March 9 2004

Additional Thermal-Mechanical Analyses

The thermal-mechanical analysis cases M01 and M02 described on p. 20 were performed using a temperature distributions obtained from the ventilated heat load (p. 5). Additional analyses were performed with the unventilated (i.e., full) heat load to explore the effects of ventilation on drift stability. Additional analyses were also performed using mean rock-strength values described on p. 11. The following table describes all the analyses

Analysis Case	Heat Load (1)	Young's modulus (GPa)	UCS (2) (MPa)	Cohesion (MPa)	Friction angle (°)
m01	Ventilated	5.0	4.8	1.12	40
m02	Ventilated	20.0	14.2	3.31	40
m11	No Ventilation	5.0	4.8	1.12	40
m12	No Ventilation	20.0	14.2	3.31	40
m21	Ventilated	5.0	13.46	3.138	40
m22	Ventilated	20.0	30.3	7.065	40

(1) See p. 5 for explanation of heat-load options.
(2) UCS = Unconfined compressive strength (see p. 11).

Results are presented in the following pages identifying potential zones of overstressed rock using the stress-to-strength ratio. That is,

$$\text{Over-stress index} = \frac{\text{Calculated Stress}}{\text{Stress that would cause rock failure}}$$

The stress that would cause rock failure is defined in terms of the Mohr-Coulomb failure criterion (see p. 21 for implementation of the calculation).

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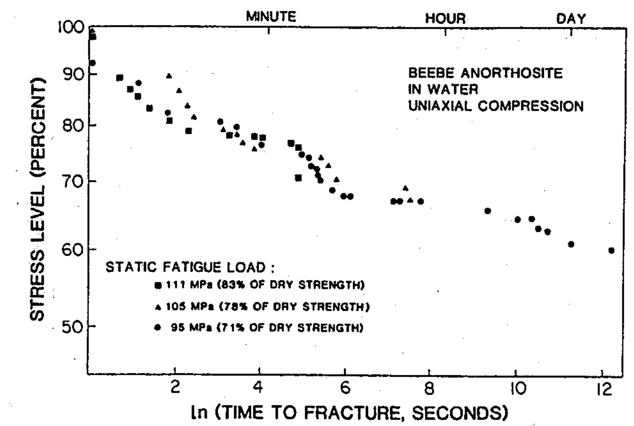
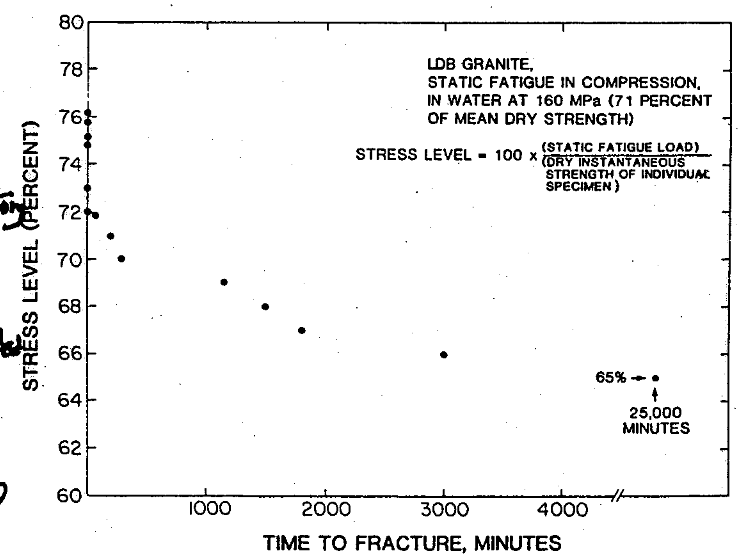
March 11 2004 Note Continuation

To interprete the calculated results: GHO

(1) The values of over-stress index should be divided by 0.6 to account for the reduced strength of rock when subjected to sustained loading (see data on the right side). The strength data used for the calculations were taken from conventional laboratory testing, in which the rock specimens were loaded rapidly to failure. GHO



The trend of static fatigue data from three series of tests on Beebe anorthosite

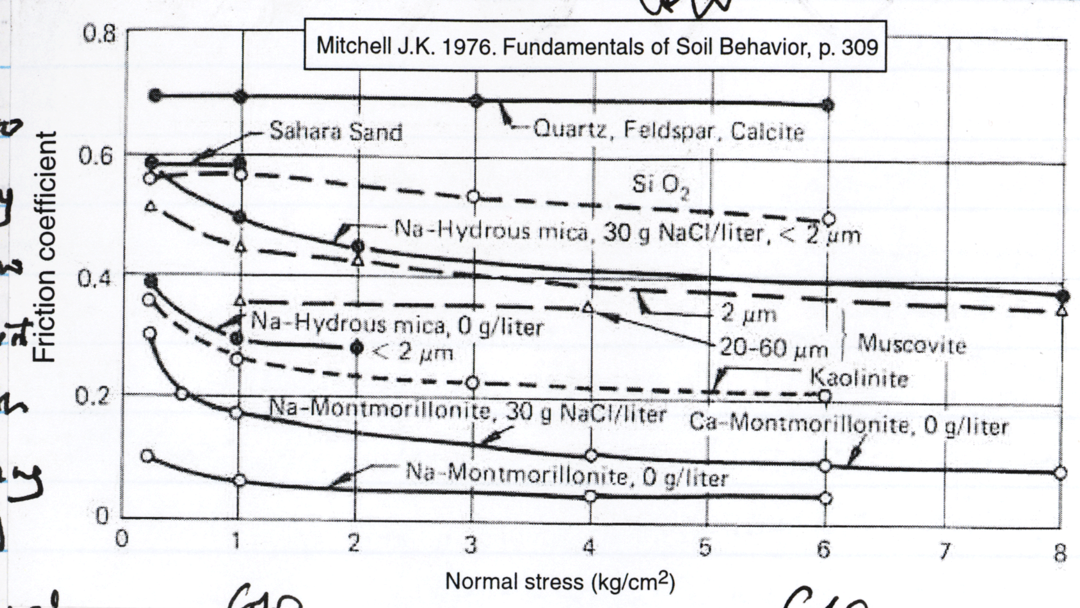


Time to fracture at different levels of stress. The linear scale plot shows the gradual flattening of the static fatigue curve suggesting the possible existence of a static fatigue limit for Lac du Bonnet granite

GHO

From Lajtai E.Z. and R.H. Schmidtke. Delayed failure in rock loaded in uniaxial compression. Rock Mechanics and Rock Engineering, 19: 11-25. 1986.

(2) The overstress index may also be divided by a factor as low as 0.2 to account for rock-strength reduction owing to geochemical alteration. Such



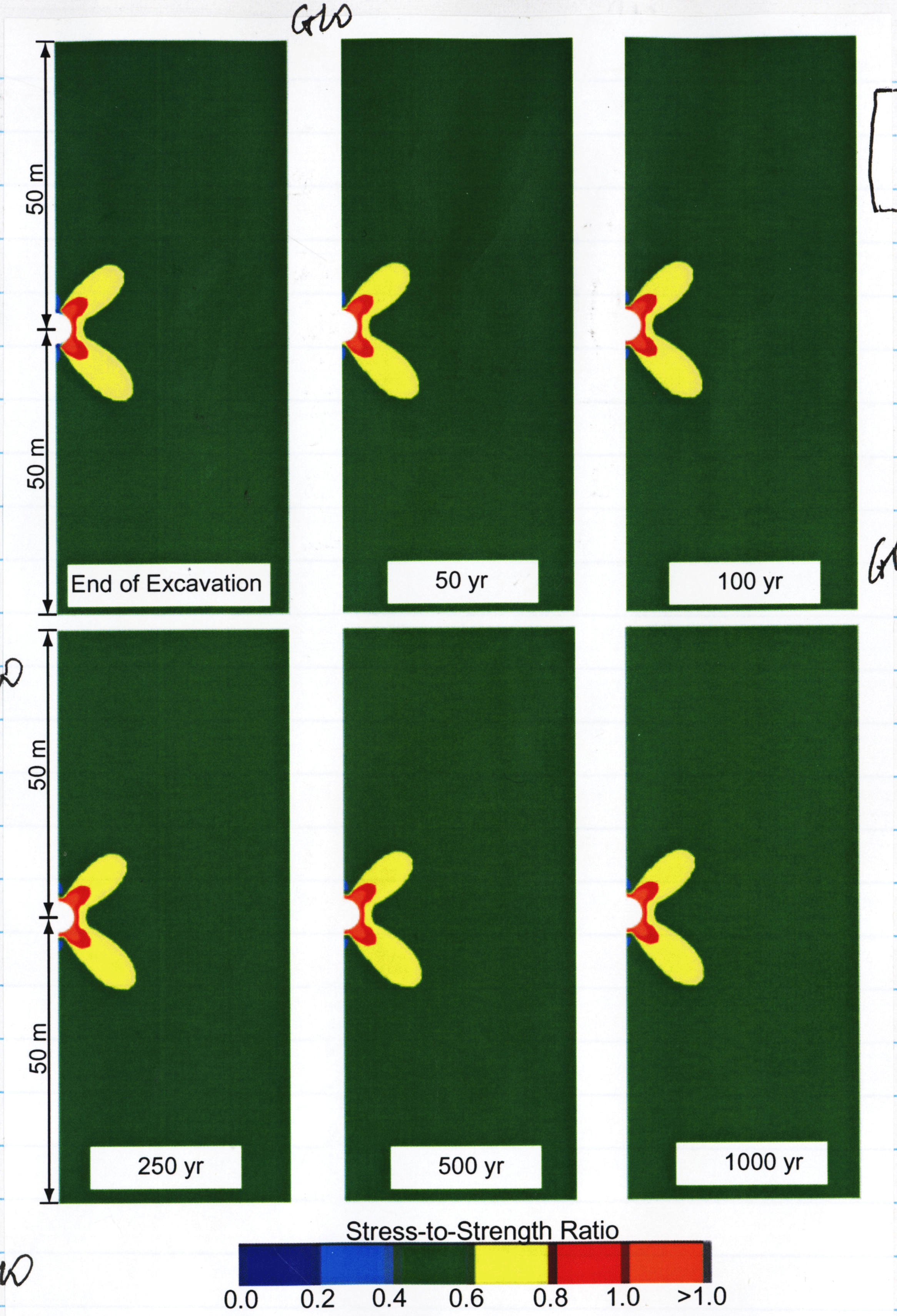
alteration, which would occur at critically loaded asperities subjected to heat and moisture for an extended time, would result in primary minerals such as feldspars changing to secondary minerals such as clays. The strength-reduction implications can be deduced from above figure, and may range from a factor of about 0.2 to about 1.0, depending on the extent of alteration.

A value of over-stress index of 1.0 or greater, after application of the two strength-reduction factors, indicates rock that is subjected to loading greater than its load-bearing capacity.

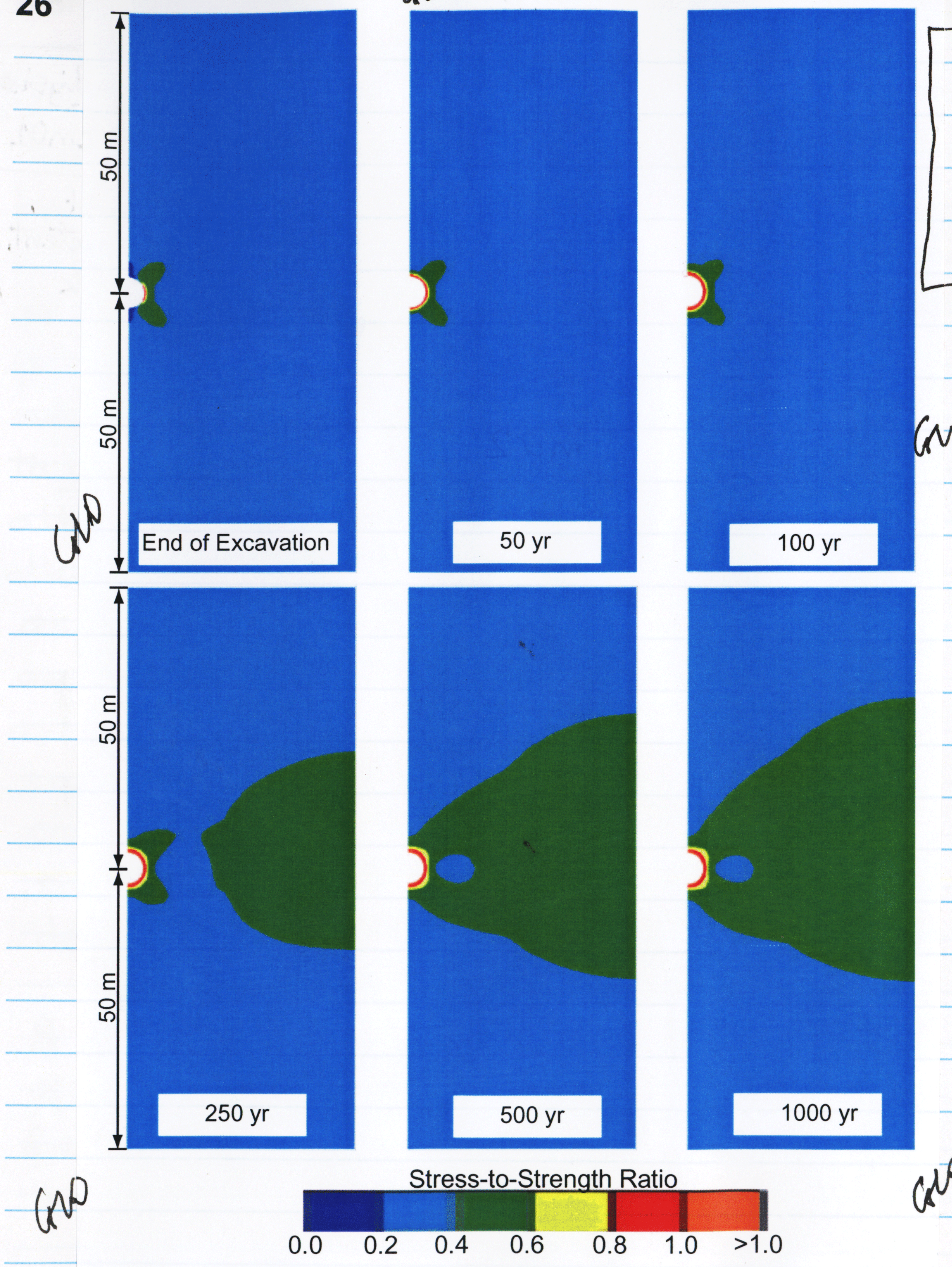
Model m01 (see p. 22 for parameter values)
Initial zone of overstressed rock (yellow, red, orange) caused by excavation. Thermal loading would not have any effect on potential failure in areas occupied

Analysis casem01

Least Competent Rock

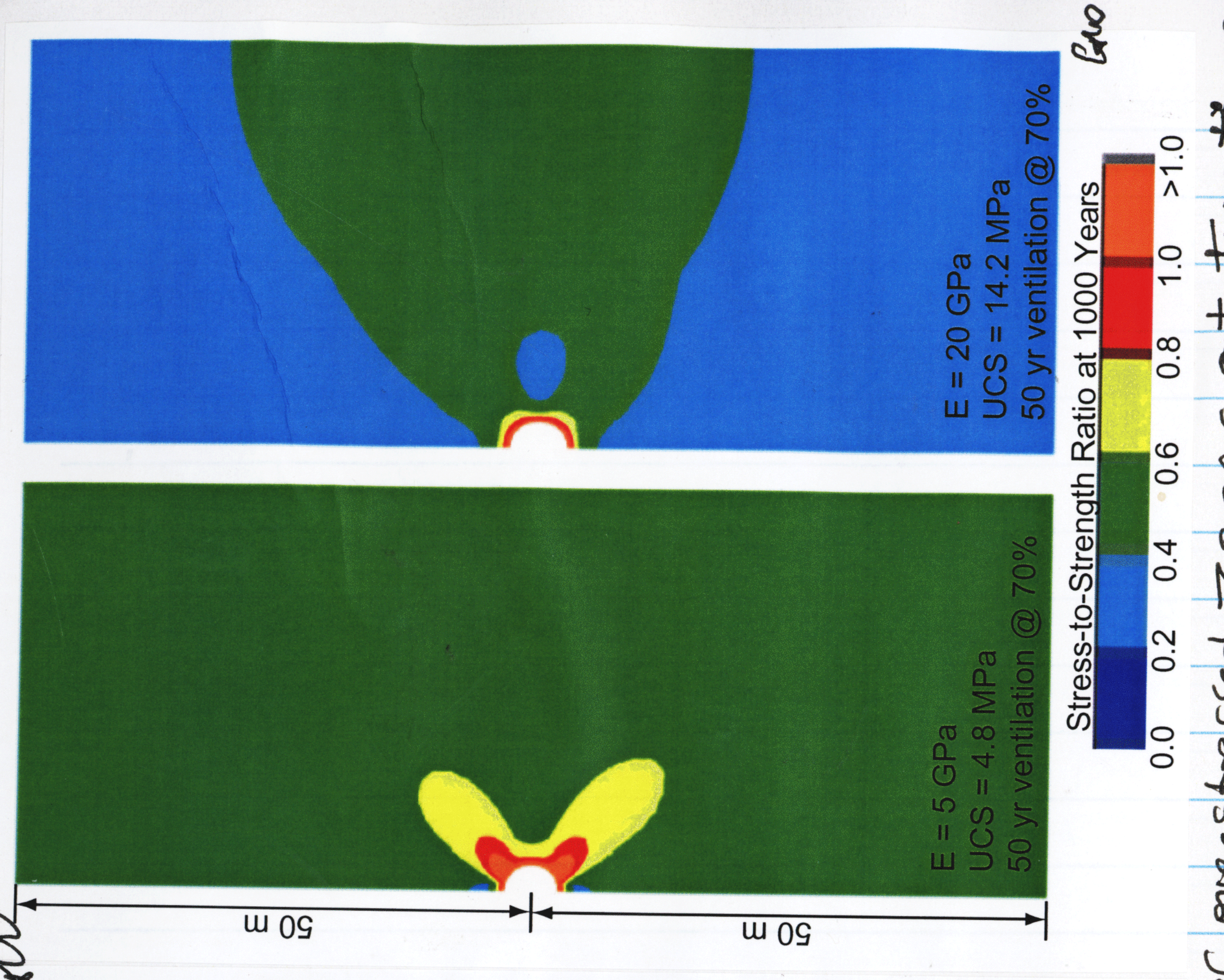


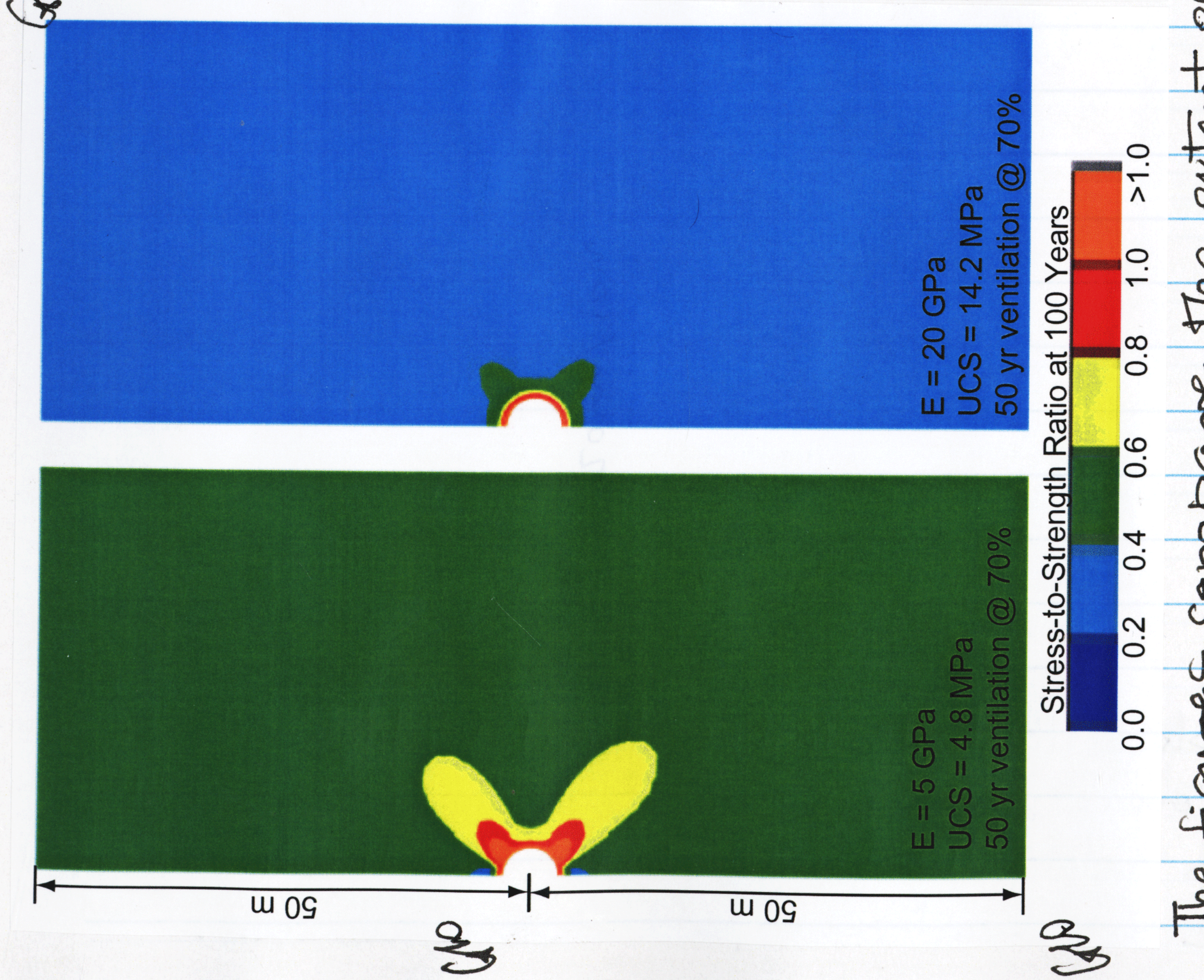
by this rock group (E = 5 MPa) if there is sufficient ground support preventing failure of the over-stressed rock. Without adequate ground support, the over-stressed rock would break up and fall changing the shape of the opening.



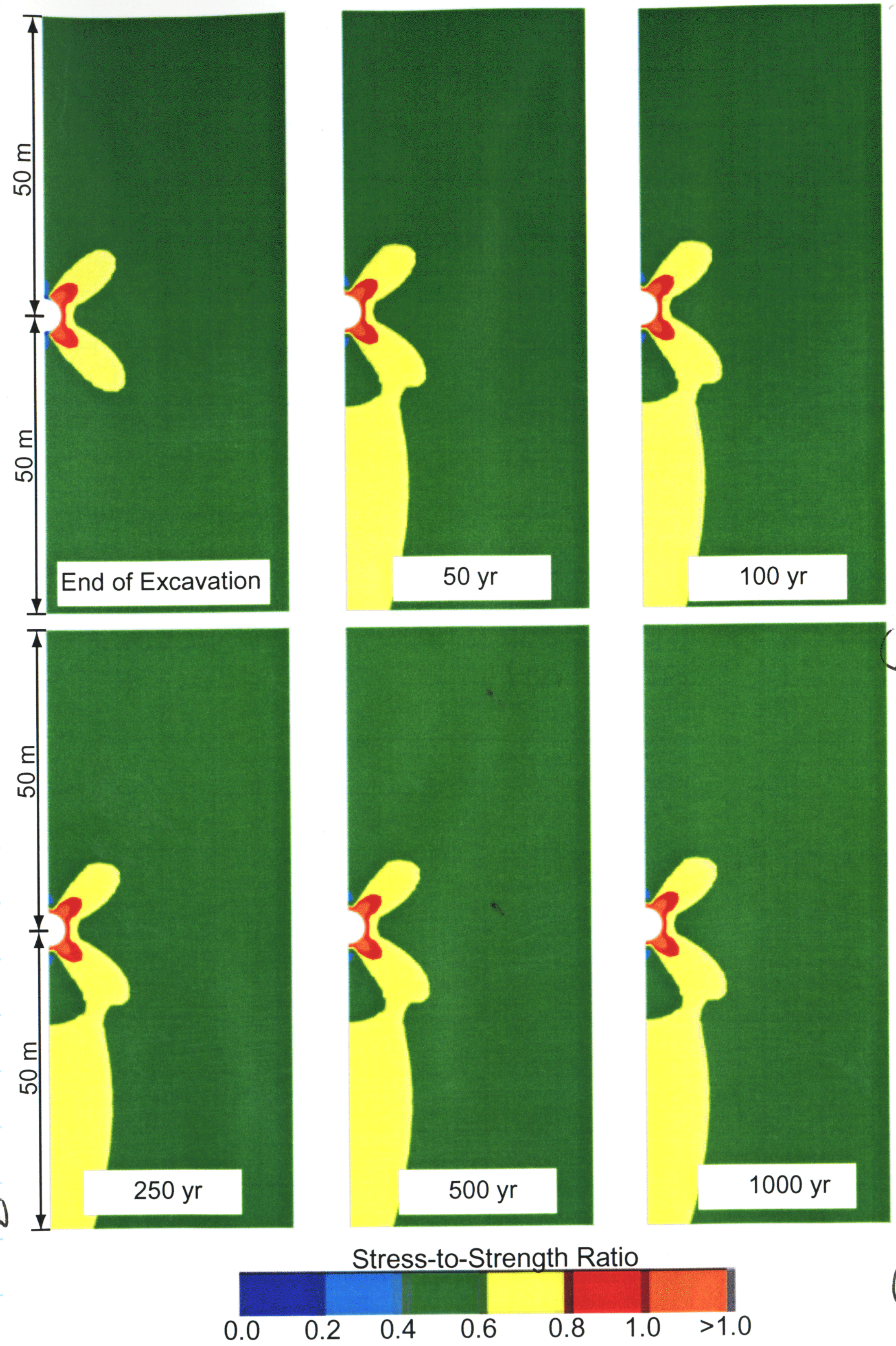
Analysis Case M02 Most Competent Rock

Thermal load has a strong effect on the occurrence of over-stress in these rocks. The zone of over-stress may extend into the pillar at late times.



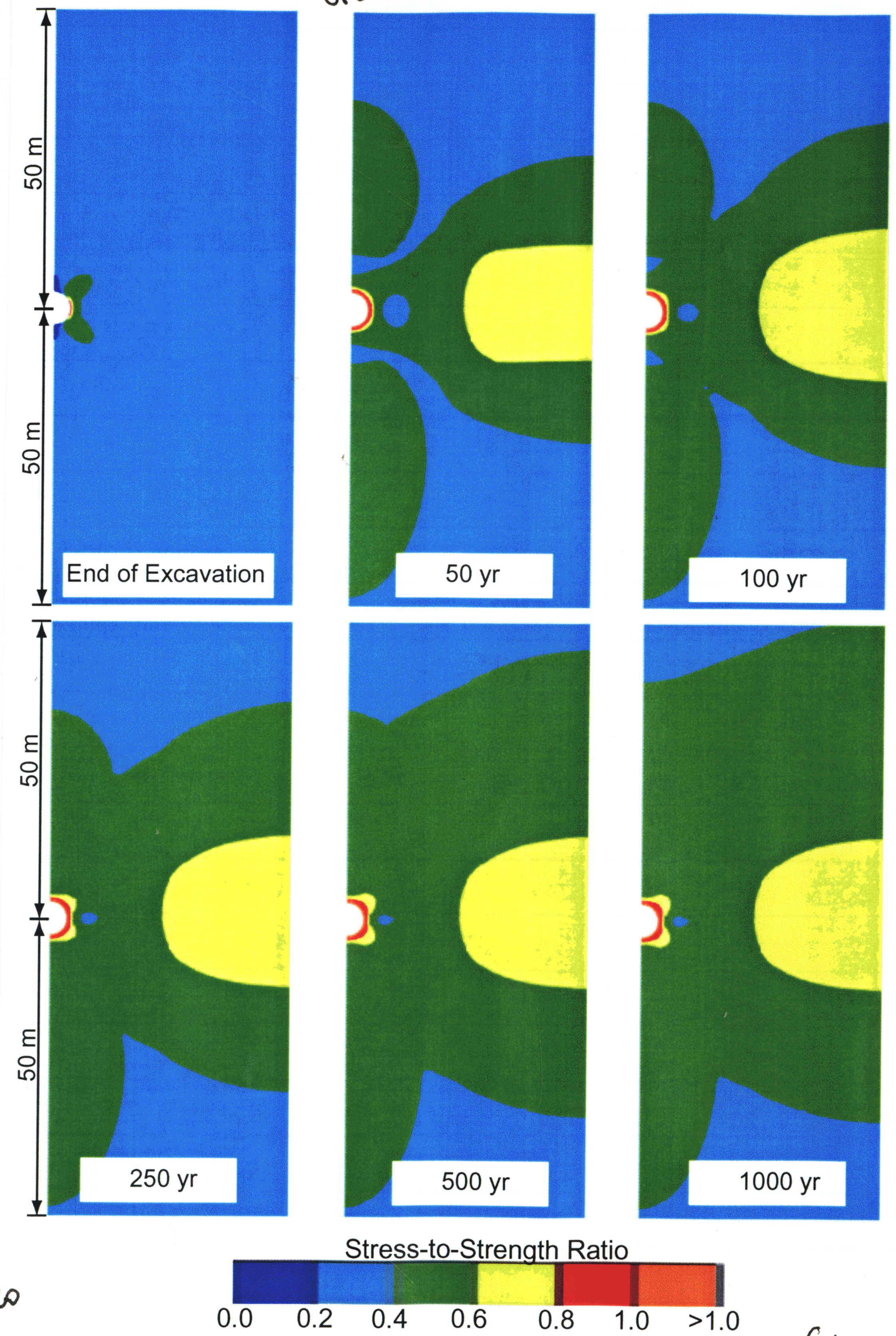


The figures compare the extent of overstressed zones at two times (100 yr and 1000 yr) and in two grades of rock quality, assuming that any over-stressed zones that develop at earlier times are successfully restrained from failure.



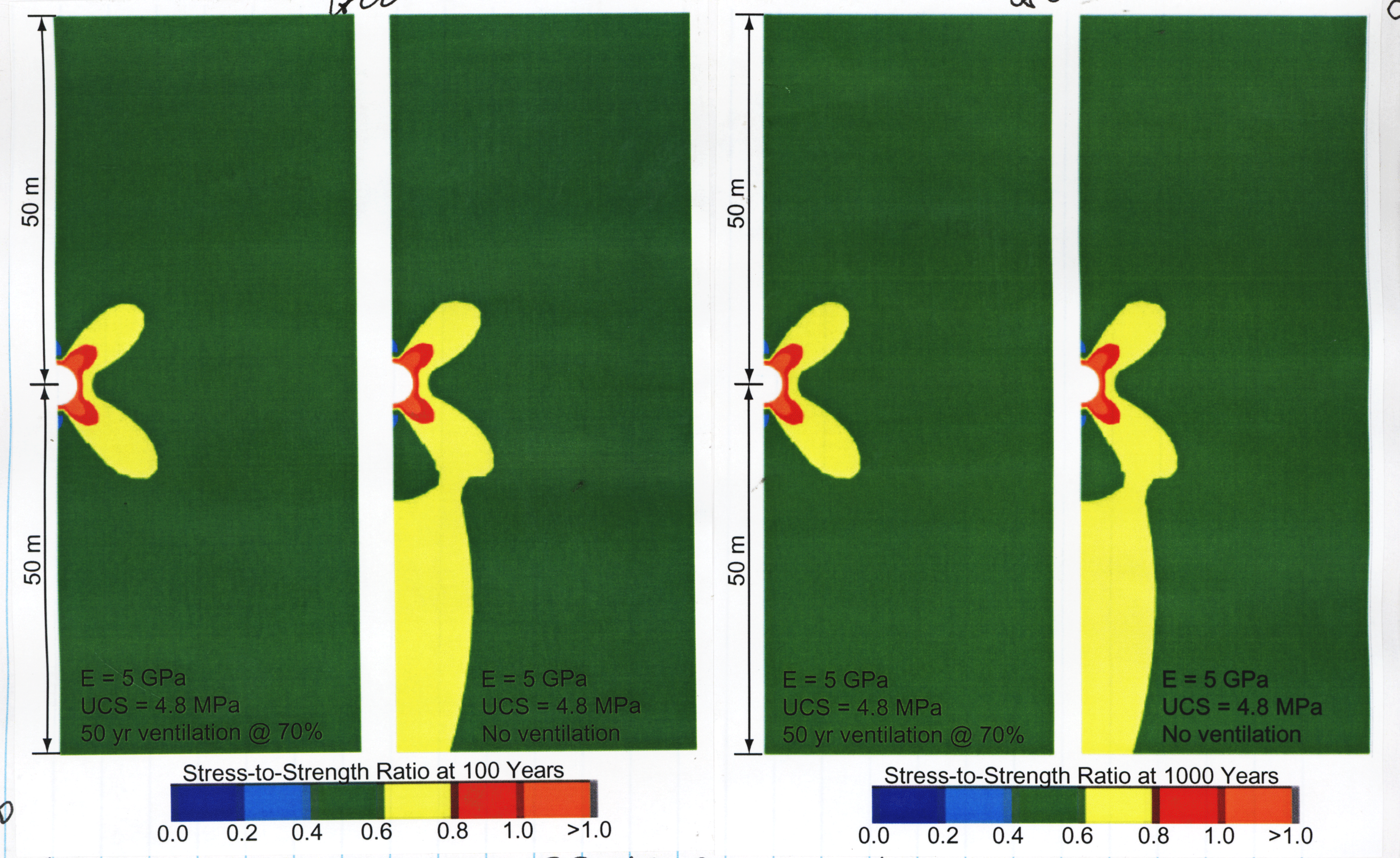
Analysis Case m11: Least Competent Rock; No Ventilation.

These plots illustrate that; without ventilation, an additional zone of over-stressed rock would develop below the tunnel floor during the thermal regime in least-competent rock areas.

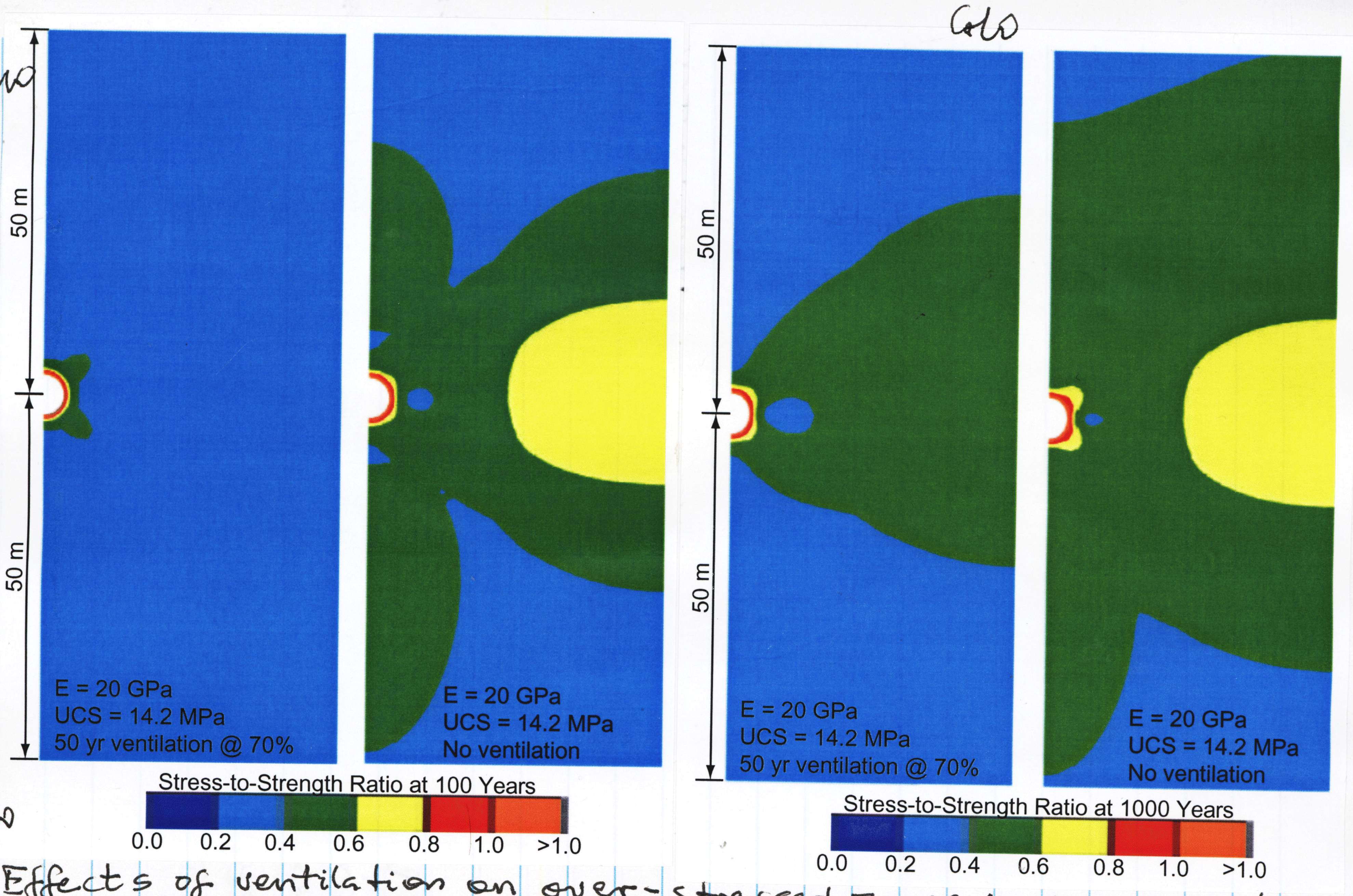


Analysis case m12: Most Competent Rock; No Ventilation

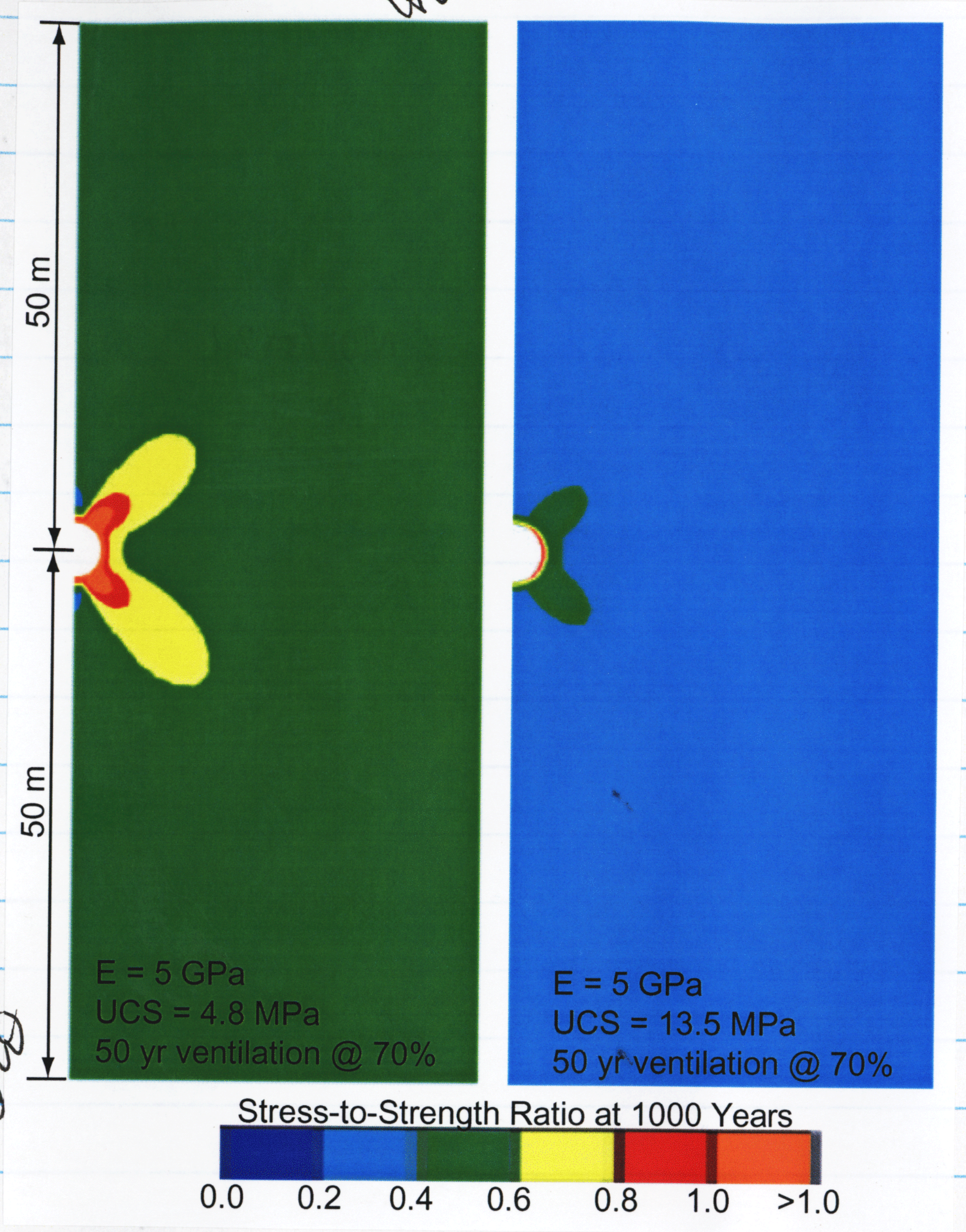
An additional zone of over-stressed rock would develop in the pillar during the thermal regime in most-competent rock areas, if there is no ventilation. The over stress may be relieved through tension cracking or through a reverse-faulting style shear failure. The fact that ventilation would essentially eliminate such failure conditions means that heat removal by ventilation is important to safety.



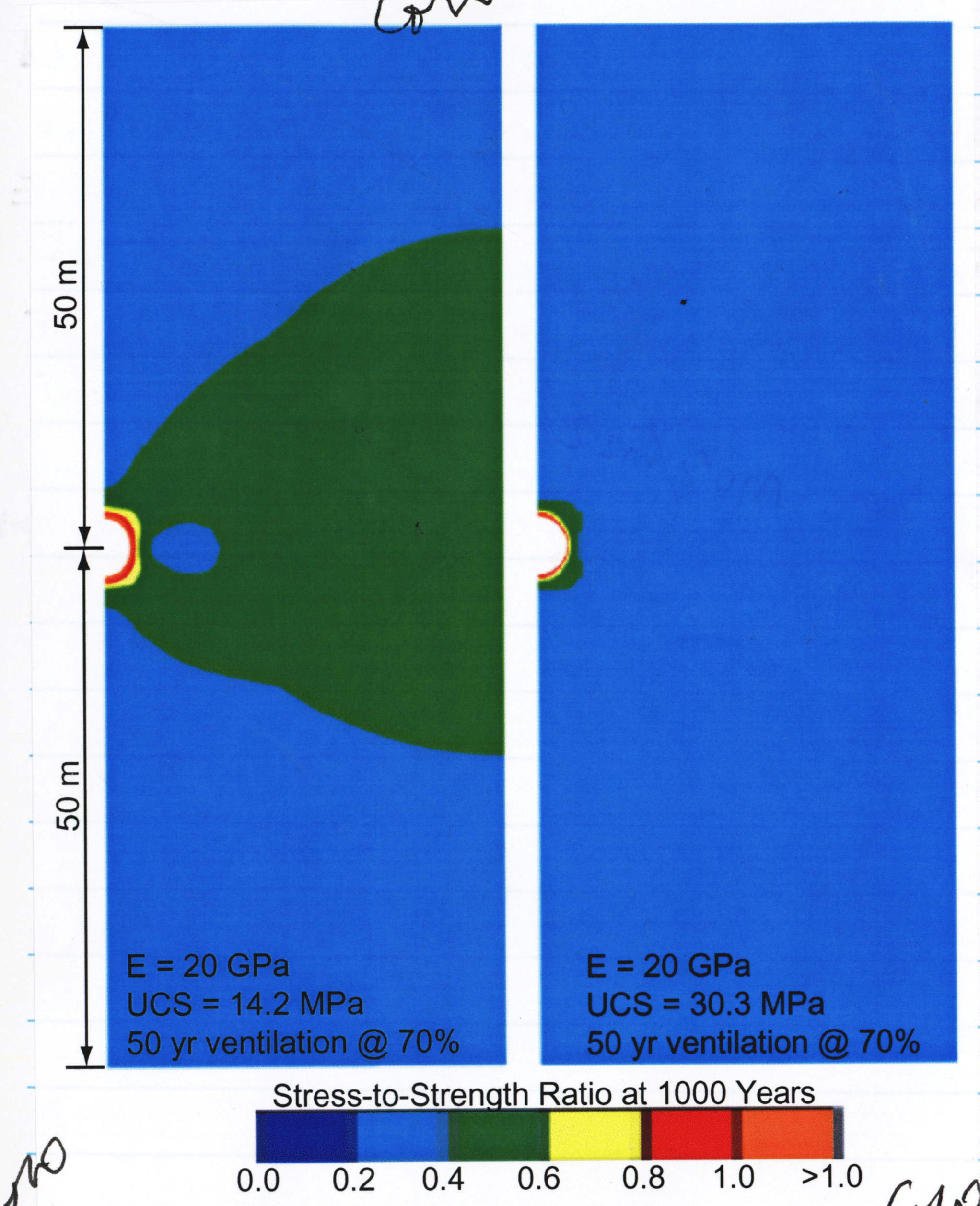
This plot illustrates the effects of ventilation on zones of overstress in the weak-rock area at two times (100 yr and 1000 yr), assuming that overstress zones that develop at earlier times are restrained from failing.



Effects of ventilation on over-stressed zones in the competent rock areas at 100 yr and 1000 yr, assuming that zones of over stress that develop at earlier times are restrained from failing.

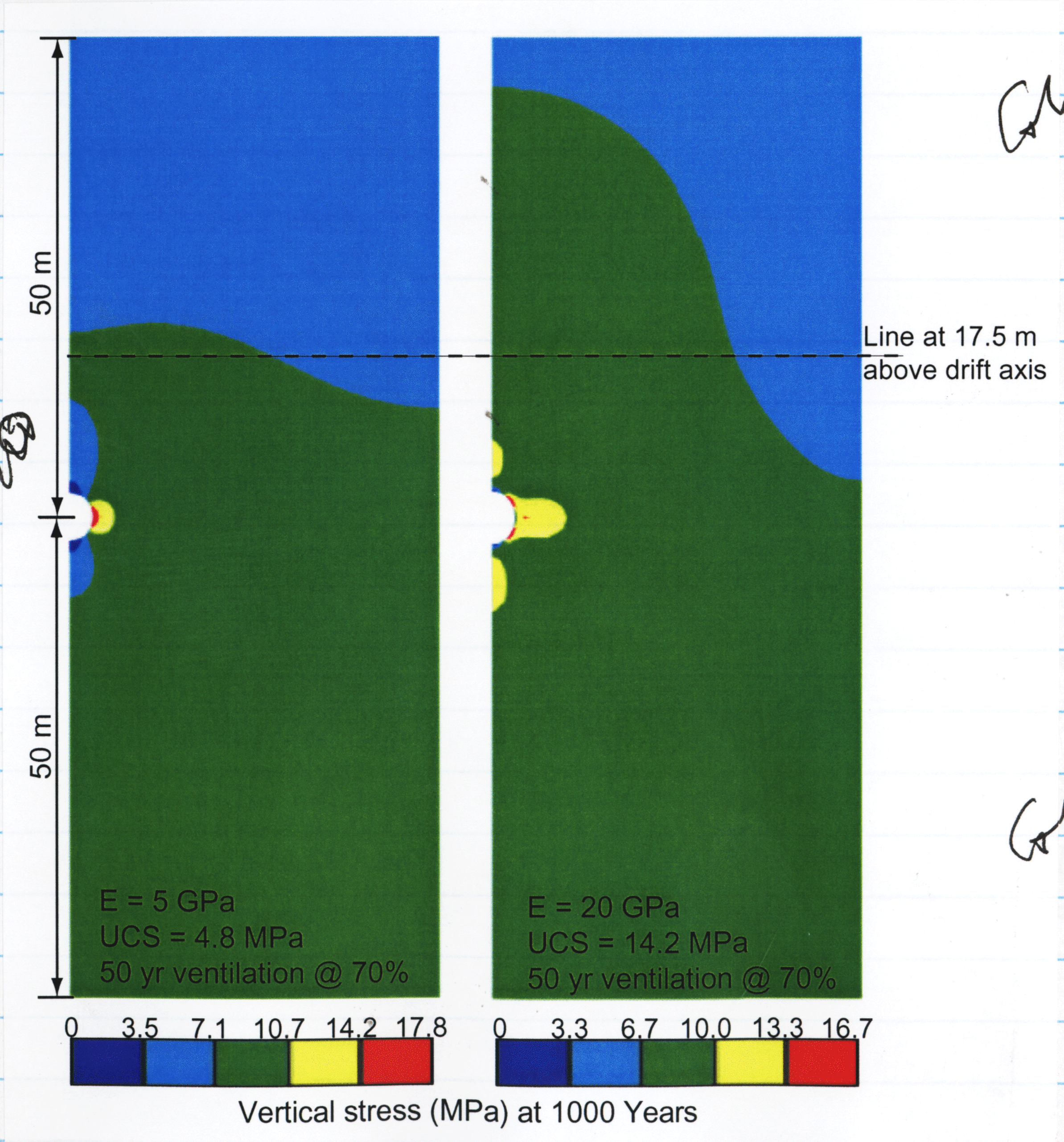


Effects of rock-strength uncertainty on the potential occurrence of over-stressed zones in the least-competent rock areas. Based on these results, drifts located in this grade of rock quality would develop over-stressed zones if the strength value lies within the lower 95% confidence strength and the mean strength. The likelihood of overstress is less near the mean strength and is expected to decrease further as the strength value exceeds the mean strength.

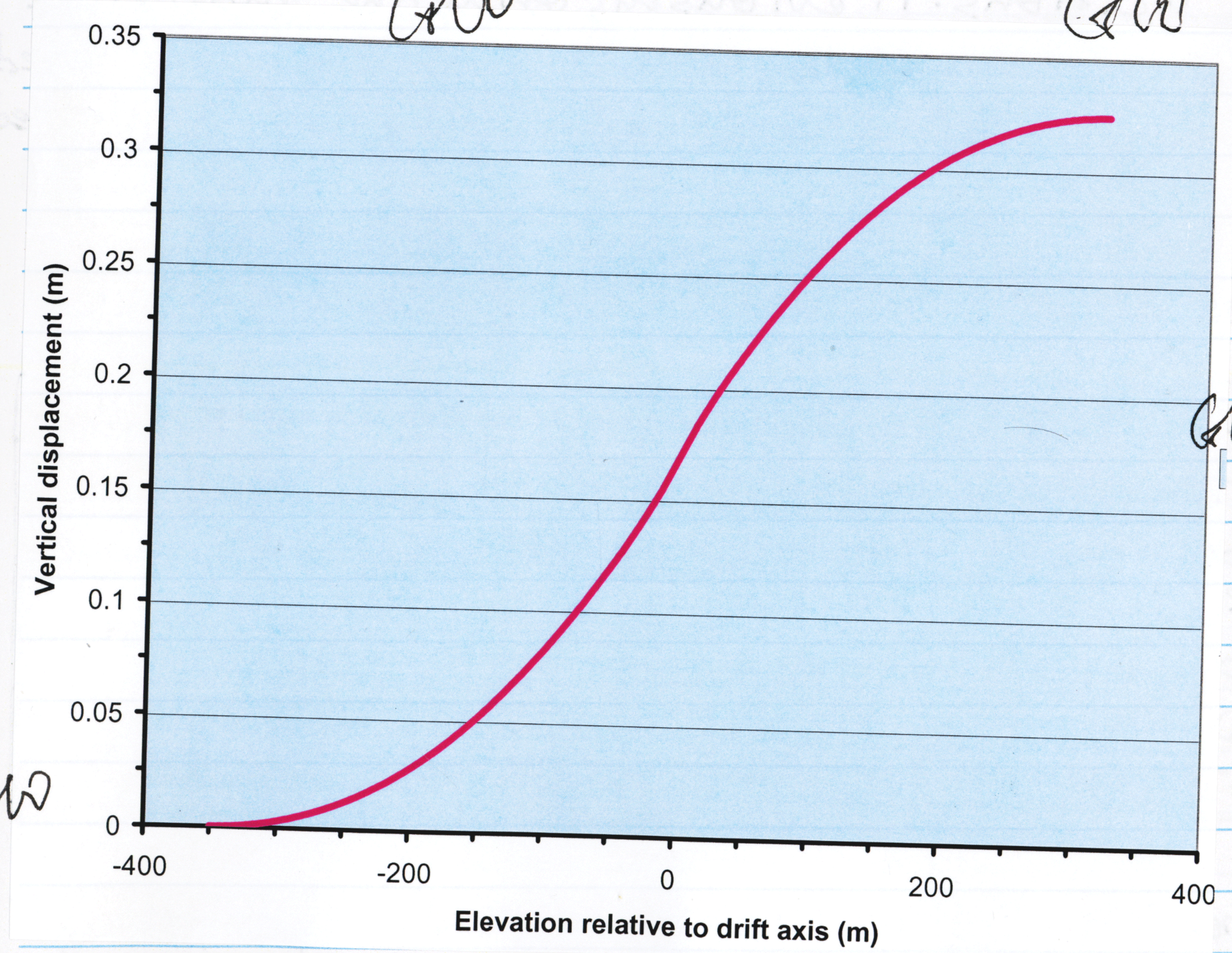


Effects of rock strength uncertainty on potential occurrence of over-stressed zones in the most-competent rock areas. The results suggest that drifts located in this rock-quality grade would develop over-stressed zones if the rock strength lies within the lower 95% confidence strength and the mean strength. The occurrence of over-stressed zones is less likely if the rock strength is near the mean strength, and the likelihood of overstress would likely decrease further as the strength increases above the mean strength.

The next two plots (p. 34 and 35) were developed to illustrate that the boundary conditions used for thermal-mechanical response analysis in DOE drift degradation report (page 180 of report cited on p. 1) are wrong and inappropriate. The plot below shows that the condition of constant and uniform vertical stress imposed at 17.5 m above the drift axis in the DOE model is inappropriate



A condition of zero vertical displacement was imposed at 17.5 m below the drift axis in the DOE model. The plot below shows that such a boundary condition is inappropriate. The boundary conditions used in the analyses described in this notebook are given on p. 14–15.



Vertical displacement along the vertical plane through the drift axis at 1000 yr (Cases m01 and m02)

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