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THE 2005 LA CONCHITA LANDSLIDE, CALIFORNIA: PART 1 - GEOLOGY

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ABSTRACT

This is Part I of a two-part causation analysis of the January 10, 2005 La Conchita, California, USA landslide. This paper describes the geology and geomorphology of the event, which killed 10 persons and damaged or destroyed 36 residences. The landslide is located in a complex and active tectonic setting. It was triggered by two weeks of heavy rainfall, which initiated a failure in the backscarp of a large slump that had occurred ten years earlier. The 2005 landslide displaced older landslide deposits derived from Tertiary sedimentary rocks. Over 30,000 m^3 of wet debris was mobilized in the event, which formed two distinct lobes of debris. The main lobe, comprising 90% of the deposit, rapidly transformed into a large scale debris flow, eroded and entrained over 4,000 m^3 of material along its path, overran a temporary wall, then flowed into the residential community. This lobe exhibits characteristic debris flow textures, including raised lateral levees and a surface pattern of ridges and troughs. The minor lobe, comprising about 10% of the total landslide volume, was deposited in pulses that arrived from different directions at different times. This material impacted and locally breached the temporary wall, but did not flow into the community below.

Key words: *Debris flow, La Conchita, geology, geomorphology, landslide*

INTRODUCTION

The community of La Conchita is located along the sparsely developed coastline between Los Angeles and Santa Barbara, California, USA at latitude 34.36° N, longitude 119.45° W. Although the region is known for its mild climate, powerful winter storm sequences occasionally pummel the region. In late 2004 and early 2005, an intense series of rainstorms impacted the region, causing flooding and triggering numerous landslides. The January 10, 2005 La Conchita landslide was the deadliest single event triggered by the 2004-2005 storm sequence in southern California.

The 2004-2005 winter rainfall season was marked by a series of major Pacific storms that brought heavy precipitation to California. The first major Pacific storm of the season occurred in October. Heavy rainfall then returned on December 27th. The storms took a consistent track colloquially known as the "Pineapple Express." During this storm sequence, Los Angeles had its wettest 15-day period on record. Between January 6th and 11th, over 500 mm of rainfall was recorded at mountain weather stations in Santa Barbara, Ventura, and Los Angeles Counties (NCDC, 2005).

Approximately 378 mm of rain fell in the City of Ventura between December 27th and January 10th, only slightly less than the 390 mm average yearly rainfall for the region (Schiek & Hurtado, 2005).

The January 10, 2005 La Conchita landslide was initiated at the head of a shallow swale located along the eastern lateral margin of a prior slump failure that

Fig. 1 - Comparison of aerial photos of the La Conchita area taken in 2002 (left) and 2005 (right). The photo at left shows the approximate limits of the 1995 slump failure, the location of drainage improvements (DI) to convey water across the slump (yellow dotted line), and the location of a temporary wall (TW) constructed in 2000 to allow reopening of Vista del Rincon Avenue (solid yellow line). The photo at right defines the main (eastern) and minor (western) lobes, shows the inferred movement direction of the debris in these lobes, the location of a breach (B) in the wall caused by impact of the debris, and locations affected by emergency grading after the event (E)

affected a much larger portion of the slope in 1995 (Fig. 1). Material from the initial slope failure rapidly transformed into a large-scale debris flow. The majority of the debris flow (main lobe) traveled down the swale between the 1995 slump and the adjacent intact slope area, and entered the residential community of La Conchita. This lobe of the debris flow traveled about 100 m through the community, destroying approximately 30 homes and resulting in the deaths of 10 persons (Gurrola, 2005). A second lobe of the debris flow, containing about 10% of the total mobilized volume of debris (minor lobe), traveled down the heavily vegetated slope to the west of the main lobe. The minor lobe impacted and partially breached the central part of a temporary retaining wall located along Vista del Rincon Avenue (see Fig. 1), but caused no additional personal property damage or loss of life. Remarkably, a television news crew that was in the area to cover earlier rain-related highway and rail line closures videotaped the incipient failure and much of the debris flow as it descended the slope.

The La Conchita area has a long history of landslide activity. The Southern Pacific Railroad laid rail lines through the area in 1887, but sections of the tracks were already impacted by landslide debris by 1889. The tracks were moved in 1909 after a work train was buried in a landslide. That year the railroad leveled the area between the tracks and the slope to act as a catchment for landslide debris and thus reduce the hazard posed by the steep bluff face. The original use of the leveled area was soon forgotten, however, and the La Conchita residential development was established on the leveled area in 1924 (Hemphill, 2001).

The bluff and hilltop terrace areas upslope from La Conchita formed a portion of the La Conchita Ranch property (Ranch). The Ranch originally practiced grazing and dry agriculture, then switched to irrigated agriculture in the mid-1970s (Hemphill, 2001). In March 1995, a large slump failure occurred on the bluff following a period of heavy rainfall. This event damaged or destroyed seven residences, destroyed a portion of Ranch Road, an access road that traversed the bluff face, and covered a major street in the community, Vista Del Rincon Avenue, with up to about 6 m of debris (Fig. 1). Despite its large volume, estimated at between 200,000 and 460,000 m^3, the 1995 landslide was anticipated and slow moving, allowing residents time to evacuate (O'Tousa, 1995; Harp *et alii*, 1995).

The slump failure was never remediated. By early 1996, the Ranch had performed minor earthwork to convey stormwater from the truncated uphill portion of Ranch Road across the slump to a point along the toe of the 1995 slump at the northern end of Fillmore Avenue. These drainage improvements (DI) are indicated on Fig. 1. Also shown in the figure is a steep-sided channel incised by surface runoff draining toward the western side of the slump by 2002.

In 2000, the County of Ventura constructed a temporary soldier pile wall consisting of steel H-piles and a wood lagging wall along the northern margin of Vista del Rincon Avenue to allow the removal of debris from the street. The wall was 82 m long, stood between 1.5 and 7.2 m above the road surface (including a guardrail at the top), and had a freeboard of about 1.2 to 2.7 m, including the guardrail.

GEOLOGICAL CONDITIONS

The 2005 slope failure originated in old landslide deposits near the crest of a 180 m high, southwest-facing coastal bluff. The bluff represents a modified Holocene sea cliff that is capped by the 45,000 yr BP Punta Gorda marine terrace. The Punta Gorda ter-

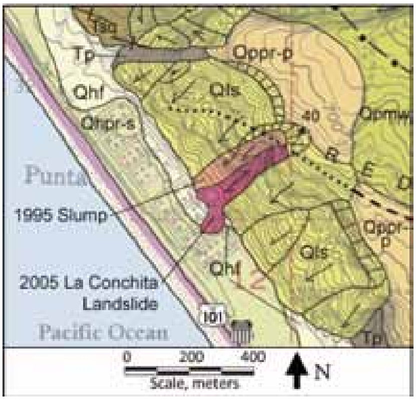

Fig 2 - Geologic map of the 2005 La Conchita landslide and vicinity. The Red Mountain fault extends through the headscarp of the 1995 and 2005 slope failures. Geologic unit designations: Qls–Landslide deposits; Qhf–Undivided alluvial and colluvial deposits ; Qhpr-s–Terrace deposits associated with 1,800-5,800 BP Sea Cliff marine terrace; Qppr-p–Terrace deposits associated with 40,000-60,000 BP Punta Gorda marine terrace; Qpmw–Undivided Pleistocene talus, colluvium, and landslide deposits ; Tp–Pliocene Pico Formation; Tsq–Miocene-Pliocene Sisquoc Shale. Dash-dot line indicates inferred shoreline angle of Punta Gorda terrace. Modified from Geologic Map of the Pitas Point 7.5-Minute Quadrangle (USGS, 2005)

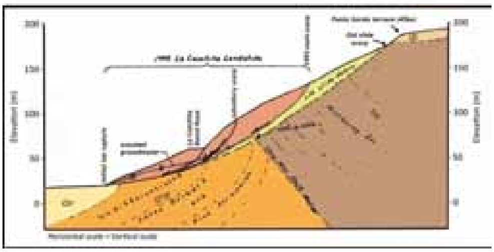

Fig 3 - Conceptual geologic cross section through the bluff face in the vicinity of the 1995 and 2005 La Conchita landslides (modified from Rogers et alii, 2007)

Fig 4 - View of stratigraphy exposed in test pit excavated into minor lobe of the landslide. Arrows indicate layer of vegetation sandwiched between pulses of debris

race formed when sea level stood about 38 m below present-day sea level, indicating that the terrace is rising at a long-term geologic rate of over 4 mm/yr (Huftile *et alii*, 1997).

As shown on Fig. 2, most of the bluff above the communty of La Conchita is mantled by landslide deposits. These landslides occurred within a sequence of poorly indurated sedimentary rocks of Tertiary age. The principal geologic units in the vicinity include the Upper Middle Miocene Monterey Formation (shale, siltstone, and sandstone), the Miocene-Pliocene Sisquoc Shale (silty shale and claystone) and the Pliocene Pico Formation (sandstone and conglomerate). The distribution of bedrock units in the bluff is obscured by the thick mantle of landslide deposits and complicated by the presence of the Red Mountain fault, which is mapped intersecting the slope face in the source area of both the 1995 and 2005 landslides (Fig. 2).

The Red Mountain fault is a major, active reverse fault. Huftile *et alii* (1997) observed 34 m of vertical separation of the Punta Gorda wave-cut platform along the fault, corresponding to a dip-slip rate of about 1.5 mm/yr. Figure 3 shows an interpretation of the subsurface conditions underlying the bluff above the community of La Conchita, including the inferred location and orientation of the Red Mountain fault, offset bedrock units, pre-existing landslide deposits, and the Punta Gorda marine terrace (Rogers *et alii*, 2007)

. SEDIMENTOLOGY

Test pits excavated into the minor lobe of the La Conchita landslide behind the temporary wall encountered pale yellow-brown, low plasticity silt exhibiting a massive, ungraded texture (Fig. 4). The test pits also exposed slope-parallel layers of pulverized vegetation located at approximately 1.2 m vertical intervals. This evidence indicates that the minor lobe was deposited in discrete pulses.

VEGETATION

At the time of the 2005 landslide, thick chaparral vegetation mantled most of the surface of the 1995 slump. Somewhat lighter vegetative cover was present in the area of the drainage improvements made by the Ranch, which included regrading the Ranch Road

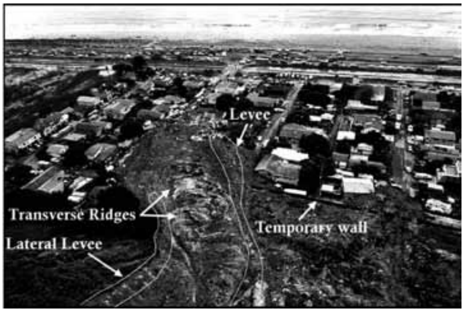

Fig. 5 - Oblique ground photo of the La Conchita landslide taken shortly after the 2005 event. The lateral margins of the main lobe are marked by moderately well developed levees (circled). The interior of the deposit exhibits a ropey pattern of ridges and troughs aligned transverse to the travel direction. The location of the temporary wall constructed to reopen Vista del Rincon Avenue is indicated in right center of image. The dashed portion of the line indicates portions of the wall that were breached or otherwise covered with debris following the event

volume – upper depletion zone 27,190 m^3
volume – lower depletion zone 4,140 m^3
total depletion volume 31,330 m^3
accumulation volume 27,090 m^3
estimated removals 4,240 m^3
average thickness 1.8 m
length (L) 407 m
maximum fall height (H) 152 m
H/L (fahrböschung) 0.37
tan^{-1} (H/L) 20.5°
maximum width 76 m
velocity – slope area ~6-10 m/s
velocity – community ~5 m/s

Tab. 1 - Key physical measurements of the January 10, 2005 La Conchita landslide

where it had been displaced in the 1995 event. The terraced area at the top of the bluff was developed by the Ranch as an avocado orchard

MORPHOLOGY

The principal morphological elements of the 2005 La Conchita landslide are illustrated on Fig. 5, a ground photo taken on the day of the event. The main lobe of the deposit exhibits raised lateral levees, a common feature of small scale mudflows and debris flows (Sharp & Nobles, 1953; Johnson, 1970), as well as a ropy pattern of ridges and troughs aligned transverse to the direction of movement. This ropy pattern is similar in appearance, though not scale, to the morphology that commonly develops on fluid lava flows (pahoehoe). A similar surface texture has also been described from a very large debris flow deposit in central Idaho (Shaller, 1991a) and from several giant martian landslides (Shaller, 1991b).

The minor lobe of the La Conchita deposit lacks these morphological characteristics, and instead exhibits a hummocky, irregular surface texture. The contrast in surface morphologies between the two lobes implies differences in their emplacement mechanisms. The geometry and morphology of the minor lobe suggest it formed by way of: 1) fluid debris entering the Ranch Road drainage channel, then overflowing onto the slope face; and 2) overflow of debris from the western edge of the main lobe due to superelevation as the debris flow banked to the left in the mid-slope area (Fig. 1). The overflow appears to have occurred before the main lobe incised its bed, which subsequently lowered its level relative to the surrounding slope area.

No morphological evidence was observed indicating that the temporary wall erected by the County in 2000 altered the direction of movement of the debris flow. As shown on Fig. 5, the levee bounding the western (right) side of the main lobe shows no significant deflections where it crosses the eastern margin of the temporary wall. This observation is consistent with the behavior of large, rapid landslides elsewhere. Due to their substantial thickness and momentum, these landslides rarely demonstrate significant deflections unless the object encountered cannot be overridden, crushed, or displaced by the onrushing debris. Examples of the interaction of large-scale landslides with obstacles in their path are available in a series of photos of rapid landslides triggered by the 2002 Denali earthquake that traveled across Black Glacier, Alaska (USGS, 2008). Many of these images show the landslide debris draped over ~10 m high medial moraines located across their path.

PHYSICAL DIMENSIONS

Key physical measurements of the January 10, 2005 La Conchita landslide are reported in Table 1 and illustrated in Fig. 1 of the companion article (Shrestha *et alii*, 2011). The volume of the initial slope failure was approximately 27,190 m^3, corresponding to the upper area of depletion located between elevation 76 and 162 m (Tab. 1). Geomorphic evidence and the available video footage indicate that, once initiated, the landslide rapidly transformed into a large-scale debris flow. As it traveled downslope, the main lobe eroded and entrained material along its path, creating the lower zone of depletion shown on Fig. 1 in Shrestha *et alii* (2011). This conclusion is based on the following observations:

- The lower depletion zone was located directly in the path of the main lobe;
- The material occupying the swale was likely in a wet and easily erodible condition due to the heavy antecedent rainfall; and
- The elongated shape and U-shaped profile of the lower depletion zone mimics the shape of glacially-carved valleys, consistent with theory that debris flows should exhibit glacier-like erosional behavior (Johnson, 1970).

Scouring added approximately 4,140 m^3 of material to the debris flow, corresponding to about 13% of the total depletion volume (Tab. 1). Comparison of the total depletion and accumulation volumes indicates a deficit of approximately 4,240 m^3 in the accumulation figure. This difference appears to correspond to debris removed from Santa Barbara Avenue during the initial emergency response. The average thickness of debris in the accumulation zone is estimated at 1.8 m, though the thickness exhibited significant local variation. The thickest accumulations of debris, locally exceeding 4.5 m, occurred near the toe of the main lobe.

As indicated on Table 1, the maximum (horizontal) length of the 2005 La Conchita landslide was 407 m between the crown of the headscarp and the toe of the main lobe, corresponding with an elevation drop of 152 m. The corresponding average travel path slope or "fahrböschung" (Heim, 1932; Hsü, 1975) was 152/407 = 0.37 or tan (20.5°). The latter inclination (20.5°) represents the angle between the toe of the debris flow and the crown of the headscarp. By comparison, the angle of repose of loose rock typically varies between about 32° and 45°. Hence, the debris flow traveled much farther from the mountain front than would be anticipated from a "normal" dry rock landslide and is one likely reason for the high casualty and damage figures resulting from the event. Such "long runout" behavior is characteristic of both wet and dry landslides with volumes exceeding ~106 m^3 (~1.3 million yd^3), and is pronounced in landslides arising from weak or highly fragmented source materials (Shaller, 1991b). No scientific consensus yet exists as to the origin of this behavior (Shaller & Shaller, 1996).

VELOCITY

Based on a review of the video coverage of the event, the main lobe locally appears to have been moving at a velocity of around 6 m/s where its western margin was filmed just downslope from Ranch Road. Likely, the central portion of the flow was moving somewhat faster (~10 m/s). Upon entering the community the velocity was substantially lower, probably 5 m/s or less, based on eyewitness accounts of some residents outrunning the advancing flow.

An independent check on these velocity estimates was made using a method set out by Prochaska *et ali*i (2008). This method involves back-calculation of debris flow velocity using superelevation. In this method, fluid pressure is equated to centrifugal force using the forced vortex equation (McClung, 2001):

$$v = \sqrt{\frac{R_c g}{k} \frac{\Delta h}{b}} \qquad (1)$$

where v is the mean flow velocity (m/s), Rc is the channel's radius of curvature (m), g is the acceleration of gravity (m/s^2), is the superelevation height (m), k is a correction factor for viscosity and vertical sorting, and b is the flow width (m).

The velocity was estimated for a location near the toe of slope (see profile a-a' on Fig. 4 of the companion article, Shrestha *et alii*, 2011). Key input values were Rc = 107 m, g = 9.8 m/s^2, = 3.2 m, b= 38 m and k = 1. These input values yield a mean flow velocity, v, of approximately 9 m/s, generally consistent with the velocities estimated from the video coverage.

Notably, similar conditions should have prevailed at profile location b-b' (see Fig. 4 of the companion article, Shrestha *et alii*, 2011), i.e., ~3 m, though only ~1 m of elevation difference occurs between the paired levees at this location. This finding appears to support the conclusion that debris was shed from the outer (western) edge of the debris flow as it rounded the curve near profile b-b' because the swale was not initially deep enough to contain the entire flow.

CONCLUSIONS

Intense rainfall coupled with unfavorable geologic conditions triggered the 2005 La Conchita landslide, which transformed into a giant debris flow containing over 30,000 m^3 of wet soil and rock. A combination of poorly cemented bedrock, active tectonics, rapid uplift, steep slopes, and pre-existing landslides all helped set the stage for the event. The landslide debris separated into two lobes during its emplacement. The main lobe of the debris flow, containing 90% of the mobilized debris, flowed downslope at velocities up to 10 m/s, scoured over 4,000 m^3 of debris along its path, and entered a residential neighbourhood, killing 10 persons and damaging or destroying 36 residences. This lobe exhibited many common morphological characteristics of small scale debris flows, and even of fluid lava flows (pahoehoe). The minor lobe was formed by the deposition of multiple waves of debris. This debris impacted and breached a temporary wall at the base of the slope but inflicted no additional casualties within the subdivision.

REFERENCES

Davies T.R.H. (1997) - *Using hydroscience and hydrotechnical engineering to reduce debris flow hazards.* In *Debris-Flow Hazards Mitigation: Mechanics, Prediction and Assessment,* Chen C.L., ed., ASCE, New York, N.Y.**:** 787-810.

Gurrola L.D. (2005) - *Recent landslides in La Conchita, California belong to a much larger prehistoric slide, report geologists.* U. C. Santa Barbara, press release (October 19).

Harp E.L., Jibson R.W., Savage W.Z., Highland L.W., Larson R.A. & Tan S.S. (1995) - *Landslides triggered by January and March 1995 storms in southern California.* Landslide News, **9:** 15-18.

Heim A. (1932) - *Bergsturz und Menschenleben. Fretz & Wasmuth A.G., Zurich:* 218 pp. (English translation by N.A. Skermer, BiTech Publishers, Vancouver, BC).

Hemphill, J.J. (2001) - *Assessing landslide hazard over a 130-year period for La Conchita, California. Proc. Assoc. Pacific Coast Geogr.* Ann. Mtg, Santa Barbara, CA, September 12-15, 2001.

Huftile G.J., Lindvall S.C., Anderson A., Gurrola L.D. & Tucker M.A. (1997) - *Paleoseismic investigation of the Red Mountain fault: Analysis and trenching of the Punta Gorda terrace*. On-line document accessible at: http://www.scec.org/research/97research/97huftilelindvalletal.html

Hsü K.J. (1975) - *Catastrophic debris streams (sturzstroms) generated by rockfalls.* Bull. Geol. Soc. Am., **86:** 129-140.

Johnson A.M. (1970) - *Physical processes in geology*. Freeman, Cooper & Co., San Francisco, Calif.: 433-459.

McClung D.M. (2001) - *Superelevation of flowing avalanches around curved channel bends*. J. Geophys Res., **106:16:** 16,489-16,498. National Climatic Data Center (2005) - 2004/2005 winter storms: California and the southwest U.S. www.mhsweather.org/images/Meteorology_2005_Jan_Feb_ So_Cal_Rain_Events.doc

O'Tousa J. (1995) - *La Conchita landslide, Ventura County, California*. AEG News, **38**/4: 22-24.

Prochaska A.B., Santi P.M., Higgins J.D. & Cannon S.H. (2008) - *A study of methods to estimate debris flow velocity.* Landslides, **5:** 431-444.

Rogers J.D., Watkins C.M., Rock F., Kane W.F., Owen J. & Bell M. (2007) - *The 1928 St. Francis Dam Failure and the 1995/2005 La Conchita landslide: The Emergence of engineering geology and its continuing role in protecting society.* Guidebook, Assoc. of Env. & Eng. Geol., 50th Anniv. Ann. Mtg., Los Angeles, CA, September 24-29**:** 52 pp.

Schiek C.G. & Hurtado J.M. (2005) - *Analysis of the 1995 and 2005 La Conchita, CA Landslides using Aerial Photographs and ASTER Satellite data.* AGU Fall Meeting, abstract #G11A-1179.

Shaller P.J. (1991a) - *Analysis of a large moist landslide, Lost River Range, Idaho, USA.* Can. Geotech J., **28:** 584-600.

Shaller P.J. (1991b) - *Analysis and implications of large martian and terrestrial landslides*. Ph.D. dissertation, California Institute of Technology: 586 pp.

Shaller P.J. & Shaller A. (1996) - *Review of proposed mechanisms of Sturzstroms (long-runout landslides)*. In: Sturzstroms and Detachment Faults, Anza-Borrego State Park, California, Abbot P.L. & Seymour D.C., eds., South Coast Geological Society, Annual Field Trip Guidebook, **24**: 185-202.

Sharp R.P. & Nobles L.H. (1953) - *Mudflow of 1941 at Wrightwood, southern California*. Bull. Geol. Soc. Am., **64**: 547-560. U. S. Geological Survey (2008) – USGS On-line Video and Image Gallery, glacier images, http://gallery.usgs.gov/tags/glacier/list/eiy4Cpo00V_3/1.