CHAPTER 4—GEOTECHNICAL

This chapter describes geotechnical topics such as the installation and monitoring of landslide monitor stakes (rebars), inclinometers, and testing of earth materials. Drilling methods for piezometers are described in Chapter 6 (Groundwater Hydrology).

4.1 Methods

4.1.1 Landslide Monitoring Pins

In 1995, the RCE (1995) geologic hazards report identified the East Slide as the most potentially hazardous area on Snodgrass. Immediately thereafter, Schmusser Gordon Meyer (SGM) placed 9 rebar stakes on this area of the mountain in order to monitor future surface movement (Test 1 through Test 9 on Fig. 4-1). The stakes were 18" lengths of ½" diameter rebar, pounded vertically into the ground until their stickup was only 2-3". The location of the rebar top was then measured via a survey-grade GPS.

Stake locations were first surveyed on 17-NOV-1995, and then at roughly 1-year intervals through August 2007, except for 1998 and 1999, when no measurements were made. A map showing these initial 9 rebar stakes (labeled Test 1 through Test 9) along with later ones is shown in Appendix 4-1, along with all the measurements from Nov. 1995 through August 2007.

Test 1 was located on a stable ridge of Mancos Shale to the east of the Snodgrass landslide area, and was presumably sited there to serve as a stable reference unaffected by landslide movement.

During the early stages of this geologic study in late 2006, it became apparent that we needed additional landslide monitor stakes on the southeast slope of Snodgrass, away from the 9 stakes placed near the East Slide in 1995. Therefore, from 6 to 8-NOV-2006, SGM placed an additional 10 stakes (Test 10 through Test 19) to the west and north of the East Slide. These stakes have only been remeasured once, on 6-AUG-2007. In late Fall 2007 SGM placed an additional two pins (Tests 20, 21) on the East Slide flanking Test 4.

4.1.2 Inclinometers

All of the inclinometer holes were drilled using a Dietrich D-50 track-mounted auger drill rig with a 6-inch diameter solid stem auger system. The boreholes were not logged because (except for I-SG5) they were all adjacent to piezometer holes that were logged and sampled (see details in Chapter 6). In compliance with the Decision Memo (USFS, 2007), the cuttings from the drilling activities were placed back in the borehole and/or contoured around the vicinity of the borehole.

Boreholes were completed through the landslide deposits to the top of the Mancos Shale at a minimum, and if possible, as far into the shale as the rig could penetrate before refusal. This is because we anticipated that the basal landslide failure plane lay at or near the basal contact of landslide deposits lying atop Mancos Shale bedrock. After hole completion, we installed snap-lock, 85 mm-diameter inclinometer casing from Slope Indicator Company. The "A" set of grooves was oriented in the upslope-downslope direction. Due to the presence of the end cap on the bottom of the casing, the casing would tend to "float" when it penetrated the water table. To get the casing to settle to the bottom of the drilled hole, we filled the casing with water to give it negative buoyancy. After the casing was set to the hole bottom, it was then cemented with grout from bottom to ground surface, following the grout mixture recommendations of Slope Indicator Company.

Inclinometer surveys were performed using a Slope Indicator Company vertical inclinometer system owned by GEO-HAZ, and operated by Ms. Deborah Green, principal of Tilford & Green consultants (Placitas, New Mexico). The inclinometer probe was 2.0 ft long and a 100 ft-long cable was used. The probe was lowered to the bottom of the water-filled casing and allowed to calibrate to temperature for 10 minutes. The probe was then slowly raised to the ground surface, with successive tilt readings made on 2 ft centers. We performed 2 initial surveys of each inclinometer and checked their respective CHECKSUMS. If these were consistent and within factory-prescribed error limits, we did not perform a 3rd initial survey. All initial surveys were performed between 24-JUL-2007 and 20-SEP-2007. Resurveys were made on inclinometers I-2, I-4, and I-8 in late September 2007.

Table 4-1. Dates and numbers of initial and repeat inclinometer surveys on Snodgrass.

Inclinometer	Initial Survey	Repeat Surveys
I-2	24-25 JUL 2007 (n=3)	20 SEP 2007 (n=1)
I-4	24-25 JUL 2007 (n=3)	20 SEP 2007 (n=1)
I-8	25 JUL 2007 (n=3)	20 SEP 2007 (n=1)
I-11	19 SEP 2007 (n=2)	
I-13	19 SEP 2007 (n=2)	
I-16	19 SEP 2007 (n=2)	
I-SG5	20 SEP 2007 (n=2)	

4.1.3 Material Testing

Material testing was performed on split-spoon samples from boreholes, and on grab samples from test trenches. All testing was performed by Professional Services Industries (PSI) in Thornton, CO. Split-spoon samples were collected in a standard 1.25-inch diameter drive tube and were about 12 inches long, but in some cases where rocks were sparse or absent, we used the larger California sampler tube.

Hand-carved grab samples were collected from the two 10 ft-deep backhoe trenches on the lower East Slide, and included shear zones and landslide deposits.

Bulk Density: PSI used the xxx method to measure bulk density.
Cohesion and friction angle: for most split-spoon samples, PSI used the direct shear method on remolded samples. For the hand-carved samples, PSI tested

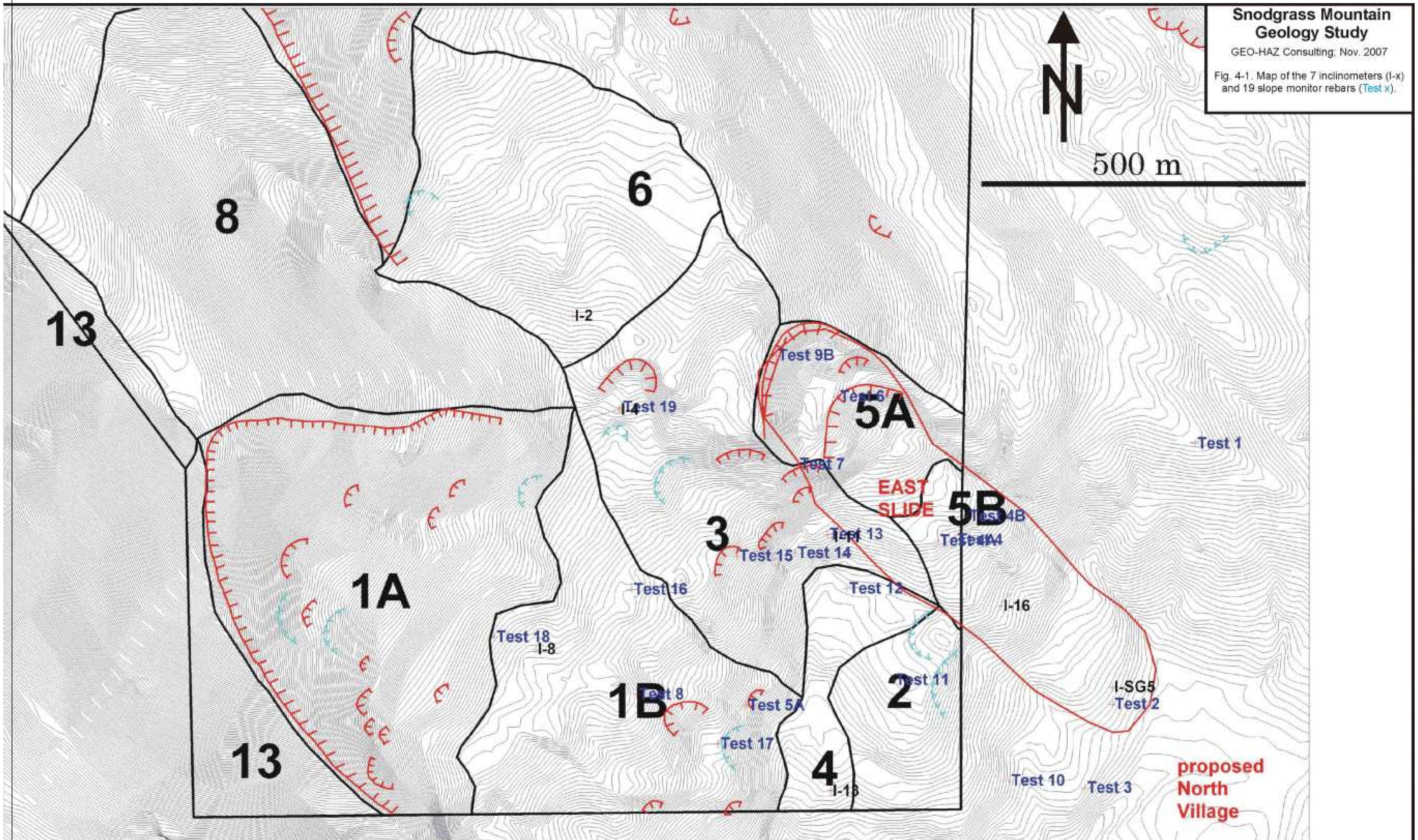

Fig. 4-1. Location map of the 19 landslide survey pins (labeled Test x in blue) and inclinometers (labeled I-x in black) on the SE slope of Snodgrass Mountain. Contour interval is 5 ft. Large black lines and numbers show GHUs.

undisturbed samples in direct shear, oriented to shear along the preexisting shear fabric.

4.2 Landslide Monitoring Pins Results

4.2.1 Pins Installed in 1994 (Test 1 through Test 9)

In 1995 Schmuser-Gordon-Meyer (SGM) placed 9 rebar survey stakes on lower Snodgrass to monitor any surface slope movement. Of these 9 stakes, 2 were on stable bedrock and 7 were on landslide deposits. Of the 7 stakes on landslide deposits, 5 were located on the East Slide, which in 1995 was thought to be the only young slide on the mountain (Fig. 2-12). The stakes have been remeasured nearly every year in the Fall, from 1996 to 2007. In this section we discuss only the stake movement up to the Fall 2006 resurvey.

The Fall 2007 resurvey, which occurred on 6-AUG-2007, displays a very weird result, in that all 9 original pins (and additionally, all 10 new pins) are shifted northward about 0.06 ft, and a lesser amount to either E or W. This shift results in most of the survey stakes moving uphill between 2006 and 2007, although the pattern is not consistent with the local slopes to the SE. In other words, some pins apparently moved NW (upslope) and gained elevation, whereas others moved in a similar direction and lost elevation. The apparent horizontal movement thus contradicts most of the elevation change data. This shift is very different from the pattern of the preceding 10 years, and is always northward whether the pins are on landslide or bedrock, steep or gentle slopes, etc. We surmise that this consistent shift results from some type of calibration error by the surveyors, but GEO-HAZ has no method of correcting it. Therefore, the discussion below omits the Fall 2007 resurvey data.

Fig. 4-3 and Table 4-2 show that 7 of the 9 stakes have moved in the SE direction, 1 stake moved SW, and 1 moved E, in an amount that is larger than the expected measurement error (ca. 0.1 ft). The largest displacement is that of stake 4, located in the center of GHU 5B, which moved 0.82 ft between 1995 and 2006, in the direction S30E (parallel to the fall line). Other stakes moved 0.59 ft (stake 2), 0.34 ft (stake 3), and 0.3 ft (stake 1), all in the direction of the local fall line. All of these movements exceed the measurement error, estimated by SGM as approximately 0.1 ft.

Table 4-2. Net movement of landslide monitoring stakes, 1995-2006, listed by stake number.

Stake no.	GHU/ polygon	Age	Movement (ft)	Direction
1	Km bedrock	N/A[1]	0.30	S20E
2	5B/ 34	Qlsiy	0.59	S26E
3	2/ 12	Qls	0.34	S20W
4	5B/ 36	Qlsy	0.82	S30E
5	1B/ 1	Qefy	0.23[2]	S70E
			0.14[3]	S20E
6	5A/ 30	Qlsi	0.50	S40E
7	5A/ e	Scarp of 30 (Qlsi)	0.27	S50E
8	1B/ 6	Qlsio	0.06	S45 E
9	Tp bedrock	N/A	0.04[3]	E

[1] not applicable, because substrate is not a landslide. Stake movement in bedrock must be due to shallow soil creep; [2] from 1995 to 2000; [3] from 2004 to 2006

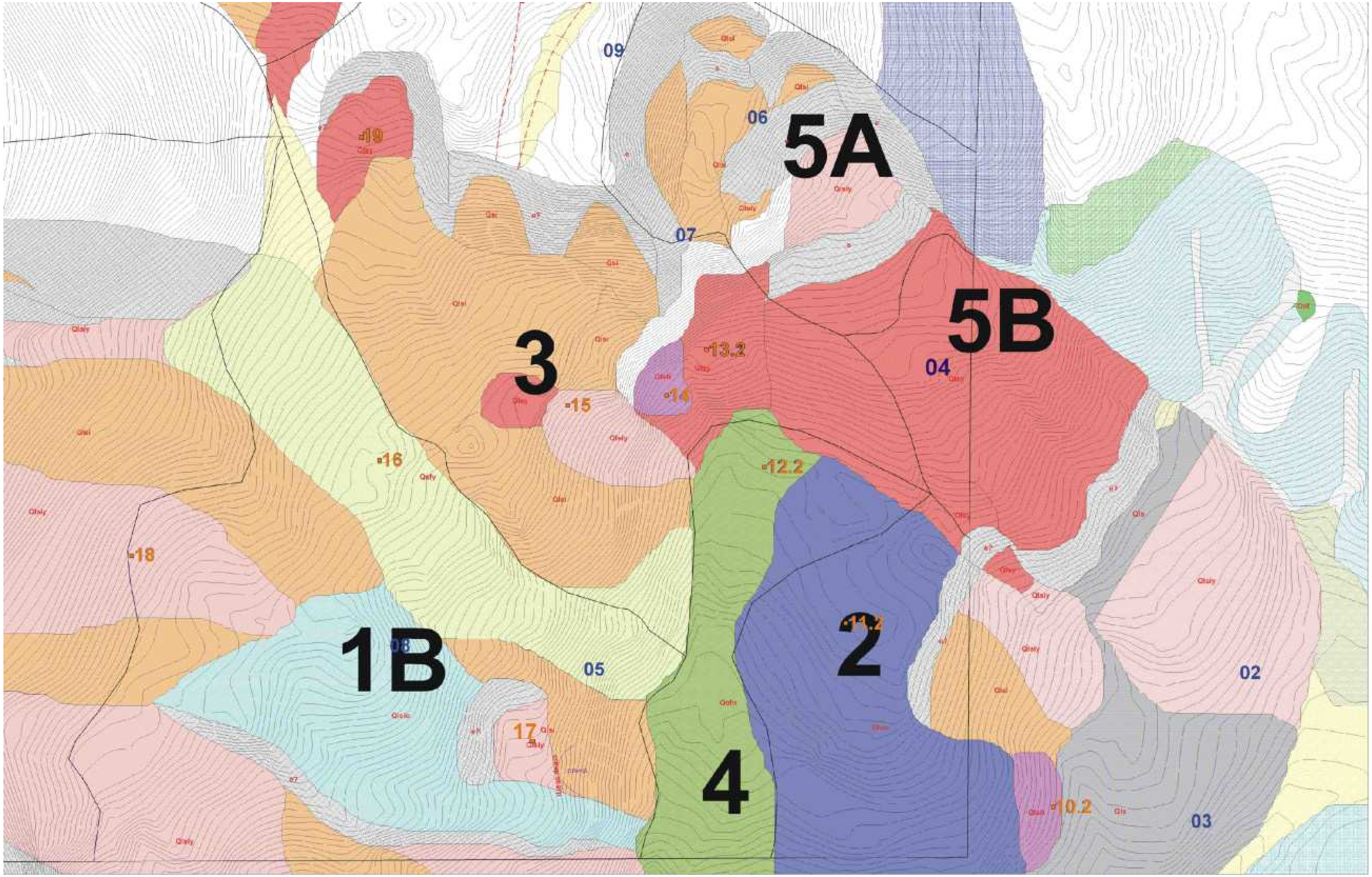

Fig. 4-2. Landslide and GHU map of lower Snodgrass, showing the locations of survey stakes 2-9 (large blue numbers) installed by SGM in Nov. 1995, and stakes 10-19 (orange squares and large numbers), installed by SGM in Oct. 2006. For the newer stakes, a decimal number of x.2 means that the stake was relocated to avoid tree canopy cover.

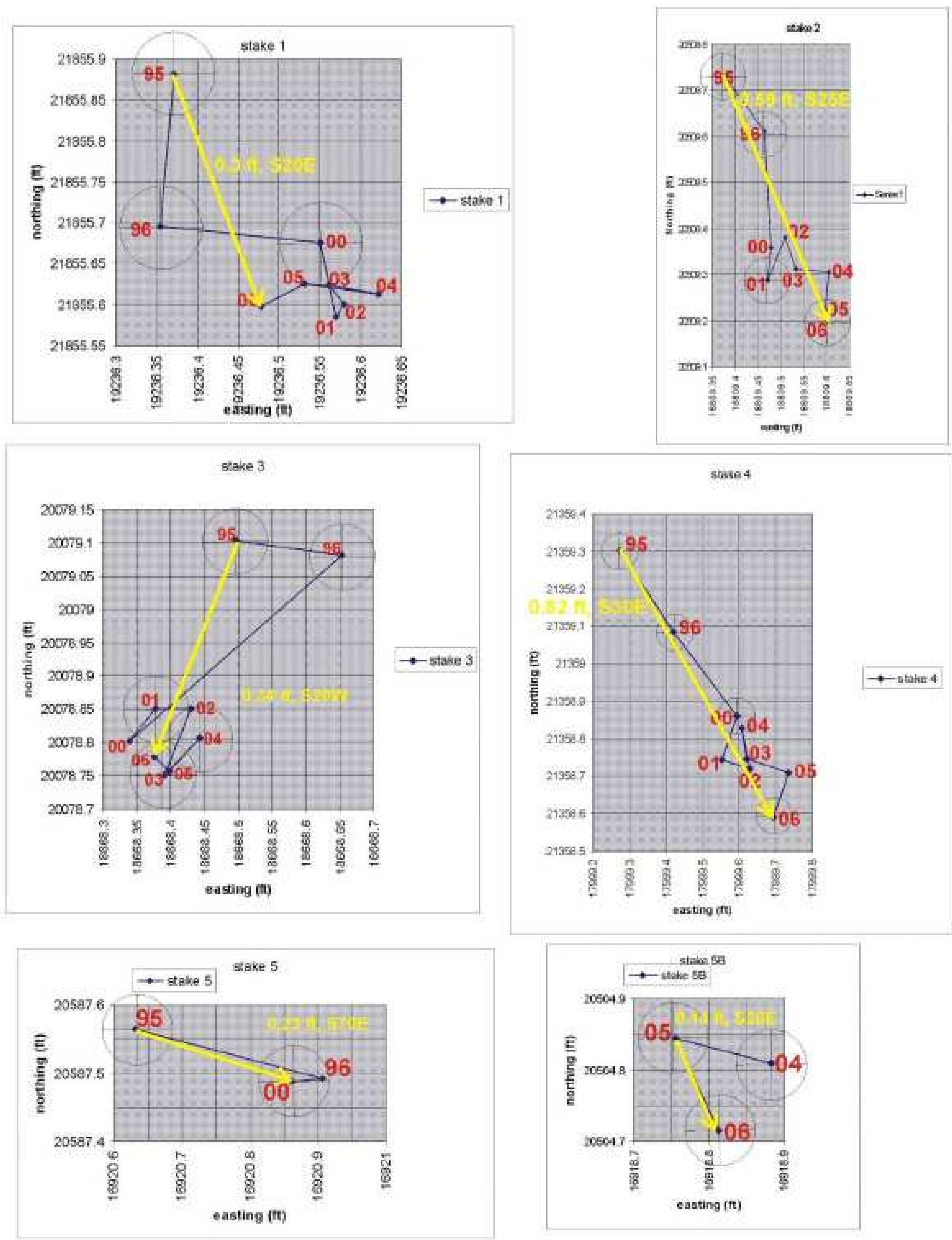

Fig. 4-3. Position data for landslide monitoring stakes 1-5, from 1995 to 2006. Year of measurement is in red. Circles denote approximate measurement uncertainty (0.1 ft). Yellow arrow shows length and bearing of net movement vector.

Of the 9 stakes, 7 (stakes 1-7) have a net movement between 1995 and 2006 of roughly 0.3-0.8 ft, with an average of 0.46 ft. This equates to an average movement rate of 0.042 ft/yr, or 0.5 inch/yr.

This movement could have two possible explanations. The first explanation is that movement is due to surface creep caused by freezing and thawing of the surface soil. If this is the case, then the stakes that moved the farthest should be the ones where the local ground surface slope is steepest. Based on a preliminary examination of the data, there is not a strong correlation movement and slope angle (Table 4-3), although we only measured the slope angle at 4 of the 9 stakes.

Table 4-4. Net movement of landslide monitoring stakes, 1995-2006, listed in order of increasing age of underlying landslides.

Stake no.	GHU/ polygon	**Age**	Movement (ft)	Direction	surface slope & direction (degrees)
4	5B/ 36	**Qlsy**	0.82	S30E	8°, S70E
5	1B/ 1	**Qefy**	0.23[2]	S70E	20°
2	5B/ 34	**Qlsiy**	0.59	S26E	
6	5A/ 30	**Qlsi**	0.50	S40E	
7	5A/ e	**Scarp of 30 (Qlsi)**	0.27	S50E	23°, S60E
3	2/ 12	**Qls**	0.34	S20W	
8	1B/ 6	**Qlsio**	0.06	S45 E	9°
1	Km bedrock	**N/A[1]**	0.30	S20E	
9	Tp bedrock	**N/A**	0.04[3]	E	

[1] not applicable, because substrate is not a landslide. Stake movement in bedrock must be due to shallow soil creep; [2] from 1995 to 2000; [3] from 2004 to 2006

The second explanation is that movement reflects deep-seated creep on the entire 30-50 ft-thick landslide deposit underlying the stake. If this is the case, then we would expect the most movement on the youngest landslides, and the least on the oldest landslides. So far, that correlation seems weakly supported by the data in Table 2-4, which shows that: (1) the largest movements tend to have occurred on the younger landslides, but (2) there are numerous exceptions to the trend, including stakes on Mancos Shale bedrock that have moved up to 0.3 ft over 11 years. That amount of movement either reflects shallow creep of regolith over bedrock on a slope, or a systematic drift in the GPS calibration over 11 years. Nevertheless, it cannot represent landslide movement.

4.2.2 Pins Installed in 2006 (Test 10 through Test 19)

On 6-NOV-2006 we installed an additional 10 rebar stakes in areas to the west and north of the 1995 stakes (Figs. 4-1, 4-2). These new stakes expand the coverage of the monitoring network to cover all GHUs 1-5. These stakes have only been resurveyed once, on 6-AUG-2007, so we only have 9 months of movement data.

Unfortunately, all of these stakes show an identical apparent movement of ca. 0.06 ft to the N, resulting in an apparent increase in elevation for nearly every stake. As previously discussed, this pattern likely results from a systematic surveying error. The fact that the movement is so consistent among the 10 pins, suggests that there has no downslope movement of any pin greater than the measurement error (0.1 ft).

4.2.3 Pins Installed in 2007 (Test 20-21)

During a field review of the East Slide in Fall 2007, we noticed that in the vicinity of Test 4 (which displays the largest movement of any stake), the USFS boundary fence had been bowed out in the downslope direction. In this area, the surface of the East Slide (polygon 36, Qlsu) is composed of two bouldery ridges trending downslope (SE), and an intervening sediment-filled swale. Test 4 is located in the swale. We further noticed that the fenceline was considerably more bowed where it crossed the swale, than where it crossed the two bouldery ridges. Thus, the possibility arose that some part of the 0.82 ft of cumulative downslope movement of Test 4 might be due to surficial soil creep in the swale, rather than movement of the entire landslide.

To test this hypothesis, we added one additional monitor stake on the crest of each ridge flanking Test 4. If these new stakes show identical movement with Test 4, then movement of the entire slide is indicated. Conversely, if the two new stakes show significantly less movement than test 4, it is likely their movement reflects landslide movement, and Test 4 reflects landslide movement plus additional surficial soil creep.

Because the two new pins (Test 20, 21) were installed late in 2007, and have not yet been resurveyed, so we will not know the results of this test until summer of 2008.

4.2.4 Fence posts surveyed in 2007

As described above, a N-S fence crosses the approximate center of the NW-SE-trending East Slide, crossing the entire width of the East Slide at about a 45-degree angle (black line on Figs. 4-1, 4-2). This fence parallels the USFS boundary but lies about 50 ft from it. The fence presented an opportunity to detect movement of the East Slide since the fence was constructed (roughly 70-80 yrs ago; J. Norton, pers. commun., 2007).

The fence is composed of 2 types of posts, treated wooden 8x8s (railroad ties), and steel T-posts. Along much of the fence, the wooden 8x8s are tilted significantly downslope, whereas the T-posts between them are either untilted, or tilted to a lesser angle. This pattern suggests that the wooden posts are significantly older than the T-posts.

In October 2007 SGM surveyed the position of the bases of the 101 fenceposts that comprise this N-S fenceline. Of this number, 43 posts are on the East Slide. Approximate GPS point accuracy is 0.1 ft, per personnel communication with Schmuser Gordon Meyer. Deviation of the surveyed bottom of each fencepost was measured in MapInfo GIS perpendicular to the (inferred) original straight fence line.

As can be seen on a close-up map (Fig. 4-4), the fenceline is not a straight line today, either off the Slide or on it. Compared to a straight line drawn across the Slide, there are 4 zones of differing deviation from a straight line, described below from S to N (Fig. 4-5).

Zone of Small or Upslope Deviations: The southernmost 140 ft of the fence displays either no deviation from a straight line, or small deviations to the upslope side of the straight line. Because we do not believe that the fence has actually moved uphill, we interpret the deviations in this zone as indicative of either as-built inaccuracies in post placement, survey error, or both.

Southern Bulge: Over the next 200 ft the fence describes a broad bulge in the downslope direction. In the center of the bulge posts have a maximum deviation from the straight line of nearly 4 ft (Fig. 4-5). The southern bulge is approximately coincident with the sediment-filled swale (Fig. 4-4) which contains monitor stake Test 4.

Central Zone of Small Deviations: In the next 120 ft of fence, post deviations slowly decrease to a low point of zero in the center of the zone. Unlike the other zones, in this zone the fence descends nearly straight down the local fall line, rather than across the slope.

Northern Bulge: The final 220 ft of the fence describes another downward bulge-deviation from a straight line, which reaches a maximum deviation of 6 ft. This bulge decreases to zero (by definition) at the NE margin of the East Slide.

In addition to these short-wavelength deviations, there is an overall long-wavelength deviation that increases from SW to NE, and 5-ft misalignment of the fence across the NE margin of the East Slide. Both the long-wavelength deviation and the misalignment could be the result of a non-straight original fence configuration. Alternatively, they could be explained by deep-seated deformation of an originally straight fence, as discussed below.

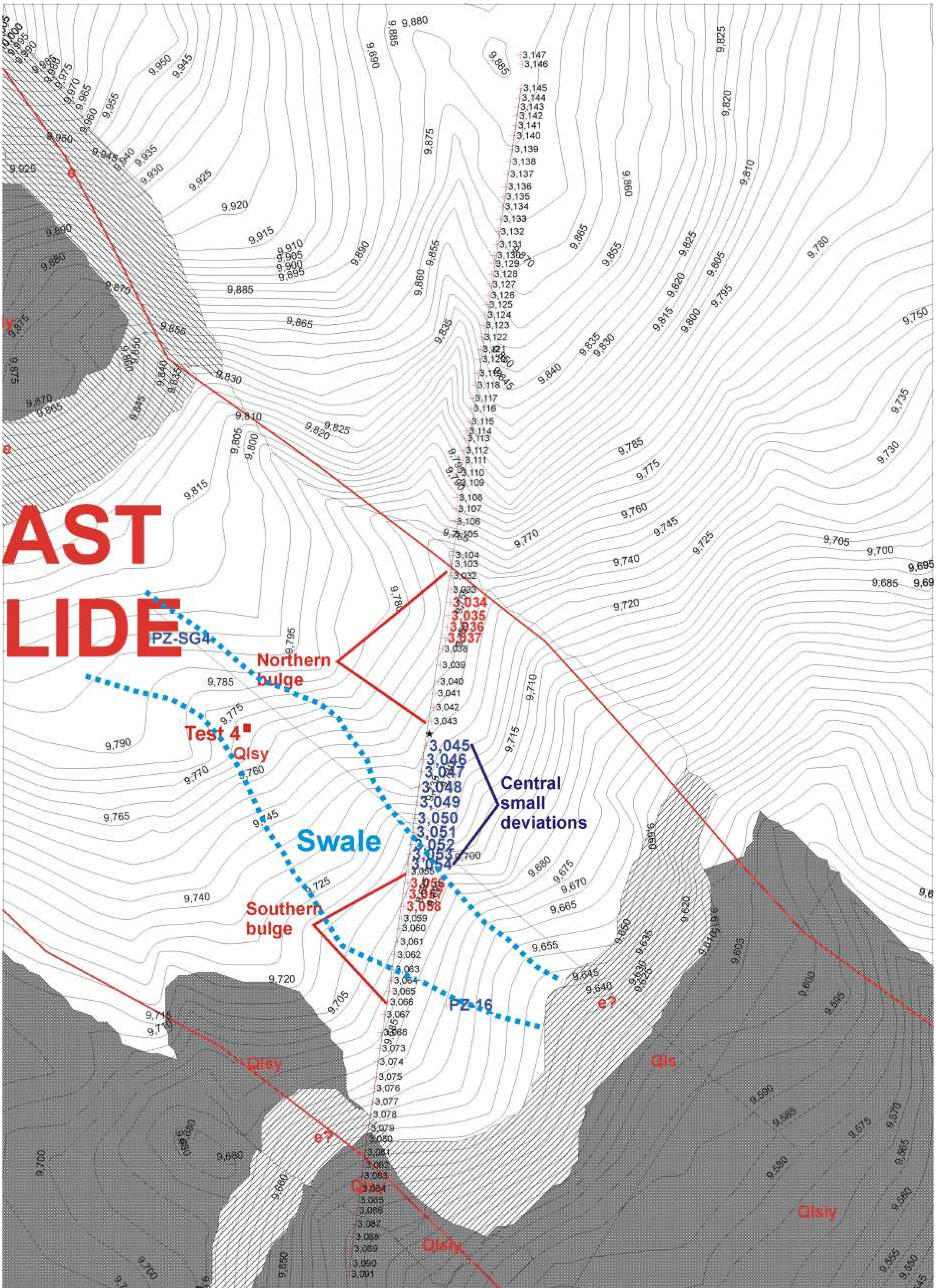

Fig. 4-4. Map of surveyed fenceposts (crosses) along the fenceline crossing the East Slide. Straight line is added to show amount and sense of deviations of fenceposts from a straight line. The central sediment-filled swale is outlined by blue dotted lines, and contains monitor stake Test 4, which has moved 0.82 ft SE between 1995 and 2006. Survey point numbers in red bold indicate the 4 largest deviations in each bulge area; posts in the zone of central small deviations are also bolded.

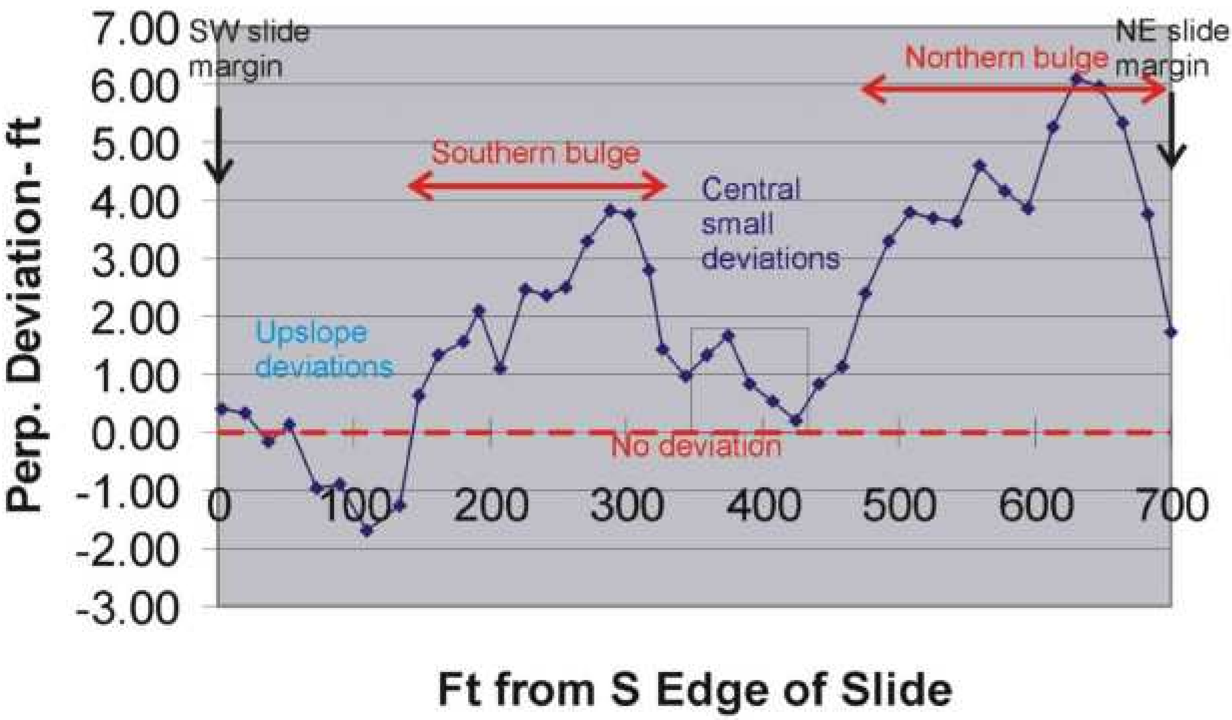

Fig. 4-5. Deviation of fence post locations from a straight line, as a function of distance of the post from the SW edge of the East Slide. Deviations were measured perpendicular to the straight line. Deformation zones correspond with those shown in Fig. 4-4 and described in the text.

4.2.4.1 Interpretation of the fence post deviation pattern

Because we do not know the original, as-built shape of the fenceline, there are at least 5 hypotheses to explain its present shape. Below we describe each hypothesis, how we tested it, and the results of the test. Several of these hypotheses are related, and thus not totally independent.

Hypothesis 1: the fenceline was originally straight between the surveyed endpoints (3091 at South, 3145 at North).
Test 1: fenceposts can only move downhill by soil creep or slide movement. If any posts are uphill of the straight line between the endpoints, then either they have moved uphill (unlikely), OR, the line was not originally straight, OR there is surveying error.
Result of Test 1: compared to a straight line between the endpoints, 32 of the 101 fenceposts on the East Slide (and south of it) lie uphill of that line. It is physically unlikely that 1/3 of the fenceposts could have moved uphill from their original positions.
Conclusion: Hypothesis is FALSE; the original fence was not a straight line between the surveyed endpoints. [Note: Unfortunately, because this hypothesis is false, and the

fenceline is now deformed in a complex manner, it is impossible to know precisely the original configuration of the fenceline].

Hypothesis 2: the fenceline was NOT originally straight between the surveyed endpoints (3091 at South, 3145 at North). The northernmost 2 points (3146, 3147) are clearly discordant with all of those to the south. The southernmost 12 points (3080-3091) define a line with a different bearing than the remainder of the line. The remaining 87 points on the fenceline are assumed to have originally defined a straight line. In addition, the first post south of the East Slide (3079) is assumed to be stationary; if this assumption is not made, movement of fenceposts on the East Slide becomes unbounded. Finally, the first post north of the East Slide has moved, as have all points to the north (3106-3139), which form a bow-shaped pattern, due to shallow soil creep to the SW on the steep moraine slope (there is no landslide there). In order for this creep to decrease to zero at the crest of the lateral moraine (point 3139), post 3105 must have moved 4.1 ft perpendicular to the fenceline. This requires that the N-most post on the East Slide (3104) has moved 0.85 ft downhill.
Test 2: this hypothesis cannot be rigorously tested, because the original fence configuration is unknown. However, these assumptions minimize the amount of downslope movement predicted for fenceposts on the East Slide.

Hypothesis 3: Assuming that Hypothesis 2 is true, all deviations of the central 87 fenceposts from a straight line result from deep-seated movement of the East Slide in the approximate direction S50E.
Test 3: if deep-seated movement along a consistent vector were responsible for moving the fenceposts, they would all be moved approximately the same amount, to the SE, away from the original straight line. For example, in rigid block movement, all the posts on the slide mass would have moved the same distance in the same SE direction, and there be would be a sudden, major misalignment of fenceposts across both margins of the East Slide.
Result of Test 3: There is no sudden, major misalignment of posts across the southern slide margin, but there is a ca. 4 ft misalignment across the northern margin. In addition, the posts on the East Slide have not been moved a consistent distance along the length of the fence, but display a complex deviation pattern from the (inferred) straight line. This deviation pattern can be subdivided into an 4 “short wavelength” anomalies: (1) an asymmetrical Northern Bulge in the downslope direction, (2) a central area of small deviations, (3) an asymmetrical Southern Bulge in the downslope direction, and (4) decreasing deviations to the south slide margin (Fig. 4-4). The Southern Bulge is coincident with a slopewash-filled trough in the center of the slide mass.
Conclusion: Hypothesis is MOSTLY FALSE; the observed deviations of the fenceposts from a straight line are too complex to result from rigid slab-type movement of the entire East Slide block. However, there may be some rigid shear across the northern margin. This margin is the wettest margin, since the stream drainage from most of the East Slide travels down this marginal gully.

Hypothesis 4: Assuming that Hypothesis 2 is true, all deviations of the central 87 fenceposts from a straight line result from shallow, surficial soil creep.

Test 4a: if shallow soil creep were responsible for moving the fenceposts, they would all be moved in the direction of the local slope, and possibly, in an amount proportional to the sine of the slope.
Result of Test 4a: The central area of low deviations coincides with a part of the fence that is going straight down the local fall line. In contrast, the two bulges coincide with parts of the fence that are perpendicular to the local fall line. This pattern suggests that the movement of fenceposts is strongly influenced by the local slope direction.

Test 4b: if shallow soil creep were responsible for moving the fenceposts, they should be tilted in the direction of the movement, and older (wooden) posts should be tilted more than younger (steel) posts.
Result of Test 4b: In the two bulges, the larger the deviation of the posts from the straight line, the more they are tilted downslope; wooden posts are tilted much more than the steel posts.
Conclusion: <u>Hypothesis is TRUE; the observed deviations of the fenceposts from a straight line coincide with changes in the relative orientation of the fenceline versus the local fall line, AND the observed tilt of the fenceposts coincides with the amount of deviation from a straight line.</u>

Hypothesis 5: Assuming that Hypothesis 2 is true, deviations of the central 87 fenceposts from a straight line result from **<u>both</u>** block movement of the East Slide and shallow, surficial soil creep.
Test 4: unexplained residuals from Tests 3 and 4 suggest that locally, both styles of deformation may be occurring.
Result of Test 4: The pattern of fencepost deviations on the East Slide mainly coincides with the local slope direction. However, regardless of where the original fence line is postulated to be, there is a 4 ft misalignment across the north boundary of the East Slide. If this is not an original feature of the fence, it implies block movement.
Conclusion: Most of the short-wavelength deviations can be explained as the result of shallow soil creep. However, there is also a long-wavelength trend where deviations increase from south to north<u>. This pattern can be interpreted as the entire slide block moving SE, hinged at the south lateral margin, with increasing displacement (4 ft? since the fence was built; ca 70-80 yrs) toward the north lateral margin. Such differential movement might be explained by a higher water table beneath the north margin gully.</u>

IN CONCLUSION: The deviations of the central 87 fenceposts from a straight line may result from both shallow, surficial soil creep, AND a hinge-type block movement of the East Slide. As shown by the results of hypothesis tests 2-4, the short-wavelength deviations of the fenceline are NOT likely original features or the result of deep-seated movement of the East Slide. In contrast, the long-wavelength deviation trend is not likely to reflect local soil creep, either; if it is not an original fence feature (?), it must represent deeper-seated block movement of the East Slide.

The magnitudes of these movements over the past 70-80 years yield long-term maximum surface creep rates ranging from 6 ft/70-80yrs (***0.075-0.086 ft/yr***) given the maximum size of the Northern Bulge, to 10 ft/70-80 yrs (***0.13-0.14 ft/yr***) for the Northern

Bulge plus an additional 4 ft of "block movement" of the entire Slide. Estimated mean surface creep rates on the East Slide would be about half of those amounts, considering that both the shallow creep ("half-maximum" rate of ***0.038-0.043 ft/yr***)and deep movement decrease to zero within the fence transect.

These reconstructed annualized movement rates for the East Slide can be compared to the shorter-term (1995-2006) mean annualized movement rates measured at the 8 landslide monitoring pins NOT on the East Slide (Tables 4-2, 4-3). At those pins, the mean annualized surface movement on landslides of various ages (which presumably includes both surface creep and deep-seated components, if either exist) ranges from ***0.005 ft/yr to 0.054 ft/yr***, with a mean of ***0.03 ft/yr***. Thus, the mean annualized total surface movement rates beyond the East Slide at Snodgrass over the past 11 years (***0.03 ft/yr***) are essentially identical with the "half-maximum", annualized rate calculated for the East Slide fence over the past 70-80 years (***0.038-0.043 ft/yr***).

Therefore, the 11 years of data from 9 stakes and the 70-80 year record of fenceline deformation, suggest the following: on any mapped landslides on the SE slope of Snodgrass, one can reasonably expect an annualized surface movement rate in the downslope direction in the range ***0.03-0.04 ft/yr*** (***0.36-0.5"/yr***), mainly from shallow soil creep (see confirming data in next section describing Inclinometers). This relatively small amount of creep has not created obvious surface cracks, tilted trees, or other visible manifestations at Snodgrass, even on the East Slide. Thus, this slow surface movement could not have been detected without a monitoring network or old cultural features such as fencelines. However, even such small movements may have a cumulative impact over decades, so should be considered when planning ski area infrastructure (see Chapter 9). Because this movement is probably caused by shrink-swell or freeze-thaw, we assume that it decreases rapidly with depth, as indicated by inclinometer data (next section).

Additionally, if landslide block movement is also occurring (such as on the NE slide of the East Slide), the annualized surface movement rate may rise to as much as 4 times larger (up to ***0.14 ft/yr, or 1.7"/yr***). At that maximum rate, sensitive facilities such as lift towers will have to be designed to accommodate long-term cumulative movement, particularly if the movement vector is oriented at a high angle to the lift line (see Chapter 9). However, because most lift lines ascend nearly straight up the fall line on the mountain, the perpendicular component of creep should be a small fraction of the total movement.

4.3 Inclinometer Results

Of the 8 inclinometers installed in late July 2007, only 3 received repeat surveys by before the snow fell in Fall, 2007. We did not expect that detectable motion would occur in the 2 dry months since installation, given the lack of surface evidence for ongoing movement, so these 3 resurveys (I-2, I-4, and I-8) were performed mainly as a training exercise. At all 3 inclinometers, the A0 direction points directly downslope, A180 points directly upslope, and B0 and B180 are perpendicular to the left and right of the A0 direction, respectively.

4.3.1 Inclinometer I-2

Inclinometer I-2 is located next to piezometer PZ-2 in the lower part of the Chicken Bone area, on a slide mapped as Qlsi. Inclinometer depth was limited to 21 ft BGS, due to drill rig refusal at that depth on Mancos Shale.

The 2-month repeat survey shows no deflections of the borehole, within the accuracy of the inclinometer (Fig. 4-6). This was the expected result, given the age of the landslide (Qlsi), the short time period covered, and fact that the probe CheckSums on the initial and repeat surveys were similar (Table 4-.

4.3.2 Inclinometer I-4

Inclinometer I-4 is located on the small Qlsy just east of Ken's Crux (polygon 22), next to piezometer PZ-4. Inclinometer depth was limited to 42 ft BGS, due to drill rig refusal at that depth on Mancos Shale.

The SEP-2007 repeat survey shows 2 deflections have occurred since July. The first is a deflection of 0.05" in the downslope (A0) direction, which is limited to the upper 2 ft of the casing (Fig. 4-7). This deflection probably indicates surface soil creep. An annualized rate of movement based on this 2-month value would be ***0.3"/yr***, or ***0.025 ft/yr***. By comparison, this value is in the range of long-term observed surface creep rates from landslide monitor pins in the area.

The second deflection is a persistent tilt of the entire casing in the B180 direction, amounting to a cumulative 0.09". At I-4, the B180 direction is perpendicular to the local fall line. This tilt is consistent throughout the 42 ft of the casing, and resembles the bias shift error of Cornforth (2006, p. 78-79; also called zero shift or offset error, or the "windshield wiper" effect). The most common cause of a bias shift error is widely different CheckSums between two consecutive surveys. Unlike I-2, where CheckSums were very similar between the initial and repeat surveys, on I-4 the B-axis checksum was quite large (-40.4) on the 1 initial survey, much larger than the B-axis checksum of the repeat survey (-11.3; Table 4-5). We suspect that this is the cause if the "windshield wiper effect".

We plan to resurvey all the inclinometers in May 2008 as soon as the snow melts, and at I-4 will ensure that checksums for the June-08 resurveys are compatible with those of the July-07 survey; this should eliminate bias shift error from subsequent survey comparisons.

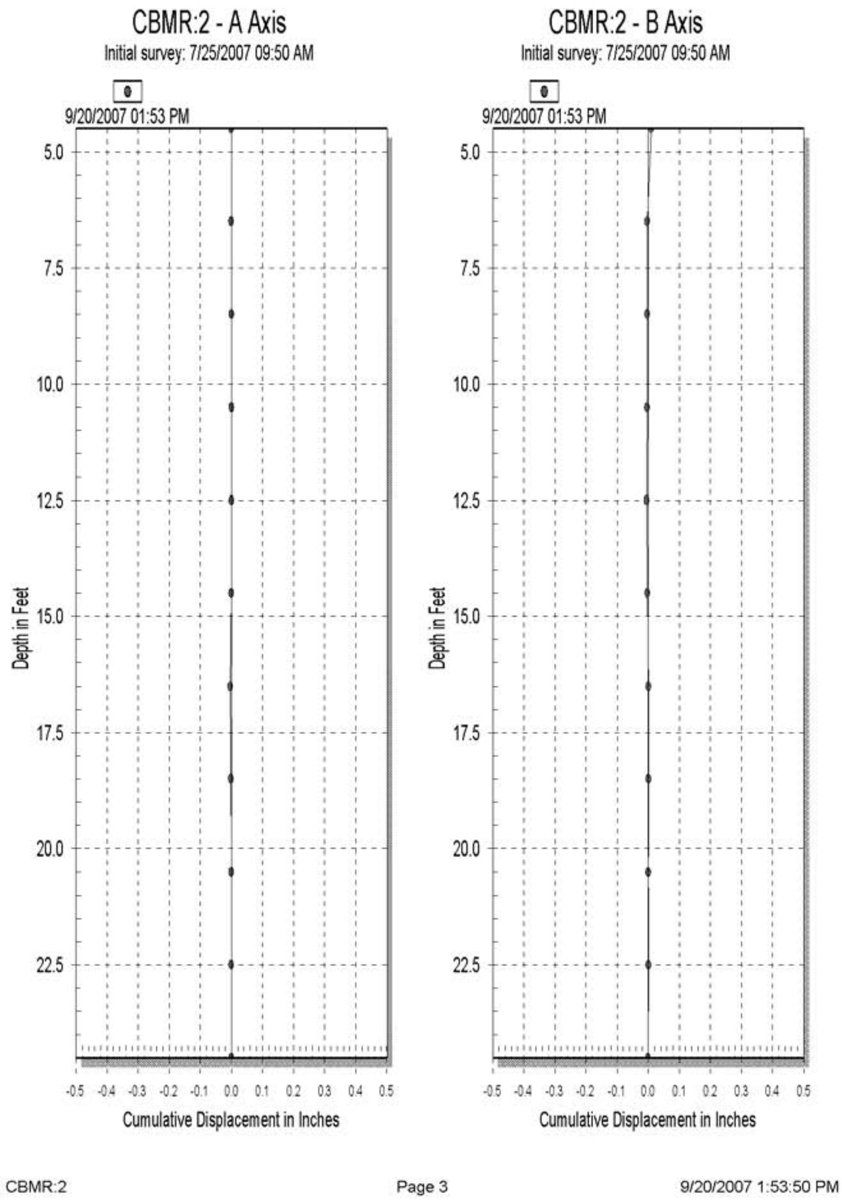

Fig. 4-6. Repeat inclinometer surveys of I-2, between 25-JULY-2005 and 20-SEP-2007. Vertical line at center is the reference line from the base survey. Depths shown are below TOC; subtract 4 ft for depth BGS. Black circles show relative shape deviations detected on 20-SEP-2007. On A axis, positive deflections are in A0 (downslope) direction. On B axis, positive deflections are in the B0 direction (to the left looking downslope).

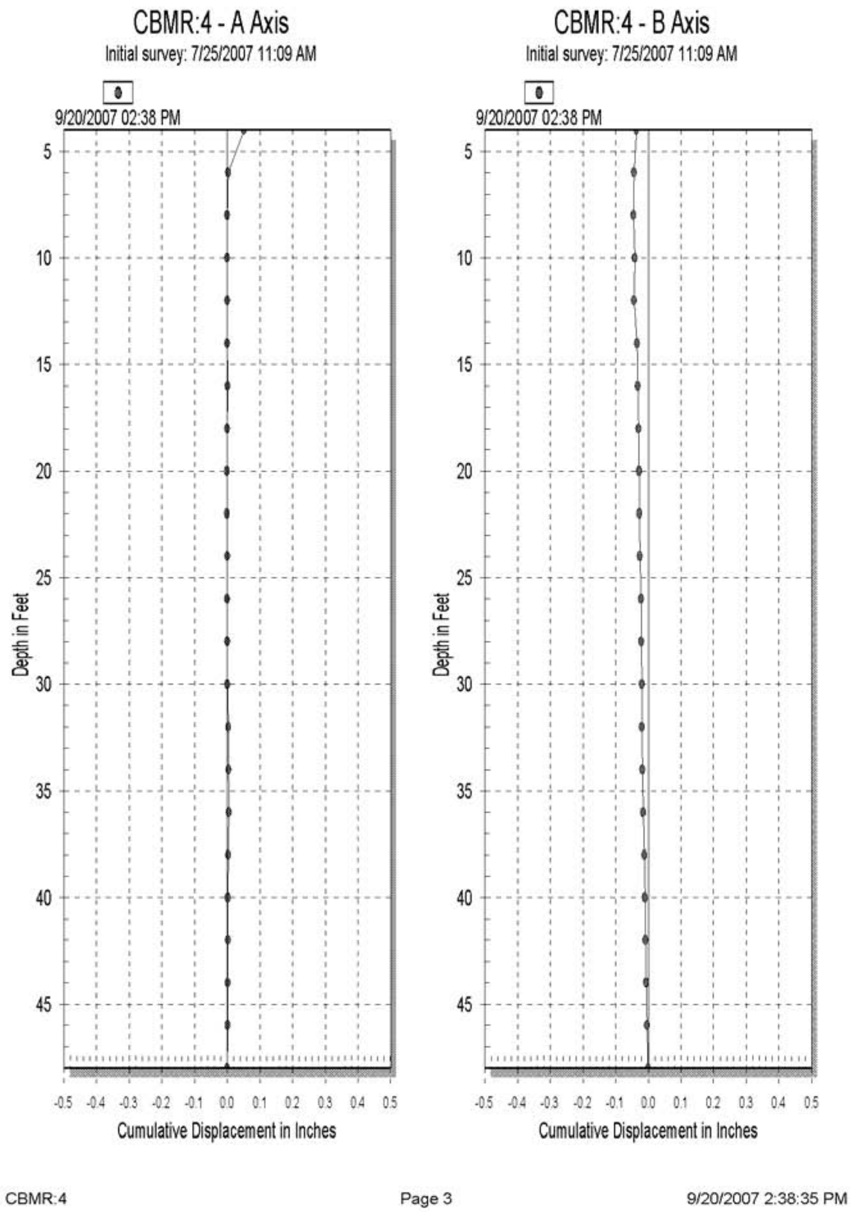

Fig. 4-7. Repeat inclinometer surveys of I-4, between 25-JULY-2005 and 20-SEP-2007. Vertical line at center is the reference line from the base survey. Depths shown are below TOC; subtract 4 ft for depth BGS. Black circles show relative shape deviations detected on 20-SEP-2007. On A axis, positive deflections are in A0 (downslope) direction. On B axis, positive deflections are in the B0 direction (to the left looking downslope).

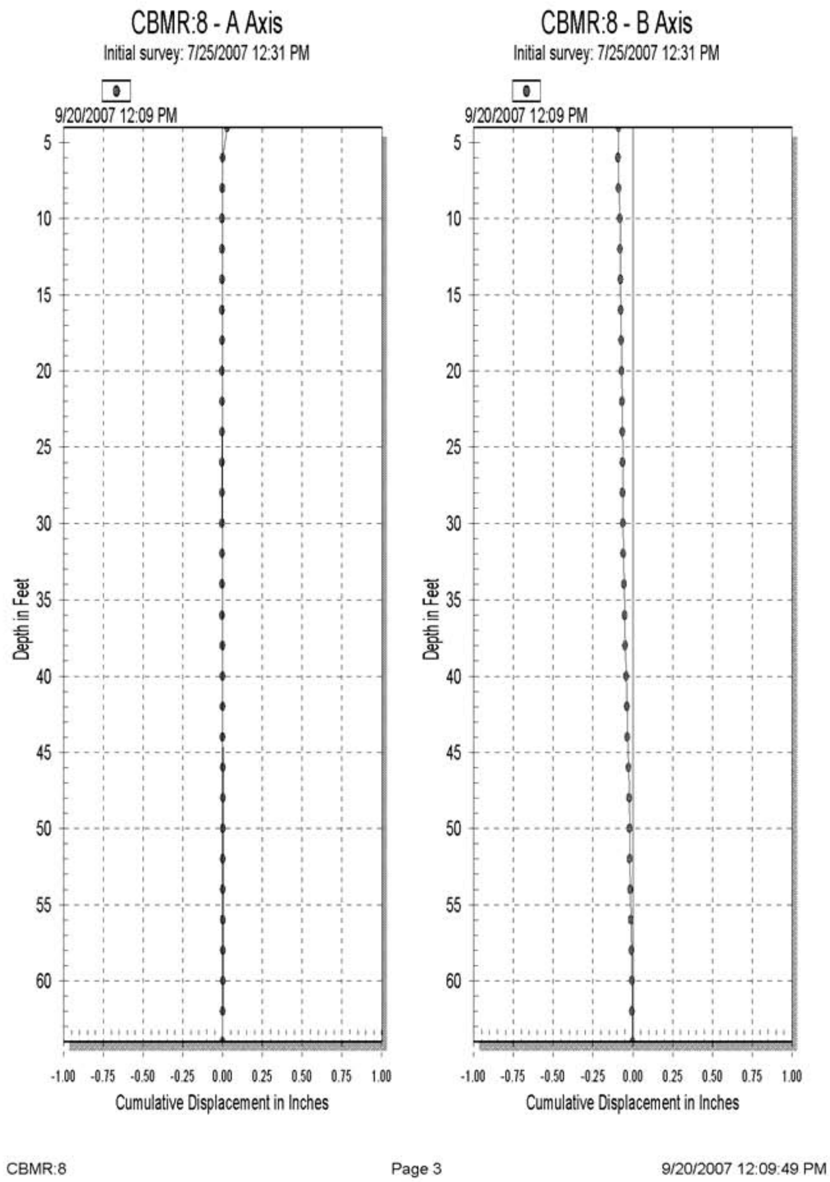

Fig. 4-8. Repeat inclinometer surveys of I-8, between 25-JULY-2005 and 20-SEP-2007. Vertical line at center is the reference line from the base survey. Depths shown are below TOC; subtract 4 ft for depth BGS. Black circles show relative shape deviations detected on 20-SEP-2007. On A axis, positive deflections are in A0 (downslope) direction. On B axis, positive deflections are in the B0 direction (to the left looking downslope).

Table 4-5. CheckSums of the initial and repeat surveys of Inclinometers I-2, I-4, and I-8. Bold values indicate significant differences, which are the probable cause of the small apparent tilts of I-4 and I-8..

Inclinometer		INITIAL SURVEY		REPEAT SURVEY	
	Parameters	A Checksum	B Checksum	A Checksum	B Checksum
I-2	Mean	6.8	-12.0	6.3	-15.3
	Std. Dev.	2.4	5.0	2.5	5.5
I-4	Mean	7.3	**-40.4**	6.9	**-11.3**
	Std. Dev.	1.6	4.2	1.6	4.2
I-8	Mean	7.6	**-36.5**	8.0	**-8.3**
	Std. Dev.	2.1	6.0	1.8	5.6

4.3.4 Inclinometer I-8

Inclinometer I-8 is located near the center of the Western Slide Complex, just downslope of the Bike Trail and adjacent to piezometer PZ-8. Inclinometer depth was limited to 60 ft BGS, due to drill rig refusal at that depth on Mancos Shale.

The SEP-2007 repeat survey shows 2 deflections have occurred since July. The first is a deflection of 0.04” in the downslope (A0) direction, which is limited to the upper 2 ft of the casing (Fig. 4-8). This deflection may indicate surface soil creep. An annualized rate of movement based on this 2-month value would be ***0.24”/yr***, or ***0.02 ft/yr***. By comparison, this value is in the range of long-term observed surface creep rates from landslide monitor pins in the area.

The second deflection is a persistent tilt of the entire casing in the B180 direction, amounting to a cumulative 0.1”. At I-8, the B180 direction is parallel to contours and points toward a small drainage on the eastern edge of a large flat meadow. This tilt is consistent throughout the 60 ft of the casing, and resembles the bias shift error of Cornforth (2006, p. 78-79; also called zero shift or offset error, or the “windshield wiper” effect). The most common cause of a bias shift error is widely different CheckSums between two consecutive surveys. Like on I-4, on I-8 the B-axis checksums were quite large (-37.3, -36.4, -36.5) on all 3 initial surveys, much larger than the B-axis checksum of the repeat survey (-8.3; Table 4-5). We suspect that this is the cause if the “windshield wiper effect”.

We plan to resurvey all the inclinometers in May 2008 as soon as the snow melts, and at I-8 will ensure that checksums for the June-08 resurveys are compatible with those of the July-07 survey; this should eliminate bias shift error from the comparison of future surveys.

4.4 Material Properties of Landslide and Non-Landslide Deposits

<u>4.4.1 Previous Geotechnical Studies</u>

Only two previous geotechnical studies have been performed on Snodgrass. The first was performed by Resource Consultants & Engineers in 1995 (RCE, 1995) specifically to look at slope stability of the SE slope of Snodgrass. They collected 48 split-spoon drive samples from their 5 boreholes at Snodgrass (SG-1 through SG-5), but these samples were discarded in 1995 without being measured for density or strength.

Their report does contain SPT blow counts and Unified Soil Class for all 48 samples, however.

A few years later Lambert & Associates (1998) performed a geotechnical study for the Reserve subdivision, which was to be built on the lower east slope of Snodgrass Mountain near Gothic Road. Based on 28 test borings they performed 8 swell-consolidation tests and 3 California Bearing Ratio tests. In addition, they derived these geotechnical parameters for 5 split-spoon samples drawn from 3 materials (Pinedale till, colluvium, and weathered shale): dry density, moisture content, peak internal angle of friction, and peak cohesion (Table 4-4).

Table 4-6. Geotechnical data from the Lambert & Associates 1998 report.

Boring	Depth (ft)	Dry Density (pcf)	Moisture Content (%)	Pk. Internal angle of friction (°)	Pk.Cohesion (psf)	Deposit[1]
9	3	91	9.3	20	250	Qpt
22	4	90	11.2	20	230	Qpt
18	4	101	8.2	11	110	Qc?
27	4	111	10.3	22	345	Qc?
27	9	114	8.0	26	875	Wx shale

[1] Qpt, Pinedale till; Qc?, inferred colluvium; Wx shale, weathered Mancos Shale

The data indicate consistent properties for shallow Pinedale till (density 90-91 pcf, peak friction angle 20°, peak cohesion 230-250 psf). The inferred colluvium samples are more variable, probably resulting from different source areas or processes. Weathered Mancos Shale displays a higher density, friction angle, and cohesion than the Quaternary deposits, as expected.

Additional geotechnical data were collected by CTL Thompson (1999, 2000) on the East Trade Parcel on the eastern slope of Mt. Crested Butte. The East Trade Parcel contains Quaternary and bedrock deposits very similar to those of Snodgrass Mountain. According to this data (Table 4-5), competent Mancos Shale yields significantly higher strengths than the weathered shale measured by Lambert & Associates.

Table 4-5. Summary of selected geotechnical test data from CTL Thompson studies on Mt. Crested Butte.

GEOTECHNICAL SAMPLES FROM East Trade Parcel on Mt. Crested Butte

		Shear Strength--undisturbed, direct shear		**Shear Strength--remolded, direct shear**		**Shear Strength-- remolded, triax UU**	
reference	**Texture**	**Friction-deg**	**Cohesion-psf**	**Friction-deg**	**Cohesion-psf**	**Friction-deg**	**Cohesion-psf**
CTL Thompson 1999	sandy clay	29	800	38	1000	29	800
page 13	silty gravelly clay	41	0	43	300	35	400
average values	claystone bedrock	nd	nd	39	750	28	900
actual sample, TP-3	*Mancos Shale*			*40 peak*	*750 peak*		
				39 residual	*750 residual*		
actual sample, TP-25	*clay, silty, gravelly*			*45 peak*	*260 peak*		
				43 residual	*290 residual*		
actual sample, TP-11	*clay, sandy*			*41 peak*	*980 peak*		
				38 residual	*1040 residual*		
actual sample, TH-9B	*clay, sandy*	*32 peak*	*1330 peak*				
		33 residual	*1050 residual*				
actual sample, TH-11	*clay, sandy*	*25 peak*	*540 peak*				
		24 residual	*530 residual*				
actual sample, TH-27	*clay, silty, gravelly*	*38 peak*	*590 peak*				
		41 residual	*0 residual*				
		Residual Friction	**Residual cohesion**	peak friction	peak cohesion		
CTL Thompson 1999	sandy clay	**33-38**	**200-400**	24-29	200-400		
page 14	silty gravelly clay	**38-43**	**0**	30-35	100-200		
values used in slope stability analyses	claystone bedrock	**34-39**	**200-400**	23-28	200-400		
				Residual Friction	**Residual Cohesion**		
CTL Thompson 2000	fill			**24**	**200**		
Section C, page 2	sandy clay			**24**	**200**		
values used in slope stability analyses	silty gravelly clay			**30**	**100**		

In the following sections we describe the density and shear strength of 7 types of earth materials that occur in our slope stability cross-sections (Chapter 8). Not all materials occur in each cross-section. The listing of all drive samples and their accompanying blow counts is given in Table 4-6. Densities are in table 4-7, and strengths in Table 4-8.

4.4.2 Pinedale till (map unit Qpt)

We did not sample Pinedale till for geotechnical testing, because it was not present in most of our stability cross-section. Instead, we assign values to unit Qpt based on values from Lambert & Associates (1998) and CTL Thompson (1999, 2000).

4.4.2.1 Density

Dry densities range from 90-91 pcf at depths of 3-4 ft (Lambert & Associates, 1998). **For this study, we assume a wet density of 131 pcf.**

Table 4-6. Density and strength test results from this study, for major geologic units from Snodgrass Mountain.

Geologic Unit/ CROSS-SECTION/ sample*	Wet Unit Weight (pcf) **	Dry Unit Weight (pcf)	Peak		Residual	
			Friction (degrees)	Cohesion (psf)	Friction (degrees)	Cohesion (psf)
Qpt/ WEST/ 13-7	131	116.5	30.6	870	13.8	330
Qpt/ CENTRAL/ 14-7	118	107.7	45.5	170	-	-
Qot/ CENTRAL/ 14-9	135	121.7	46.3	0	19.2	140
Qefy/ CENTRAL/ 6-6	122	112.2	42	0	23.1	0
Qlsy/ EAST/ UT-10	110	101	25.3	560	18.7	170
Qlsio/ WEST/ 9-8	130	116.9	27.5	390	25.2	190
Shear zone/ EAST/ LT-1	121	106.2	40.3	150	22.5	0
Wx shale/ WEST/ 8-11	128	111.2	40	50	11.7	260
Wx shale/ CENTRAL/ 1-7	126	115	33.2	350	17.9	74
Km/ WEST/ 8-13	127	108.1	29.8	150	10.5	120
Km/ CENTRAL/ 4-15	96	93.4	39.5	0.0	10.5	0.0

* Qpt, Pinedale till; Qot, older till; Qefy, young earthflow; Qlsy, young landslide; Qlsio, intermediate-old landslide; shear zone, 10-40 cm-thick shear zones exposed in trenches; Wx shale, weathered shale; Km, Mancos Shale; samples list piezometer number followed by sample number (see Table 4-6).
**Samples were soaked a minimum of 24 hours each.

4.4.2.2 Strength

For till, Lambert & Associates (1998) cite a peak friction angle of 20° and cohesion of 230-250 psf. On Mt. Crested Butte the "silty gravelly clay" tested by CTL Thompson (1999, 2000) is probably mostly till, according to the geologic map of Gaskill et al (1991). For their stability analyses, CTL (1999) used peak friction=30-35° and cohesion=100-200 psf, whereas CTL (2000) used a residual friction of 30° and cohesion of 100 psf. **For this study, we assume a peak friction of 25° (conservative) and cohesion of 150 psf.**

4.4.3 Older Till

Inferred "older till" exists in the subsurface of some profiles (e.g., Central Line, S Half).

4.4.3.1 Density

Dry density is 122 pcf and wet density is 135 pcf.

4.4.3.2 Strength

Based on direct shear tests performed after the manner of Blake et al (2002), peak friction and cohesion are 46° and 0 psf, and residual friction and cohesion are 19° and 140 psf.

4.4.4 Landslide Deposits

We collected 78 drive samples from landslide deposits at Snodgrass (Table 4-6), but only tested representative samples from the three geophysics/slope stability transects (West Line, Central Line, East Line).

4.4.4.1 Density

To estimate the material properties of landslide deposits, we tested Young Landslide Deposits (Qlsy; 1 sample) and also Intermediate-Old Landslide Deposits (Qlsio; 1 sample). As expected, the older landslides were denser (117 pcf dry, 130 pcf wet) than the young landslides (101 pcf dry, 110 pcf wet).

4.4.4.2 Strengths (peak and residual)

Young landslide deposits had peak friction and cohesion of 25°/ 560 psf and residual friction and cohesion of 19°/170 psf. In comparison, older landslides were slightly stronger (peak friction/cohesion of 28°/390; residual friction/cohesion of 25°/190).

Table 4-6. Summary of drive samples and their characteristics, from piezometer borings on Snodgrass, 2007.

GEOTECHNICAL SAMPLES FROM SNODGRASS					split-spoon samples			
			Depth Range (ft)	**Lithology**				**Blow Count**
Borehole	**Map Unit**	**Sample No.**	**marked on bag**	**from well log**	**Date**	**Deposit**	**Texture**	**N**
PZ-1	Qc	1-1	0-5	topsoil	10-Jun-07	colluvium		
PZ-1	Qc	1-2	5-10	silty clay & cobbles	10-Jun-07	colluvium		7
PZ-1	Qc	1-3	10-15	silty clay & cobbles	10-Jun-07	colluvium		13
PZ-1	Qc	1-4	15-20	silty clay & cobbles	10-Jun-07	colluvium		15
PZ-1	Qc	1-5	20-25	silty clay & cobbles	10-Jun-07	colluvium		10
PZ-1	Qc	1-6	25-30	silty clay & cobbles	10-Jun-07	colluvium		14
PZ-1	Km	1-7	51- shale boundary	weathered shale	10-Jun-07	shale bndy	shale	-
PZ-1	Km	1-8	67	Mancos shale	10-Jun-07	shale	shale	-
PZ-2	Qlsi	2-1	0-5	topsoil	11-Jun-07	landslide		-
PZ-2	Qlsi	2-2	5-10	clayey silt & cobbles	11-Jun-07	landslide		7
PZ-2	Qlsi	2-3	10-15	clay and sparse sm cobb	11-Jun-07	landslide		8
PZ-2	Qlsi	2-4	15-20	clay and sparse sm cobb	11-Jun-07	landslide		10
PZ-2							shale	28
I-2	Qlsi	2-5	? Not labeled		11-Jun-07	landslide		
I-2	Km	2-6	? Not labeled-wx transitional shale		11-Jun-07	shale		
I-2	Km	2-7	? Not labeled-bottom layer shale		11-Jun-07	shale		
PZ-4	Qlsy	4-1	4-5	topsoil	11-Jun-07	landslide	gravelly sand	
PZ-4	Qlsy	4-2	9-10	clayey silt & cobbles	11-Jun-07	landslide	loam	10
PZ-4	Qlsy	4-3	14-15	clayey silt & cobbles	11-Jun-07	landslide	clay loam	8
PZ-4	Qlsy	4-4	19-20	silty clay & cobbles	11-Jun-07	landslide	gravelly clay	12
PZ-4	Qlsy	4-5	24-25	silty clay & cobbles	11-Jun-07	landslide	gravelly clay	22
PZ-4								50
PZ-4	Qlsy	4-6	29-30	silty clay & cobbles	11-Jun-07	landslide	gravelly clay	
PZ-4	Qlsy	4-7	30-30.75	silty clay & cobbles	11-Jun-07	landslide	gravelly clay	
PZ-4	Qlsy	4-8	30.75-31.5	silty clay & cobbles	11-Jun-07	landslide	gravelly clay	
PZ-4	Qlsy	4-9	31.5-32	clay & sparse sm cobbles	11-Jun-07	landslide	gravelly clay	45
PZ-4	Qlsy	4-10	32-33	clay & sparse sm cobbles	12-Jun-07	landslide	gravelly clay	38
PZ-4	Qlsy	4-11	33-34	clay & sparse sm cobbles	12-Jun-07	landslide	gravelly clay	27
PZ-4								50

PZ-4								56
PZ-4	Qlsy	4-12	38.5-39	clay & sparse sm cobbles	12-Jun-07	shear zone?	sandy clay	10
PZ-4	Qlsy	4-13	39.75-40	clay & sparse sm cobbles	12-Jun-07	shear zone	sandy clay	
PZ-4	Km-wx	4-14	41-41.5	Km	12-Jun-07	Km	shale	
PZ-4	Km	4-15	41.5-42	Km	12-Jun-07	Km	shale	
PZ-5	Qlsi	5-1	0-5	topsoil	13-Jun-07	landslide		-
PZ-5	Qlsi	5-2	5-10	topsoil	13-Jun-07	landslide		20 (6 -7')
PZ-5	Qlsi	5-3	10-15	silty clay & cobb, some gr	13-Jun-07	landslide		12 (11-12')
PZ-5	Qlsi	5-4	15-20	silty clay & cobb, some gr	13-Jun-07	landslide		9 (16-17')
PZ-5	Qlsi	5-5	20-25	silty clay & cobb, some gr	13-Jun-07	landslide		10 (21-22')
PZ-5	Qlsi	5-6	25-30	silty clay & cobb, some gr	13-Jun-07	landslide		
PZ-5	Qlsi	5-7	30-35	silty clay & cobb, some gr	13-Jun-07	landslide		25 (31-32')
PZ-6	Qefy	6-1	0-5	topsoil	16-Jun-07	landslide		-
PZ-6	Qefy	6-2	5-10	topsoil	16-Jun-07	landslide		20 (6-7')
PZ-6	Qefy	6-3	10-15	silty clay & cobb, some gr	16-Jun-07	landslide		14 (11-12')
PZ-6	Qefy	6-4	15-20	silty clay & cobb, some gr	16-Jun-07	landslide		29 (16-17')
PZ-6	Qefy	6-5	20-25	silty clay & cobb, some gr	16-Jun-07	landslide		48 (21-22')
PZ-6	Qefy	6-6	25-27	silty clay & cobb, some gr	16-Jun-07	landslide		15 (26-27')
PZ-6								21 (31-32')
PZ-6	Qefy	6-7	85	Km	16-Jun-07	Km	shale	-
PZ-8	Qlsi	8-1	0-5	topsoil & cobbles	18-Jun-07	landslide		-
PZ-8	Qlsi	8-2	5-10	topsoil & cobbles	18-Jun-07	landslide		27 (6-7')
PZ-8	Qlsi	8-3	10-15	topsoil & cobbles	18-Jun-07	landslide		15 (11-12')
PZ-8	Qlsi	8-4	15-20	silty clay & cobb, some gr	18-Jun-07	landslide		16 (16-17')
PZ-8	Qlsi	8-5	20-25	silty clay & cobb, some gr	18-Jun-07	landslide		19 (21-22')
PZ-8	Qlsi	8-6	25-30	silty clay & cobb, some gr	18-Jun-07	landslide		21 (26-27')
PZ-8	Qlsi	8-7	30.25-31	clay & very sm sparse cobb	18-Jun-07	landslide		19 (31-32')
PZ-8	Qlsi	8-8	31-35	clay & very sm sparse cobb	18-Jun-07	landslide		
PZ-8	Qlsi	8-9	35-40	clay & very sm sparse cobb	18-Jun-07	landslide		36 (36-37')
PZ-8	Qlsi	8-10	40-45	clay & very sm sparse cobb	18-Jun-07	landslide		30 (41-42')

PZ-8	Qlsi	8-11	45-50	clay & very sm sparse cobb	18-Jun-07	shear zone/ wx shale	35 (46-47')
PZ-8	Qlsi	8-12	50-55	wx shale	18-Jun-07	shale	37 (51-52')
PZ-8	Qlsi	8-13	52	wx shale	18-Jun-07	shale	-
PZ-8	Qlsi	8-14	55.5-56.5	wx shale	18-Jun-07	shale	
PZ-8	Qlsi	8-15	56.5-57	Km	18-Jun-07	shale	>50 (refusal) (56-56.5')
PZ-8	Qlsi	8-16	60	Km	18-Jun-07	shale	>50 (refusal) (60-60.5')
PZ-9	Qlsi	9-1	0-5	Topsoil and cobbles	17-Jun-07	landslide	-
PZ-9	Qlsi	9-2	5-10	Topsoil and cobbles	17-Jun-07	landslide	14 (6-7')
PZ-9	Qlsi	9-3	10-15	Silty clay and cobbles, some gravel, scattered boulders	17-Jun-07	landslide	10 (11-12')
PZ-9	Qlsi	9-4	15-20	“	17-Jun-07	landslide	12 (16-17')
PZ-9	Qlsi	9-5	20-25	“	17-Jun-07	landslide	7 (21-22')
PZ-9	Qlsi	9-6	25-30	“	17-Jun-07	landslide	15 (26-27')
PZ-9	Qlsi	9-7	30-35	Mud and medium cobbles	17-Jun-07	landslide	32 (31-32')
PZ-9	Qlsi	9-8	35-37	“	17-Jun-07	landslide	23 (36-37')
PZ-11	Qlsy	11-1	0-5	Topsoil and cobbles	29-Jul-07	landslide	-
PZ-11	Qlsy	11-2	5-10	“	29-Jul-07	landslide	-
PZ-11	Qlsy	11-3	10-15	Clayey silt and cobbles, some gravel	29-Jul-07	landslide	8 (11-12')
PZ-11	Qlsy	11-4	15-20	Silty clay and cobbles	29-Jul-07	landslide	6 (16-17')
PZ-11	Qlsy	11-5	20-25	“	29-Jul-07	landslide	9 (21-22')
PZ-11	Qlsy	11-6	25-30	“	29-Jul-07	landslide	14 (26-27')
PZ-11	Qlsy	11-7	30-35	“	29-Jul-07	landslide	16 (31-32')
PZ-11	Qlsy	11-8	35-40	“	29-Jul-07	landslide	26 (36-37')
PZ-11				Wx shale			46 (41-42')
PZ-11	Qlsy	11-9	42-43	“	29-Jul-07	landslide?	
PZ-11				shale		shale	No Drive (in shale; 45-47')
PZ-11	Qlsy	11-10	50-52	“	29-Jul-07	shale	58 (50-51')
PZ-11				“			>50 (refusal) (51-51.5')
PZ-12	Qefo	12-1	0-5	Topsoil and cobbles	28-Jul-07	landslide	-
PZ-12	Qefo	12-2	5-10	Silty clay and cobbles,	28-Jul-07	landslide	11 (6-7')

				some gravel, scattered boulders				
PZ-12	Qefo	12-3	10-15	“	28-Jul-07	landslide		9 (11-12')
PZ-12	Qefo	12-4	15-20	“	28-Jul-07	landslide	rock?	36 (16-17')
PZ-12	Qefo	12-5	20-25	“	28-Jul-07	landslide		12 (21-22')
PZ-12	Qefo	12-6	25-30	“	28-Jul-07	landslide		16 (26-27')
PZ-13	Qefo	13-1	0-5	Topsoil and cobbles	24-Jul-07	landslide		-
PZ-13	Qefo	13-2	5-10	Gravelly silt and cobbles	24-Jul-07	landslide	rock?	27 (6-7')
PZ-13	Qefo	13-3	10-15	Silty clay and cobbles, some gravel	24-Jul-07	landslide		7 (11-12')
PZ-13	Qefo	13-4	15-20	“	24-Jul-07	landslide		13 (16-17')
PZ-13	Qefo	13-5	20-25	“	24-Jul-07	landslide		5 (21-22')
PZ-13	Qefo	13-6	25-30	“	24-Jul-07	landslide		21 (25-27')
PZ-13	Qefo	13-7	30-35	“	24-Jul-07	landslide		15 (31-32')
PZ-13	Qefo	13-8	35-36	“	24-Jul-07	landslide		11 (36-37')
PZ-14	Qpt	14-1	0-5	Topsoil and cobbles	27-Jul-07	till		-
PZ-14	Qpt	14-2	5-10	“	27-Jul-07	till		31 (6-7')
PZ-14	Qpt	14-3	10-15	Silty clay and cobbles, some gravel, scattered boulders	27-Jul-07	till	rock?	25 (11-12')
PZ-14	Qpt	14-4	15-20	“	27-Jul-07	till		20 (16-17')
PZ-14	Qpt	14-5	20-25	“	27-Jul-07	till		17 (21-22')
PZ-14	Qpt	14-6	25-30	“	27-Jul-07	till	rock?	32 (26-27')
PZ-14	Qpt	14-7	30-35	Saturated small to medium cobbles	27-Jul-07	outwash	rock?	48 (31-32')
PZ-14	Qlso	14-8	35-40	“	27-Jul-07	landslide		21 (36-37')
PZ-14	Qlso	14-9	40-45	“	27-Jul-07	landslide		17 (41-42')
PZ-14	Qlso	14-10	45-50	Clay and cobbles	27-Jul-07	landslide		12 (46-47')
PZ-14		no sample		“				26 (51-52')
PZ-15		15-1	5-6	Clayey silt and cobbles, little gravel	14-Nov-06	till?		n.a.
PZ-15		15-2	5-10	“	14-Nov-06	till?		n.a.
PZ-15		15a-3	10-15	“	14-Nov-06	till?		n.a.
PZ-15		15a-4	15-20	“	14-Nov-06	till?		n.a.

PZ-15		15a-5	20-22	“	14-Nov-06	till?		n.a.
PZ-15		15a-6	27-30	“	14-Nov-06	shale?	shale chips	n.a.
PZ-15		15a-7	35	Weathered shale	14-Nov-06	shale?	shale chips	n.a.
PZ-15		15a-8	39-40	“	14-Nov-06	shale?	shale chips	n.a.
PZ-15		15a-9	45	shale	14-Nov-06	shale?		n.a.
PZ-16	Qlsy	16-1	10	Clayey silt and cobbles, little gravel	14-Nov-06	landslide		20 (11-12')
PZ-16	Qlsy	16-2	15	“	14-Nov-06	landslide		19 (16-17')
PZ-16				“				13 (20-21')
PZ-16				“			rock?	>50 (refusal) (21-21.5')
PZ-16	Qlsy	16-3	25	“	14-Nov-06	landslide		28 (26-27')
PZ-16	Qlsy	16-4	30	“	14-Nov-06	landslide		21 (31-32')
PZ-16	Qlsy	16-5	35	“	14-Nov-06	landslide		27 (36-37')
PZ-16	Qlsy	16-6	40	shale	14-Nov-06	shale?	shale chips	28 (41-42')
								56 (46-47')

4.4.5 Landslide Shear Zones

We collected 2 drive samples and 6 hand-carved trench samples from landslide shear zones at Snodgrass. However, we only tested one representative sample (most of the 6 trench samples were duplicates of a few shear zones).

4.4.5.1 Density

Dry density was 106 pcf and wet density was 121 pcf.

4.4.5.2 Strength (residual)

Due to the inclusion of sand in all the sampled shear zones, strengths were comparable to those of tills and landslide deposits. For the tested sample from shear zone SZ-2 in the lower trench, peak friction/cohesion were 40°/150 psf and residual friction/cohesion were 23°/0 psf.

4.4.6 Tertiary porphyry

We did not collect any samples from Tertiary porphyry at Snodgrass because porphyry mainly occurs in our stability cross-sections as detached, "floating" masses within landslides. For those few instances where the basal rock in a cross-section might be Tp rather than Km, we assume "typical" strength values for quartz monzonite from the Society for Mining, Metallurgy, and Exploration website: (http://books.smenet.org/Surf_Min_2ndEd/sm-ch06-sc08-ss00-tbl004.cfm).
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4.4.6.1 Density

For this study, we assume a typical density of 165 pcf (granite and similar intrusives).

4.4.6.2 Strength

For this study, we assume a peak strength of 31° and cohesion of 2000 psf. We do not use a residual strength, because we do not think that failure planes enter Tp, as long as there is adjacent, much weaker Km to fail.

4.4.7 Weathered Shale

We collected 6 drive samples from weathered Mancos Shale at Snodgrass (Table 4-6), but only tested representative samples from the two of the geophysics/slope stability transects (West Slide, Middle Slide).

4.4.7.1 Density

Dry densities range from 111-115 pcf and wet densities from 126-128 pcf.

4.4.7.2 Strength

Peak friction/cohesion ranged from 33°/350 psf to 40°/50 psf, whereas residual friction/cohesion ranged from 12°/260 psf to 18°/74 psf. As explained in Chapter 8, we used the composite minimum values (12°/74 psf) in the stability analysis.

4.4.8 Competent Mancos Shale

We collected 14 drive samples from competent Mancos Shale at Snodgrass (Table 4-6), but only tested representative samples from the three geophysics/slope stability transects (West Slide, Middle Slide, East Slide).

4.4.8.1 Density

Tested densities were variable, ranging from 108 pcf dry/ 127 pcf wet, to 93 pcf dry and 96 pcf wet.

Table 4-7. Densities and strengths of weathered and unweathered Mancos Shale from This Study and the other nearby consulting reports.

Unit/ Section/ Sample/Reference	Wet Unit Weight (pcf)	Saturated Unit Weight (pcf)	Peak		Residual	
			Friction (degrees)	Cohesion (psf)	Friction (degrees)	Cohesion (psf)
Wx shale/ WEST/ 8-11/ THIS STUDY	128	111.2	40	50	11.7	260
Wx shale/ CENTRAL/ 1-7/ THIS STUDY	126	115	33.2	350		
Km/ WEST/ 8-13. THIS STUDY	127	108.1	29.8	150	10.5	120
Km/ CENTRAL/ 4-15/ THIS STUDY	96	93.4	39.5	0.0	10.5	0.0
Km/ CTL Thompson, 1999		*Direct shear*	40	750	39	750
		Triaxial	28	900		
	Used in	CTL analyses	23-28	200-400	34-39	200-400

4.4.8.2 Strength

The strength values to use for Mancos Shale are among the most critical values in our stability analyses (Chapter 8). As shown in Table 4-7, our peak strengths (30-40°) are similar to those obtained by CTL Thompson (1999; 28-40°) from sites on Mt. Crested Butte. However, our residual strengths (10.5-11.7°) are much lower than peak strengths (30-40°). These residual strengths were obtained by repetitive shearing of a sample in the direct shear box under constant normal stress, until residual strengths no longer decreased with additional shearing (after the method of Blake et al., 2002, p. 45-46). In that sense, they might be termed “ultimate” residual strengths. We consider the use of these low values conservative.