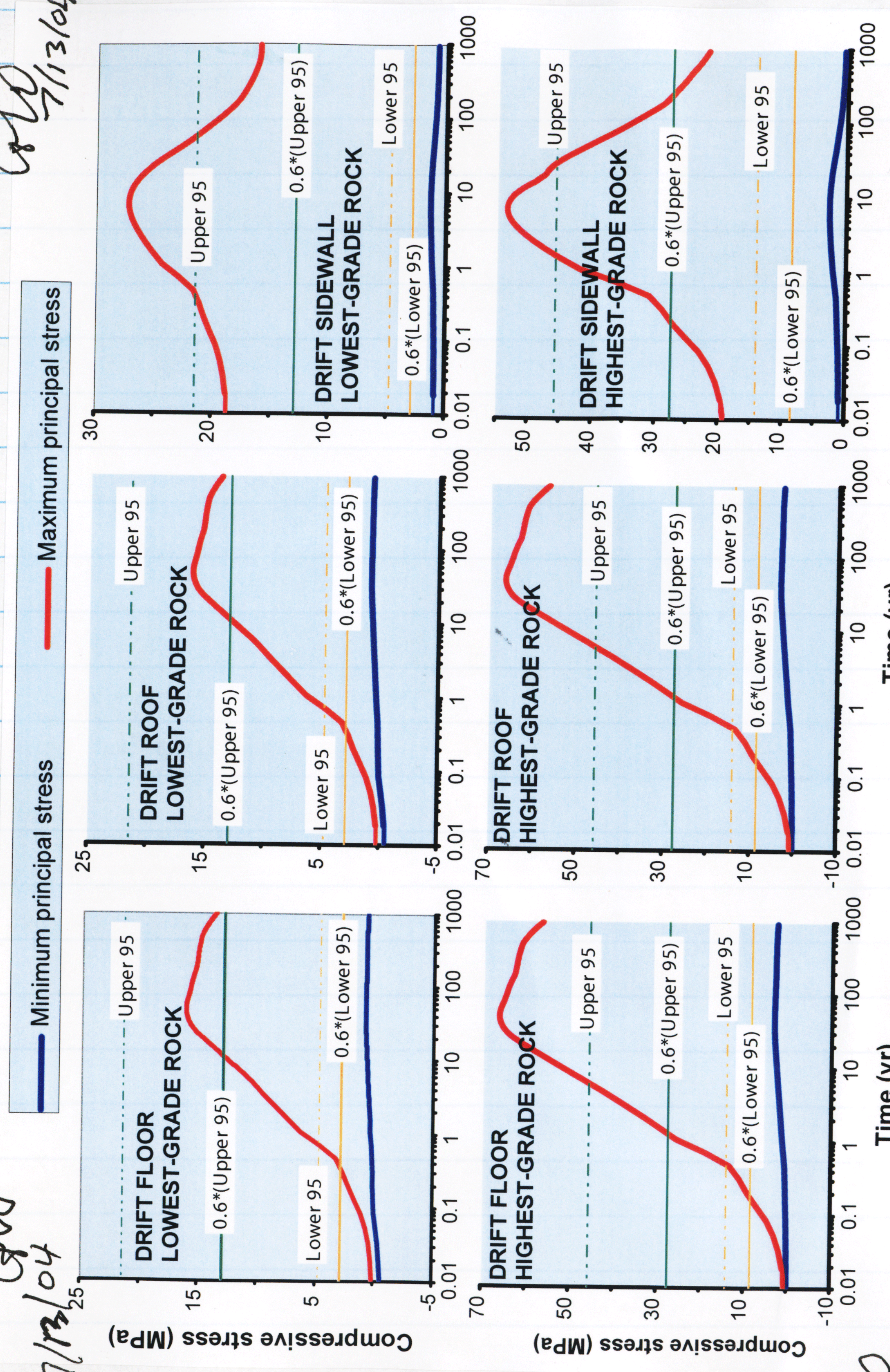
GWO 7/13/04



100% OF THERMAL LOAD APPLIED FOR 1000 YR (HEAT REMOVAL BY VENTILATION NOT INCLUDED). HORIZONTAL LINES REPRESENT UPPER 95% AND LOWER 95% CONFIDENCE LIMITS FOR UNCONFINED COMPRESSIVE STRENGTH. VALUES OF MAXIMUM PRINCIPAL STRESS GREATER THAN THE APPLICABLE UNCONFINED COMPRESSIVE STRENGTH INDICATE POTENTIALLY UNSTABLE CONDITIONS.

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The stress histories on pages 50–52 indicate potential instability of the emplacement drifts as follows.

Case of 90% Heat Removal Ratio (10% of Thermal Load Applied) for 50 Years

GWO 7/19/04

For the lowest-grade rock

- Stresses in the roof and floor are smaller than the estimated rock strength for 50 years. Stresses in the roof and floor areas increase rapidly thereafter and reach potentially unstable conditions for values of rock strength equal to or smaller than the estimated mean strength. The potentially unstable conditions would persist for more than 1,000 years.
- Stresses in the sidewall indicate potentially unstable conditions all the time for most values of rock strength.
- Instability of the sidewall areas would ultimately lead to instability in the roof areas. Such progression of instability would result in bell-shaped failure zones.

For the highest-grade rock

- Stresses in the roof and floor areas are smaller than the estimated rock strength for 50 years. The stresses increase rapidly thereafter and attain potentially unstable conditions everywhere. The potentially unstable conditions in the roof and floor areas would persist for more than 1,000 years.
- Stresses in the sidewall are smaller than the estimated rock strength at most places, except where the rock strength is close to the estimated lower bound.
- Occurrence of instability in the roof areas with the sidewalls remaining stable would result in chimney-shaped failure zones.

Case of 70% Heat Removal Ratio (30% of Thermal Load Applied) for 50 Years

The occurrence of potential instability follows the same pattern described for the case of 90% heat removal, except for the following differences.

- Potentially unstable conditions may develop within 10 years at locations where the rock strength is close to the estimated lower bound.

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Case of No Heat Removal (100% of Thermal Load Applied)

GWO 7/19/04

Unstable stress conditions would develop everywhere within 10 years and would persist for more than 1,000 years.

These results contrast with the DOE assessment of the potential for thermally induced rockfall as discussed on the following pages.

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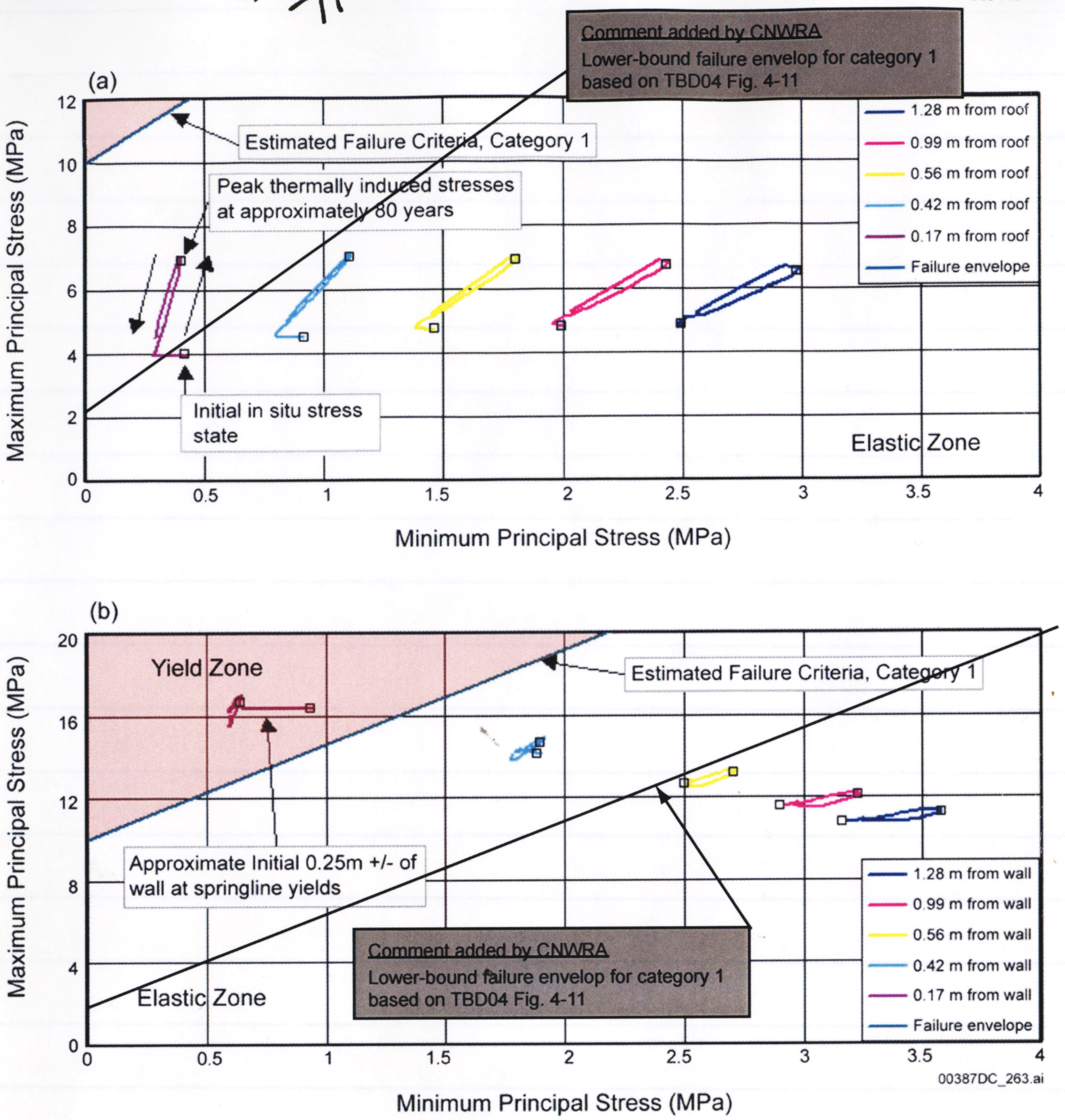

Source: BSC 2004a, Figures 6-144 and 6-143.

NOTE: Only minor yield (approximately 0.25 m depth) occurs in drift springline area for this lowest strength category. This yield is predicted to occur prior to initiation of heating. Estimated failure envelope is shown for comparison to the stress conditions. Initial point is at preheating stress state, followed by path through 10,000 years of heat-up and cool-down.

Figure 5-5. Elastic Principal Stress Path Histories for Points at Increasing Depth from Emplacement Drift Crown (a) and Springline (b) for Lithophysal Rock, Modulus from Lowest Quality Category 1

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See p. 56 for full document reference

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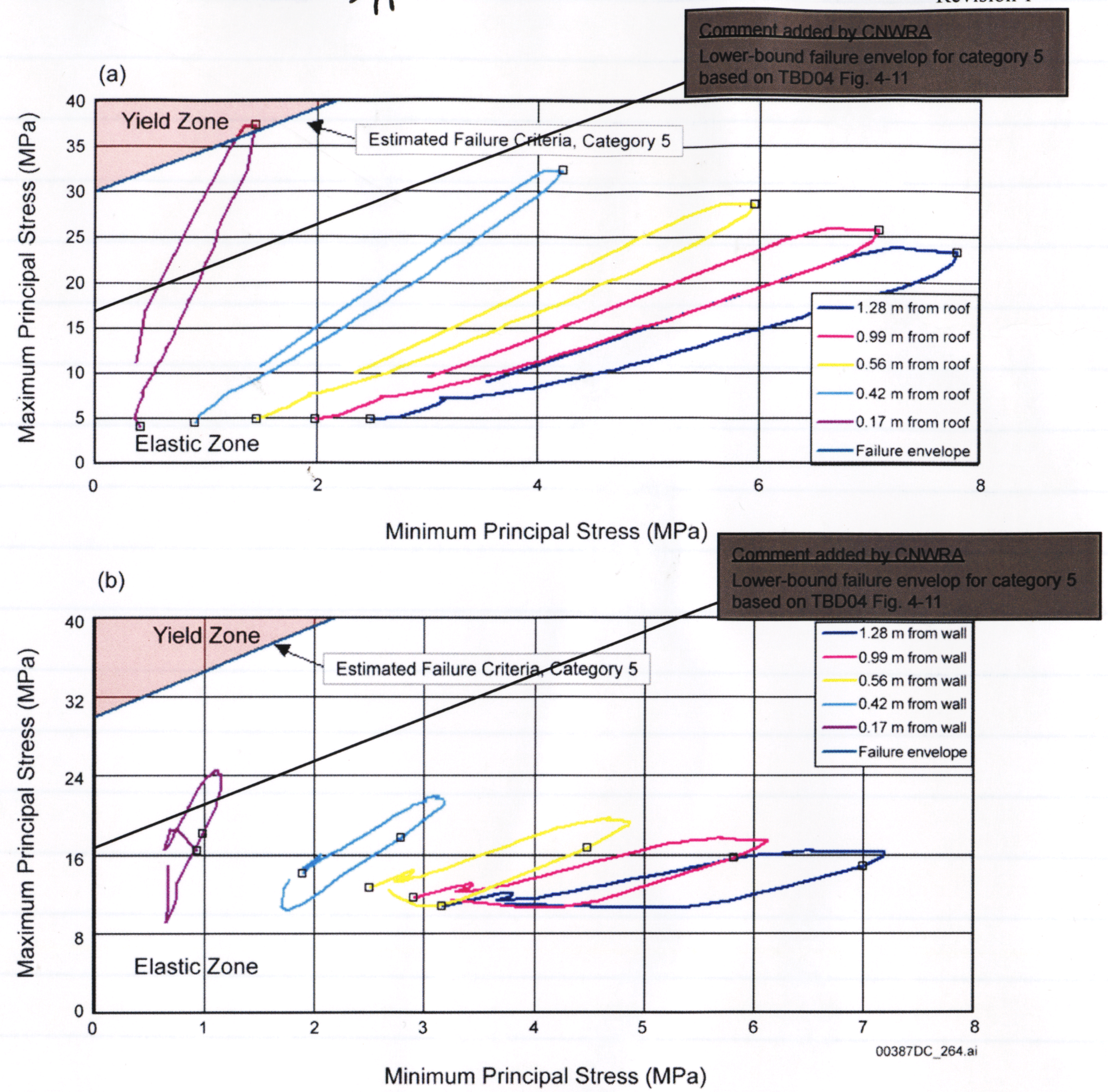
GLO 7/19/04



Source: BSC 2004a, Figures 6-146 and 6-145.

NOTE: Only minor yield (less than about 0.25 m depth) occurs in drift crown area for this highest lithophysal strength category. This yield is predicted to occur after 80 years of heating. Larger stress change occurs in crown for higher modulus category as compared to Figure 5-5. Estimated failure envelope is shown for comparison to the stress conditions. Initial point is at preheating stress state, followed by path through 10,000 years of heat-up and cool-down.

Figure 5-6. Elastic Principal Stress Path Histories for Points at Increasing Depth from Emplacement Drift Crown (a) and Springline (b) for Lithophysal Rock, Modulus from Highest Quality Category 5

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GLO 7/19/04

See p. 56 for full document reference

Title page of DOE document cited on p54-55, and referred to hereafter as TBD #4

QA: NA

June 2004

BECHTEL SAIC COMPANY LLC

Technical Basis Document No. 4: Mechanical Degradation and Seismic Effects

Revision 1

GWO 7/19/04

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POTENTIAL FOR THERMALLY INDUCED ROCKFALL BASED ON DOE ANALYSIS

GWO 7/19/04

The DOE assessment of the potential for thermally induced rockfall is summarized on p. 5-7 of TBD #4 where it is stated that combined in situ and thermally induced stresses would not cause any significant ground collapse in the emplacement drifts. The basis for this conclusion is summarized in figures 5-5 and 5-6 (p. 5-9–5-10) of TBD #4. Lines were inserted into the two figures by CNWRA staff (p. 54 and 55 of this notebook) to represent the lower-bound rock strength provided by DOE. The lower-bound rock strength was taken from figure 4-11 (p 4-21) of TBD #4. DOE based its conclusion on comparing its calculated stresses with the estimated mean rock strength.

The DOE conclusion, however, would have been different if the full range of rock strength between the upper and lower bound were considered in the interpretation of the calculated stresses. The following observations arise from comparing the lower-bound strength with the calculated stresses.

For the lowest-grade rock (category 1)

- Stresses near the drift surface in the roof area would attain potentially unstable conditions if the rock strength is close to the estimated lower bound.
- Stresses near the drift surface in the sidewall area indicate potentially unstable conditions for values of rock strength close to or smaller than the estimated mean strength.
- The DOE plot does not include the time dimension that would have indicated the persistence of the potentially unstable stress conditions. Sidewall instability, if persistent, would ultimately cause the roof areas to be unstable. Such progression of instability would result in bell-shaped failure zones.

For the highest-grade rock (category 5)

- Stresses near the drift surface in the roof area would attain potentially unstable conditions if the rock strength is close to or smaller than the estimated mean strength.
- Stresses near the drift surface in the sidewall area indicate potentially unstable conditions for values of rock strength close to the estimated lower-bound strength.
- The DOE plot does not include the time dimension that would have indicated the persistence of the potentially unstable stress conditions. Occurrence of instability in the roof areas with the sidewall remaining stable would result in chimney-shaped failure zones.

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These observations based on re-interpreting the DOE calculation are similar to the observations on p. 53 based on the analysis results on p. 50–52.

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POTENTIAL FOR ROCKFALL OWING TO TIME-DEPENDENT ROCK DEGRADATION BASED ON DOE ANALYSIS

The results of DOE assessment of potential rockfall from time-dependent rock degradation are summarized on p. 5-62–5-69 of TBD #4. The effects of combining time-dependent rock degradation with thermally induced stresses were also considered in the DOE analysis. The results of the DOE calculation suggest no appreciable rockfall resulting from either time-dependent degradation alone or from combining any occurrence of time-dependent degradation with thermally induced stresses.

The primary input data for the DOE analysis are (p. 5-53 of TBD #4)

(1) Time to failure data obtained by Martin et al. (1997, cited in TBD #4) through static-fatigue testing of nonlithophysal rock specimens from Busted Butte. This data is summarized in table 5-8 (p. 5-53) of TBD #4.

(2) Time to failure data from static-fatigue testing of Lac du Bonnet granite and Beebe anorthosite (Lajtai and Schmidtke, 1986; see p. 23 of this notebook). This data is included in figure 5-34 (p. 5-53) of TBD #4 and is referred to hereafter as the Canadian data.

Time-to-failure data (Martin et al., 1997; cited in TBD #4 Table 5-8) based on static fatigue tests on saturated cylindrical specimens of nonlithophysal tuff under confining pressure of 5 MPa and pore pressure of 4.5 MPa.

Driving stress, σ (MPa)	Stress ratio (σ/σ_c)		Time to failure	
	σ_c = 105 MPa	σ_c = 200 MPa	Seconds	Descriptive time
149.0	1.0	0.75	1.2	1.2 sec
141.0	1.0	0.71	4.0	4 sec
134.6	1.0	0.67	250	4.2 min
134.2	1.0	0.67	636	10.6 min
132.8	1.0	0.66	5,848	1.62 hr
127.8	1.0	0.64	1.96×10^6	22.7 day
131.4	1.0	0.66		
131.3	1.0	0.66		
115.0	1.0	0.58		

The Martin et al. (1997) data is reproduced in the above table. Information provided by DOE indicate the value of σ_c (compressive strength under instantaneous loading) for normalizing the applied stress in the Martin et al. static-fatigue tests may range from 105 to 200 MPa. DOE used 151 MPa but did not provide a justification. Values of σ/σ_c in the table were calculated using σ_c=105 and σ_c=200 MPa, but only the 200 MPa provides useful information because all the test stresses are greater than 105 MPa. As shown in the table, the specimens failed essentially

instantaneously for values of σ/σ_c>0.7 (approximately) whereas time-dependent behavior occurred for 0.7>σ/σ_c>0.64. The Canadian data for Lac du Bonnet granite indicate remarkably similar behavior. The Canadian data also indicate values of stress ratio smaller than approximately 0.6 would not cause rock failure.

DOE used micromechanics-based modeling with the particle flow code to calculate the effects of lithophysae on the time to-failure data, thereby extending the data to include the behavior of lithophysal tuff. The calculation is described on p. 5-54–5-55 of TBD #4. The results are summarized in figures 5-36 and 5-37 (p. 5-57) of TBD #4 and are reproduced in the following table.

Time to failure calculated from PFC modeling to account for the effects of lithophysae on the Martin et al (1997) data [From TBD #4 Figure 5-37]

Driving stress ratio σ/σ_c	Time to failure for lithophysal porosity of 0%, 11%, and 20% as tabulated below					
	0%		11%		20%	
	sec	Descriptive time	sec	Descriptive time	sec	Descriptive time
0.8	10^4	2.8 hr	10^2	1.7 min	10	10 sec
0.6	10^6	11.6 day	$10^{4.5}$	8.8 hr	10^4	2.8 hr
0.4	10^8	3.2 yr	10^7	116 day	10^7	116 day
0.2	$10^{10.5}$	1,003 yr	10^{10}	317 yr	10^{10}	317 yr

The results of the DOE calculation indicate the effects of lithophysae can be summarized as follows.

- The threshold value of stress ratio that would cause rock failure is decreased from approximately 0.6 for nonlithophysal rock to smaller than 0.2 for lithophysal rock.
- The time to failure for rock under a given stress ratio is reduced by the occurrence of lithophysae in the rock.

These observations based on the DOE calculation can be explained by considering the effects of stress concentrations around the lithophysal holes. It is also important to note the DOE calculation (summarized in the above table) indicates rock failure would occur within 300–1,000 years at locations in the rock mass subjected to sustained loading with a stress ratio of approximately 0.2 or greater. This result is in remarkable agreement with the estimated time to collapse provided in the MECHFAIL report.

DOE did not use the information in the above table for its rockfall assessment reported in TBD #4. Instead, DOE re-interpreted the Martin et al. (1997) data without the Canadian data and without accounting for the effects of lithophysae. The resulting DOE interpretation is shown in Figure 5-39 (p. 5-59) of TBD #4. Recall that the driving stress ratio (σ/σ_c) in this figure is based on an unjustified assumption of σ_c=151 MPa instead of 105–200 MPa provided by the original authors. The input information used for the DOE rockfall calculation was derived from this figure and is illustrated in Figure 5-40 (p. 5-60) of TBD #4. This information is reproduced in the table below to help illustrate its impact on the DOE rockfall calculation.

Time to failure information used in DOE modeling to calculate time-dependent rockfall and drift degradation in lithophysal rock [From TBD #4 Figure 5-40]

Driving stress ratio σ/σ_c	Time to failure	
	sec	Descriptive time
0.9	10^3	16.7 min
0.8	10^6	11.6 yr
0.7	10^9	31.7 yr
0.6	10^{12}	31.7×10^3 yr
0.5	10^{15}	31.7×10^6 yr
0.4	10^{18}	31.7×10^9 yr
0.3	$10^{21.5}$	
0.2	10^{24}	

It is important to compare the DOE input information (this table) with the original data (table on p. 58) or with the result of DOE calculation to account for the effects of lithophysae on the original data (table on p. 59). Two questions need to be asked.

- How is the time to failure in the above table (DOE model input) related to the time to failure in either the original data (table on p. 58) or the data modified to account for lithophysae (table on p. 59)?
- Why did DOE decide to not use the information in Figure 5-37 of TBD #4 (reproduced here as the table on p. ____), which is the result of its own effort to account for the effects of lithophysae on time to failure?

August 17, 2004

CONTOURS OF OVER-STRESS RATIO

Contours of over-stress ratio are presented on pages 62 and 63, illustrating the potential effects of repository thermal loading on rock stress for the case of 90% thermal load removed through ventilation during the first 50 yr. The results on p. 62 represent conditions in the lowest-grade rock (E = 5 GPa) with the rock strength set equal to the lower 95% confidence value. Similarly, the results on p. 63 represent conditions in the highest-grade rock (E = 20 GPa) with the rock strength set equal to the lower 95% confidence value. The rock-strength statistics are defined on p. 11. The effects of rock-strength uncertainty on the occurrence of over stress is illustrated on page 32 for the lowest-grade rock and on page 33 for the highest-grade rock.

The DOE time-to-failure information for lithophysal rock (p. 59) suggests a potential implication of the over-stress distributions. The DOE information indicates lithophysal rock subjected to a sustained over-stress ratio of 0.2 or greater would experience failure within a few hundred years (300–1,000 yr). The DOE information and the existing data on the failure of rocks subjected to sustained loading (e.g., p. 23), indicate the threshold over-stress ratio needed to cause failure in the lithophysal rocks may lie in the range of 0.2–0.6. The DOE information further indicates that lithophysal rocks subjected to a sustained over-stress ratio of 0.2–0.6 would likely fail within a few hundred years. The contours of over-stress ratio on pages 62 and 63 (with the effects of rock-strength uncertainty on pages 32 and 33) indicate thermal loading of the emplacement drifts would cause potentially unstable stress conditions in the pillars.

Values of over-stress ratio greater than 0.2 would occur everywhere irrespective of rock type. Therefore, if the threshold over-stress ratio that would cause failure is approximately equal to 0.2 as suggested by the DOE information, then most of the emplacement drifts would collapse within a few hundred years. If the threshold over-stress ratio is between 0.2 and 0.6, with a mean value of approximately 0.4; wide-spread drift degradation would occur, but the rate and extent of degradation would vary depending on the lithophysal rock grade.

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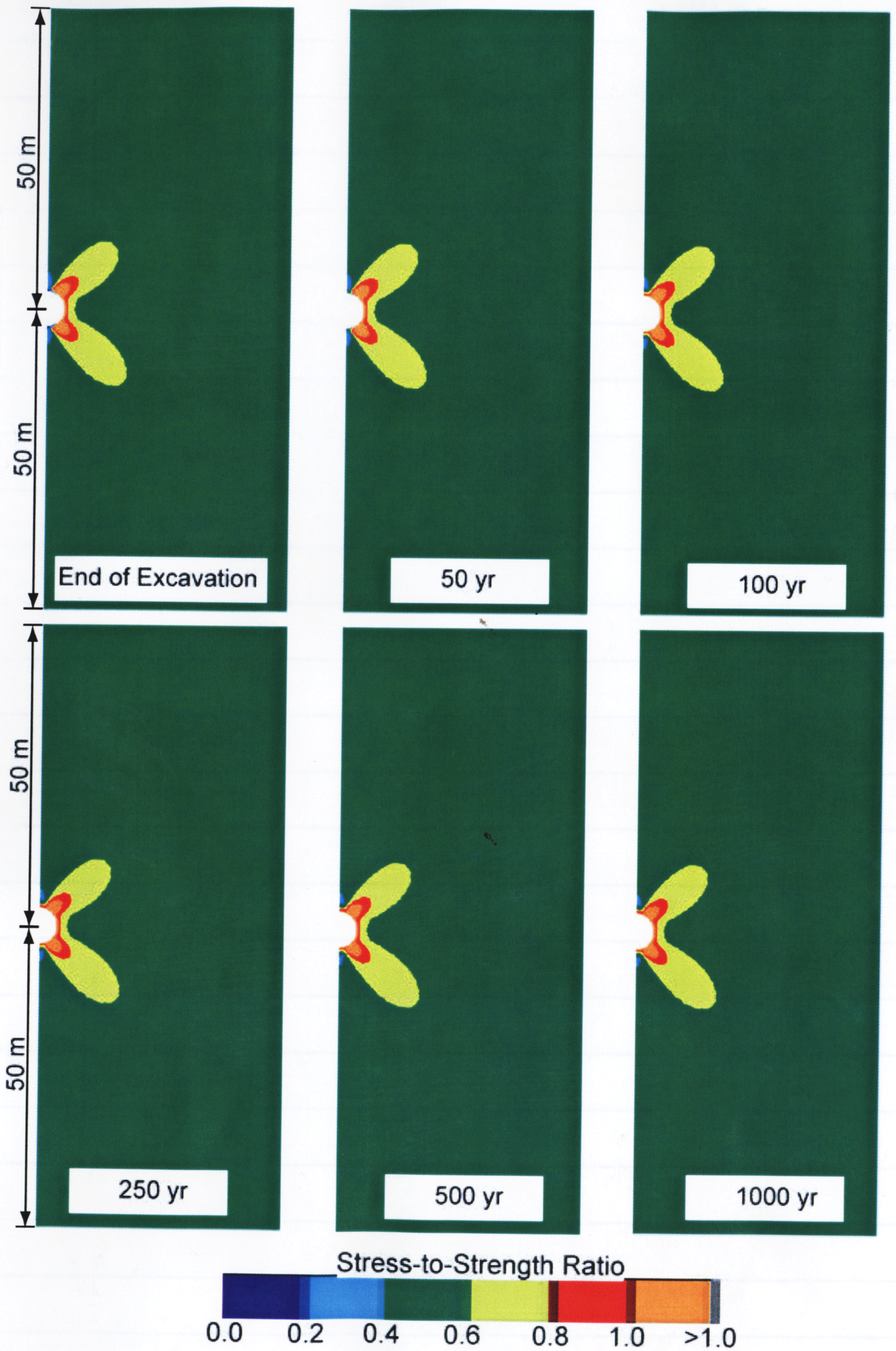

E = 5 GPa; UCS = 4.8 MPa
50 yr Ventilation @ 90%

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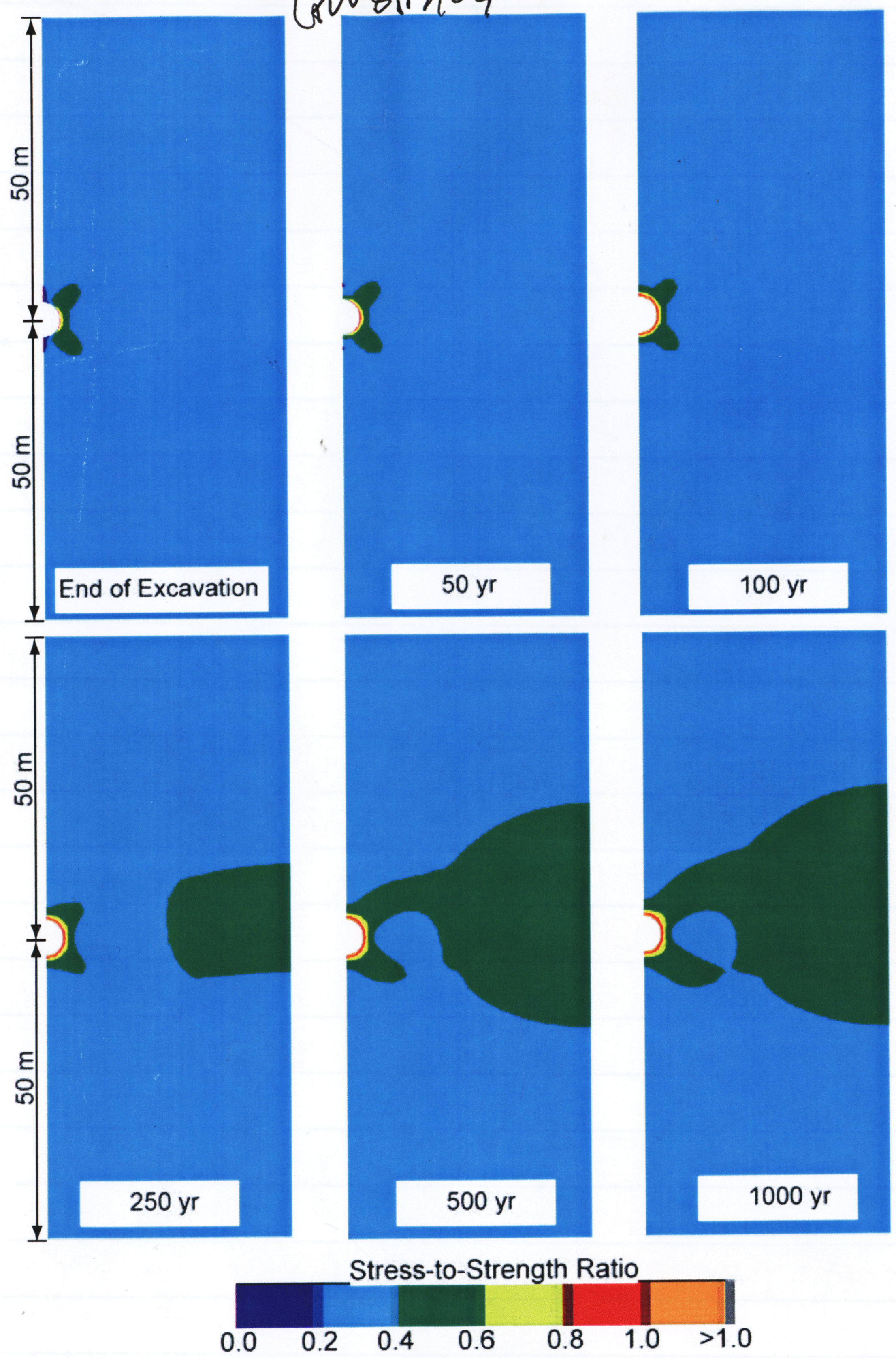

E = 20 GPa; UCS = 14.2 MPa
50 yr Ventilation @ 90%

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I have reviewed this scientific notebook and find it in agreement with QAP-001.

[signature]
4-18-05