The purpose of this letter is to provide supplemental analyses that have been conducted for Landslide C. These analyses are in response to questions raised during the most recent field review of trenches excavated to investigate this landslide. The report, Stability Investigation, Landslide "C", SunCrest, Draper, Utah (April, 2004) described in some detail the studies conducted to investigate and confirm "Landslide C" in terms of its location, its configuration and its properties as related to evaluation of the stability of the landslide mass itself. The study included a description of the setting, the location of the landslide as interpreted from the investigation, and analyses of the overall stability of the landslide mass (as described) under a variety of conditions, both existing and hypothetical. The analyses concluded that under existing and hypothetical conditions the landslide mass remained stable, and therefore should be considered suitable for the planned development.

A question was raised by the reviewers of the Landslide C study regarding the certainty behind the location of the head of Landslide C. During the field review of trenches (in early July), a question was also raised regarding the certainty of the location of the toe of Landslide C, and recommendations were made that the trench at the toe of the landslide be extended to the south. The extension of the toe trench was subsequently made. During the review of the extended trench (end of July, 2004) there was still speculation as to whether the toe of the landslide extended further south than the existing trenching, perhaps as far south as the southern property boundary.

The Landslide C study evaluated a wide variety of conditions to capture the effects of engineering and geologic uncertainties on the conclusions regarding stability of the landslide mass itself. These included effects of various groundwater conditions, various material property values assigned to the slide plane (both friction angle and cohesion values), and earthquake shaking. The potential uncertainty in the location of the landslide (the absolute location of either the head or the toe) **was not** evaluated. Thus, the speculation during the field review could not be addressed directly.

To address these questions, an evaluation of the overall stability of the landslide was undertaken. This evaluation considers the possibility that both the location of the head and the location of the toe might be incorrectly located; that is the landslide itself might extend higher toward the head scarp (north) and extend significantly farther south than the toe as currently mapped. The results of these analyses are presented here.

SUPPLEMENTAL ANALYSES

All analyses have been conducted using the most current post construction ("as-built") topography. This topography includes not only the planned infrastructure, but also the current mass grading plans for Maple Hollow 10 and 11. The initial analyses (Landslide C report) evaluated a suite of conditions defining the landslide. The cases were evaluated individually and in some cases combined to calculate corresponding factors of safety for the landslide mass. The supplemental analyses (presented here) were conducted following the same general format as the original work, with changes as noted. The suite of conditions considered here include the strength properties of the failure surface, the thickness of the landslide mass itself, the location of the head and toe failure planes, the water level within the landslide mass, and the degree of earthquake shaking applied to the landslide mass.

Material properties used for the failure plane in Landslide C were derived from direct shear testing of samples obtained from the toe thrusts exposed in trench C-3. The two samples offered two distinctly different values for angle of internal friction and cohesion. One material was classified as dark brown "fat" clay, with a friction angle of 20 degrees and a cohesion of 1000 pounds per square foot (psf). The second material classified as clayey sand with a friction angle of 36 degrees and a cohesion value of 600 psf.

To supplement these two values, a sample taken from the shear zone in the head of landslide A was evaluated; this sample was clayey sand with a friction angle of 23 degrees, and a cohesion value of 550 psf. Finally, the weakest material found on the mountain to date was also used; this sample came from Boring A1 and was classified as a green clayey sand (logged as a "fat" green clay) with a friction angle of 19 degrees and a cohesion of 760 psf. The base case for analysis is taken as the dark brown clay found in the toe trench. To evaluate the sensitivity of the analyses to this selection, two other cases were evaluated. The properties of the shear zone materials found in the head of Landslide A were considered, and the green clay sample found in a borehole just to the north of Landslide A was also used.

For purposes of this evaluation, three cases are used. Friction angles of 20 degrees with cohesion of 1000 psf is taken as the base case for the slide, and two alternative materials (23 degrees with a cohesion of 550 psf, and 19 degrees with a cohesion of 750 psf) which are used to capture the effects of small changes in material properties. The material with a 36 degree friction angle was dropped from the analyses.

These values were compared to published data from the Utah Geological Survey Landslide Shear Strength Database. This database contains shear strength parameters from various sites throughout Utah. Soil types similar to those investigated were compared and were found in general agreement with our laboratory results. The following table summarizes other published data consisting of volcanic material and how it compares with laboratory results from Landslide C:

Table 1: Published shear strength parameters for similar materials.

Location	**Soil Type**	**Angle of Internal Friction, (degrees)**	**Cohesion, (psf)**	**Residual Friction Angle (Degrees)**
Coyote Cyn B-1	Silty Sand	50	0	
Coyote Cyn B-1	Clayey Sand	21	2300	
Coyote Cyn B-3	Silty Sand	21	750	
Coyote Cyn B-2	Clay	32	250	33
Coyote Cyn B-2	Silt	39	400	
Coyote Cyn B-2	Silt	30	0	
Coyote Cyn B-3	Clay	30	0	
Coyote Cyn B-8	Clay	40	200	35
Coyote Cyn B-12	Silt	38.5	200	35
Coyote Cyn TP-33	Clayey Sand	30	50	
Jordanelle TP-15	Fat Clay	30	260	31

The **thickness of the landslide mass itself and the locations of the head and toe failure planes** in the initial study had geologic constraints used that were derived from interpretations of trench data as well as regional geologic information. The head scarp failure was thought to be limited to the north by trench CT-9, where no landslide deformation was observed. The landslide toe was located by interpretation of data from trenches CT-11 and CT-3. Tertiary beds in Landslide C were found to dip approximately 13 degrees to the southeast, and hence nominal bedding plane failure with that orientation was used for the analyses.

For the cases being analyzed here, the weakest possible failure configuration is being sought, without geologic constraints. This case is termed an unconstrained failure plane definition, where the analysis program, **GSTABL7**, is allowed to search for and generate a circular failure surface with the lowest factor of safety for the material properties being considered. This varies the thickness of the slide itself, and allows the location of the head and toe of the failure plane to move within prescribed bounds. In this case, the head and toe were forced to be at the nominal locations identified during the field review, as well as the landslide mass geometry as originally defined in the Landslide C report. Because the actual location of the failure plane was not known and the computer program was allowed to search for the most critical failure surface, soil strengths used to characterize the failure surface were initially used in the entire soil profile.

Two different scenarios were investigated with the first being the big landslide scenario and the second being the small landslide scenario. Boundaries were set just beyond the southern property boundary for the toe and just north of the original headscarp location to evaluate the stability of a potential big landslide. The computer program was allowed to search for the critical failure surface based on the boundaries set. The method for identifying the small landslide critical failure surface was similar to the big landslide scenario, where the computer program was allowed to search for the most critical failure surface based on the boundaries that were set. Figure A-1 shows the cross section location with the head and toe of the landslide being identified. The results of the stability analyses are shown below.

Table 2: Summary of stability analyses for Landslide C.

Landslide Scenario	Topography	Site Conditions (groundwater[3] and seismic[4] considerations)	Min Factor of Safety[1]		
			A	B	C
Big[2]	**Post-Construction**	**Static/ Dry**	**3.25**	**3.46**	**2.49**
Big	Post-Construction	Static/Groundwater at the ground surface	1.80	1.86	1.64
Big[2]	**Post-Construction**	**Seismic MHA = 0.23g / Dry**	**1.73**	**1.85**	**1.59**
Big	Post-Construction	Seismic/MHA = 0.65g / Dry	1.11	1.18	1.02
Small[2]	**Post-Construction**	**Static/Dry**	**2.81**	**2.87**	**2.55**
Small	Post-Construction	Static/Groundwater at the ground surface	1.63	1.60	1.46
Small[2]	**Post-Construction**	**Seismic MHA = 0.23g /Dry**	**1.65**	**1.70**	**1.50**
Small	Post-Construction	Seismic/MHA = 0.65g / Dry	1.09	1.14	1.00

1. Factors of safety were calculated based on soil strengths A: phi = 20 degrees, c = 1000 psf, B: phi = 23 degrees, c = 550 psf, C: phi = 19 degrees, c = 760 psf
2. Slide passes screening test if F.S. > 1.5 (static) and 1.0 (seismic)
3. Groundwater conditions are assumed to be bone dry, i.e. groundwater table is beneath stability cross section and no perched water exists in the cross section, as occurs today;
4. Seismic loading used in the analysis is 10% in 50 years (MHA = 0.23g, k = 0.12, feq = 0.5) and 2% in 50 years (MHA = 0.65g, k = 0.26, feq = 0.4)

Unlike the original landslide study, no geologic constraints were applied to these landslide scenarios. As a point of comparison, this change in slide plane configuration leads to a difference in the calculated factor of safety for the smaller (initial) landslide geometry of about ten percent—that is, the factor of safety calculated for the unconstrained failure geometry is about 2.5, and the geologically constrained geometry for the same slide mass is 2.8. Hence, it is concluded that using the unconstrained geometry does not add an inordinate amount of conservatism to the overall analyses. For the larger landslide geometry (the extended head and toe locations), the difference is slightly greater. The factor of safety for the unconstrained geometry of the landslide mass is approximately 3.0, whereas the geologically constrained geometry for the same slide mass is 3.5.

The water level within the slide mass also has a significant influence on the calculated stability of the landslide. Assumed water levels are used in the analyses because groundwater has not actually been encountered at SunCrest. The justification for assuming a rise in groundwater levels can be found in observations made by Ashland in *Special Study 105* of the Utah Geological Survey. He documented a three foot rise in groundwater elevation at the Sunset Drive landslide in Layton, Utah during the summer months which he attributes to irrigation waters. Given the planned development at SunCrest, it is plausible that a rise in groundwater level may occur here as well.

The occurrence of seeps in deep road cuts have been observed in two locations, however—one along Traverse Ridge Road, just west of the head scarp of the Little Valley Landslide, and the other along the deep cut at the southern end of SunCrest Drive. Both seeps are seen as essentially point source seeps, and neither has much flow. The fact that they persist through the summer months suggests that they are less transient than the highly seasonal snow melt infiltration waters seen across the mountain, however.

Perched water may have been encountered at a depth of about 160 feet in Boring A 7 in the area of Landslide A. No standing water level was ever observed, but a wet zone was encountered during the actually drilling. Other deep boreholes drilled in the area of Landslide A and Landslide B did not encountered water.

To evaluate the influence of groundwater on the calculated stability of the landslide, several scenarios were evaluated. As a limiting case, both initial and extended landslide geometries were evaluated with groundwater at the ground surface. While this is not a credible condition, it does demonstrate that the landslide remains stable under all groundwater conditions. The calculated factors of safety for this case, with groundwater assumed at the ground surface are 1.63 for the initial landslide, and 1.80 for the larger (extended) landslide geometry.

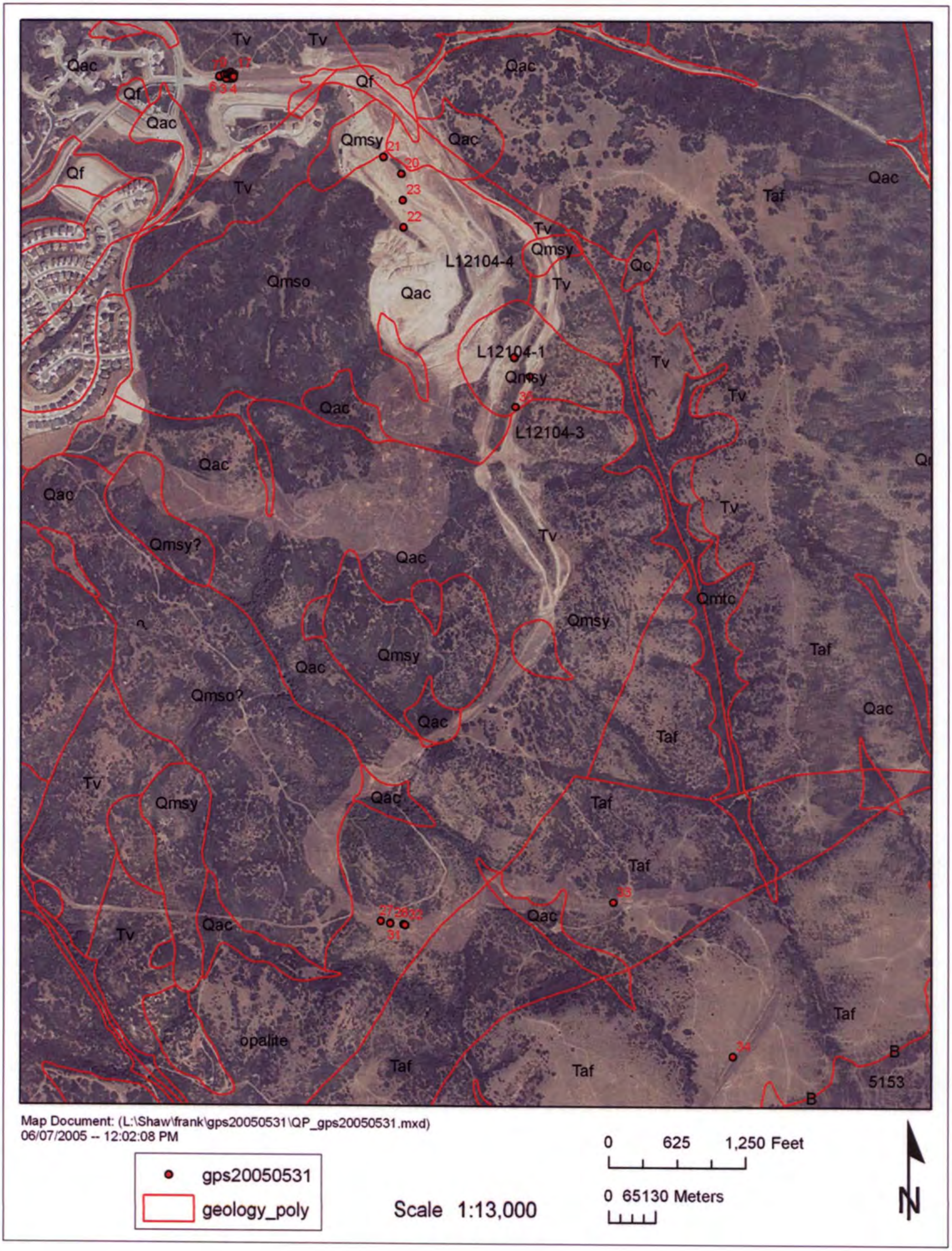
The degree of earthquake shaking analyzed is consistent with the level of shaking outlined in the guidance document referenced in the Draper City Ordinance. That document, *Recommended Procedures for Implementation of DMG Special Publication 117 Guidelines for Analyzing and Mitigating Landslide Hazards in California* (June, 2002), compiled by Blake and others, suggests that the appropriate level of earthquake shaking to be used in landslide stability analyses is that ground motion that has a ten percent chance of being exceeded in a fifty year period. That value of peak horizontal ground acceleration for SunCrest is 0.23 g. As described in the guidance document, the peak acceleration values were translated into an effective acceleration for subsequent failure analyses.

Using the peak ground acceleration value of 0.23 g, both the initial (smaller) landslide and the larger landslide with extended head and toe areas were evaluated. Both landslide geometries were found to be stable with calculated factors of safety of 1.65 for the smaller landslide geometry, and 1.73 for the larger landslide geometry. The guidance document suggests that the landslide need only have a factor of safety greater than 1.0 to be considered stable under these conditions.

Finally, the system was checked for catastrophic failure potential using ground shaking associated with the maximum event along the Wasatch Fault Zone (taken as having a two percent in 50 year chance of being exceeded, or 0.65g). While this is beyond any suggested design consideration for any development like SunCrest, the evaluation is made to see the robustness of the analyses used for design. The factors of safety associated with peak ground accelerations of 0.65g result in calculated factors of safety of 1.09 for the initial landslide and 1.11 for the larger landslide.

CONCLUSIONS

Given the above analyses, we conclude that Landslide C is stable. This is true under the suggested screening conditions as presented in the guidance document, and under reasonable variations in material properties, geometries, groundwater conditions and earthquake loading. It is believed that the conclusions regarding the stability of the landslide are robust, and therefore development of Maple Hollow 10 and 11 should not be compromised by the existence of Landslide C.



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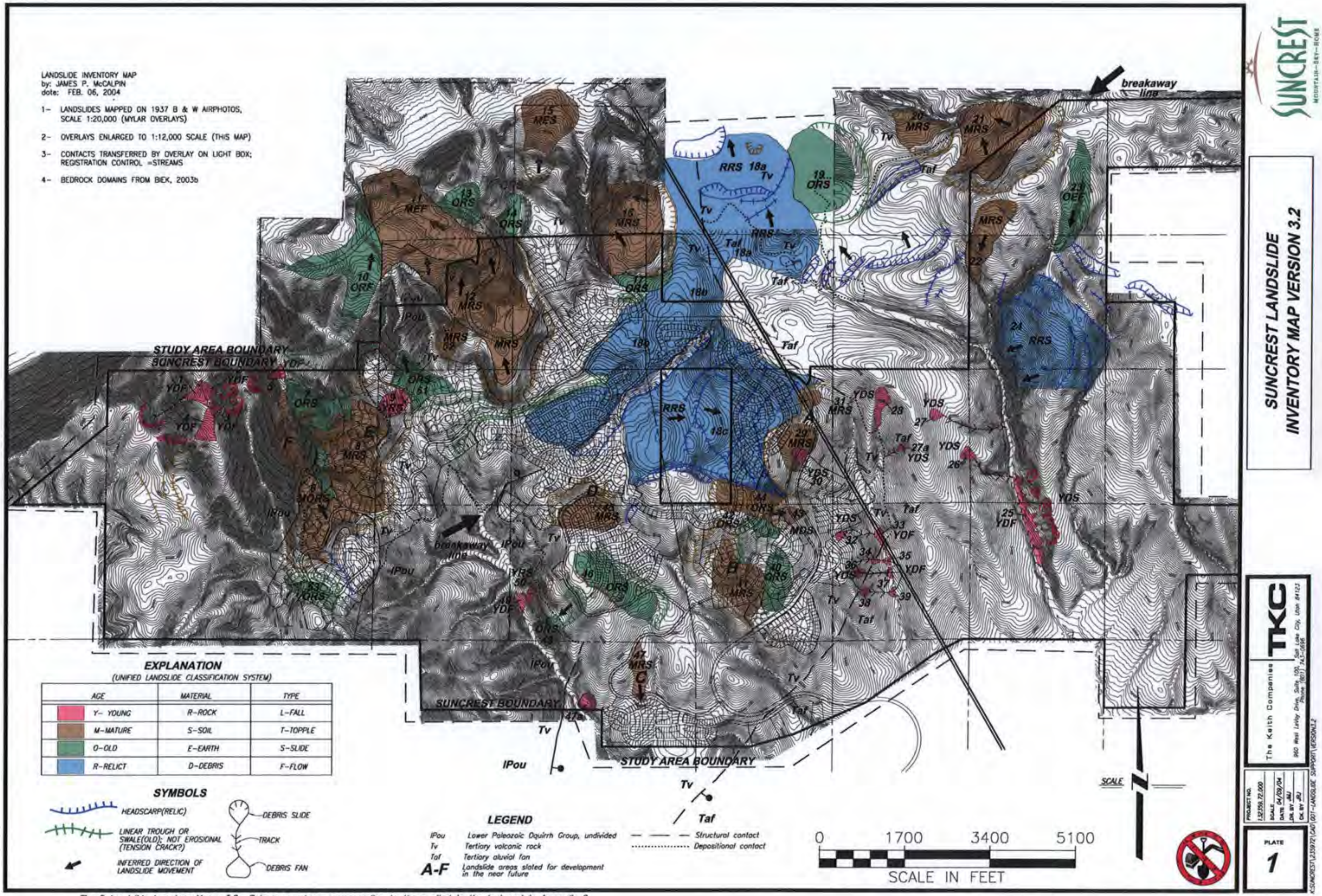

Fig. 5 Landslide Inventory Map v.3.2 Polygon numbers corresponding to those cited in the text and in Appendix 2