Section 9.3.2.2 (Reference 2.2.1).

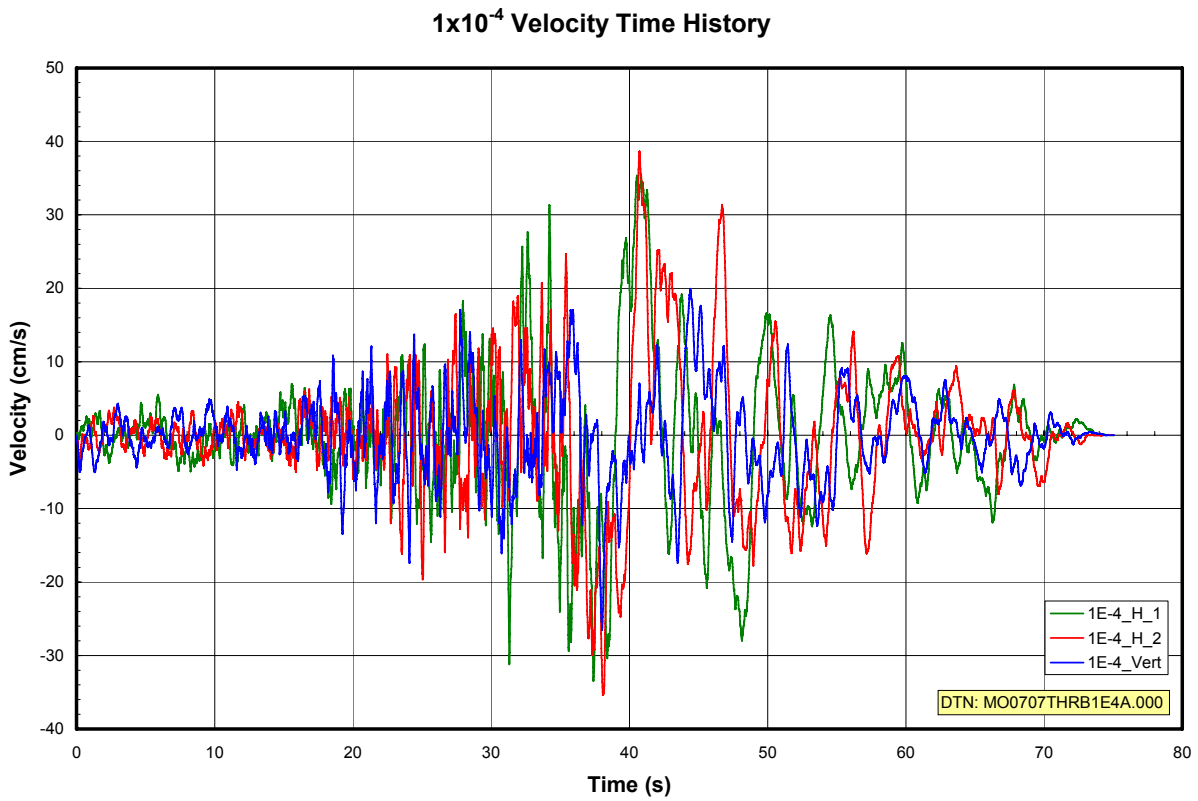
6.11 SEISMIC INPUTS

Seismic velocity histories for the mean annual probability exceedance (APE) of 5×10^{-4} (2,000-year return period, Reference 2.2.48) and 1 x 10^{-4} (10,000-year return period, Reference 2.2.47) are shown in Figure 6-3 and Figure 6-4, respectively.



Source: MO0707THRB5E4A.000 (Reference 2.2.48)

Figure 6-3 Time Histories of Velocity Components of Seismic Motion for Mean APE of 5×10^{-4}



Source: MO0707THRB1E4A.000 (Reference 2.2.47)

Figure 6-4 Time Histories of Velocity Components of Seismic Motion for Mean APE of 1×10^{-4}

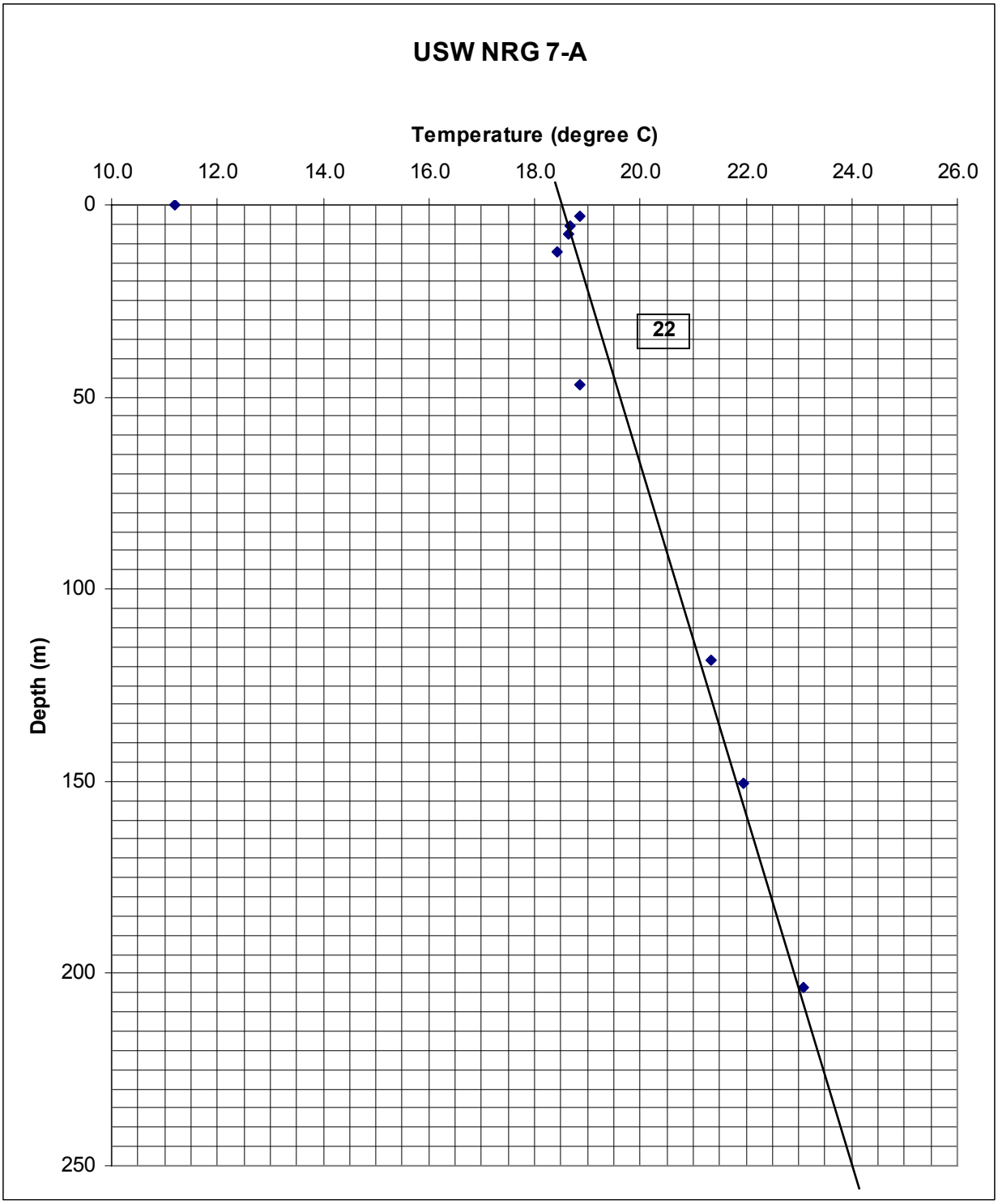
7 RESULTS AND CONCLUSIONS

Section 6 provides input parameters to be used in the ground support design analysis for post-License Application design. The majority of these parameters are obtained from SGPR Rev 00 (Reference 2.2.23) and the TDMS. Parameters not included in this calculation should be justified by the user.

For the purpose of ground support design, the input parameters presented in Section 6 are considered appropriate since the data are current and qualified. It should be noted that this calculation is considered a living document that will be updated as new information on input parameters becomes available.

ATTACHMENT I

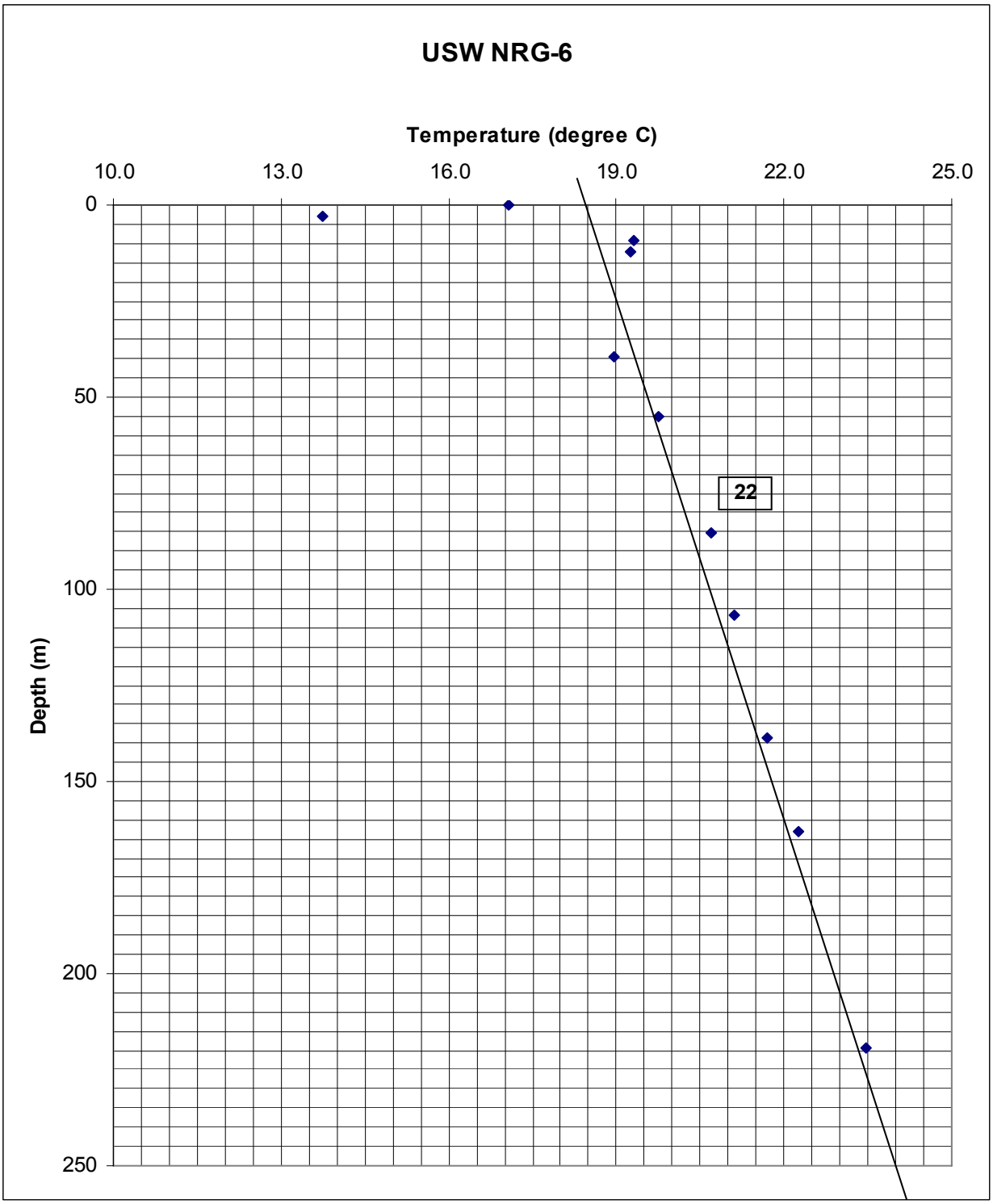
IN-SITU ROCK THERMAL GRADIENT ESTIMATES



Source: LB0708WTTEMDAT.001 (Reference 2.2.41)

Note: The number presented in the figure represents estimated thermal gradient in °/km.

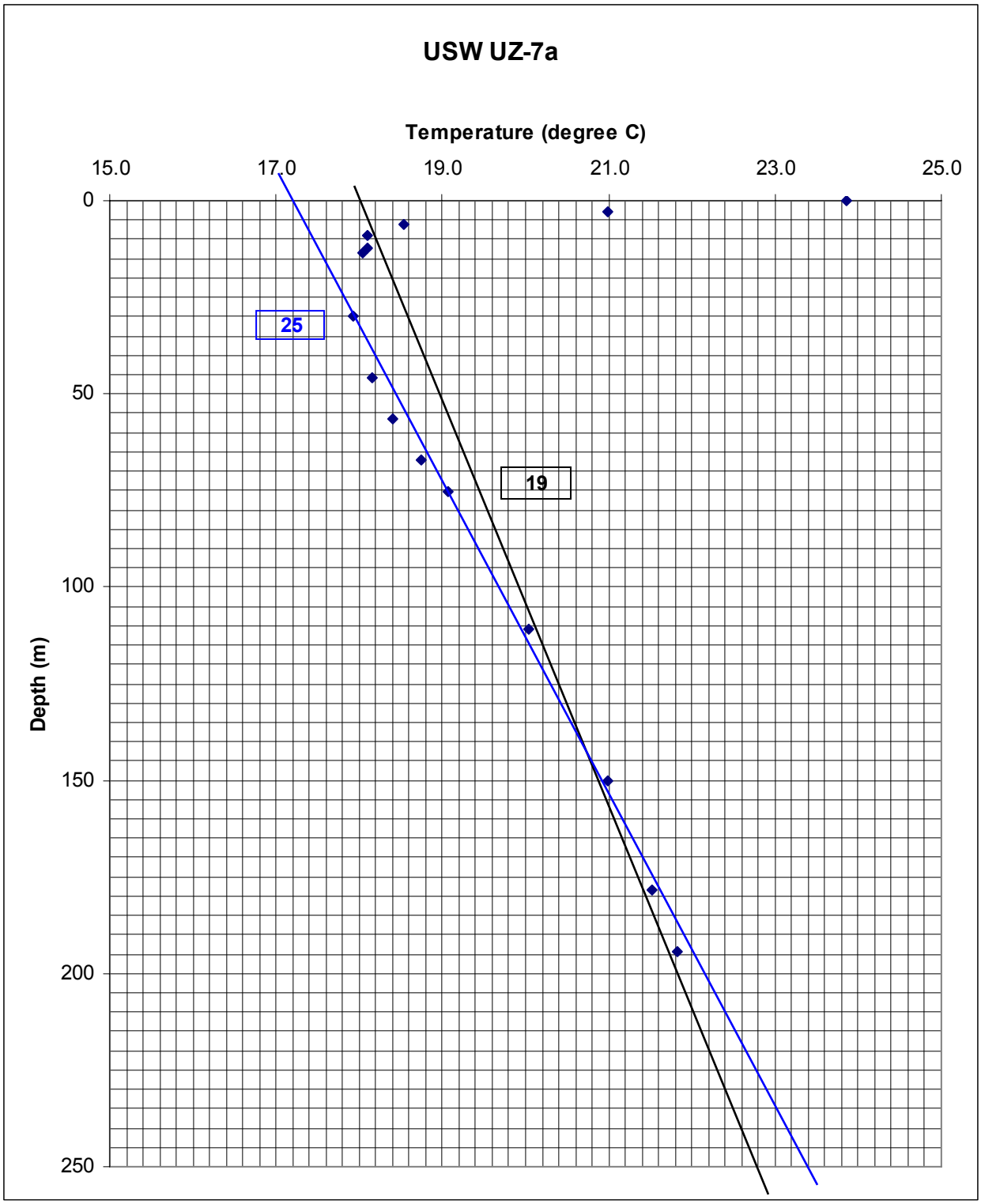
Figure I- 1 Temperature at Borehole USW NRG 7-A



Source: LB0708WTTEMDAT.001 (Reference 2.2.41)

Note: The number presented in the figure represents estimated thermal gradient in °/km.

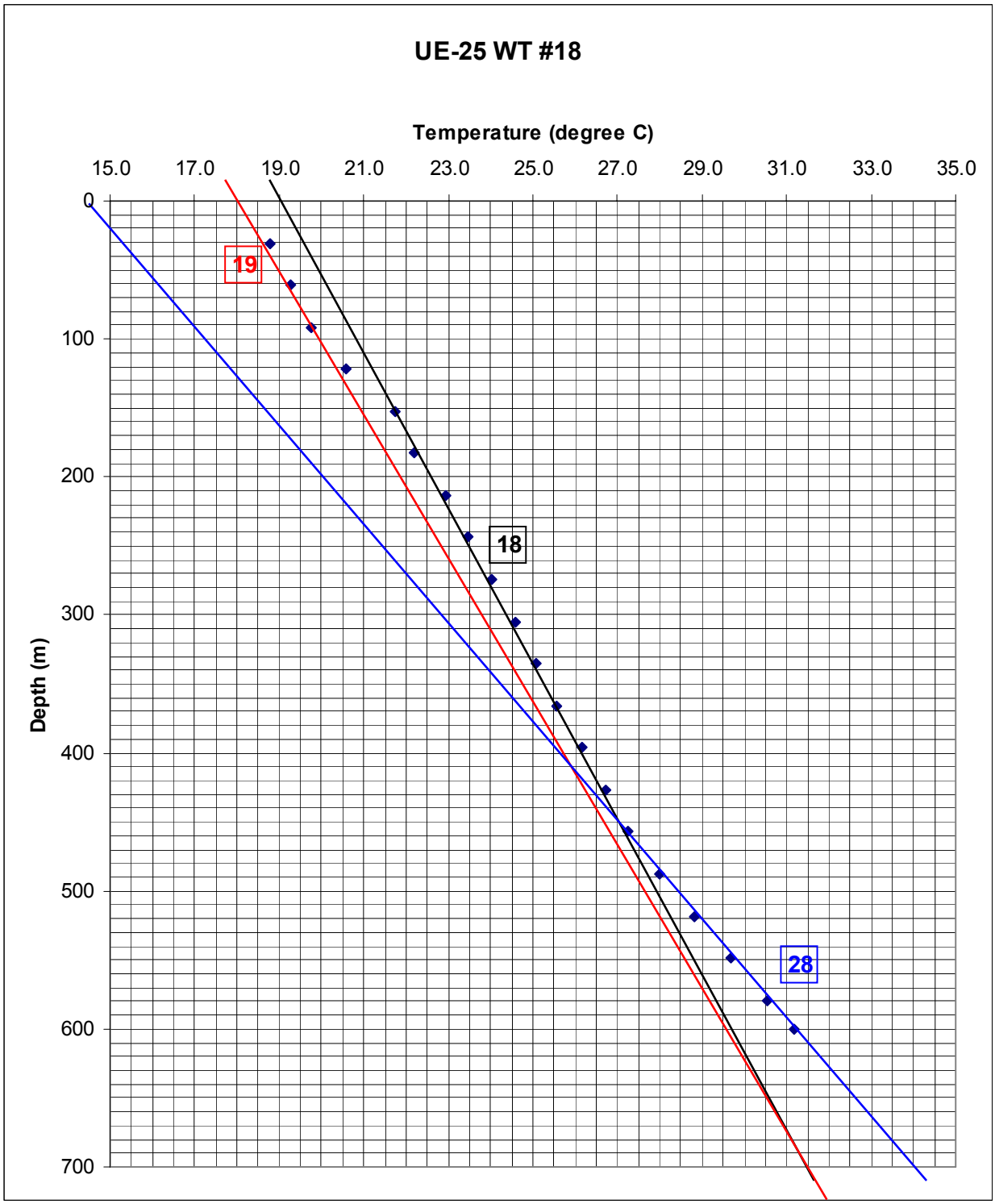
Figure I- 2 Temperature at Borehole USW NRG-6



Source: LB0708WTTEMDAT.001 (Reference 2.2.41)

Note: The number presented in the figure represents estimated thermal gradient in °/km.

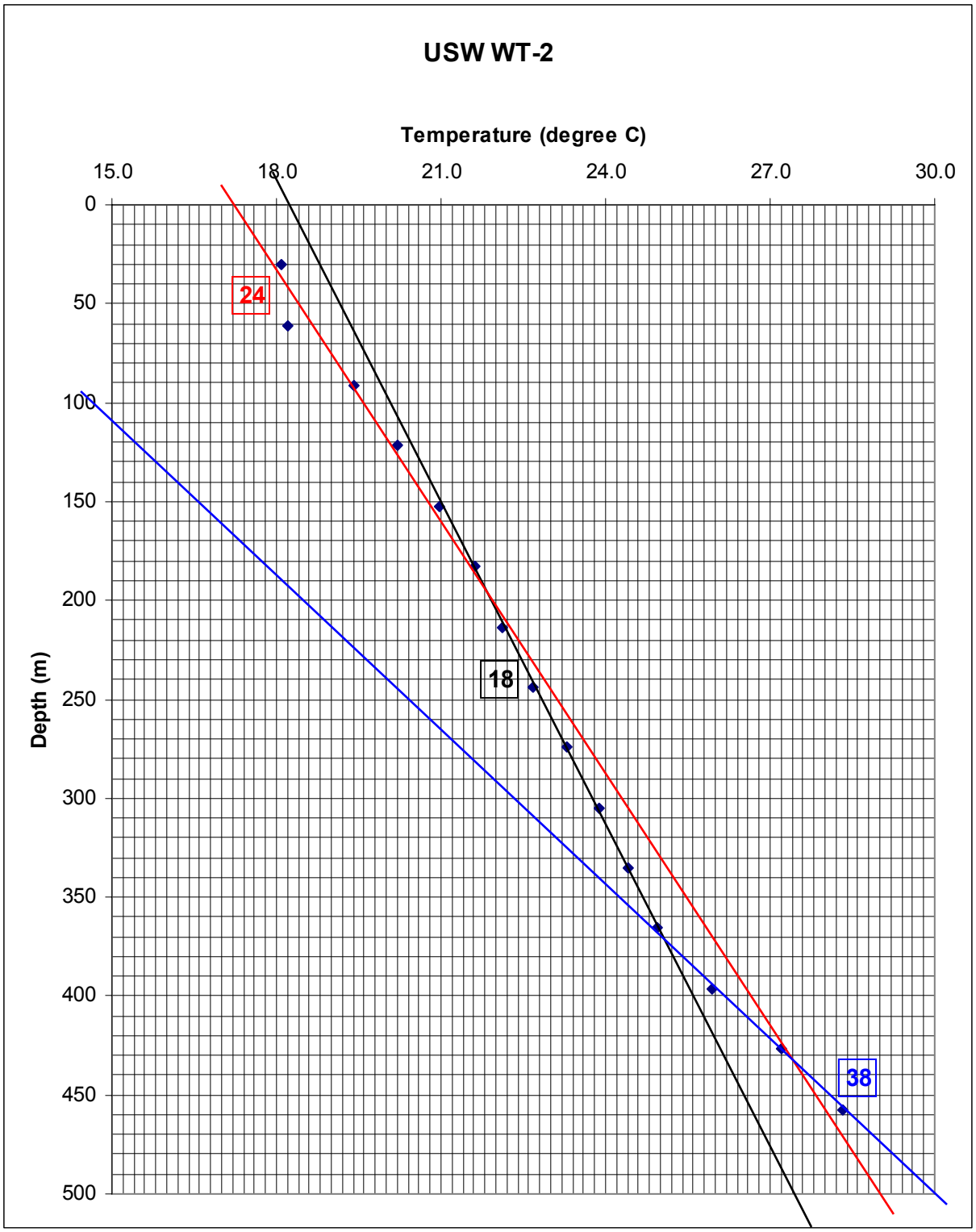
Figure I- 3 Temperature at Borehole USW UZ-7a



Source: LB0708WTTEMDAT.001 (Reference 2.2.41)

Note: The number presented in the figure represents estimated thermal gradient in °/km.

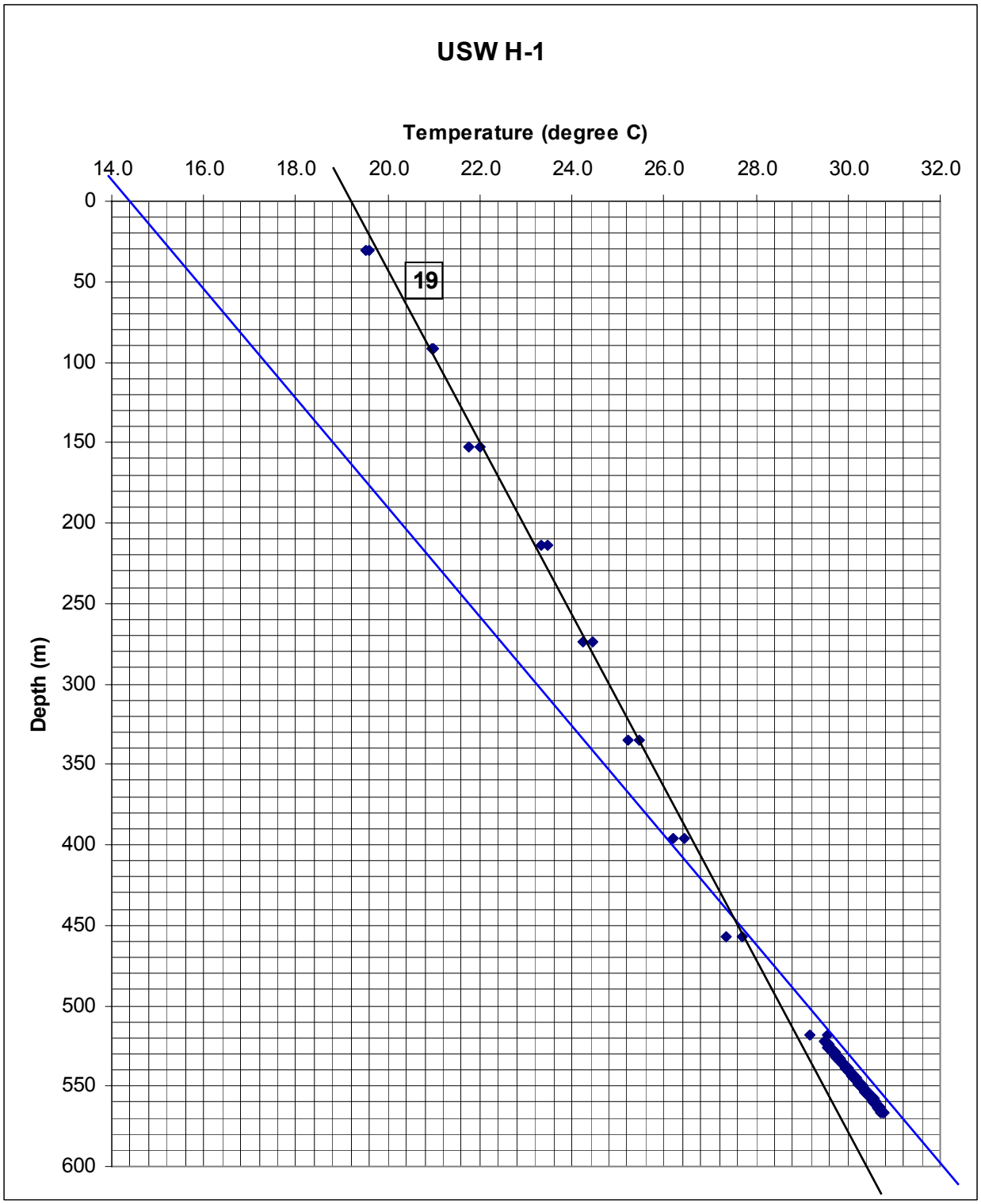
Figure I- 4 Temperature at Borehole UE-25 WT #18



Source: LB0708WTTEMDAT.001 (Reference 2.2.41)

Note: The number presented in the figure represents estimated thermal gradient in °/km.

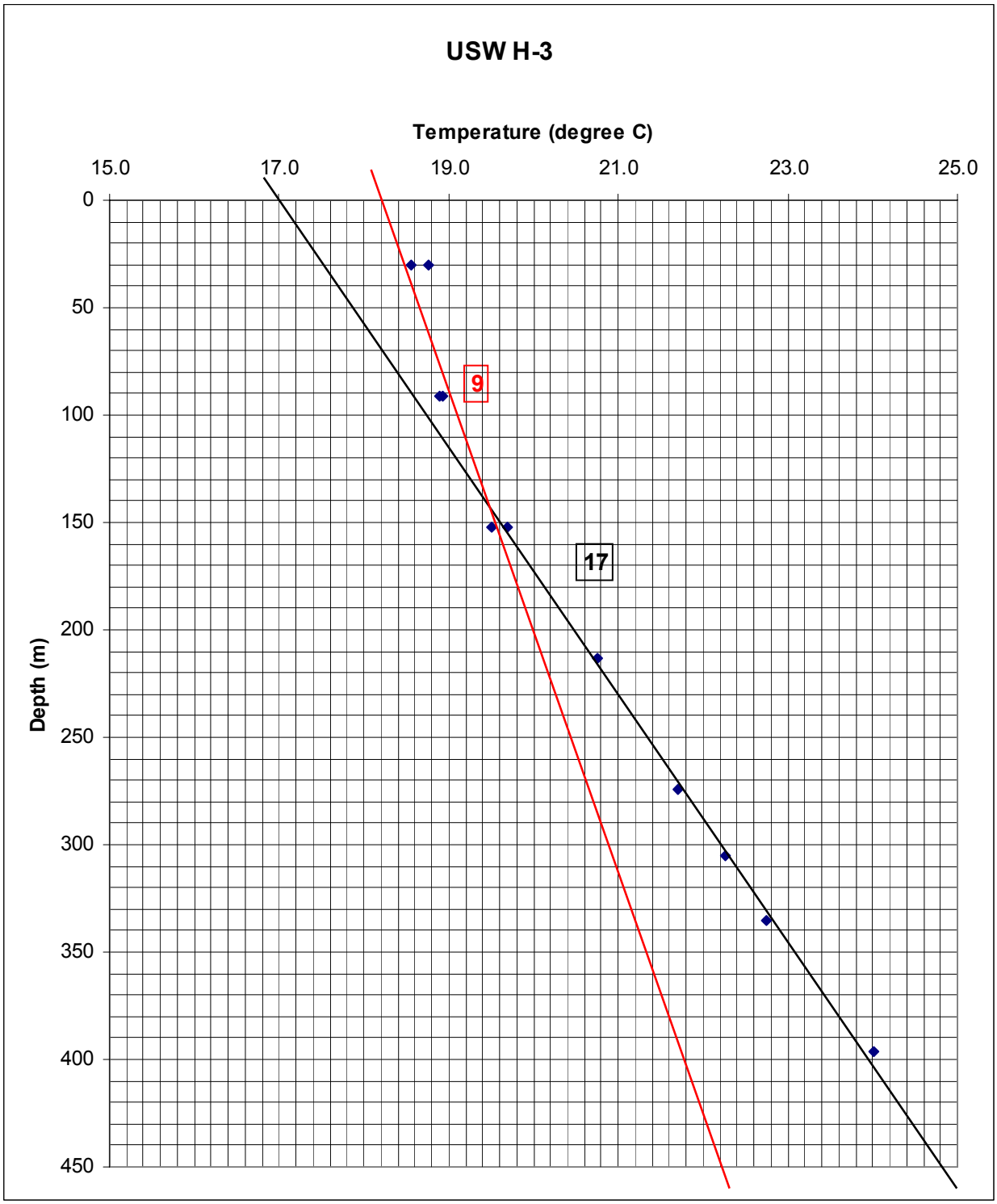
Figure I- 5 Temperature at Borehole USW WT-2



Source: LB0708WTTEMDAT.001 (Reference 2.2.41)

Note: The number presented in the figure represents estimated thermal gradient in °/km.

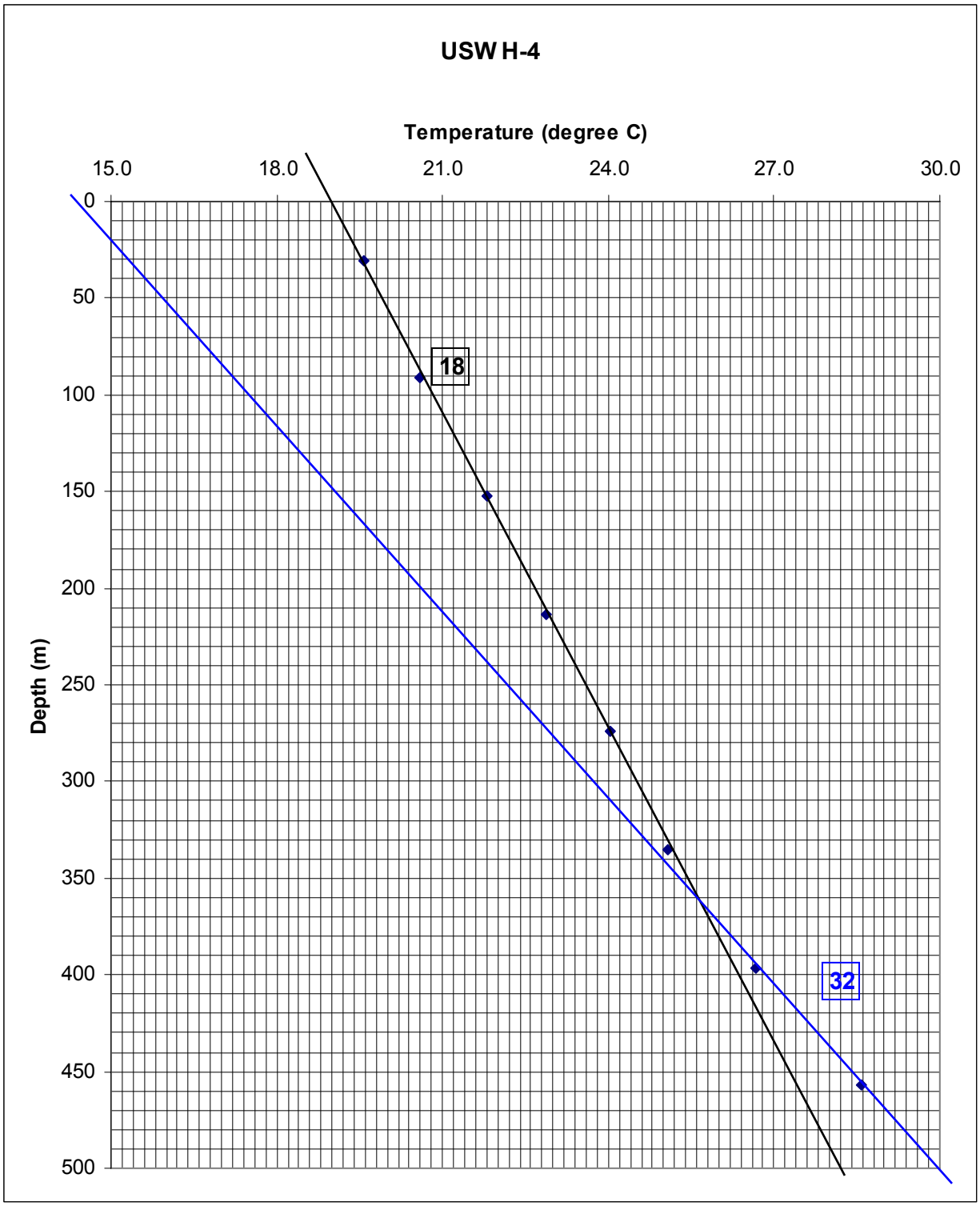
Figure I- 6 Temperature at Borehole USW H-1



Source: LB0708WTTEMDAT.001 (Reference 2.2.41)

Note: The number presented in the figure represents estimated thermal gradient in °/km.

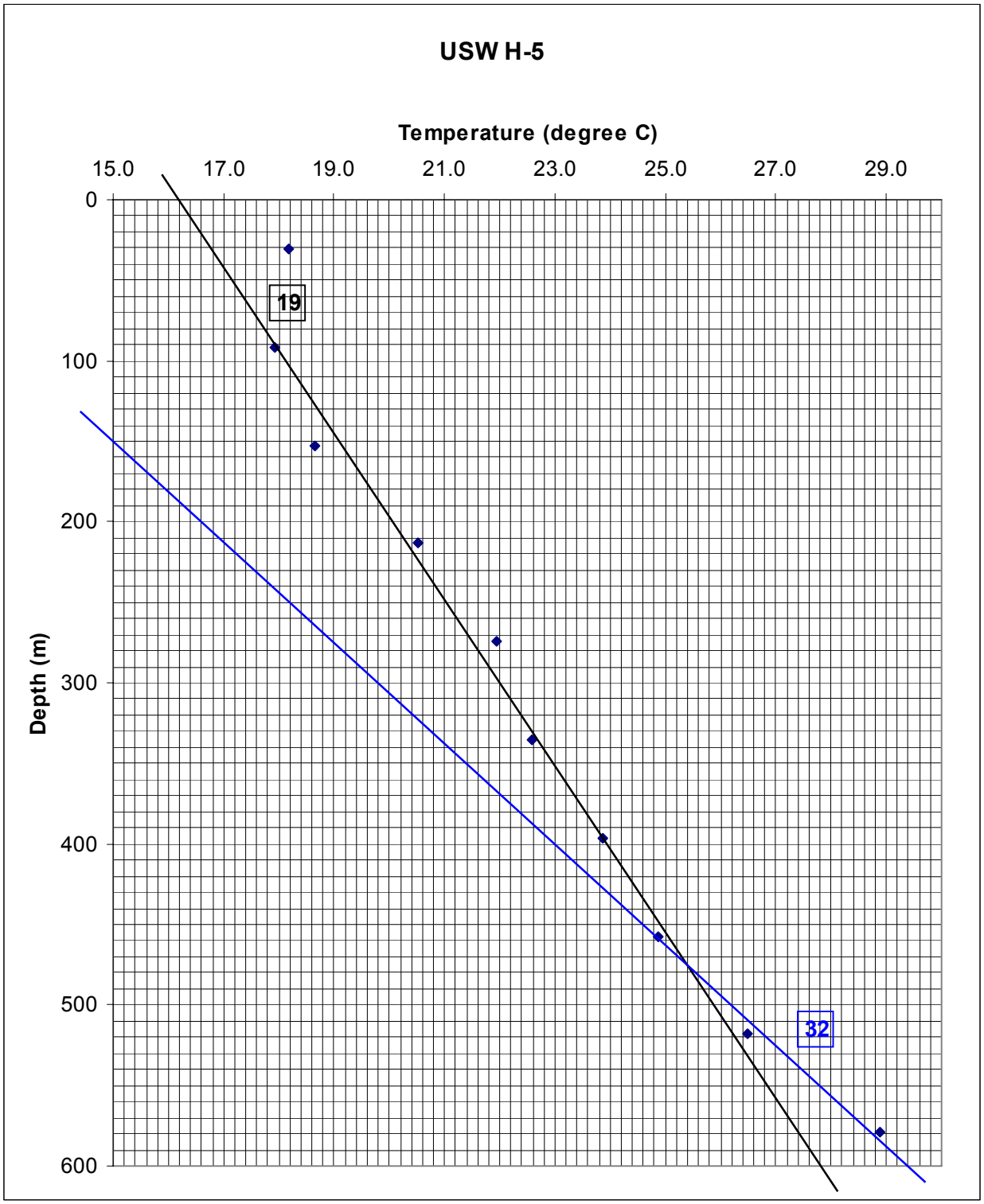
Figure I- 7 Temperature at Borehole USW H-3



Source: LB0708WTTEMDAT.001 (Reference 2.2.41)

Note: The number presented in the figure represents estimated thermal gradient in °/km.

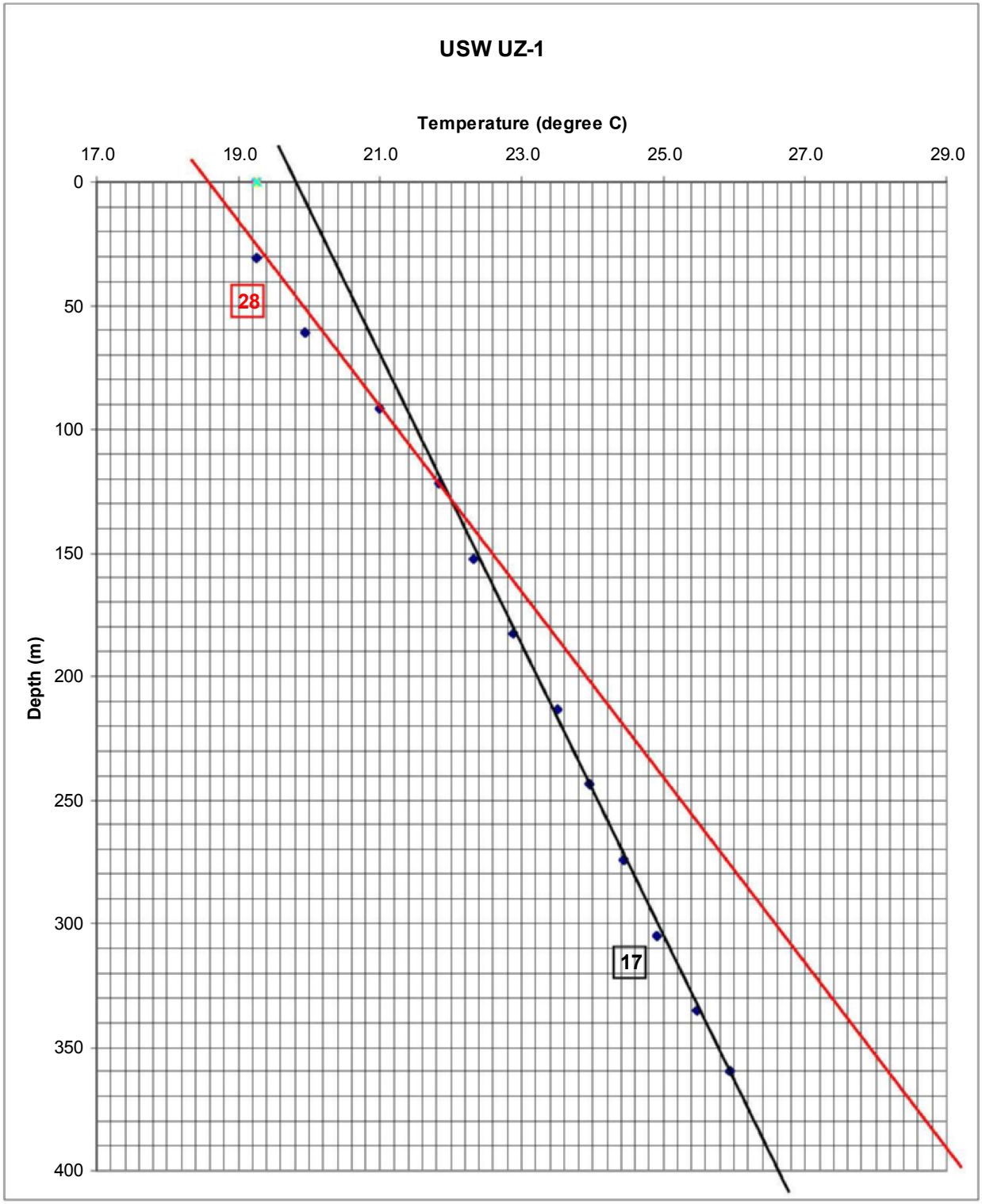
Figure I- 8 Temperature at Borehole USW H-4



Source: LB0708WTTEMDAT.001 (Reference 2.2.41)

Note: The number presented in the figure represents estimated thermal gradient in °/km.

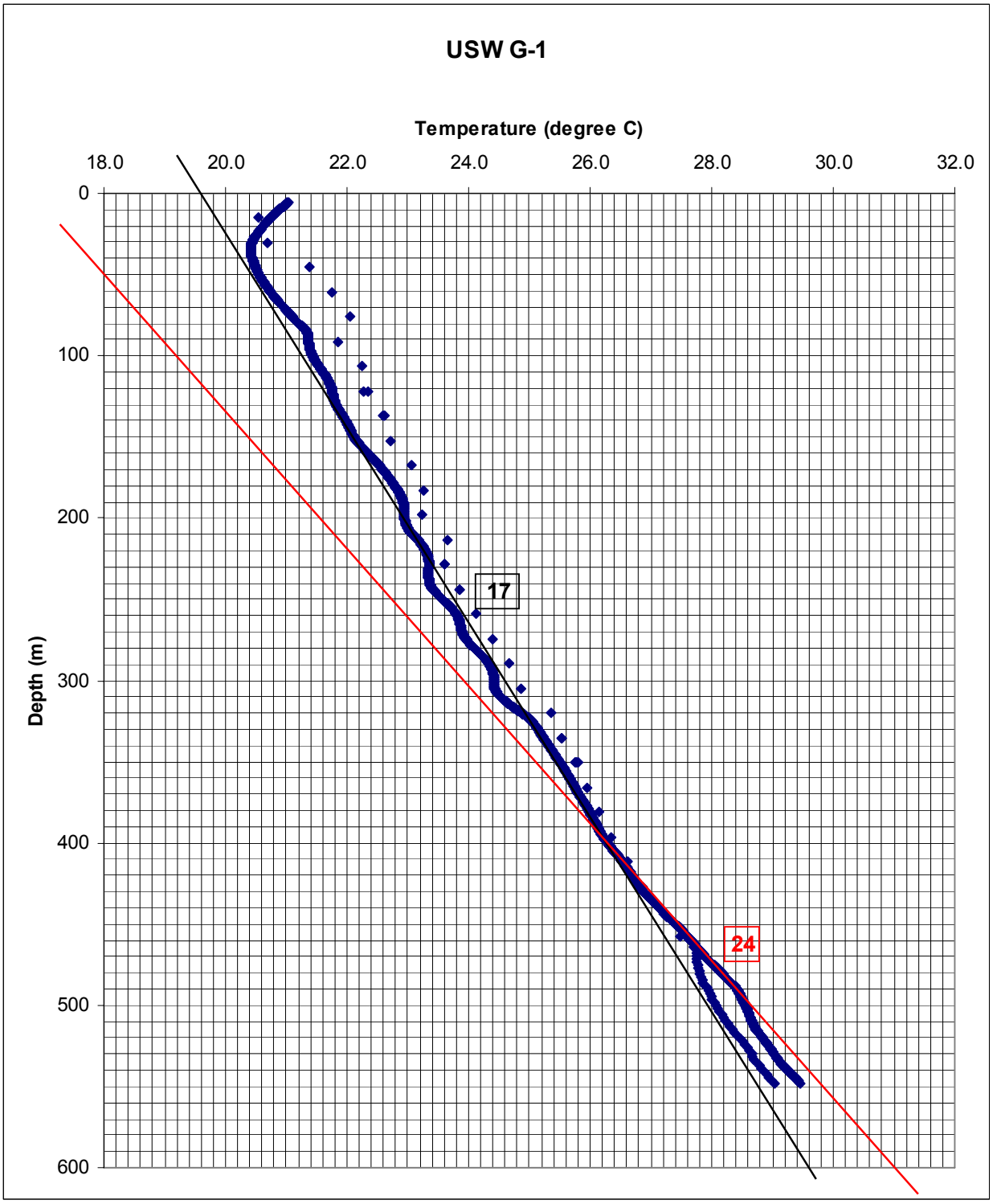
Figure I- 9 Temperature at Borehole USW H-5



Source: LB0708WTTEMDAT.001 (Reference 2.2.41)

Note: The number presented in the figure represents estimated thermal gradient in °/km.

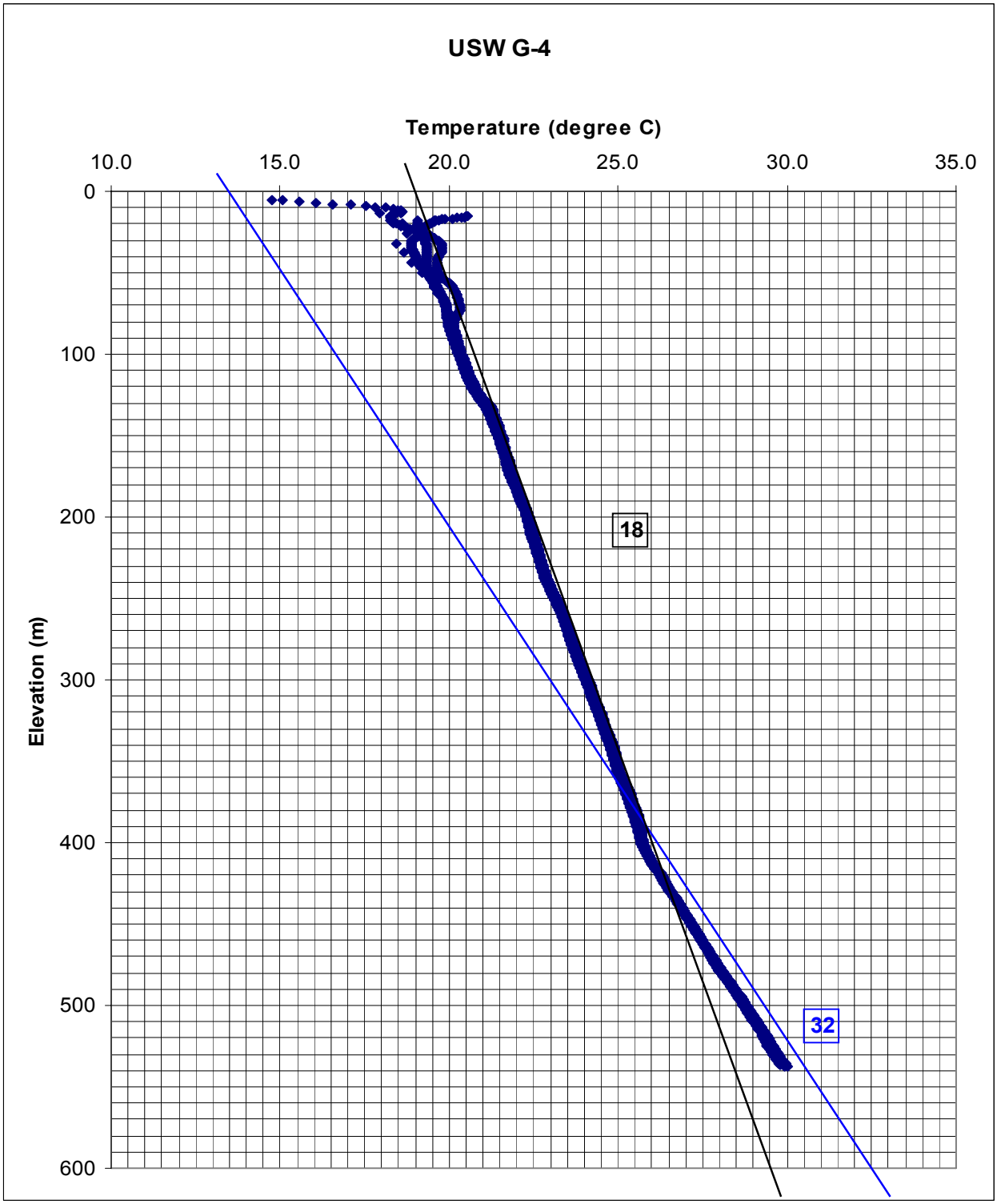
Figure I- 10 Temperature at Borehole USW UZ-1



Source: LB0708WTTEMDAT.001 (Reference 2.2.41)

Note: The number presented in the figure represents estimated thermal gradient in °/km.

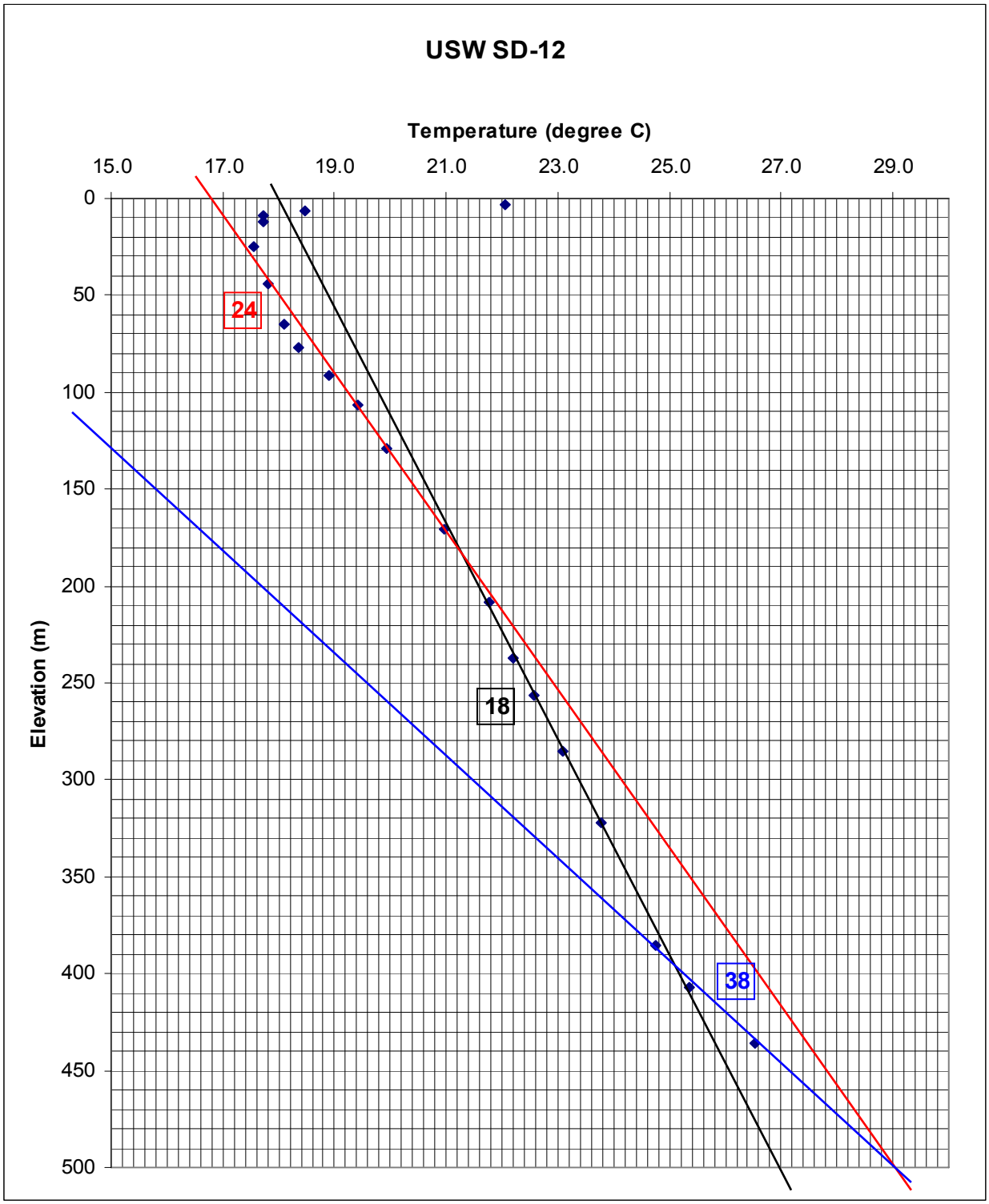
Figure I- 11 Temperature at Borehole USW G-1



Source: LB0708WTTEMDAT.001 (Reference 2.2.41)

Note: The number presented in the figure represents estimated thermal gradient in °/km.

Figure I- 12 Temperature at Borehole USW G-4



Source: LB0708WTTEMDAT.001 (Reference 2.2.41)

Note: The number presented in the figure represents estimated thermal gradient in °/km.

Figure I- 13 Temperature at Borehole USW SD-12

Table I-1 Summary of In-Situ Rock Thermal Gradient (deg C/km)

Borehole	Depth (m)											
	0-50	50-100	100-150	150-200	200-250	250-300	300-350	350-400	400-450	450-500	500-550	550-600
NRG-7A	0.022	0.022	0.022	0.022								
NRG-6	0.022	0.022	0.022	0.022	0.022							
USW UZ-7a		0.025	0.025	0.019								
UE -25 WT #18	0.019	0.019	0.019	0.018	0.018	0.018	0.018	0.018	0.018	0.028	0.028	0.028
WT-2		0.024	0.024	0.018	0.018	0.018	0.018	0.018	0.038	0.038		
USW H-1	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.029	0.029	0.029	0.029
USW H-3	0.009	0.009	0.009	0.017	0.017	0.017	0.017	0.017				
USW H-4		0.018	0.018	0.018	0.018	0.018	0.018	0.032	0.032			
USW H-5			0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.032	0.032	0.032
USW UZ-1	0.028	0.028	0.028	0.017	0.017	0.017	0.017	0.017				
USW G-1		0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.024	0.024	0.024	
USW G-4		0.018	0.018	0.018	0.018	0.018	0.018	0.018	0.032	0.032	0.032	
SD-12		0.024	0.024	0.018	0.018	0.018	0.018	0.018	0.038			
Avg.(deg C/km)	0.020	0.020	0.020	0.019	0.018	0.018	0.018	0.019	0.029	0.031	0.029	0.030
Min (deg C/km)	0.009	0.009	0.009	0.017	0.017	0.017	0.017	0.017	0.018	0.024	0.024	0.028
Max (deg C/km)	0.028	0.028	0.028	0.022	0.022	0.019	0.019	0.032	0.038	0.038	0.032	0.032
Avg. (°/km)	**0-150 m: 0.020**			**150-400 m: 0.018**					**400-600 m: 0.030**			