

RE-EXAMINING SHORELINE ELEVATIONS AT ANCIENT LAKE
CHEWAUCAN IN CENTRAL OREGON, USA

by

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A THESIS

Presented to the Department of Geography

in partial fulfillment of the requirements

for the degree of Bachelor of Science and Departmental Honors

June 2019

AN ABSTRACT OF THE THESIS OF

Brianna N Kendrick for Departmental Honors in Geography presented on June 10, 2019.

Title: Re-examining Shoreline Elevations at Ancient Lake Chewaucan in Central Oregon, USA

Approved: _____

Pat McDowell

The Chewaucan Basin in Eastern Oregon provides a unique environment for pluvial lake geomorphology research, as lake oscillations in the last 30,000 years have formed shoreline features that wrap around the basin. Over the last century, multiple scholars have published works describing shorelines of the ancient lakes using various elevation data collection methods, including USGS topographic maps, Digital Elevation Models, and survey equipment. By revisiting accessible shoreline sites and measuring elevations using a TopCon RTK GPS I found that Topographic Maps vary between 0.2 and 11 meters off and Digital Elevation Models, which are developed using the historical topographic maps, vary in accuracy between 2.5 and 12.25 meters, when compared to the TopCon measurements. These discrepancies reveal that historical elevation data needs to be evaluated when studying the geomorphology and other issues in the basin.

ACKNOWLEDGEMENTS

I would like to sincerely thank everyone who has helped me out along the way, through field work assistance, editing all of the drafts and posters, getting me to conferences, moral support, and being a friend during the stressful times. Thank you to the University of Oregon Geography Department for the advice, support, and equipment, special shout out to Dan Gavin, Leslie McLees, Lisa Knox, and Nyease Somerset. Thank you to the UO Undergraduate Research Opportunity Program and Karl Reasoner for funding my fieldwork, this couldn't have happened without the support from your mini grant. Thank you to my wonderful adviser, Pat McDowell, this has been a labor of love for both of us. Chantel Saban, thank you for getting me into geography and Pat Luther, thank you for helping me get out into the world, both in the field and conferences. Thank you to Haden Kingrey and Richard-Patrick Cromwell for being such great friends and working out in the cold, snowy Chewaucan Basin for the sake of science. Thank you to Dennis Jenkins for inspiring me to get out to Eastern Oregon for the first time almost three years ago, going to that field school was one of the best decisions I have ever made. Thank you to my wonderful mom, Sara Kendrick, for shaping me into a scientist and teaching me to never stop learning. And last but not least, thank you Joshua Rollo. You have been the best, most supportive partner through this process. Thank you for listening to me try to figure the data out, sort through my writing nonsense, and complain about general research stress. Thank you for making me dinner when I was stuck to my computer and always helping me out, even when you were bogged down with your own projects. I am eternally grateful for everyone who helped me with this project, thank you for your love, patience, and support.

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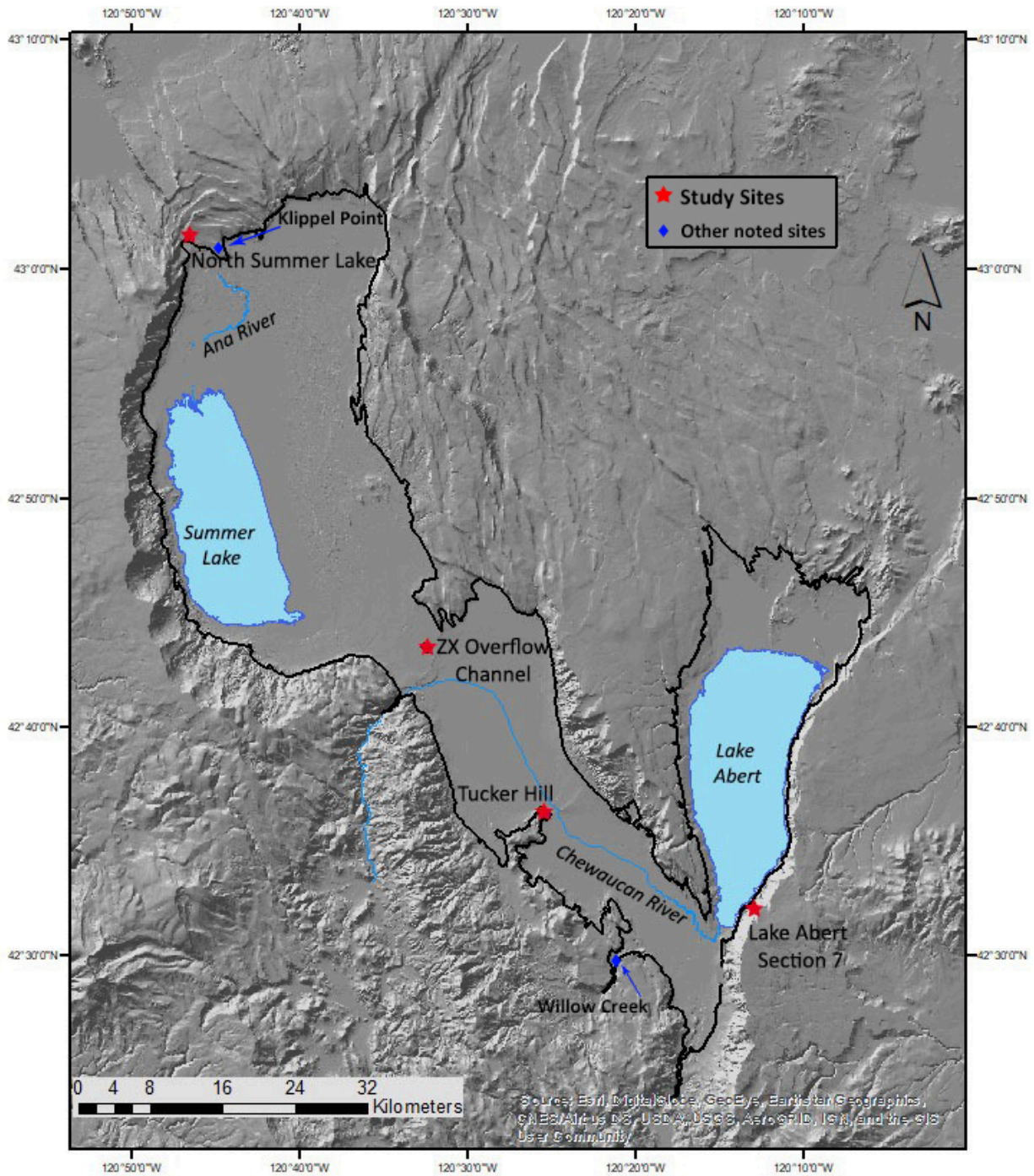


Figure 1 Study Sites and Other Notable Sites

Introduction

The Chewaucan Basin in Eastern Oregon has been the subject of numerous studies and notable archaeological finds, including the oldest known human remains in North America. While currently a high desert, 20kya it held Lake Chewaucan, a vast lake covering 1,244km² and up to 114 meters deep. As people were entering the basin, about 15kya, Lake Chewaucan was receding from its most recent high stand and provided inhabitants with freshwater resources. 14kya, there was a period of lake level rise and ZX Lake overflowed into receding Winter Lake. This event could have happened multiple times, but was most likely brief. Following this, climate warmed and the lakes continued to recede, exposing the dry basin floor. Today, Summer Lake and Lake Abert are the remnants of what used to be Lake Chewaucan. Due to the archaeological significance of the region, it remains imperative to build on the previous lake-level research and develop the most accurate shore-line map possible in the hopes of supporting further archaeological and paleo-environmental research in the Great Basin.

This project re-examines previous lake-levels studies through the use of an RTK GPS system to obtain more accurate elevations from previously identified lake shore sites and then maps those elevations using current satellite imagery and DEM data. Shoreline profile elevations obtained from different data sources are then compared to discuss accuracy and potential errors within the data in order to find the best method of collecting elevation data.

Introduction to the Study Area

The Chewaucan Basin is a fault-bounded basin with closed drainage in central Oregon, USA. It stretches 63 km north to south and occupies 1244 sq. km (Fig. 1). According to (MacArthur, 1973) the name “Chewaucan” derives its origin from the Klamath Indians’ word for wild potato (tchua) and a suffix denoting locality (keni). The small town of Paisley, Oregon is located in the center of the basin and is the only town in the basin. Today the basin has a cold semi-arid climate with

precipitation ranging from eight inches in the lowlands to 30 inches in the highlands (Orr & Orr, 2014).

The regional geology consists of broad plateaus formed of Miocene/Pliocene basalt, andesite and rhyolite flows, overlying tuffs and Quaternary surface deposits (Orr & Orr, 2014). Tucker Hill, a rhyolite hill, erupted about 7.4 million years ago (Orr & Orr, 2014). Starting about 15 million years ago, the plateaus were displaced (cut) by north-south trending normal faults that produced escarpments and defined the Chewaucan Basin (Figure 2,3). The most prominent escarpments are Abert Rim, on the east side of Lake Abert (760 m tall), and Winter Rim on the west side of Summer Lake (900 m tall). There are three sub-basins within Chewaucan Basin today, the Summer Lake basin, Chewaucan marshes, and the Lake Abert basin (Fig. 1). Today

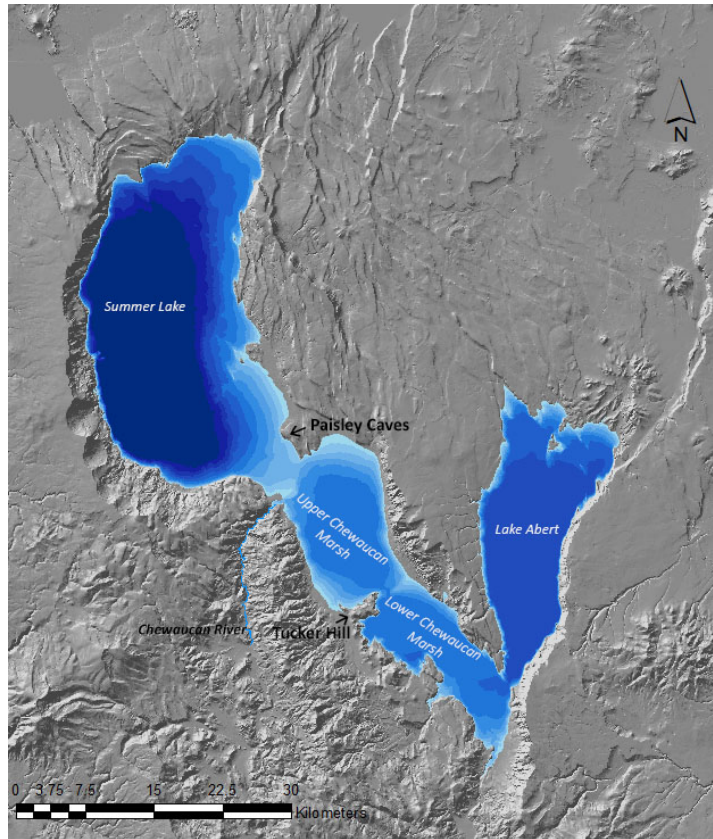


Figure 2 Ancient Lake Chewaucan at 1367 meters, the highest dated shoreline.

the uplands west of the Summer Lake basin lie at about 2000-2100 m elevation, those east of Abert lie at about 1500m and the plateau between the two basins is at about 1500-1700m. The floors of Summer Lake basin, Chewaucan marshes, and Abert basin lie at about 1250-1300 m.

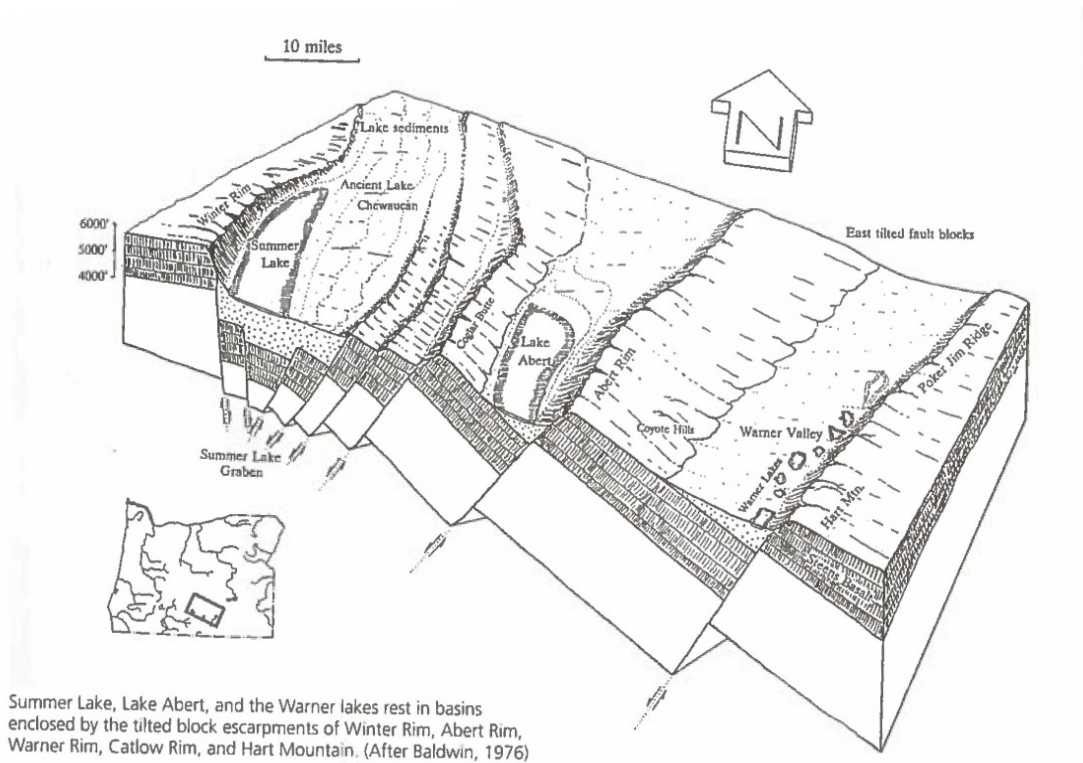


Figure 3 Orr 2014

Only one significant river feeds the Chewaucan basin today, the Chewaucan River. The Chewaucan River is 53 miles (85 km) long and begins in the east drainage of Gearhart Mountain in the nearby Fremont-Winema National Forest, and then enters the Chewaucan Basin at Paisley. It flows through the Upper and Lower Chewaucan Marshes until it enters the south end of Lake Abert. Crooked Creek, Willow Creek and Moss Creek are three smaller tributaries that flow from the south and join the Chewaucan River in the Chewaucan marshes. They are perennial creeks fed by snowmelt from the uplands. Naturally the Chewaucan River would put two thirds of its flow into the lake, but diversion of water for irrigation and drought have resulted in barely any

water making it to Lake Abert during the irrigation season (Rosner, 2016). Summer Lake's main input is the Ana River, a spring fed river on the north end of the basin. These are substantial springs that flow at about 80-90 cfs (Oregon Department of Fish and Wildlife, 2007). These springs are fed by subsurface flow from the Fort Rock Basin Aquifer southward into the Summer Lake Basin (Freidel 1993). The modern Summer Lake is almost dry in the summer, with an average depth around 1 foot (0.03 m), with a maximum depth of 5 feet (1.5 m). Other smaller springs are found along Winter Rim, Abert Rim and the north end of the Lake Abert basin. There are no other perennial water sources in the Chewaucan basin.

The Chewaucan Marshes can be divided into upper and lower marsh sections. The Upper Marsh is a lowland that is about ten miles long and up to seven miles wide. Most of the Upper Chewaucan Marsh was originally a tule-cattail swamp that has since been drained for farmland, and has an elevation of 1313.69m at the northwest end and 1310.64m where the Chewaucan River leaves the southeast corner and enters the lower half of the marshes (Allison 1982). The southeast end of the Upper Chewaucan Marsh is confined by Tucker Hill, a NE-SW rhyolite hill formed by Miocene/ Pliocene volcanic eruptions (Orr & Orr, 2014)The Narrows to the east of Tucker Hill mark the border between the Upper and Lower Marshes.

The Lower Chewaucan Marsh is ten miles long and two and a half to five miles wide. The current marsh has been ditched extensively for drainage and the Chewaucan River has been channelized. The marsh slopes from about 1310.64m on the northwest end to 1305.46m in the middle, and 1307.59m near the southeast end. Due to the dry conditions, the lake flat has undergone deflation by the wind. This has formed sand dunes about four miles long on the northeast side of the basin (Allison 1982).

Previous Lake Level Research

Researchers have used a variety of methods to reconstruct fluctuations of paleolake Chewaucan, and to determine elevations of shorelines. Radiocarbon dates on organic samples from beach deposits are associated with timing of that specific lake level. The published radiocarbon dates and their context are in Table 1. Beginning in 1939 Ira Allison, a geomorphologist from Oregon State University, then Oregon State College, started to visit the basin and map shorelines. He presented the data at Geological Society of America meetings and supported archaeologists in the region. Once radiocarbon dating became available, Allison headed back out to the basin in 1979 to collect shells and other samples to date. These trips would have most likely used topographic maps produced in 1966 for elevation data. Allison's complete study of Paleolake Chewaucan, including shoreline dates and elevations, was published in 1982, titled "Geology of Pluvial Lake Chewaucan, Lake County, Oregon".

The 1966 topographic maps were also used by Dorothy Friedel, who continued research into the shorelines as her PhD dissertation in 1993 (Friedel, 1993). She acquired radiocarbon dates of shells and tufa (calcium carbonate coating on near shore rocks). Joseph Liccardi also did his PhD dissertation in the Chewaucan and focused on cuts exposing lake sediment history. He identified new shoreline sites, obtained additional radiocarbon dates, and determined shoreline elevations by surveying from National Geodetic Survey benchmarks (Liccardi, 2001). Short articles describing these pieces of research and updates were published in the 2001 Friends of the Pleistocene Ninth Annual Pacific Northwest Cell Field Trip (Negrini, Robert M. Pezzopane & Badger, 2001).

To examine potential tectonic deformation in the Chewaucan Basin, Silvio Pezzopane measured shoreline elevations at various sites using a total station theodolite, with NGS

benchmarks as elevation control, and mapped that information on the USGS 10-meter DEM. Additionally, he used aerial photos to locate, survey, and correlate prominent shoreline features. Preliminary analysis of the Chewaucan shoreline elevations indicate there may be as much as 3 to 6 m (~10 to 20 ft) of vertical difference in the elevations of Lake Abert shorelines relative to shorelines in other parts of the basin. This research was part of his 1993 dissertation on active faults in Central Oregon and later featured in the Friends of the Pleistocene publication. In this update, he published a figure illustrating the lake level oscillations (Figure 4). He recognizes the potential error in the Digital Elevation Model by adding “The digital elevation model is from U.S. Geological Survey 7.5 minute topographic maps having 10 m vertical accuracy. Some anomalous color and textural patterns are apparent at boundaries of the quadrangles where errors in the digital elevations occur.” to the caption of the figure (Negrini, Robert M. Pezzopane & Badger, 2001)

In addition to these publications, other various researchers have studied lake level history through cores, paleomagnetic dating, and examining sediments exposed in incised stream cuts. Articles with summaries and figures of this work can be found in the Friends of the Pleistocene Field Trip Guide (Negrini, Robert M. Pezzopane & Badger, 2001).

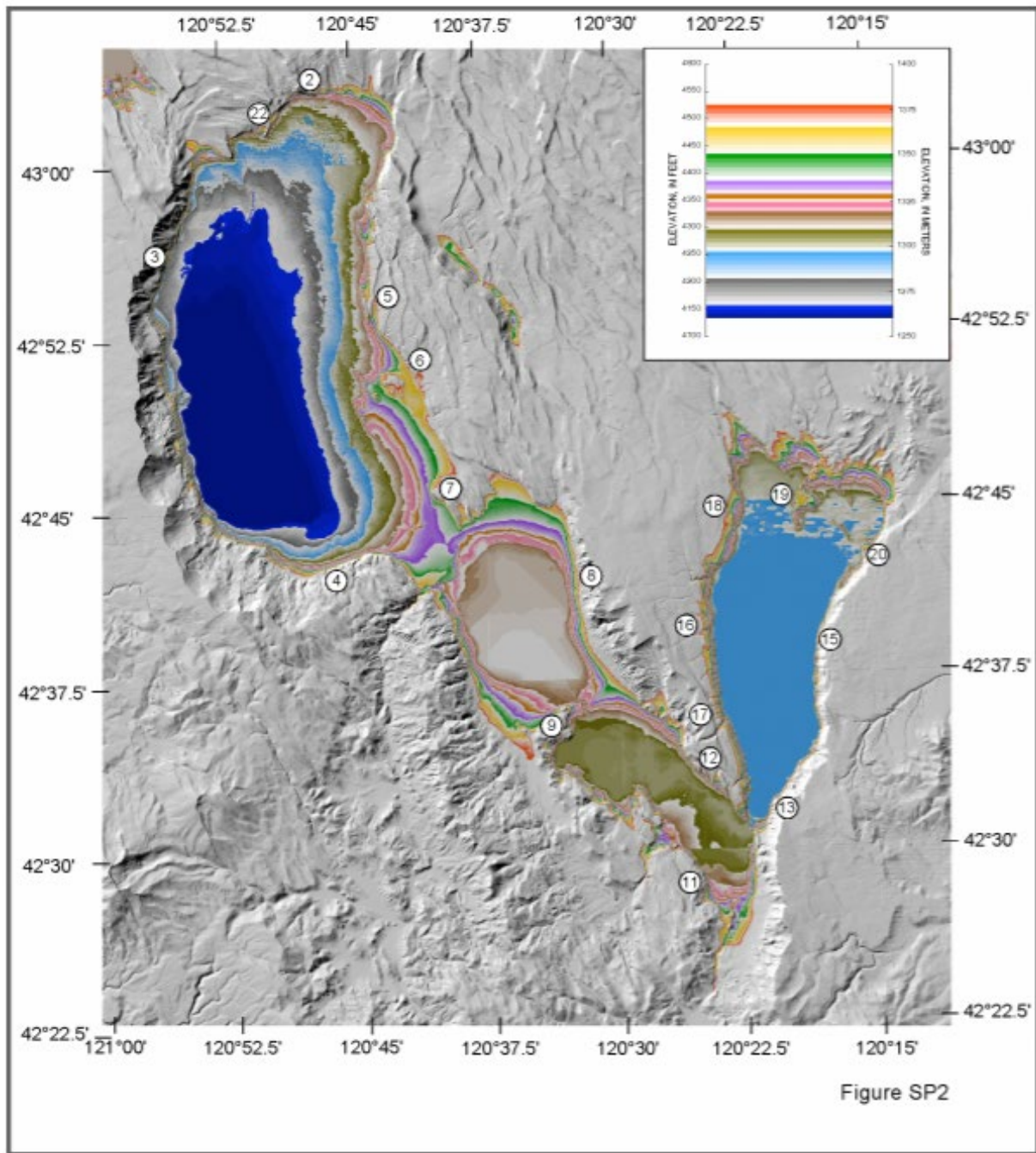


Figure 4 Shaded digital elevation model of the elevations of significant Lake Chewaucan shoreline features and the locations of shoreline profile sites. Color gradients are used to indicate the elevations of significant lake and shoreline features recognized by Allison (1984), Pezzopane (1993), and later unpublished work by S. Pezzopane. (Negrini, Robert M. Pezzopane & Badger, 2001)

Archaeological Significance

The Chewaucan Basin has been the subject of numerous archaeological finds over the last decade, most notably the desiccated human feces found at the Paisley Caves that date to 14,500 years ago (Jenkins 2013). These are the oldest known human remains in North America and support the Kelp Highway Hypothesis, a proposed method of the peopling of the Americas by sea (Erlandson et al., 2007). Additionally, the Chewaucan Basin is home to various boulder villages, rock art, and textiles with dates throughout the Holocene (Oetting, 1990). These archaeological sites were left by the Klamath and Paiute peoples. The Klamath inhabited the basin at least 9,000 years ago and the Paiute moved into the basin from the south around 1,000 years ago. These peoples used the lakes and marshes within the Chewaucan Basin for food, water, and other resources, including tule reeds for basketry and boats (Oetting, 1990). Understanding the size, shorelines, and fluctuations of the lake(s) is necessary to understand the resources available to these peoples and where undiscovered archaeological sites may be located.

Lake Level History

The period 30,000 to about 10,000 was a time of major lake level fluctuations that would have dramatically changed the lake shore and nearshore aquatic environments, and therefore food resources available for human use. The highest shoreline of Lake Chewaucan is at 1378m, and the shallow modern lakes in the two lobes of the basin are at or below about 1265m (Summer Lake) and 1295m (Lake Abert). From about 28,000 to 21,000 yr BP (including the last glacial maximum), the lake was at a low elevation of about 1280m, with some fluctuations up to 1290m (Negrini & Davis, 1992). The lake rose up to its maximum elevation between about 20,000 and 16,000 yr BP (Negrini & Davis, 1992). By 15,940cal yr BP, the lake had dropped below the 1367m shoreline, the Paisley Caves were occupied by humans, and duck bones were deposited in the basal stratum of Paisley Caves (Jenkins et al., 2013).

As Lake Chewaucan continued to drop, below 1337m it split into two separate bodies of water, Winter Lake (where modern Summer Lake is located) and ZX Lake (in the southern and eastern lobes of the basin). The divide between the two bodies of water was the Paisley fan-delta, built by the Chewaucan River near the modern town of Paisley. As the lake continued to drop, tufa deposits formed on Klippel Point, at the north end of the Summer Lake Basin, at 1310m (14,700cal yr BP and 14,390cal yr BP), suggesting a low but stable lake for at least a few hundred years (Friedel, 2001). Within a few hundred years after the period of tufa formation, the ZX Lake rose to 1337m and spilled into the lower Winter Lake, cutting an overflow channel across the fan-delta. Winter Lake rose, at least briefly, to 1321m. The ZX spillover event took place around 13,762cal yr BP (Licciardi, 2001). Sediment in the spillover channel can be described as loosely consolidated silts and sands, so forming the channel would not have taken more than a few hydrologic events.

After the spillover event, the lake receded rapidly, dropping 35 meters in about 200 years (1310m at 13,501cal yr BP and 1307m at 13,390cal yr BP) (Liccardi, 2001). Little is known about the lakes in the Holocene until the Mazama eruption 7,600cal yr BP, when tephra fell on top of dunes, small lakes, and wetlands (Hansen, 1947). Figure 5 shows the dated lake level fluctuations and the locations of the dated materials, with data from Table 1.

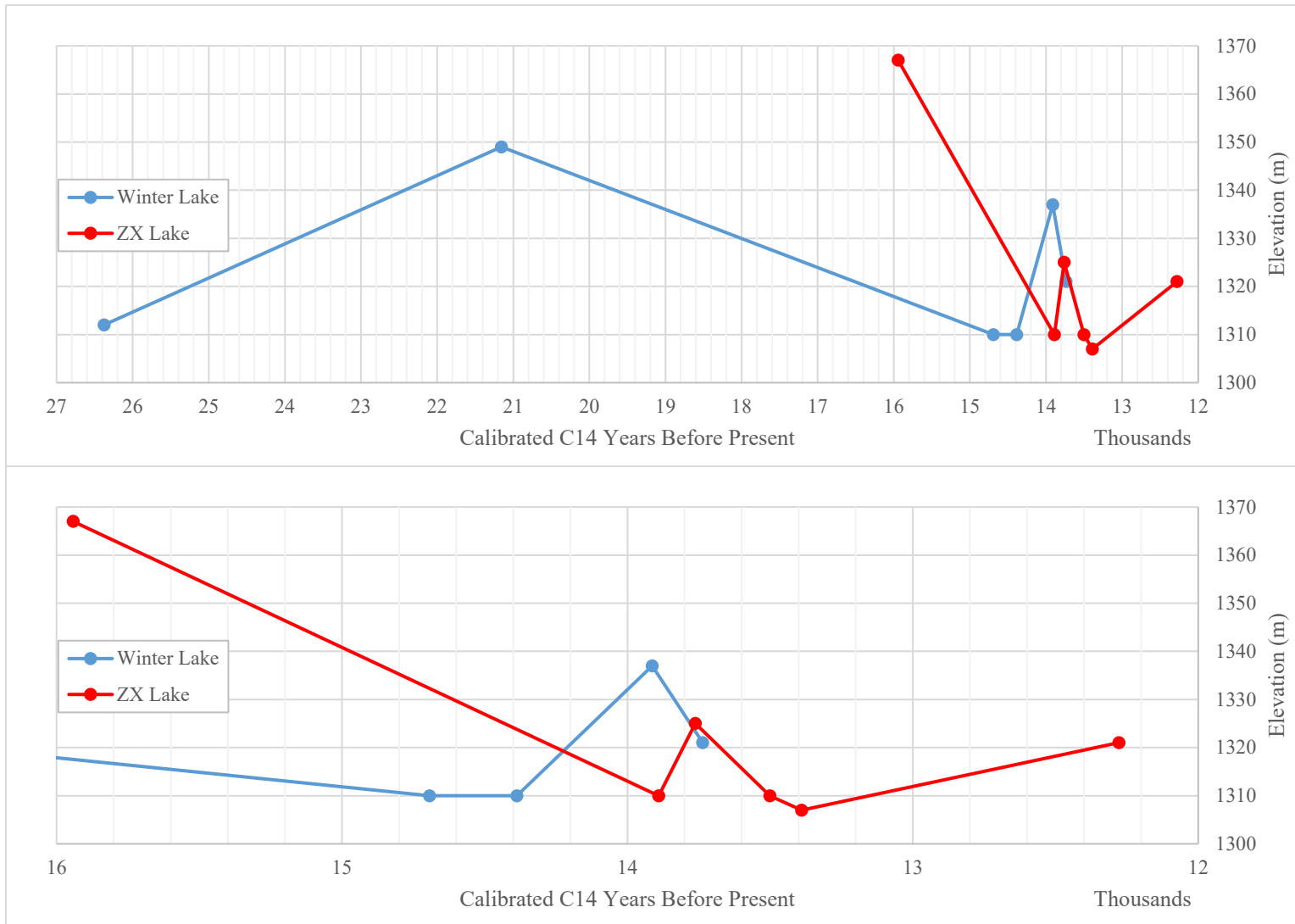


Figure 5 Top: Entire record of published shoreline feature dates and elevations. Bottom: Last 16,000 years of dates and elevations. Data from Table 1.

Approximate Elevation (m)	Approximate Elevation (ft)	Context	Dated Material	14C Age	2 σ Calibrated Age	Sample ID	Reference(s)	Latitude	Longitude	Feature	Method
1321	4333.99	Shoreline	Shell	12,170±115	12278	AA20142	Freidel (2001)	42.59013	-120.47286	Tucker Hill	Topo maps and aerial photos
1307	4288.06	Shoreline	Shell	11,560±120	13390	7EG	Licciardi (2001)	42.5351	-120.228	East Lake Abert	Jacob staff and clinometer
1310	4297.9	Shoreline	Shell	11,670±90	13501	6AV	Licciardi (2001)	42.599	-120.1845	East Lake Abert	Jacob staff and clinometer
1321	4333.99	Nearshore	Tufa	11,910±100	13736	AA25322	Freidel (2001)	43.0082	-120.74	Klippel Point	Topo maps and aerial photos
1325	4347.11	Pluvial Delta	Shell	11,930±90	13762	4F	Licciardi (2001)	42.5129	-120.3296	Willow Creek	Jacob staff and clinometer
1310	4297.9	Shoreline	Shell	12,030±90	13890	7FG	Licciardi (2001)	42.5351	-120.228	East Lake Abert	Jacob staff and clinometer
1337	4386.48	Nearshore	Tufa	12,050±130	13913	AA25323	Freidel (2001)	43.0082	-120.74	Klippel Point	Topo maps and aerial photos
1310	4297.9	Nearshore	Tufa	12,340±90	14387	AA25320	Freidel (2001)	43.0082	-120.74	Klippel Point	Topo maps and aerial photos
1310	4297.9	Nearshore	Tufa	12,495±90	14693	AA25321	Freidel (2001)	43.0082	-120.74	Klippel Point	Topo maps and aerial photos
1367	4484.91	Shoreline	Bone	13,260±60	15942	Beta-229782;	Jenkins et al. (2013)	42.76159	-120.55334	Paisley Caves	Topo maps and aerial photos
1349	4425.85	Shoreline	Shell	17,500±300	21155	I-11, 177	Allison (1982)	42.838	-120.577	Tenmile Ridge East Sun	Topo maps and aerial photos
1312	4304.46	Shoreline	Shell	22080±660	26376	I-11, 136	Allison (1982)	43.006	-120.77	Near Ana Reservoir	Topo maps and aerial photos
1377	4517.72	Shoreline					Allison (1982)	42.59013	-120.47286	Tucker Hill	Topo maps and aerial photos

Table 1 Published Lake Shoreline Feature Dates

Site Descriptions

Study site locations were chosen based on previous research, proximity to NGS (National Geodetic Survey) benchmarks, and the ability to track shorelines in a variety of places around the Chewaucan Basin. Figure 1 shows the four locations studied.

Lake Abert

I looked at Liccardi's (2001) section 7 on the east side of Lake Abert. This is an 8.0m high road-cut exposure through the outer edge of a wave formed terrace. The exposure is easily accessible, as it is just a few meters off of Highway 395. The exposure (Figure 6, Table 2) shows a shallow-water deposit (Qps) at the bottom, followed by a lake level rise (QSS), followed by a lake level fall and beach formation (Qg1), followed by a rise at about 11,500 (Qs), followed by a second fall and beach formation (Qg2), after which the site was exposed subaerially. Liccardi's elevations were acquired using a Jacob's staff and clinometer and measured from a nearby NGS benchmark. These tools are commonly used for survey in remote areas, as they are light and easily portable. A thorough description of the use of a Jacob's staff and clinometer can be found in the methods section of this report. The samples dated by Liccardi refer to a lake-level that is close to 1310m. At this elevation, ZX Lake would have encompassed modern Lake Abert and the Lower Chewaucan Marsh.

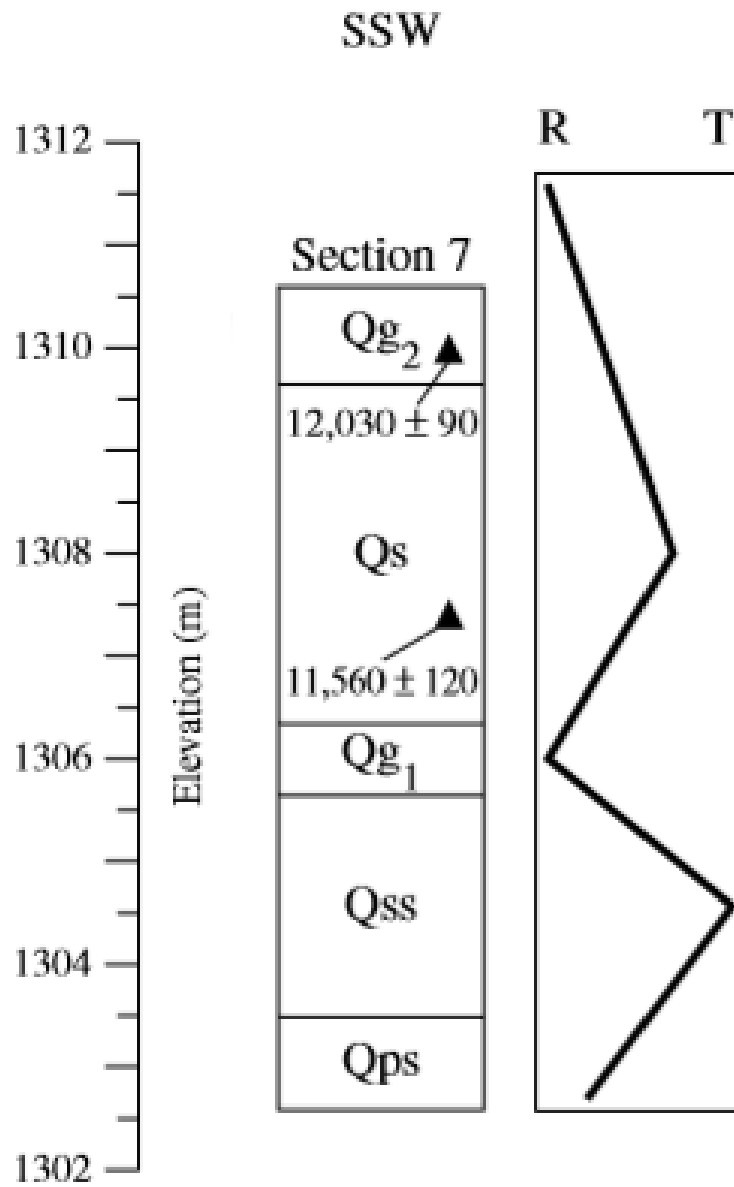


Figure 6 From Liccardi 2001 "Measured stratigraphic section 7, with a schematic curve of regressive (R) and transgressive (T) lake cycles. Black triangles mark the location of radiocarbon-dated gastropods. Ages are in 14C yr BP (uncalibrated)."

Table 2 Section 7 Stratigraphic Units and Descriptions (Liccardi 2001)

Section 7 Unit	Top Elevation (m)	Description	Interpretation
Qg2	1310.7	Matrix-supported for the lowermost 0.4 m, and grades upward into clast-supported and increasingly angular material. The matrix-supported basal portion of the gravel contains a sand matrix with occasional fossils.	Beach gravel that grades upward into colluvium-dominated material.
Qs	1309.75	3.3 m thick unit dominated by well-rounded, fine to medium-grained sand with occasional pebbles	Nearshore sand facies
Qg1	1306.45	0.7 m thick unit of well-rounded, clast-supported boulders, cobbles and pebbles	Beach gravel facies
Qss	1305.75	2.15 m of thinly bedded silt and fine sand with sparse pebbles	Offshore sediment that records a lake transgression. The occasional pebbles in unit Qss may be drop stones that were carried offshore by lake ice.
Qps	1303.5	The basal 0.9 m of section 7 consists of rounded to subrounded medium to fine sand interbedded with imbricated pebbly strata and occasional cobbles.	Wave-worked nearshore or beach environment with a northward longshore current, as indicated by the pebble imbrication. The poorly sorted character of unit Qps suggests storm-influenced episodic deposition of coarser and finer strata.

Tucker Hill

Tucker Hill is a rhyolite hill on the western side of the basin, formed by Miocene/Pliocene volcanic eruptions (Orr & Orr, 2014). Shorelines at Tucker Hill were initially described by Allison in 1982 and revisited by Friedel 2001. Allison identified shoreline features on the west end of the hill at 1332m, 1359m, and 1378m. On the east side, he recorded features at 1366m and 1359m (Figure 7). Allison acquired shoreline elevations using topographic maps. Friedel obtained a radiocarbon date of 12,278 cal BP here on the 1321 m shoreline (Table 1). Radiocarbon dates, additional elevations, and geomorphic information came from gravel pits on the south side of the hill. Fieldwork for this project aimed to visit shorelines around the gravel pits and on the north face of Tucker Hill. This captured multiple shorelines in areas where they are clearly defined on the hillside.

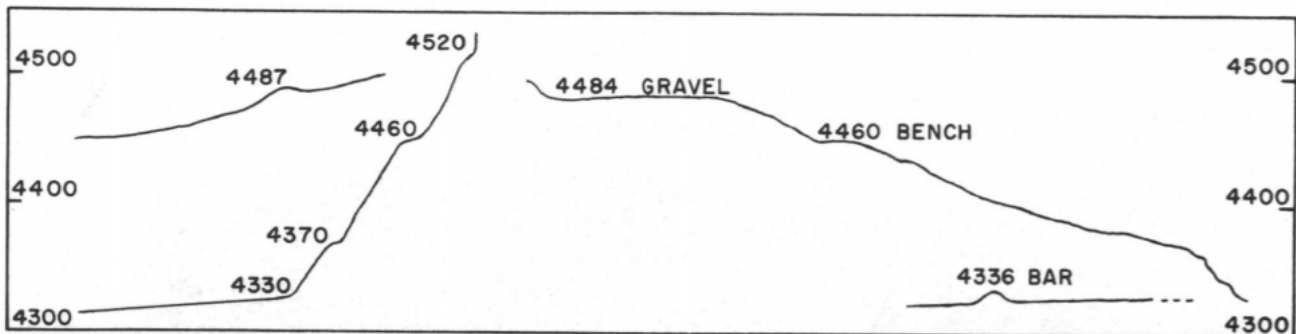


Figure 7 Top: "Wave formed lake-shore terraces on north side of rhyolite hill in Tucker Hill peninsula." Bottom: "Shore profiles showing benches and gravel ridge on north side (left) and east side (right) of Tucker Hill peninsula (vertical exaggeration 5x)." (Allison, 1982) Units in feet

ZX Overflow

As lake levels fell after the last Lake Chewaucan high stand, Winter and ZX lakes separated, and then, there was a reversal (rise) of lake level trends. ZX Lake then rose faster than Winter Lake and overflowed into Winter Lake, probably because of a larger water supply from the Chewaucan River (Allison, 1982). The ZX Overflow Channel was formed when ZX Lake reached levels above 1,337 meters and spilled over the Paisley fan-delta. The overflow channel had a sinuous course across the Paisley fan sill (Figure 8). As described by Allison, the channel is 100 or more feet wide and generally 10 to 15 feet deep, cut into the sand and pebble gravel deposits of the fan. The upper end of the channel is a slot with its base at approximately 1335.63m. The elevation of the channel intake suggests that initial overflow began at or near 1338m and that the intake was lowered by erosion by as much as 2.4m. Gravel and sand from the channel were deposited as a delta in Winter Lake, mainly below the 1323m lake level (Allison 1982). Based on a date by Liccardi (2001) at Willow Creek, this event occurred at about 13,800 cal yr BP (Table 1). Based on the elevation of the delta deposits, Winter Lake was as much as 15 meters lower than ZX lake at the time of overflow.

North Summer Lake

The north shore of Summer Lake features multiple shorelines covered in rounded beach gravels. While not dated, Allison (1982) described beach ridges at 1377.7m, 1367.03m, and another prominent beach stand at 1330.45m with a lagoon to the north. Additional stratigraphic

evidence of Lake Chewaucan can be seen in the banks of Ana River just beyond the 1330m beach.

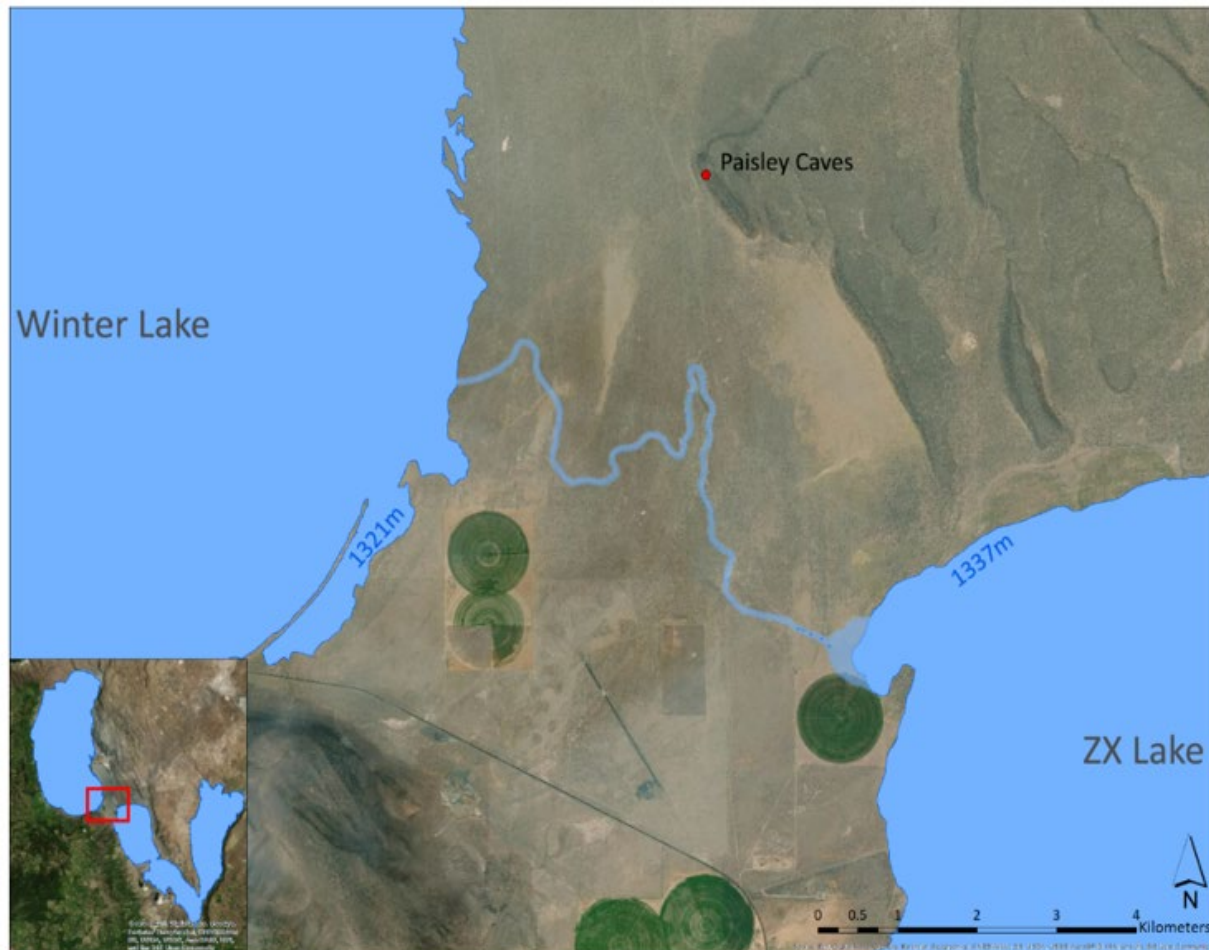


Figure 8 ZX Overflow Channel

Methods

Methods of Acquiring Elevation and Accuracy

Both Allison and Friedel used topographic maps to find elevations of the shoreline features reported in their publications. Topographic maps used for the published research reported on in this thesis include the 1966 Tucker Hill, 1966 Paisley, 1982 Egli Rim, and 1968 Lake Abert South. These maps were produced by the United States Geologic Survey and follow the U.S. National Map Accuracy Standards. These standards were originally set in 1937 and were repeatedly revised. The vertical accuracy standards are as follows, “The vertical accuracy

standard requires that the elevation of 90 percent of all points tested must be correct within half of the contour interval. On a map with a contour interval of 10 feet, the map must correctly show 90 percent of all points tested within 5 feet (1.5 meters) of the actual elevation” (Archuleta et al., 2017). The topographic maps used for this project all have contour intervals of 20 feet, so 90 percent of the points must be within 10 feet (3.33m) of the actual elevation.

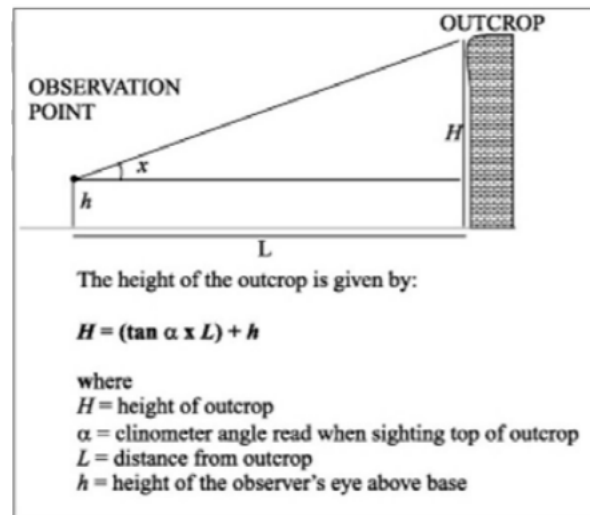


Figure 9 Collecting elevations from a known point using a clinometer (Carey, 2011)

To measure the elevations of shoreline features along Lake Abert, Liccardi measured in reference to nearby benchmarks using a Jacob’s staff and a clinometer. He states that this method is “probably accurate to within one meter” (Liccardi 2001). This method involves starting at a NGS benchmark and using the Jacob’s staff and clinometer to measure points in a stratigraphic section using trigonometry (Figure 9).

Spatial data from field work and published sources was projected on a digital elevation model (DEM). I used the National Elevation Dataset (NED) 1/3 arc-second (approximately 10 meter) resolution tiles stitched together on ArcMap. This dataset is a seamless collection of elevation data for the entire contiguous United States. From the USGS website, “The seamless datasets are created from elevation data that are sourced from multiple technologies, positional

accuracies and collection dates. Although these datasets are being continuously updated as new elevation source is acquired, much of the national coverage is derived from topographic map contours that may be decades old. The spatial metadata for each tile in a seamless DEM layer must be examined to fully determine the source datasets used to create each tile.” (Archuleta et al., 2017). While the USGS provides source metadata for most of their newly generated DEMs, the original or legacy topographic derived DEMs used in this study do not have source data available (Carlson, 2019). To provide users with more vertical accuracy information, the NED has been tested by comparing it with the geodetic control points that the National Geodetic Survey uses for gravity and geoid modeling. According to the Gesch 2014, “the overall absolute vertical accuracy expressed as the root mean square error (RMSE) is 1.55 meters.”

In the field, I used a TopCon real time kinetic (RTK) GPS system to acquire elevations of features that have been described by Allison, Friedel, and Liccardi. This system uses multiple satellites (GPS, GLONASS, GALILEO) and ground stations to calculate absolute positions. The G-3 base receiver either auto-positions itself using these satellites, or uses the coordinates of a NGS benchmark. Both methods were used during my fieldwork. The auto-position method is presumably less accurate than using a benchmark, but the accuracy level of auto-positioning is not explicitly known. Elevations of unknown points are taken using the G-3 rover receiver. A Topcon FC-500 data collector and Topcon Magnet software were used. Accuracy of the points depends on the number and geometry of satellites available. Dilution of Precision (DOP) is a statistic that represents the accuracy of an unknown point that is collected. The more the satellites in view and the better spread of those satellites, the lower the DOP number will be and

the higher positioning accuracy will be. The accuracy of each point is reported as vertical root mean squared error (VRMS) (TopCon, 2006).



Figure 10 TopCon Set Up at Lake Abert, March 2019

Field work methods

In September 2018, my team and I went to the Chewaucan Basin for the first field work phase of my thesis. Using a TopCon RTK GPS system, with G-3 receivers, we recorded elevations of shoreline features in two locations, on a north-facing slope of Tucker Hill near the gravel pits described by Friedel (1993), and at the ZX overflow channel described by Allison (1982). At Tucker Hill, this process involved using the auto-position feature on the TopCon to find our precise location, recording elevations, taking pictures, and notes while we walked down the slope of the shoreline feature. Auto-positioning was also used at the ZX overflow channel, where we recorded the cross-section of the channel and observed and recorded the sediment and geomorphology of the site.

In March 2019, my team and I headed back out to the basin to visit three more sites. We used NGS benchmarks for the GPS surveying. Photographs and geomorphic descriptions were recorded at every location. At the north end of the Summer Lake Basin, using benchmark PB0599, we recorded elevations on a south facing transect which covered multiple shoreline features. This process was repeated on the north facing slope of Tucker Hill using benchmark NY0756. Additionally, we visited Lake Abert to record elevations at Section 7, described by Liccardi 2001 (Figure 10). At this location, elevations of the section and the shoreline above the section were recorded by the TopCon, using benchmark NY0750. We recorded the upper and lower boundaries of Liccardi's stratigraphic unit Qg₁ identified by Licciardi as a beach gravel at a shoreline.

Data Processing

Elevation data was uploaded to the computer using the FC-500's simple data transfer process. Once in an Excel spreadsheet, field notes were added, and unnecessary data was removed. This revised data was then added to an ArcMap 10.5 document as individual CSV files grouped by site location, exported as shapefiles, and the data layers were added to the map. Each site was analyzed individually, and the elevation data was compared with the data previously collected by past authors and the USGS 10 Minute DEM available in this area.

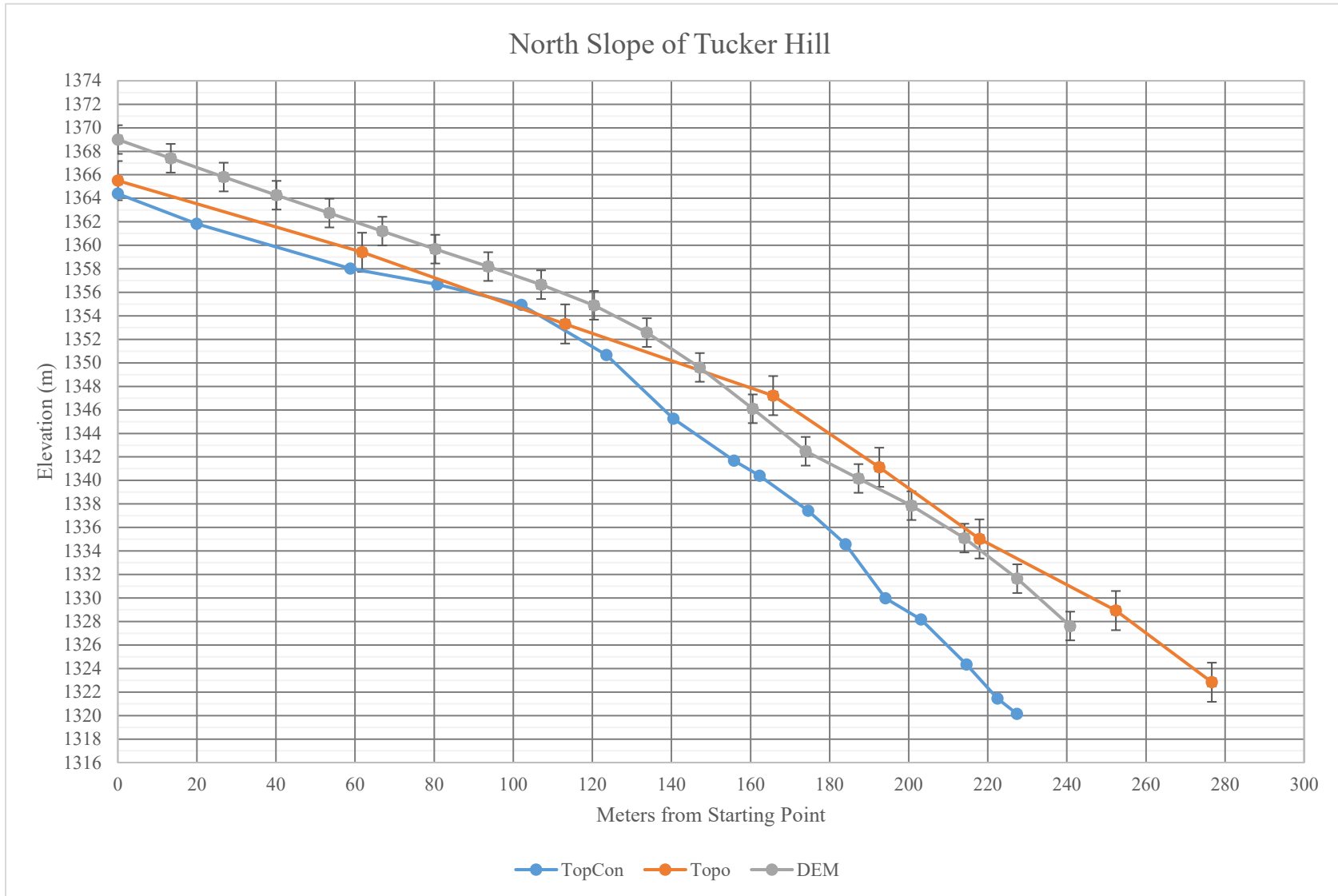
Table 3 Elevation data collection methods and their potential error

Method	Potential Error (m)
TopCon	0.007 - 0.013
Topographic Map	3.33
Digital Elevation Model	1.55
Jacob's staff and Clinometer	±1

Results

Elevations of shoreline profiles were evaluated by plotting points from the three data collection methods and the potential error (Table 3) on an excel spreadsheet. The results from each site will be discussed individually.

Figure 11 North Slope of Tucker Hill Profile using the three elevation collection methods



North Slope of Tucker Hill

The profile evaluated at the north slope of Tucker Hill (Figure 11, 12) shows substantial differences in the elevations obtained by different methods. The TopCon dataset shows greater detail and has the smallest potential error, so the topographic map and DEM profiles will be compared to the TopCon. For the entire transect, the topo map was on average 4.118 meters above the TopCon and the DEM was 5.21 meters above it. From 0 to 100m along the profile the topographic map was on average 1.202m above the TopCon and the DEM was 3.863m above the TopCon. This distance increases from 100 to 220m, where the topo was on average 6.792m above the TopCon and the DEM was 6.446m above.

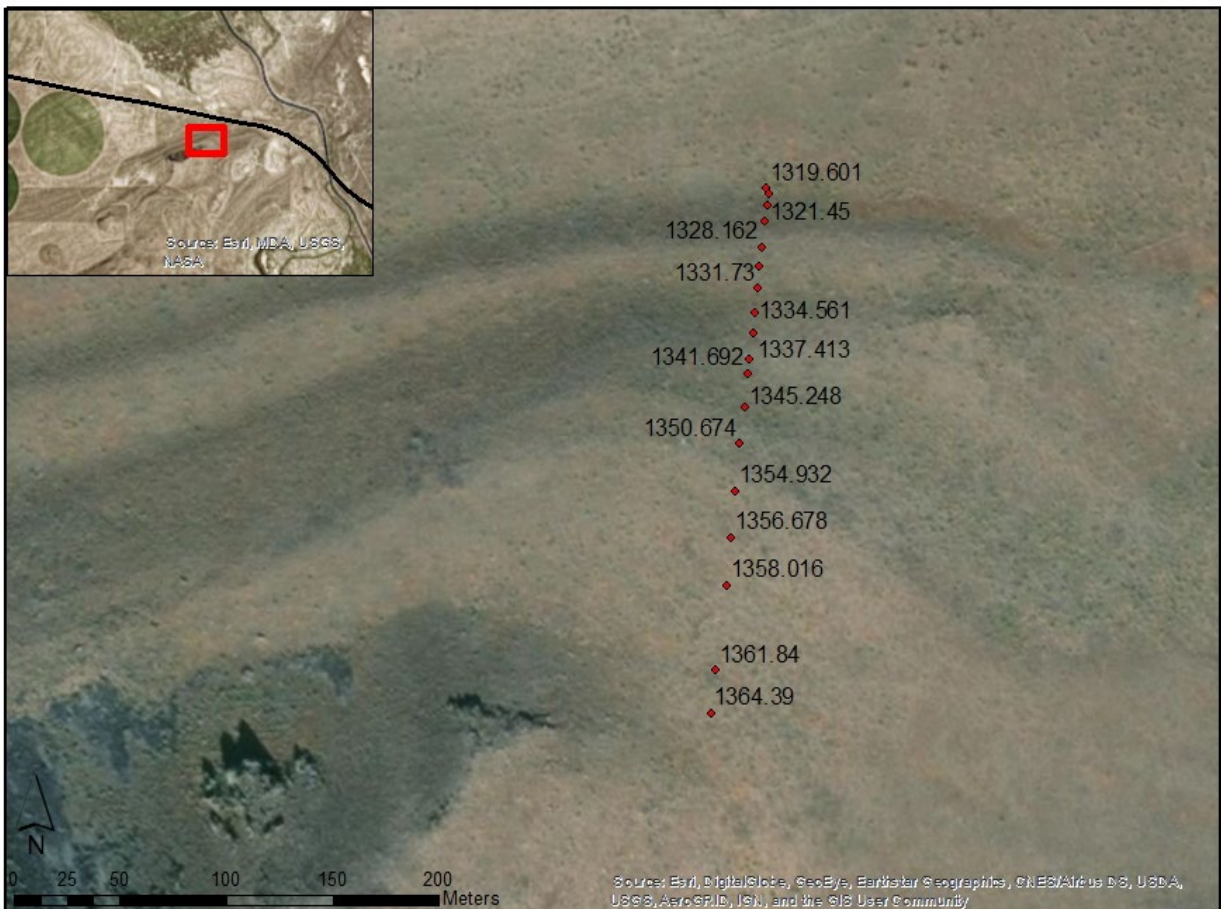


Figure 12 Tucker Hill Transect with elevations of points (m).

Previously described shorelines based on topographic maps elevations are at 1367 meters, 1337 meters, and 1321 meters. Due to signal issues with the TopCon, I was able to start my

transect at 1366 meters and ended at 1320 meters. The shoreline originally described by Allison at 1337 meters is at 1325.8 meters, 210 meters down the transect. This is a difference of 11.2 meters. Additionally, the survey with the TopCon captured a beach crest at 1354.932 meters 100 meters down the transect (Figure 11).

ZX Overflow Channel

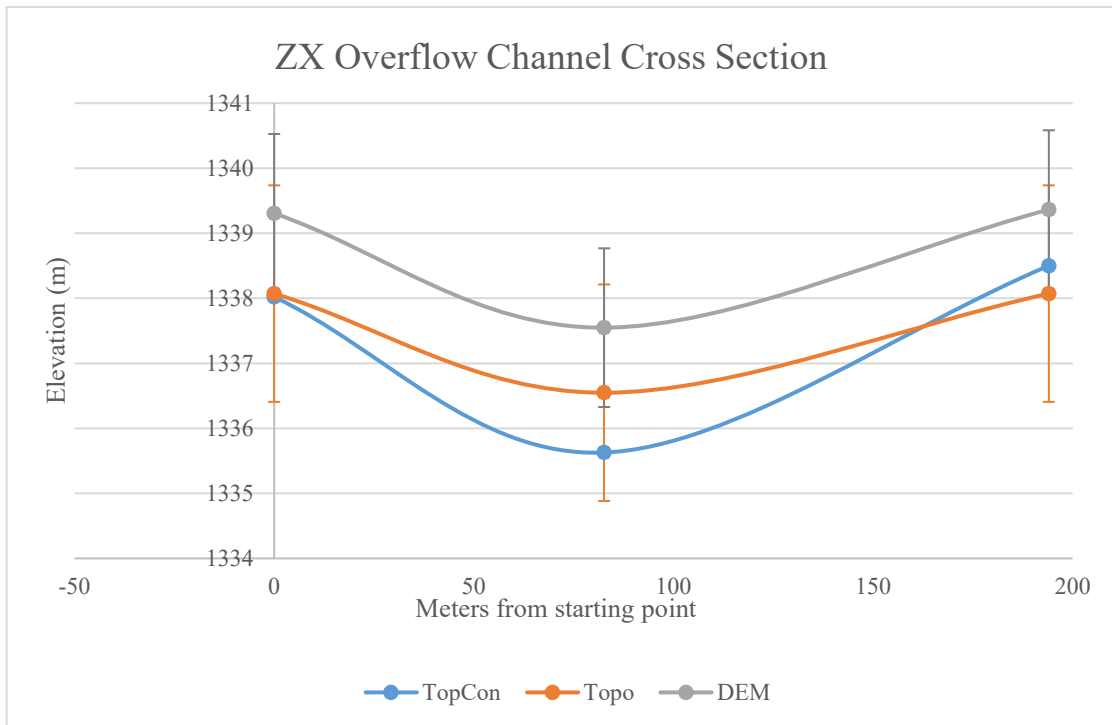


Figure 13 ZX Overflow Cross Section using the three elevation collection methods

At the ZX Overflow Channel, we captured a simple cross section of the channel (Figures 13,14). At the 0-meter mark, the elevations of the TopCon and the topo are the same, but the base of the channel is better represented by the TopCon, which shows greater detail. The elevation of the channel bed is 1 meter below the Topographic map and 2 meters below the DEM. The DEM is consistently about 1 meter above the topographic map.

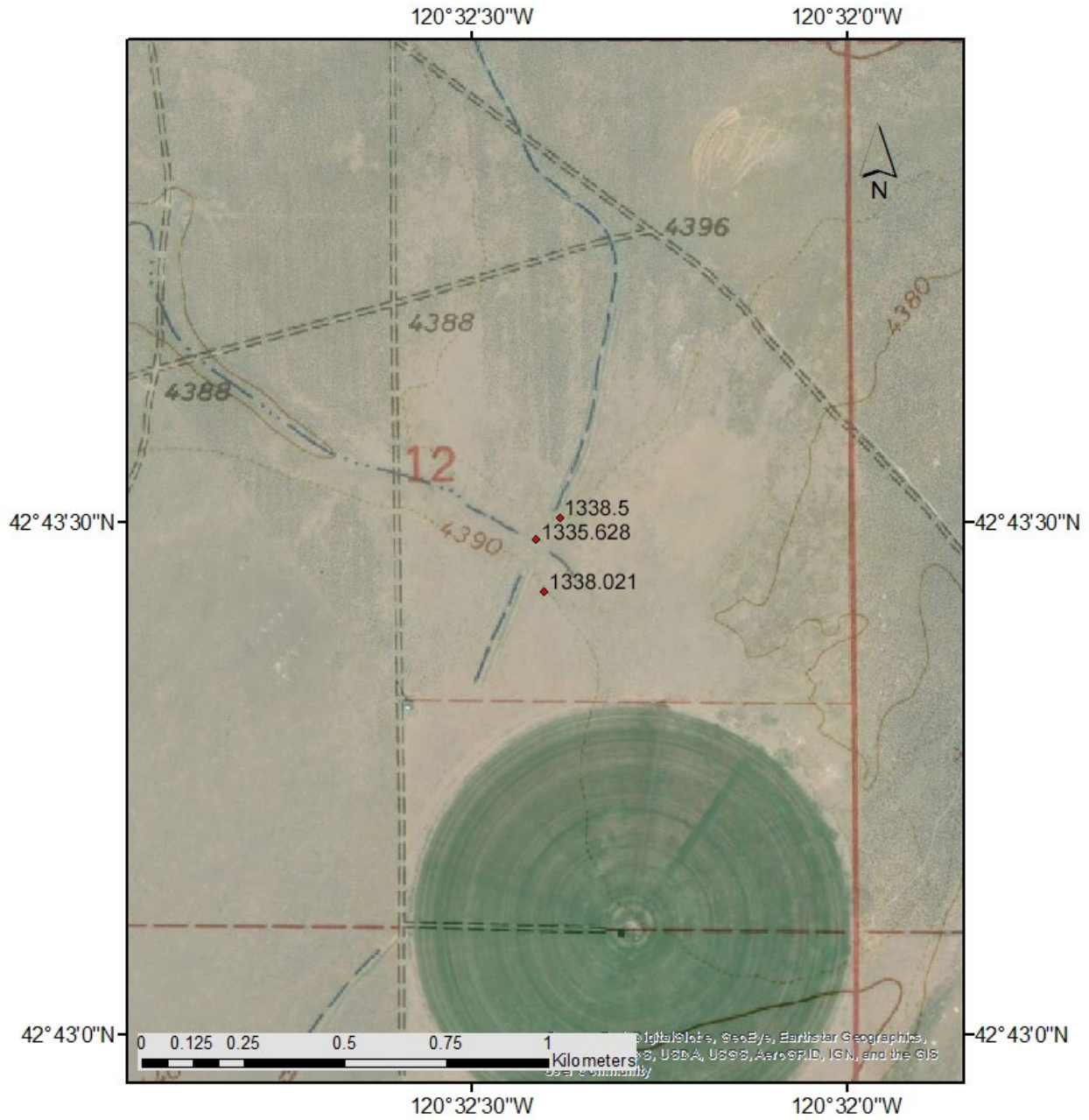


Figure 14 ZX Overflow Cross Section Point Elevations (m)

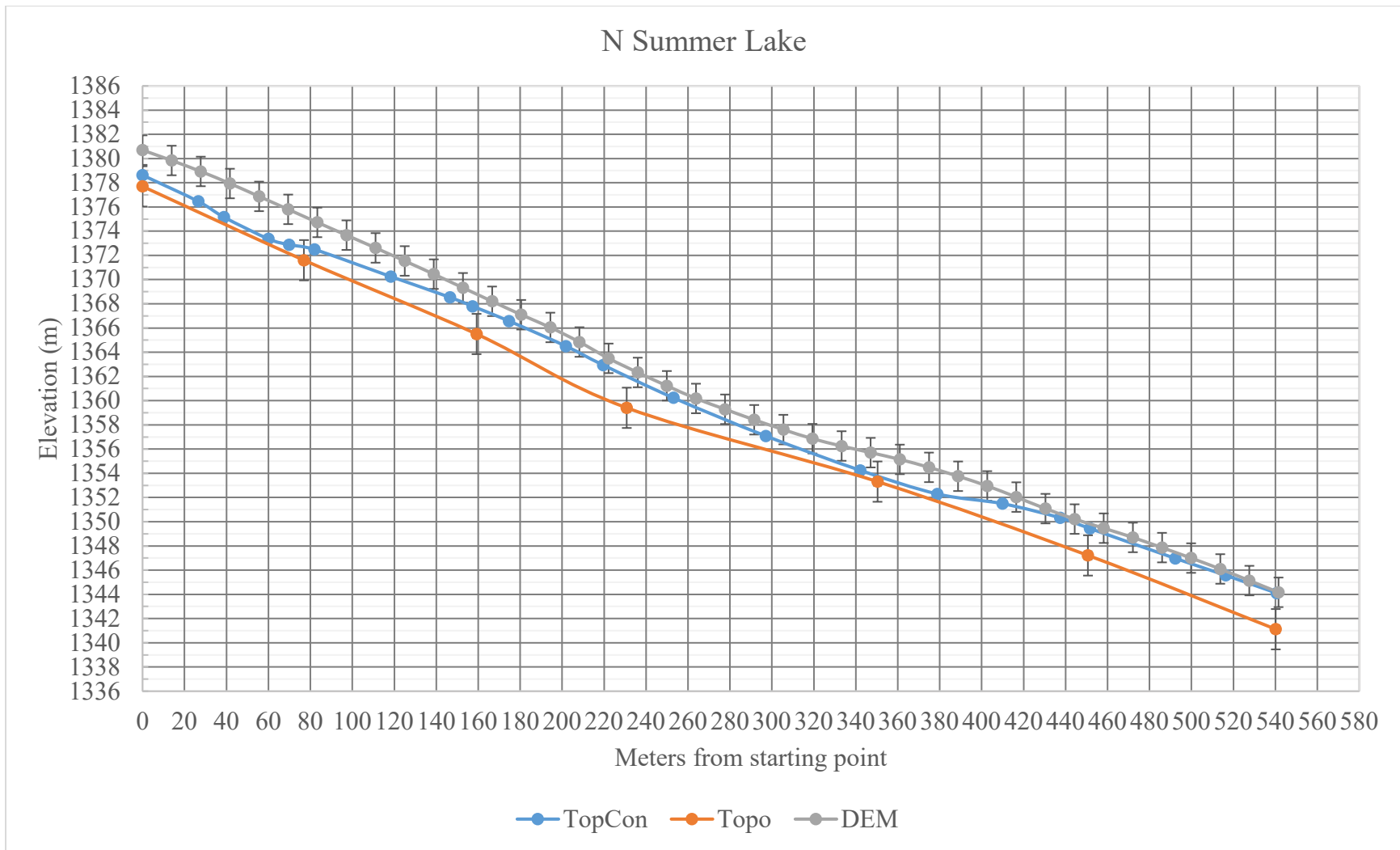


Figure 15 North Summer Lake Elevation Profile

North Summer Lake

The North Summer Lake profile depicts a gentle slope over 540 meters (Figure 15,16). The TopCon shows more fine detail than the other two elevations, but the overall error is not particularly significant. On average, the topographic map is 1.682 meters below the TopCon, while the DEM is 1.316 meters above the TopCon. From 40-60 meters and 320-380 meters, the error between the TopCon and the topo is less than a meter.

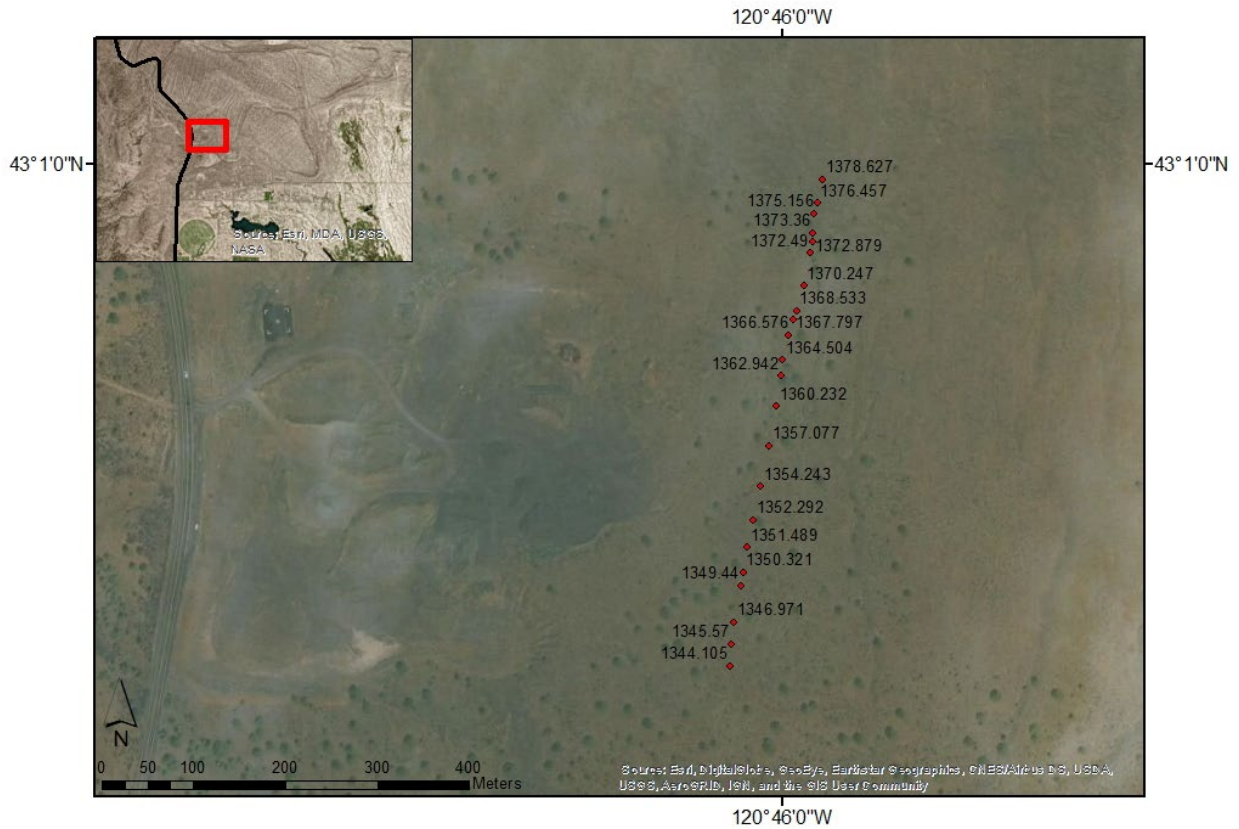


Figure 16 North Summer Lake Elevation Points (m). To the west, a gravel pit and Hwy 31

Lake Abert Profile

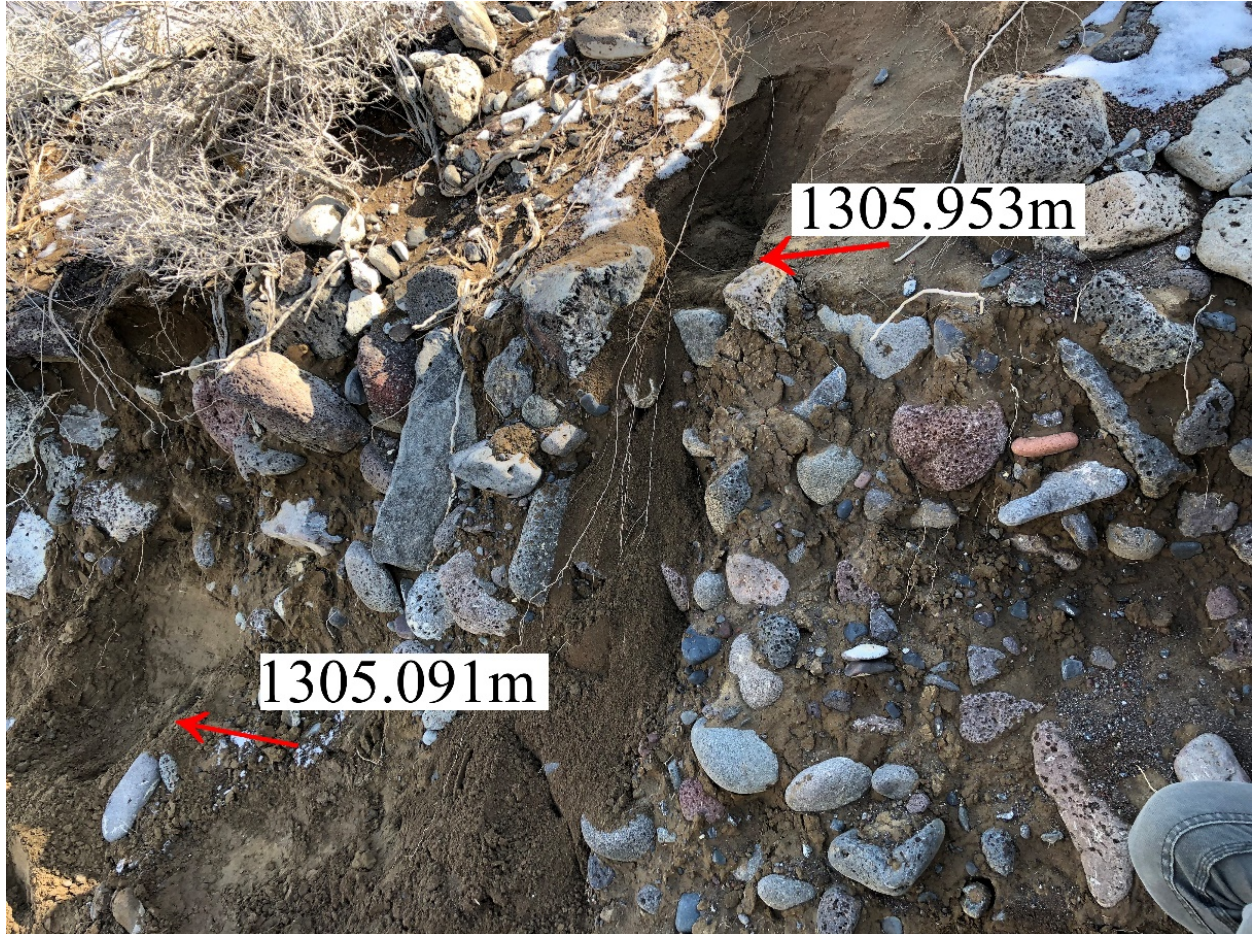


Figure 17 Qg1 boundary elevations recorded with the TopCon.

We visited the Section 7 roadcut and recorded the elevations of the upper and lower boundaries of Qg1. This unit is described as “well-rounded, clast-supported boulders, cobbles and pebbles” interpreted as being beach gravels. This is pictured in Figure 17. Liccardi measured the boundaries at 1305.75m and 1306.45m with the Jacob’s staff and clinometer. These measurements are 0.659m and 0.497m above elevations recorded with the TopCon.

Discussion

Average distances between the topo and DEM measurements and the TopCon measurements are in Table 4. The ZX Overflow and N Summer Lake sites are mostly within the potential errors from the USGS in Table 3. However, the Tucker Hill data shows a substantial distance outside the error range. This increase in error cannot be explained by this study, but potential error due to an increase in slope will be discussed. At all three sites, DEM elevations are higher than topographic map-derived elevations, suggesting some systematic difference in these two sources.

Table 4 Elevation Errors

	Average Distance from TopCon Measurements (m)	
	Topo	DEM
Tucker Hill	4.118	5.21
ZX Overflow	0.181	1.356
N Summer Lake	-1.682	1.316

While the beginning of the N Tucker Hill topo profile in Figure 11 was within the error range, once the slope began to increase, from -0.09 to -0.28, the error increased. The N Summer Lake profile has a slope of -0.06. This suggests that topographic maps and DEMs may capture

accurate elevation data in areas with less slope, but in areas with greater slope, details may be missed by these methods and tools with greater accuracy are necessary to capture the accurate landscape. This is also suggested by the ZX Overflow, where the bottom of the channel is one meter below the elevation from the topographic map.

Lake Abert Section 7 elevations captured using the Jacob's staff and clinometer proved to be within the ± 1 meter error described by Liccardi. The two points measured with the clinometer

were 0.659m and 0.497 meters above the elevations recorded with the TopCon. This suggests that the method used by Liccardi is a reliable option when executed correctly.

Conclusion

Understanding the fluctuations of pluvial lake basins is essential to estimating the surrounding environments and where those who took advantage of these beaches and marshes lived and collected resources. While estimating the elevations of shorelines with topographic maps was adequate and worked for researchers in the past, the advanced technology we have today can be used to refine data and obtain highly accurate elevation measurements. This project has shown that elevations of shoreline features on topographic maps can be off by 11 meters. This difference is significant and demonstrates that we must use modern technology to re-evaluate elevation data. This can be in the form of an advanced GPS, such as the TopCon, drone imagery, or fine satellite elevation data, such as new, high resolution DEMs or LiDAR. In order to properly track the shorelines in the Chewaucan Basin, shoreline features all around the basin need to be studied and a better DEM is needed for mapping the data.

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