The Otay Mesa Lateral Spread, a Late Tertiary Mega-Landslide in Metropolitan San Diego County, CA

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ABSTRACT

A pre–late Pliocene mega-landslide was discovered in southwest San Diego County during grading of several residential subdivisions. Outcrop evidence indicates that a single lateral spread occurring on a single continuous, bentonitic clay bed and encompassing approximately 125 km^2 occurred between 1.5 and 28 Ma. Steeply dipping shears separating lateral spread blocks mimic the structure in the nearby La Nacion fault zone. Future studies of faults in areas suspected to be within the lateral spread will need to differentiate tectonic faulting from lateral spread deformation. Investigations should include deep borings to determine if bentonite clay beds exhibit evidence of vertical offsets as a result of normal faulting. In addition to a well-developed basal rupture surface, the lateral spread debris contains discontinuous and unpredictably-oriented internal shears and fractures within large blocks of debris that will affect slope stability. Because much of the structure cannot be evaluated completely by subsurface investigations, in-grading mapping and engineering analysis are necessary to provide appropriate recommendations for stabilization of site-specific slopes.

INTRODUCTION

This paper describes the history, stratigraphy, lithology, and geotechnical engineering implications of an ancient mega-landslide underlying a rapidly developing portion of San Diego County, CA. The discovery of the Otay Mesa Lateral Spread was made possible by detailed geologic mapping during earthwork construction of numerous large residential subdivisions. The discovery underscored the importance of "as-built" mapping during construction as well as collaboration between often competing geotechnical consultants.

The southwest portion of San Diego County is an area that has seen tremendous growth in the past 20 years (Figure 1). It is this growth that has shed new light on the geology of this portion of the county. Large residential developments, including Eastlake (Locality 1, Figure 1), Rancho Del Rey (Locality 2, Figure 1), and Otay Ranch (Locality 3, Figure 1), and the major roads associated with these developments have provided geologists with countless new outcrops, without which, the mid-Cenozoic geology of the area would not have been well understood.

The natural topography in southwestern San Diego County consists primarily of gently rolling hills dissected by numerous westward-draining canyons (Figure 2). Alluvial deposits within the canyons in many areas range from 6.1 m to 15 m thick, and a shallow mantle of colluvium covers the hillsides. There are typically few naturally occurring outcrops. Prior to development, knowledge of the geology was based on isolated road-cut exposures, particularly Chester Grade (Locality 4, Figure 1), and exposures in open-pit bentonite mines south of the Otay River. Beginning in the late 1980s and early 1990s, residential developments began moving farther eastward and southward from Interstate 805. These developments were generally limited to the ridge or mesa tops and canyon bottoms, and, as such, earth moving was relatively minimal. More recent grading, beginning in the mid- to late 1990s, began to provide better geologic exposures as residential and commercial development advanced into areas previously utilized for agriculture and ranch land.

Features in sedimentary rocks that are now attributed to a mega-landslide, here designated the

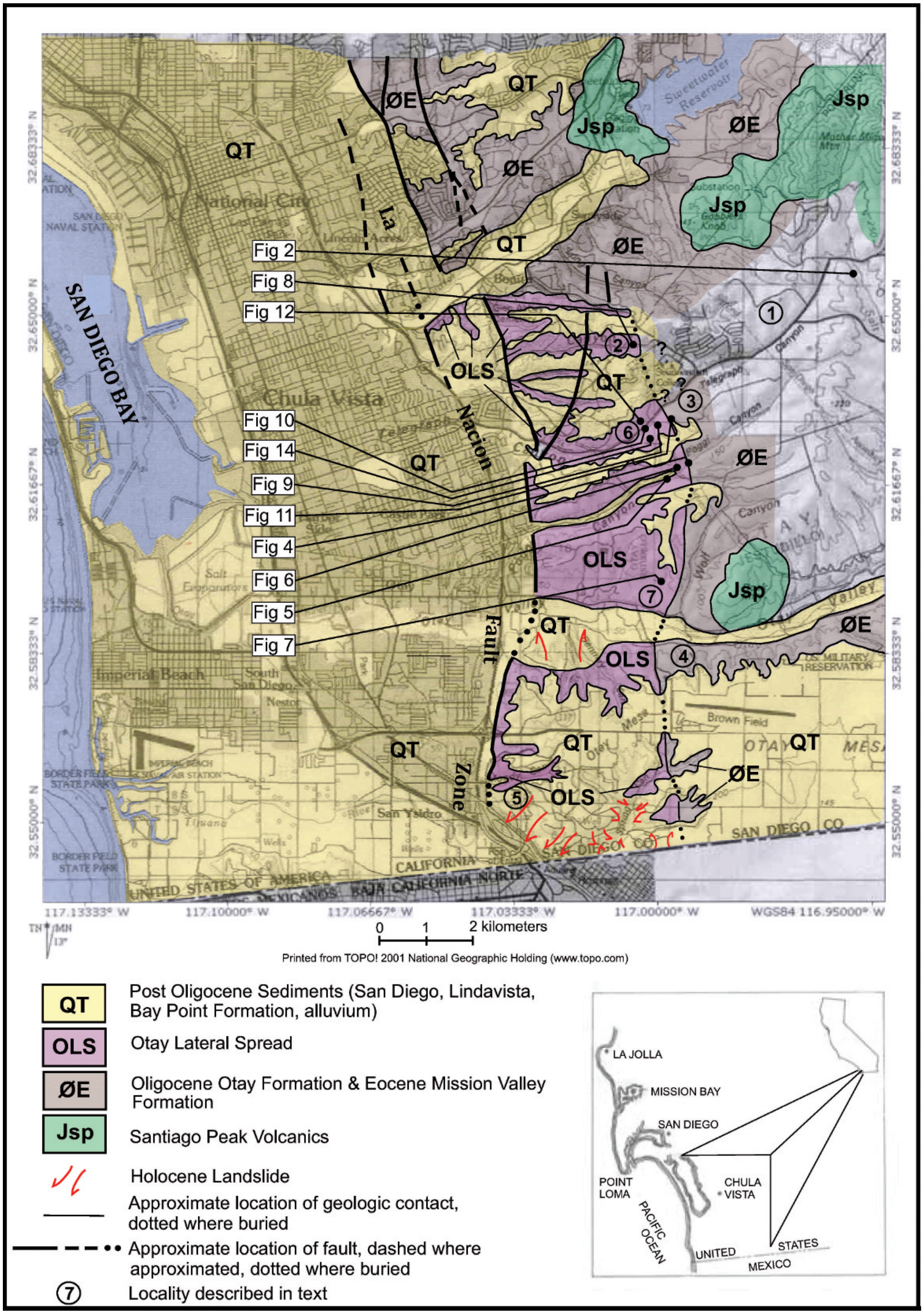

Figure 1. Geologic map of southwest San Diego County showing localities and figures discussed in the text. The depicted geology is a compilation of the authors' field work and aerial photographic analysis over the last 30 years.

Figure 2. Photograph of the Otay Mesa–Chula Vista area showing the gently rolling terrain prior to development. View is to the southwest along Salt Creek toward Otay Valley. Note the lack of outcrops.

Otay Mesa Lateral Spread, were observed in southwest San Diego County as early as 1988. These features included locally-faulted or deformed clay bodies (diapirs), exhibiting structures that resembled soft-sediment deformation, such as oversized flame structures and rip-up clasts. These deformation features were thought to be associated with the nearby La Nacion fault, or record soft-sediment deformation during or shortly after deposition of the Oligocene Otay Formation. A 1988 geotechnical investigation in San Ysidro (San Diego Geotechnical Consultants, Inc., 1988) concluded that syn-depositional landsliding or deformation due to faulting on the La Nacion fault was responsible for unusual geologic structure observed near San Ysidro (Locality 5, Figure 1). Hart and Murbach (1995) and Berry (1999) observed 3- to 8-m-high apparent flame structures in bentonite within cut slopes along Telegraph Canyon Road near the intersection with Otay Lakes Road (Locality 6, Figure 1) during widening of Telegraph Canyon Road in the early 1990s. Berry (1999) thought that the flame structures occurred during deposition due to the weight of the overlying sediments and poor consolidation of the volcanic ash and sediments. During the grading of Rancho Del Rey (Locality 2, Figure 1), located roughly between the Sweetwater River valley and Telegraph Canyon, in 1985 to 1989, abundant intrusive, diapir-like bodies of bentonite were observed at lower elevations of the site (Richard Cerrutti, George Copenhaver, Pat Thomas, Brad Riney, 1996, personal communication). North-south–striking, linear, clay-filled shears were also observed. The shears were continuous over several hundred meters and were interpreted to be inactive traces of the La Nacion fault. Exposures in the Otay Landfill (Locality 7, Figure 1) showed a sheared bentonite clay layer forming a classic décollement with tilted and deformed bedding overlying horizontal undeformed sediments (Hart and Murbach, 1995). By 1993, geotechnical consultants working in the area, either through published papers or by informal discussion, acknowledged the presence of some type of intra-formational landslide or landslide-like feature within the pre-Pliocene sediments. However, the geometry and genesis of the feature were not known.

In 1995, development of residential tracts began south of Telegraph Canyon, and the Otay Landfill was enlarged by removing large quantities of earth from the perimeter of a deep canyon in the southern portion of the property. Geotechnical investigations conducted for the new residential developments did not encounter anything extraordinary other than the presence of a single persistent bentonite clay bed. Within the first week of grading, it was apparent that the geology above the clay layer was substantially different than that below the layer, similar to the exposures in the Otay Landfill. Initially, detachment or thrust faulting was hypothesized as a possible cause of the deformation. As grading proceeded, the

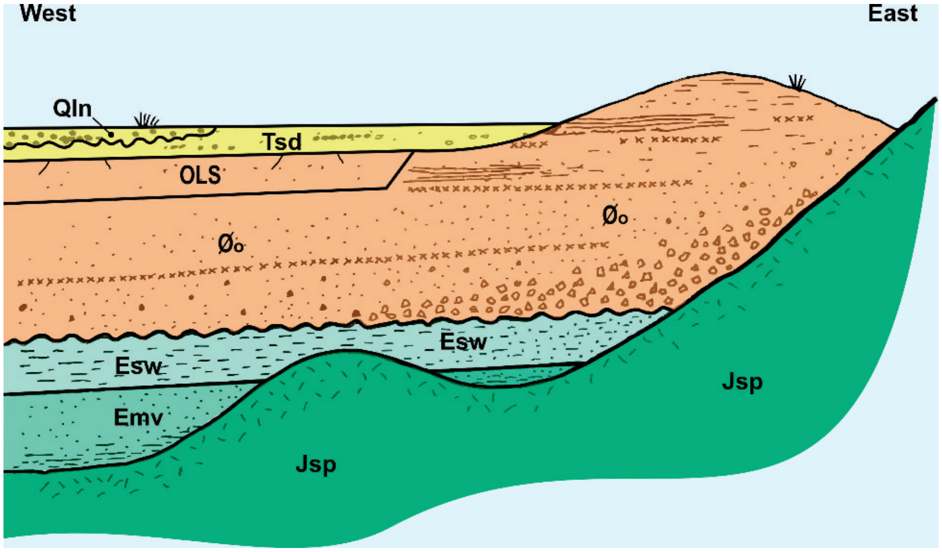

Figure 3. Generalized geologic cross section of southwest San Diego County. Jsp, Santiago Peak Volcanics; Emv, Eocene Mission Valley Formation; Esw, Eocene Sweetwater Formation; Øo, Oligocene Otay Formation; OLS, Otay Mesa Lateral Spread; Tsd, Pliocene–Pleistocene San Diego Formation; Qln, Pleistocene Lindavista Formation. Figure is modified from Walsh and Demere (1991).

eastern limit of the décollement and a 250-m-long cross section through the axis of the now-apparent lateral spread were exposed.

GEOLOGIC SETTING OF SOUTHWEST SAN DIEGO COUNTY

The geology of southwest San Diego County consists of nearly flat-lying sequences of marine and non-marine sedimentary rocks of Tertiary and Quaternary age that unconformably overlie Jurassic metamorphic and volcanic rocks (Walsh and Demere, 1991). Figure 3, a schematic, east-west section through southwest San Diego County, shows the stratigraphic and spatial relationship between the units. The basement consists of Jurassic to Cretaceous volcanic rocks known as the Santiago Peak Volcanics (Larsen, 1948; Fife et al., 1967; and Herzig and Kimbrough, 1991). A high-relief non-conformity separates the overlying Tertiary sedimentary rocks from the basement. The Tertiary sedimentary rocks are divided into the middle Eocene Mission Valley and Sweetwater Formations (Walsh and Demere, 1991), the late Oligocene Otay Formation (Demere, 1988), the late Pliocene to early Pleistocene San Diego Formation (Hertlein and Grant, 1944; Demere, 1983), and the Pleistocene Lindavista Formation (Kennedy and Tan, 1977).

In general, the sedimentary units have a gentle regional dip to the southwest. A north-south–striking buttress unconformity is present where the Pliocene shoreline was cut into the Otay Formation, and the San Diego Formation was subsequently deposited against this near-vertical feature. The major structural feature in the area is the La Nacion fault, which is composed of anastomosing, near-vertical, down-to-the-west normal faults. The faults appear to have formed in the late Pliocene to early Pleistocene in response to motion on the Rose Canyon fault zone farther to the west (Marshall, 1989; Treiman, 1993).

OTAY FORMATION

General Lithology

The Otay Formation is a fluvial deposit, consisting of basal conglomerate, middle gritstone, and upper sandstone-mudstone members, with bentonite claystone beds throughout (Walsh and Demere, 1991). It fines upward and westward (distally), as depicted schematically in Figure 3. The 12-m-thick basal conglomerate is composed of pebble, cobble, and boulder beds with a coarse sand matrix. Clasts within the conglomerate are meta-volcanic and granitic in origin. The middle gritstone unit is roughly 16 m thick and consists of coarse to gravelly sandstone. Clasts are typically quartz, feldspar, and plutonic rocks, with lesser amounts of meta-volcanic rock fragments. Rare beds of bluish-gray bentonite claystone are also present. The upper sandstone-mudstone unit is at least 35 m thick and consists of massive beds of light-brown and light-gray sandstone with thinner interbeds of reddish-brown to green to olive siltstone and claystone. The uppermost exposures of the Otay Formation contain distinct red, green, and brown claystone and siltstone beds, dubbed the "Christmas

Beds." The upper unit was eroded prior to deposition of the San Diego Formation.

Bentonite

The existence of bentonite claystone (commercial term for volcanic ash–derived smectitic clay) in the Chula Vista area has been known since the beginning of the 1900s. This material was mined from the Otay Formation between 1917 and 1957 for use as a cleaning and de-colorizing agent for petroleum (Cleveland, 1960). It has also been used as a drilling fluid and in impermeable membrane applications. Otay Bentonite is a Clay Minerals Society Source Clay, consisting almost entirely of mixed-layered illite-smectite (Berry, 1999). Argon/argon dating of a bentonite bed within the upper sandstone-mudstone unit of the Otay Formation yielded an age of 28.86 Ma (Walsh and Demere, 1991), corresponding to the late Oligocene. The generally accepted theory for the formation of bentonite involves the deposition of volcanic ash in seawater. The "…general consensus is that primary waxy bentonites result from the fall of (probably hot) volcanic ash directly into water that is at least brackish… The alteration takes place in a matter of hours or days, and the resulting deposit of pure, unconsolidated bentonite must be left undisturbed for a longer time until it develops its coherent waxy character" (Berry, 1999; p. 71). As observed during earthwork construction, the geology associated with the bentonite in the Otay Formation is somewhat at odds with a marine or brackish depositional environment. The sedimentary structures, lithology, and paleontology of the Otay Formation indicate a fluvial system with a freshwater fauna, as opposed to an estuarine or shallow-marine environment.

Although bentonite beds occur throughout the Otay Formation, they are most common and continuous in the upper sandstone-mudstone member. The most persistent layer occurs at elevation 110 m near the intersection of Paseo Ranchero and Telegraph Canyon Road in Chula Vista. Cleveland (1960) also reported this layer in Otay Valley. The persistent bentonite layer is pink to white in color and waxy in texture, and it ranges from brittle to soft and remolded in consistency. The persistent bentonite layer ranges from several centimeters to 2 m in thickness and is typically associated with dark-red, thinly stratified clay. The red clay is usually 1 to 2 m thick above and locally below the bentonite. The bentonite dips 1 to 2 degrees to the west-southwest. Another continuous layer of bentonite was observed at elevation 160 m near the intersection of La Media and East Palomar Street. This higher bed is associated with thinly bedded red, green, and white "Christmas Beds" claystone.

OTAY MESA LATERAL SPREAD

A lateral spread is defined as "a lateral movement in a fractured mass of rock or soil, which results from liquefaction or plastic flow of subjacent materials" (AGI, 1980; p. 15). Lateral spreads in bedrock typically involve fracturing and extension of coherent upper units on a liquefied or plastic basal sliding surface (Varnes, 1978). These features generally develop on gentle slopes, between 0.3 and 3 degrees. During movement, the lateral spread will typically break up internally, forming numerous fissures and scarps. Lateral spreads can occur at all scales and extend up to many kilometers (Varnes, 1978). Observations of lateral spreads in Russia and Libya have revealed that the cracks between the coherent blocks of bedrock were filled with soft material squeezed up from below or with detritus from above (Varnes, 1978). Factors that can lead to lateral spreading include the presence of underlying continuous zones of plastic clay or liquefiable material and proximity to a free face such as a cliff or riverbank. Lateral spreads are thought to be triggered by an earthquake, but seismic triggering is not a requirement.

General Description

The Otay Mesa Lateral Spread is an approximately 12.9-km-wide by 4-km-long tabular body exposed discontinuously between Sweetwater Valley on the north and Spring Canyon near the U.S.-Mexico border on the south. The eastern limit of the Otay Mesa Lateral Spread is well documented between Telegraph Canyon and Poggi Canyon in the Otay Ranch area (Figure 1). The exposures in the Otay Landfill extend the eastern limit in that area to at least the vicinity of Wolf Canyon, a distance of approximately 3.5 km. The precise southern limit is unknown, but exposures near San Ysidro suggest that the lateral spread extends at least to the U.S.-Mexico border. The western limit is defined by the La Nacion fault (Figure 1), based on exposures west of Paseo Ranchero, where the fault juxtaposes lateral spread debris against the down-dropped San Diego Formation (Pat Thomas, 1996, personal communication). The northern limit is more difficult to establish because it is based on recollections of geologists working the area during residential development in the 1980s. It extends, however, at least to the northern boundary of the Rancho Del Rey subdivision in the Rice Canyon area (Figure 1).

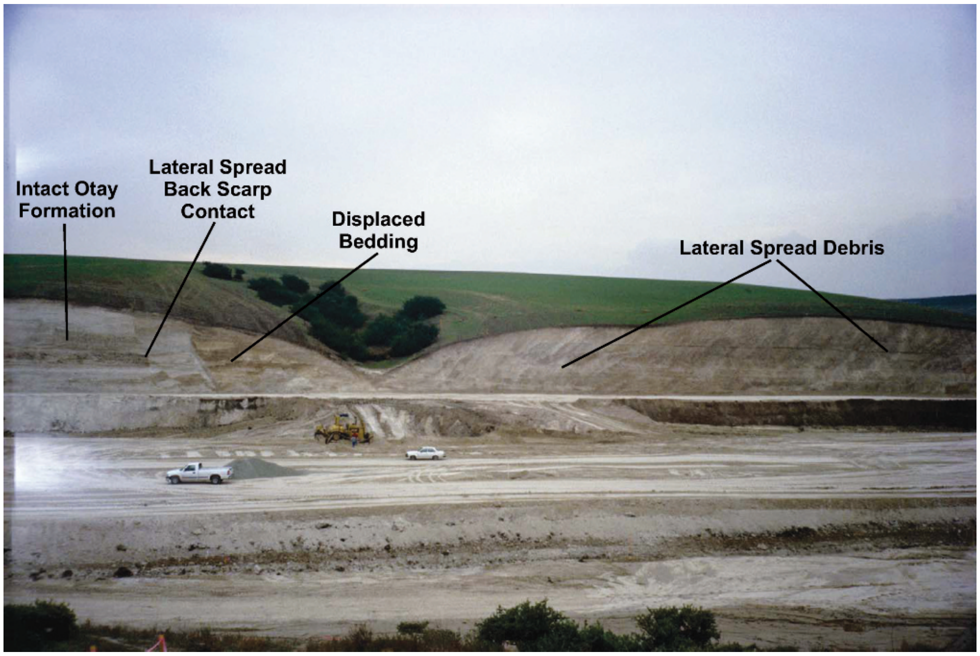

Figure 4. Photograph of a portion of a buttress back-cut slope along Poggi Canyon, looking south. Note the back scarp contact between the intact Otay Formation and the Otay Mesa Lateral Spread deposit, and the backward-rotated bedding. Of particular interest, note the lack of topographic expression of this contact.

The internal structure of the Otay Mesa Lateral Spread, observed in the Chula Vista area, is consistent with a lateral spread as defined by Varnes (1978). The best exposures are located in a long (0.7 km), continuous, buttress back-cut along the south wall of Poggi Canyon (Figures 4, 5, and 6) and at the Otay Landfill property (Figure 7). At these locations, the landslide debris consists of steeply-tilted, coherent blocks, separated by steeply-dipping shear zones. In many places, the displaced material is characterized

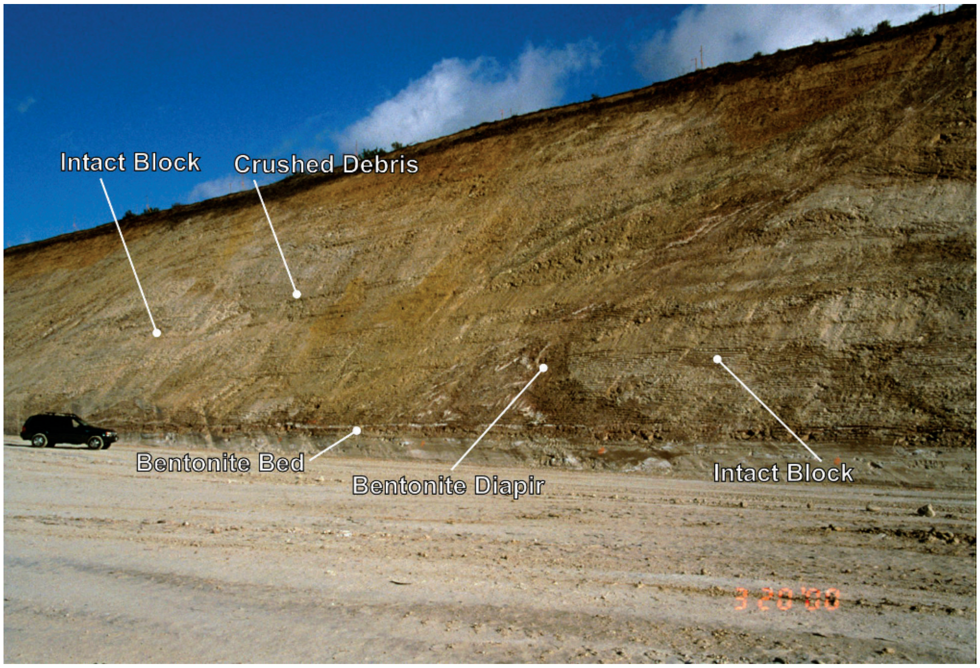

Figure 5. Photograph of a portion of a buttress back cut along Poggi Canyon, west of Figure 4. Note the intact blocks of sandstone separated by the bentonite diapir and zone of disturbed sandstone, siltstone, and claystone. The horizontal bentonite bed on which the Otay Mesa Lateral Spread failed is clearly visible.

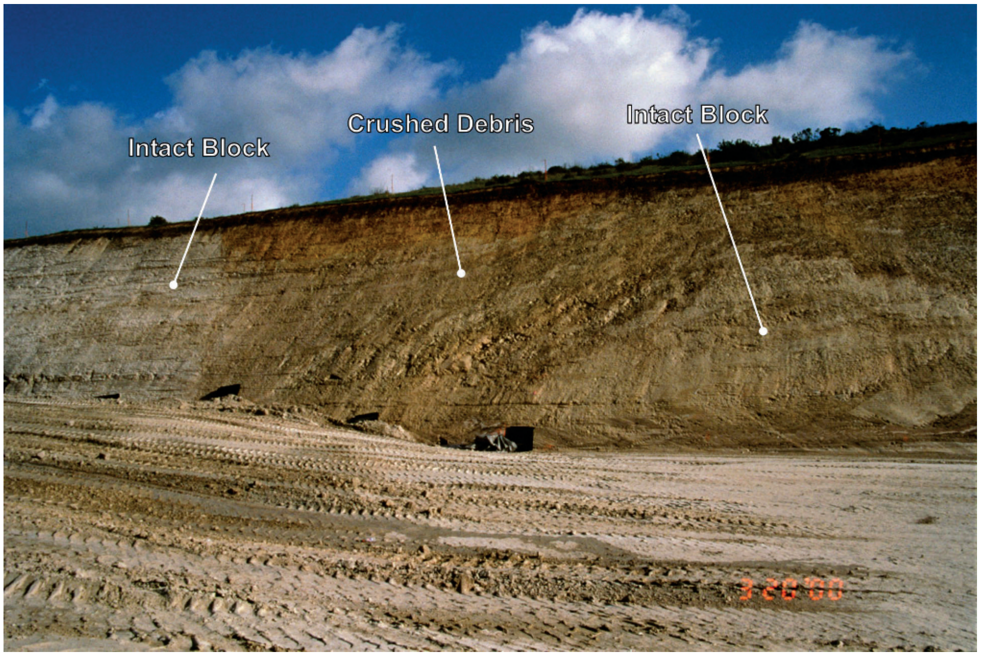

Figure 6. Photograph of a portion of a buttress back cut along the south side of Poggi Canyon east of Figure 5. Note the sheared and fractured debris zone. The reddish, oxide-stained area at the top of the cut in the fractured debris is often mistaken for San Diego Formation. As a result, the north-south–striking contact between the fractured and unfractured debris can be misidentified as a trace of the La Nacion fault.

by flame structures, composed of bentonite, extending upward from the base of the landslide over 5.5 m into the slide mass (Figure 8). The entire mass moved on the lower bentonite layer at elevation 110 m in the vicinity of Paseo Ranchero.

Tilted and sheared internal blocks average 9 m in height, 50 to 100 m in length (east-west), and 200 to 225 m in width (north-south). Some blocks are composed of relatively undisturbed massive sandstone, whereas others consist of highly fractured and

Figure 7. Photograph of the contact between the intact Otay Formation and the Otay Mesa Lateral Spread, taken at the Otay Landfill (Locality 7). The flat-lying bentonite bed is clearly visible.

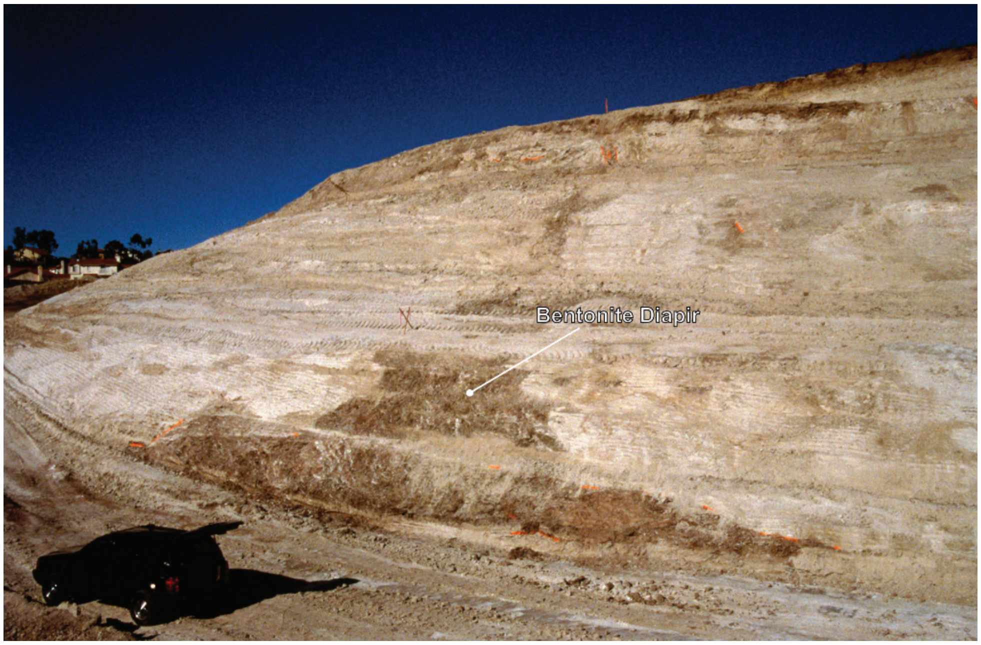

Figure 8. Photograph of a large diapir of bentonite.

sheared mixtures of claystone, sandstone, and bentonite (Figures 5 and 6). Several blocks near the head of the lateral spread exhibit steeply dipping, backward-rotated bedding (Figure 9). In all cases, the blocks are moderately well lithified or moderately cemented with calcium carbonate. Many of the blocks contain irregularly shaped bodies of bentonite ranging from 1 to 3 m in length. The bentonite bodies are internally sheared and probably formed when fragments of plastic bentonite peeled from the basal rupture surface and were dragged into the debris during the initial failure. Wherever thin bedding is preserved in the blocks, it is abruptly truncated at the basal rupture surface with no indication of soft-sediment deformation or dragging (Figure 10).

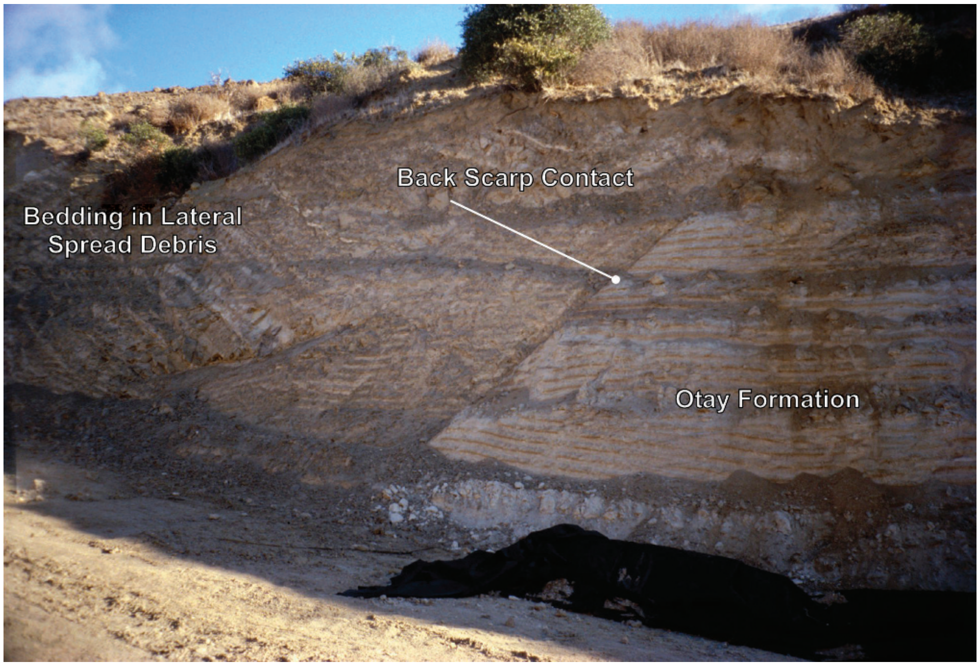

Figure 9. Photograph of the back-scarp contact on the north side of Poggi Canyon, looking northeast. Note the massive to flat-lying bedding of the intact Otay Formation, and the southeast-dipping bedding of the Otay Mesa Lateral Spread.

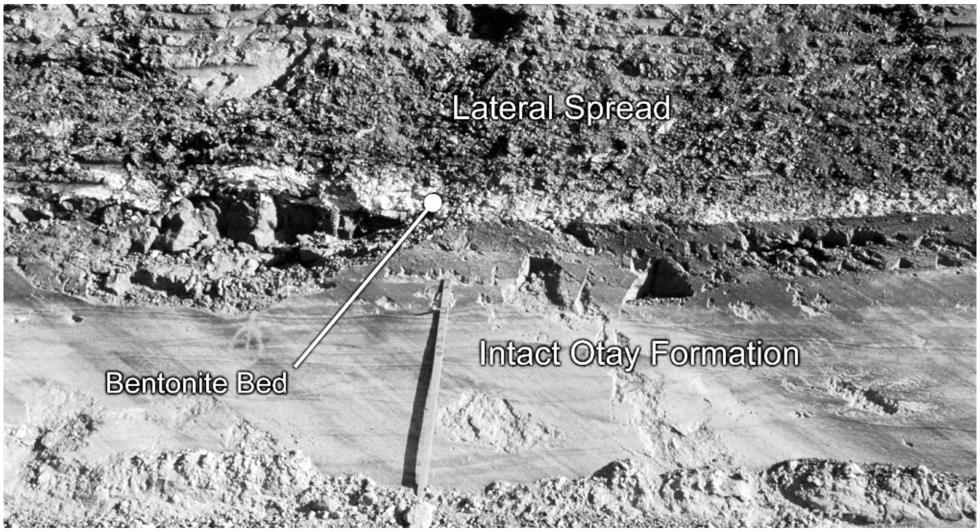

Figure 10. Close-up photograph of the contact between the intact Otay Formation and the Otay Mesa Lateral Spread in Poggi Canyon. The flat-lying bentonite bed is clearly visible. Note the loose unconsolidated appearance of the Otay Mesa Lateral Spread debris. The striations in the lower portion of the photograph were caused by grading equipment.

The shear zones between the blocks trend north-south, normal to the westward direction of movement, and can be traced over hundreds of meters. Polished shear surfaces underlain by soft clay gouge, ranging from several centimeters to several meters in thickness, define the edges of the blocks. Where the steeply dipping shear zones intersect the low-angle basal failure surface, the bentonite, in many localities, has been dragged or forced up into the shear zones in diapir-like intrusive bodies or occurs as stretched and tapered fragments (Figure 11).

The basal rupture clearly occurred on or within a thick continuous bentonite clay bed that ranges in thickness from 10 cm to 2 m (Figure 11). The upper portion of the basal rupture zone commonly exhibits soft-sediment or plastic deformation in the form of dike-like intrusive bodies into the overlying debris, or complex recumbent drag folds (Figure 11). Residual

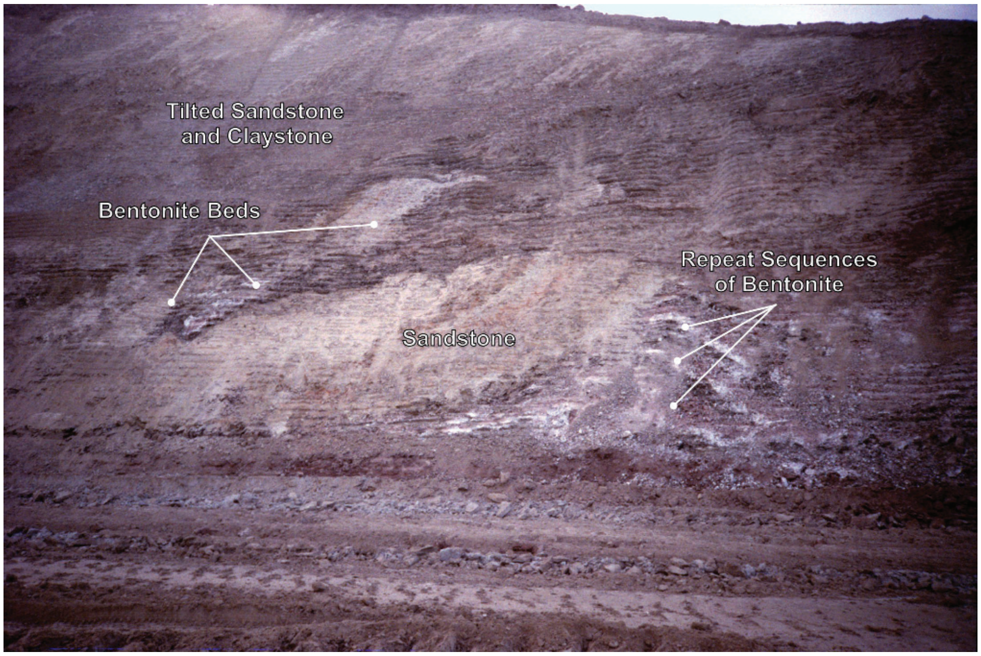

Figure 11. Photograph of a buttress back-cut slope on the south side of Telegraph Canyon Road just east of Paseo Ranchero. The bentonite has been squeezed up into the debris and folded into a complex recumbent structure.

Figure 12. Photograph of a buttress back-cut slope along the west side of Paseo Ranchero. The chaotic bedding in the Otay Mesa Lateral Spread is clearly truncated by the San Diego Formation.

direct shear tests on the bentonite gouge yield average angles of internal friction of 8 degrees with a cohesion intercept of 0 psf.

The head of the Otay Mesa Lateral Spread is marked by a clear, steeply dipping, fault-like shear that separates highly deformed and broken debris on the west from massive, undisturbed Otay Formation sandstone on the east (Figures 4 and 9). Immediately adjacent to the headscarp, the graben debris shows highly chaotic bedding with no discernible preferred orientation. However, to the west of the chaotic debris, the graben consists of a 50 m zone of nearly uniformly back-tilted (dipping 30 to 50 degrees to the east and striking within a few degrees of north-south) clay beds. The bedding observed in the graben is composed of alternating green, red, and white claystone and a thin bentonite bed that correlates well with the "Christmas Beds" found approximately 60 m higher in the Otay Formation section. This band of "uniformly disturbed beds" can be traced over 1.6 km in a north-south direction. The presence of this band of "uniformly disturbed bedding" suggests that, prior to the failure, the source material was dense enough not to liquefy, and that the mode of failure was uniform over a large area.

Age of Landsliding

The top of the Otay Mesa Lateral Spread was removed by erosion prior to deposition of the San Diego Formation. The unconformity between the Oligocene Otay Formation beds, from which the Otay Mesa Lateral Spread is derived, and the Pliocene San Diego Formation clearly separates the undisturbed San Diego Formation from the underlying Otay Mesa Lateral Spread debris (Figure 12). This relationship indicates a minimum late Pliocene–early Pleistocene age for the Otay Mesa Lateral Spread. The presence of the "Christmas Beds" in the graben indicates that failure must have occurred after the deposition of at least 60 m of Otay Formation above the basal bentonite. The lack of soft-sediment deformation in the Otay Mesa Lateral Spread debris and the fact that the sandstone and claystone blocks within the landslide were, for the most part, brittlely deformed, indicate that the Otay Formation had to have been somewhat lithified prior to initiation of the lateral spread. Finally, at least 60 m of erosion or faulting must have occurred at the toe of the landslide prior to the failure to expose the basal bentonite and destabilize the mass. Figure 14 depicts a likely sequence of events that would produce the observed geology.

FAILURE MECHANISM

The basal bentonite bed has extremely low shear strength, is highly plastic, and acts as an aquitard, creating a perched water table. Erosion of a sea cliff along a paleo-coastline could have exposed the

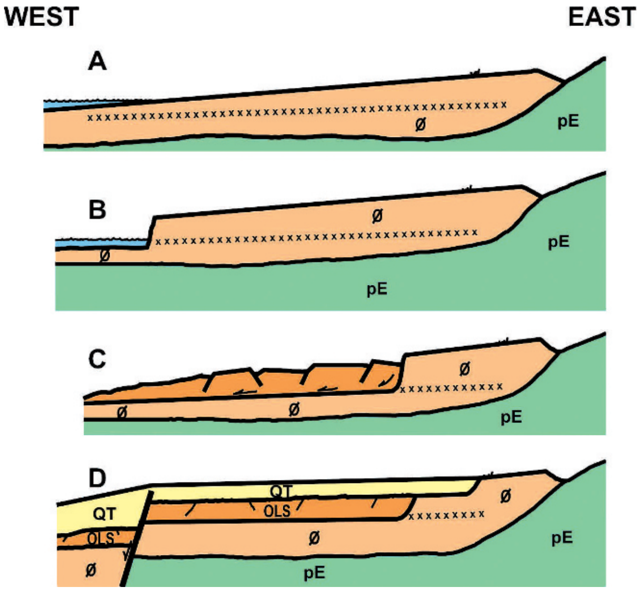

Figure 13. Idealized sequence of events related to the formation of the Otay Mesa Lateral Spread, from the late Oligocene to the present day. (A) Late Oligocene deposition of the Otay Formation, including the continuous bentonite clay bed. (B) Post-Oligocene uplift and erosion expose and undercut bentonite clay bed. (C) Pre-Pliocene lateral spreading. D) Present-day geology; Otay Mesa Lateral Spread debris buried by Pliocene San Diego Formation and later by Pleistocene Lindavista Formation. Motion on the La Nacion fault allows burial of the lateral spread debris west of the fault by Pleistocene marine and non-marine sediments.

bentonite and created a favorable situation for failure (Figure 13B). Assuming this topography, low shear strength, and perched water table, approximated back-calculations of stability indicate that seismically induced ground acceleration of only 0.12*g* could have mobilized the mass. We discount the possibility that the failure was the result of regressive landsliding occurring over a prolonged period of time because of the planar nature of the contact with the overlying San Diego Formation and the lack of evidence of erosion within the debris. A seismic trigger is not a requirement for initiating the failure; however, it seems unlikely that long-term erosion alone would be uniform enough to cause failure along a 4 km front.

GEOTECHNICAL IMPACTS

The areas underlain by the Otay Mesa Lateral Spread are currently being developed, or will be developed in the future. Although the western limits of the feature are buttressed by the down-faulted San Diego, Lindavista, and Bay Point Formations west of the La Nacion fault zone, large internal units of the debris exposed in slopes and valleys are not. One of the identifying features of natural slopes underlain by the Otay Mesa Lateral Spread is the presence of large-scale Quaternary, deep-seated landslides. The highly fractured and sheared nature of the debris, and the presence of a pre-sheared basal bentonite that possesses residual shear strength, are responsible for the large number of ancient landslides seen along the south side of Otay Valley and Smuggler's Gulch along the U.S.-Mexico border.

Graded slopes, constructed on ground underlain by Otay Mesa Lateral Spread, will also be affected by the fractured and sheared nature of the debris and low residual strength of the basal bentonite bed. The

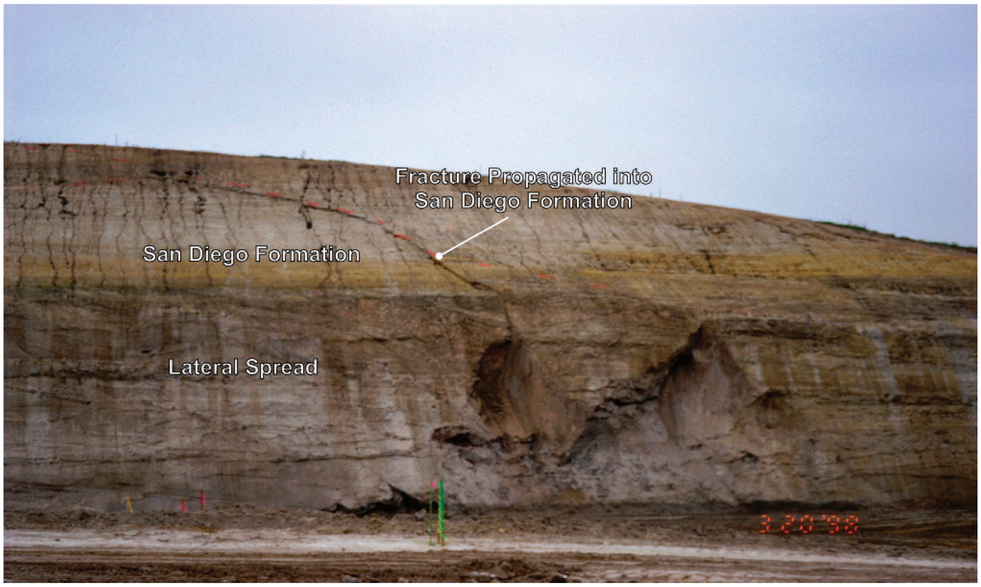

Figure 14. Photograph of a construction failure in progress. The fracture propagated up into the San Diego Formation from the Otay Mesa Lateral Spread, requiring large amounts of additional earthwork and stabilization efforts.

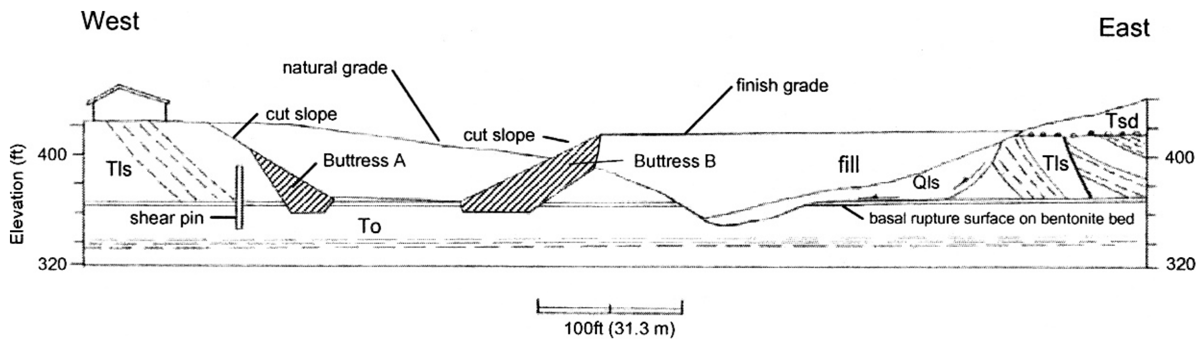

Figure 15. Cross section through a residential subdivision in Chula Vista showing typical buttressing and grading required for stabilization of Otay Mesa Lateral Spread basal rupture surface.

typical method of evaluating slope stability for future grading is to drill large-diameter (1 m) borings in areas where the slopes will be cut. The geologist enters the boring and logs it for potentially unstable geologic structure. If the boring is not drilled sufficiently deeply to intercept the basal rupture surface, or is not located in a shear zone separating the intact blocks within the debris, the potentially adverse structure will not be recognized (Figure 14).

The shear zones are also composed of irregular bodies of highly expansive bentonite and other clays. If a shear zone is located beneath a structure or shallow fill, there is potential for damaging heave if the clays become wet. The shear zones are also fault-like in appearance and may be misidentified as strands of the La Nacion fault.

An example of a typical mitigation scheme is shown on Figure 15, which is a geologic section through the southern portion of a residential subdivision in Chula Vista, CA. The section shows several types of mitigation required to place fills and excavate cut slopes in the vicinity of the landslide, as well as the contact relationship with the overlying San Diego Formation. The area depicting the two buttresses is located in a slot cut for a major access road into the subdivision. Buttressing was required on the western slope (Buttress A) to stabilize the rupture surface in an area below an existing residence. Shear pins provided temporary stability during construction of the buttress. The buttress on the east side of the road cut (Buttress B) was required to stabilize the cut slope that was surcharged by the proposed filling of an adjacent canyon. Note the presence of a Quaternary landslide that had formed on the natural canyon slope below the proposed fill.

Careful preliminary geotechnical study is not the only tool for avoiding potential hazards in grading within the Otay Mesa Lateral Spread. In-grading mapping by qualified geologists is necessary to identify the presence of the debris and to map the hazardous features. Only then will the geotechnical engineers have the three-dimensional model required to conduct a realistic analysis of stability.

CONCLUDING REMARKS

The presence of the 124 km^2 Otay Mesa Lateral Spread was not previously recognized because there were no geomorphic features or sufficient outcrops to suggest its existence. Geotechnical explorations create very small exposures of geologic features with several possible interpretations. An understanding of the ways in which the little pieces of the puzzle fit the big picture had to wait until development of this portion of San Diego County created the continuous and widespread exposures that could be mapped and interpreted correctly.

The geotechnical consulting industry can learn several lessons from the Otay Mesa Lateral Spread. Sharing of geologic information within the geotechnical community, by formal papers or presentations and informal discussions, are extremely important.

Geology is not limited by property or subdivision boundaries. We owe our clients the most complete geologic characterization of the site that we can provide, and that includes geologic data from adjacent sites. Data from outside the project limits may play a vital role in gaining an understanding of site-specific geologic conditions. Finally, we cannot be lulled into a false sense of security with regard to our investigative reports. It is a humbling experience to watch one's assumptions proven wrong during mapping of the first canyon clean-out. Geologists and engineers must react quickly and professionally to changes observed during grading, which requires careful mapping in the field and analysis of that data throughout the grading process.

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