A Map of Relict Landscapes and Landslides
Bitter Creek National Wildlife Refuge, Kern County, California, USA

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Abstract

The San Andreas Fault Zone is a great location to conduct geomorphologic research, because of its recent history of tectonism and related surface uplift. In the Bitter Creek National Wildlife Refuge - located in Kern, San Luis Obispo, Ventura, and Santa Barbara counties – a map of relict landscapes and landslides was created. The map was created using a combination of techniques of air photo mapping and field mapping. A digital version of the map was created and used for further analysis of the relict landscapes and landslides. This research serves as reconnaissance for future research in this area, and shows how maps can be applied to analyze geomorphologic processes and hazards.
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Chapter 1

Introduction

Changes in Earth’s surface are quickly erased in geologic history. Uplifted topography is eroded, structural depressions are filled with sediment, and usually, we only see either the end result or the initial condition. In few circumstances, we can see a snapshot of a process actively happening, and a fine example of this exists in the Bitter Creek National Wildlife Refuge. Here we see an old landscape being destroyed and a new landscape being created at this one moment in history, and there is much to be learned about geomorphic process at a place like this (Figure 1).

Background Information and Problem Statement

The San Andreas Fault is one of the most intensely studied faults in the world. For decades, this fault has yielded great discoveries pertaining to seismology, structural geology, and especially geomorphology. Landslides, beheaded streams, shutter ridges, and sag ponds are constantly being created and destroyed within the fault zone. The Bitter Creek National Wildlife Refuge, which is located on the San Andreas Fault, has great potential for geomorphologic studies, but has yet to be developed. Thus, to begin geomorphologic research, we must start with field reconnaissance. Creating a map using air photos and field mapping is an excellent way to conduct reconnaissance.

Statement of overall research goal

The goal of this research is to use air photos and field mapping to uncover surficial geologic events that have taken place within the Bitter Creek National Wildlife Refuge, and how
Tectonic activity along the San Andreas Fault has changed the local landscape. A map of the relict landforms and landslides sets a base line for further research. The Bitter Creek National Wildlife Refuge is an ideal location for research because the San Andreas Fault extends through the Bitter Creek National Wildlife Refuge, and the refuge contains incised drainages within its boundaries. The area is also protected, which ensures that landscapes have been untouched by humans in recent history. This research is significant because the San Andreas Fault Zone is a transform tectonic plate boundary that is visible on land, and few geomorphologic studies have been completed in the vicinity of the Biter Creek Wildlife Refuge.
Identification of subgoals

- Use air photos and field mapping to create a map of distinct and subtle landforms in the Bitter Creek National Wildlife Refuge.

- Determine the relative ages of stream terraces, thus giving the age of when landslides occurred.

Statement of subgoal to be investigated

We will use air photos and field mapping to create a map of landforms in the Bitter Creek National Wildlife Refuge.

Importance of the project

Creating a map of landscape features is important because it is the first step in any kind of geomorphologic survey. A map can not only serve as a guide to the local area, but it can record and organize information. Further analysis of the information collected can yield significant findings. The creation of a map should be one of the first goals completed in the survey of an area.

The map of the relict landscapes and landslides will be used for future studies in this area and will help set a base line for research in an area that is relatively unstudied. Our research will contribute to acquiring more funding for the Bitter Creek National Wildlife Refuge.

General Approach

We used a combination of field and laboratory work to create a map of landforms. First, we created a preliminary map of landforms based on aerial photo interpretation. Next, we took these maps into the field to verify that the features we observed in laboratory are present in the field,
and made corrections to our map. Finally, to ensure widespread distribution, we used GIS mapping software to digitally recreate our map.

**Objective Statement**

Our objective is to map relict landscapes and landslides in the Bitter Creek National Wildlife Refuge and surrounding area.
Chapter 2

Paleo-Topography and Mapping

Mapping a Relict Landscape in California

Introduction

The world is an ever changing place even if the differences in topography are too minute to see in one life time. Mountains form and oceans grow and shrink all thanks to the ever shifting tectonic plates. In most places in the world the topography takes a familiar pattern, telling the onlooker what events have taken place most recently and erasing the evidence of events past. This kind of topography is a modern landscape. There are also landscapes where past events are recorded in the hillsides, and these are called ”paleo-landscapes” or “relict landscapes”. The second type of landscape, the “relict landscape”, is the type this paper will be focusing on.

One objective of this literature review is to set the background for how uplift might have occurred at the north end of the big bend in the San Andreas Fault, and in the Elkhorn Plateau area. Other objectives include defining a relict landscape, and explaining the significance, pertaining to geomorphologic research, of different methods of mapping - such as air photo interpretation, field mapping, and digitization of surficial geologic map data.

Relict Landscapes

The following is summarized from a series of oral communications with A. F. Garcia well as Spotila et. al. (2007) and Keller et. al. (2000). California has been a long time in the making, most of what is now California is so recent that there are almost no rocks in California
that are over 600 million years old. Starting around 600 million years ago, exotic tectonostratigraphic terranes began accreting on to the west coast of North America. Many different types of landmasses accumulated along the edge of the west coast of the North American Plate forming California as we know it now (Figure 2). Accretion of tectonostratigraphic terranes culminated with the complete subduction of the Farallon Plate, whose modern remnant is the Juan de Fuca Plate (Figure 2). After the subduction of the Farallon plate was complete, there began an interaction between the Pacific Plate and the North American Plate. The Pacific Plate moves mostly transversely in relation to the North American plate, but since about 5 Ma, it has also been also converging with the North American plate (Page et. al, 1998; Figure 2). This combination of movement, as well as a bend in the San Andreas Fault, has caused compression which resulted in crust thickening and uplift, as well as base-level fall around Maricopa and Cuyama, California (Royden et. al, 2008). Fault-normal convergence rates in profiles perpendicular to the trace of the San Andreas Fault, especially near the Carrizo Plain, show a convergence rate of 0.5 +/- 1.8 mm/yr (Argus and Gordon, 2001), and there is significant evidence for uplift in the late-Quaternary (Spotila et. al, 2007).

**Differences between relatively recent landforms and relatively old landforms**

Landslide scars are clear indicators of recent landform development. In the Bitter Creek area, most, if not all, landslide scars are noticeable, even relatively small ones. Landslides scars have very easily discernable outlines that are parabolic and recent landslides (a year or so old) have little to no vegetation. The material moved during the landslide forms hummocks, which are lumpy features on a hillside, and the ‘hummocky topography’ can persist for graded timescales. Canyons cut in latest graded time have very steep sides, which in some instances are vertical cliffs. Conversely, older land forms typically constitute smooth and rolling topography.
Landslide scars are indiscernible unless they are deep seated, and the material that was moved during the slide will form hummocky topography (Kraus and Middleton, 2010).

The reason for the marked difference in the appearance of old and new topography is erosion. The longer a feature is exposed on the surface, the more time water and other elements have to weather and wear down the sharp corners and steep sides of the landscape (Clark et. al, 2005).
What is a relict landscape?

A relict landscape is a relatively old landscape surrounded by a relatively young landscape. While these relationships do exist, they are rare. For this type of relict topography to form, relatively recent and significant base-level fall must have occurred. There is only a short time span in which both landscape types can coexist. The recently sculpted landscape must have had several hundred if not thousand years to establish itself, but not enough time to overwrite the geologically old landscape. Once both topographies exist, it is only a matter of time before the geologically recent landscape destroys the gentler sloping relict landscape (Clark et. al, 2007).

The processes of geomorphologic mapping

Aerial photography and stereoscopy

Mapping features on a landscape begins with laboratory work consisting of rendering the interpretation of air photos on topographic maps. The first step in several studies (Garcia et al. 2003, He et al. 2003, Guzzetti et al. 2008) was mapping air-photo interpretations on topographic base maps. This is performed with the intention of taking a preliminary map of landscape features into the field. This type of mapping uses a stereoscope to project the landscape in three dimensions. Figure 3 was generated through interpretation of aerial photographs using stereoscope imaging (Guzzetti et al. 2008). Even large maps like the map created by Guzzetti are completed using this process. Although this process can be time consuming, the ability to see landscapes in three dimensions greatly assists the identification of features on a map.

Field mapping

In order to verify if the features seen in air photos are present in the field, researchers create a separate map of features using only field techniques. Sometimes air photos are dated,
and new features may exist that weren’t there at the time of the air photograph was taken. Other
times, the way the photo was taken can give the illusion of a feature, but this feature does not
actually exist in the field. Figure 3 used field mapping to collect data onto topographic maps of
the area (Guzzetti et al. 2008). For instance, the pink, maroon, and dark blue layers over the
existing geologic map show individual landslides and debris flows (Cardinali et al. 2001). Figure
4 also used field mapping to complete a map of debris flows that were first mapped using air
photos.

**Digital mapping**

The final step in making a map of landscape features that can be widely distributed and used to
compliment other research, is to translate map data into a digital model. Mapping software, like
Geographical Information Systems (GIS), is used to digitally recreate the map and find correlations between for example, rock type and landslides, and also to publish and easily share data with other researchers. Digital mapping also facilitates interpreting data, such as showing the extent and risk of landslides (Figure 4).

Scientific contributions from mapping

**Relict landscapes**

In the context of fluvial geomorphology, relict landscapes are surfaces that have not been affected by local stream incision. Stream incision happens when the base level of a stream is lowered, giving the stream more power to cut into a landscape. A stream’s base level can be altered when a surface is uplifted or when sea level drops. We study the genesis of relict landscapes via mapping.
Through surficial geologic mapping, many contributions have been made to the study of relict landscapes and landslides. Mapping a relict surface can yield much information about the history of an area. In Van Balen et al. (2000), a reconstruction of a relict surface was prepared to create a sediment budget for part of Western Europe. The original surface had been incised, and by reconstructing the relict surface and comparing the two surfaces, they were able to calculate the total amount of sediment lost. They then calculated the amount of sediment deposited into the stream system and into the ocean. Finally, by calculating the sediment volume found in stream terraces and plotting this eroded volume versus time, they were able to correlate erosion rate with incision history. In another paper by Garcia et al. (2003), a map of a relict landscape composed of stream terraces was also used to help date terraces and determine how they were formed.

Landslides

A map of landslides can provide information pertinent to stream terrace formation. Stream terraces are influenced by the amount of sediment that flows into a stream. A mass influx of debris can cause a stream aggradation, and can lead to stream terrace formation or obfuscation of older terraces via burial.

Maps of landslides can be adapted into landslide susceptibility maps which are critical for engineering safe buildings. By using Fig. 1 and examining the distribution of landslides, it was determined that landslides in the Upper Tiber River Basin in Italy occur most often on 5-20 degree dipslopes between 400-700 feet in elevation (Guzzetti et al. 2008). Using a GIS based map of debris flows in Xiaojiang Basin, China, it was determined that the middle reaches of the basin are the most susceptible to debris flows (He et al. 2003). These and other studies like it have a major influence on where homes and roads are built.
Conclusions

The objectives of this literature review are to show that surface uplift occurred in and around the Bitter Creek Wildlife Refuge, and to demonstrate how geomorphologic problems can be addressed through mapping techniques such as air photo interpretation, field mapping, and digitization of surficial-geologic map data.

Active plate-boundary tectonism has caused surface uplift of the Carrizo Plain/Elkhorn Plateau area, and the Bitter Creek Wildlife Refuge. This uplift causes the base level fall necessary to create a modern, incised landscape surrounding a geologically old or relict landscape.

Mapping is crucial to the study of geomorphology. In order to deduce the significant processes influencing landscape development in an area, or to deduce a landscape evolution history, preliminary mapping must be completed using air photo interpretation and topographic maps. These maps must then be checked and redrawn upon analysis in the field. Finally, a digital version of a map must be created to interpret, distribute, and publish any findings that have been made. The accuracy of these maps is also highly important, as many other fields of study use geomorphologic maps in their own research. With a mastery of mapmaking, a geomorphologist can make great contributions to the scientific world, like a Quaternary-time history of stream incision for an area, or a landslide susceptibility map.
Chapter 3

Key Factors and Variables

The key factor in creating a map of relict landscapes and landslides is how specifically one can identify these features. For the relict landscape, we searched for drastic changes in slope close to drainages. There can be problems in areas far away from the San Andreas fault trace, where elevation decreases and meets the valley – At this point it becomes difficult to define where the relict landscape ends. Landslides were identified by crescent shaped scars in a mountainside or hummocky topography. It is possible that subtle landslides were missed during the mapping process.

Scope

- Study area is limited to drainage networks within the Bitter Creek National Wildlife Refuge and a few surrounding drainage networks.
- Air photo mapping was completed using one set of air photos.
- Field study was limited by the area accessible by car, number of personnel mapping. And the allotted time on the Refuge.
- Data collected using air photo interpretation, field mapping, and Geographical Information Systems (GIS).

Objective Statement/Statement of Hypothesis

We mapped relict landscapes and landslides in the Bitter Creek National Wildlife Refuge and surrounding area. Studies by Cardinali et. al. (2001) and He et. al. (2003), indicate that it is useful to know what elevation landslides most often occur, and what rock type they most often
occur. GIS analysis was used to determine the elevation and most common rock type where landslides occur.

Assumptions

- Relict landscapes are identifiable by an abrupt change in slope from gentle to relatively steep.
- The big bend in the San Andreas Fault leads to compression and uplift (Argus and Gordon, 2001; Spotila et al, 2007).
- Uplift leads to base level fall and incision in a landscape.
- Stereoscopes show an accurate representation of a landscape.

Materials and Methods

Materials

- Stereoscope
- Air Photos
- Topographic Maps: the base maps for air photo and field mapping are the U.S. Geological Survey Santiago Creek 7.5 min. Quadrangle, and the Ballinger Canyon 7.5 min. Quadrangle.
- GIS software

Methods

Aerial Photos

Air photos of Taft County were used in the lab to complete preliminary research before going into the field. To use the air photos, two consecutive photos must be lined up side by side so that they are facing the same direction in numerical order. These photos are then placed under a stereoscope, which is a photo viewing device with a series of lenses and mirrors, and lined up
so that when looked through the stereoscope the landmarks are aligned. When this is set up correctly, the geologic features will look three dimensional and to scale with all other features in the photo (Moore, 2000).

Aerial photographs were taken of the Taft and Kern County between the years of 1989 and 1994. These photos are taken so that they overlap 60% in the path of the flight line and 30% between each row. This overlap allows for the use of a stereoscope to translate the photo to a 3-D representation of the landscape. Air-photo interpretation data provides preliminary information regarding the location of the relict surfaces, and field accessibility.

Field mapping

When creating a field map, work in the lab is the most important first step. Looking at topographic maps and air photos to find what features are accessible and relevant to the study will greatly improve efficiency and decrease the human error when locating yourself in the field. When an appropriate amount of lab data was gathered, the data generated in the lab was checked through field work and mapping. Additionally, sites that were difficult to assess using air photos were investigated in the field.

Laboratory work

The final step of our research was creating a digital map. We used Geographic Information Systems (GIS) to create our digital map. First, we obtained digital maps of the USGS Santiago Creek and Ballinger Canyon 7.5 minute quadrangles. We loaded these maps into GIS, along with data showing the boundaries of California counties. Using the editor feature in GIS, we transferred to GIS our data from the hardcopy of the field map and created georeferenced polygons that show the locations and extents of every landslide and the entire
relict surface. We classified each landslide by age (Recent, Old, and Ancient) and whether or not we were able to confirm these features in the field (Confirmed or Unconfirmed). We also classified each relict surface by whether or not we were able to confirm these features in the field (Confirmed or Unconfirmed).

**Methods of analyzing data or interpreting results**

Further analysis was performed using calculations in GIS. By adding fields in the attribute table for area, GIS calculated the area of each landslide and relict surface polygon. GIS summarization of the data revealed the total area of the relict surface, and the total area of every mapped landslide.

To find the average elevation of each landslide, a GIS “field” for elevation was created and each landslide was assigned an average elevation based on its position on the hillslope. A GIS analytical tool was used to calculate the average elevation of all the landslides.

To find the rock type where landslides most often occur, a digital version of a geologic map of the Bitter Creek National Wildlife Refuge was first located. Using the map, and creating a GIS “field” for rock type in the landslide attribute table, each landslide was assigned a certain rock type. A GIS analytical tool was used to calculate how many landslides occur in a certain rock type.
Chapter 4

Results

Overall statistics

The area of the Bitter Creek National Wildlife Refuge is 58.94 km². The total area of the relict landscapes mapped in and around the Refuge is 74.81 km². There were 131 landslides mapped, and their total area combined is 5.03 km².

Observations

Key observations were made that may lead to further research. The first was the appearance of stair-step like features in Bitter Creek. They were observed on the southern side of the largest ancient landslide depicted on the map. This may be an indication of stream terrace creation in the past.

Calcic soils were exposed alongside a road maintained by Bitter Creek National Wildlife Refuge, in the area of the refuge southwest of Cerro Noroeste Road. The calcic horizon was in place on what we classified as the relict landscape. Pedogenic calcrete development can be used to estimate the age of the relict landscape, and giving a maximum age for the start of incision (Candy et al. 2003).

Analysis

Landslides are significant in the Bitter Creek National Wildlife Refuge, as they occur with relative frequency here compared to other places. This can be attributed to the movement of the San Andreas Fault, the weak rock types present here, and relatively recent stream incision. In
order to determine a landslide risk factor, several elements of landslide failure must be considered. Rock type, slope aspect, vegetation type, soil type, and climate are all variables that contribute to cause landslides and their after effects.

Average elevation of landslides

Although elevation is not a factor in landslide development, knowing where they tend to occur is useful in land planning. It could even indicate a pattern beneath the surface in terms of rock type or faulting, as weaker rocks are expected to fail more often. The average elevation of landslides included 128 of the 131 landslides. The three landslides excluded are classified as
ancient landslides; therefore, their elevation may have changed since they occurred. The average elevation of the landslides is 3014 feet (Figure 6).

Rock type where landslides most often occur

Fundamentally, less competent rock types are expected to fail most often. The two most common rock types for failure are the sandstone member of the Temblor Formation (Tts) and black siliceous shale of the Monterey Formation (Tmb) (Kellogg, et al, 2008) (Figure 7). These are both relatively weak rock types. It is likely that the nearby San Andreas Fault can create zones of crushed rock that are also incompetent, but identifying these zones of crushed rock is beyond the scope of this study.

Other Factors

Although rock type and movement are the foundations of landslide development, there are other variables. Aspect can change overlying soil properties. In the Northern hemisphere, northeast facing slopes tend to hold more water, have deeper soils, and more vegetation than southwest-facing slopes. Vegetation is most important here, as roots hold on to soil and to each other, preventing mass wasting events from occurring. Any vegetation helps, but larger vegetation is typically better at holding soil. Type of vegetation is governed by climate, which also determines the amount of precipitation an area receives, and runoff from precipitation can start landslides.

In the Bitter Creek National Wildlife Refuge, the types of factors that influence landslides are a Mediterranean climate and short bush and grass vegetation. We can assume these are constant throughout the refuge. Aspect may have played an important role in this study, as we
Figure 6: Landslide elevation distribution, from GIS analysis. Elevation in feet is on the X-axis, number of landslides is on the Y-axis.

<table>
<thead>
<tr>
<th>Rock Type</th>
<th>Rock Name</th>
<th>Age</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>Monterey Formation - Black Siliceous Shale</td>
<td>Tmb</td>
<td>Upper-Lower Miocene</td>
<td></td>
</tr>
<tr>
<td>Temblor Formation - Sandstone Member</td>
<td>Tts</td>
<td>Lower Miocene/Upper Oligocene</td>
<td></td>
</tr>
<tr>
<td>Old Alluvium, locally deformed</td>
<td>QTa</td>
<td>Pleistocene/late Pliocene?</td>
<td></td>
</tr>
<tr>
<td>Bitterwater Creek Shale</td>
<td>Tbw</td>
<td>Upper Miocene</td>
<td></td>
</tr>
<tr>
<td>Conglomerate, sandstone, and shale member of Simmler Formation</td>
<td>Tsc</td>
<td>Oligocene?</td>
<td></td>
</tr>
<tr>
<td>Tulare Formation</td>
<td>QTt</td>
<td>Pleistocene/Pliocene</td>
<td></td>
</tr>
<tr>
<td>Apache Canyon Granite</td>
<td>Kga</td>
<td>Cretaceous?</td>
<td></td>
</tr>
<tr>
<td>Caliente Formation, undivided</td>
<td>Tc</td>
<td>Upper Miocene</td>
<td></td>
</tr>
<tr>
<td>Landslide Deposit</td>
<td>Qls</td>
<td>Holocene/late Pleistocene</td>
<td></td>
</tr>
<tr>
<td>Pattiway Formation</td>
<td>Tp</td>
<td>Paleocene</td>
<td></td>
</tr>
<tr>
<td>Temblor Formation</td>
<td>Tt</td>
<td>Lower Miocene/Upper Oligocene</td>
<td></td>
</tr>
<tr>
<td>Younger (inactive) Alluvium</td>
<td>Qya</td>
<td>Holocene/late Pleistocene</td>
<td></td>
</tr>
</tbody>
</table>

Figure 7: Table showing the distribution of rock types and how many landslides occurred on each in the Bitter Creek National Wildlife Refuge (Kellogg et al. 2008).

You would expect to see more landslides on southwest facing slopes: soil is thinner and vegetation is reduced, but this analysis is beyond the scope of this study.

Error Analysis

Error in elevation analysis can come from the fact that a disproportionate amount of landslides occur along the Bitter Creek. This elevation may not be applicable to the nearby Santiago Creek or Ballinger Canyon, as they may be higher or lower in elevation. Error can also
come from classifying landslides themselves. Many landslides at one elevation could have been one event, but mapped as different events. This would create a spike in the number of landslides at this elevation, and make the average slightly lower. This same problem can also affect the results of the rock type analysis. As stated before, zones of crushed rock may be more influential in landslide genesis than strictly rock type, but deducing where these zones are is beyond the scope of our study.

**Discussion**

The map-based method is an excellent way to survey a landscape in a place where not much is known. By mapping what is seen in the field, you begin collecting information and observing the study area. The map based approach is highly effective in that you obtain an introduction to the area, and produce a hard copy of your findings. The shortcomings of this method however, is that a trip to the field requires careful planning, as there is a risk of leaving the field without significant findings because a crucial observation is overlooked. You must use your time wisely and remain focused on exploring the area.

Creating a map of known features is the goal, but the other goal is to raise questions about the landscape. In this study, we produced several questions:

- Are stair-like features on the ancient landslide deposit evidence of ancient stream terracing?

- How much sediment has incision discharged from the Bitter Creek National Wildlife Refuge?

- What can calcic soils reveal about the age of the relict landscape?
• What subsurface properties are contributing to landslide genesis?

We now have clues as to what can be investigated in the Bitter Creek National Wildlife Refuge, making our reconnaissance study successful.
Chapter 5

Conclusion

Our study of the Bitter Creek National Wildlife refuge succeeded in completing reconnaissance: Air photos were used to create a hard copy map of features to investigate in the field. Observations in the field were made, raising questions about specific properties of the Bitter Creek National Wildlife Refuge that influence landslide susceptibility. After completing a map in the field, GIS was used to create a digital version of the map for analysis. Analysis of landslides in the area revealed that they most often occur at a common elevation, and in a certain rock type.
References


California Department of Forestry and Fire Protection, California Department of Fish and Game. 2009. 1:24,000 County Boundaries (California). www.atlas.ca.gov.


