CHAPTER 11
YELLOWSTONE LAKE: DYNAMIC SHORELINES, GIS, AND PREDICTING ARCHAEOLOGICAL SITES

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Introduction: Lakeshores and Deformations
During the recent twelve millennia the Yellowstone Lake basin experienced episodic deformation from cross cutting faulting and the aperiodic inflation and deflation of the Yellowstone caldera superposed on long term isostatic rebound from glacial unloading. Intra-caldera deformation can be up to decimeters per decade. These tectonic forces affect the lake basin and displace lake water thereby changing the elevation of the shoreline at the time of deformation. During any particular stand of the lake, wave erosion forms a wave-cut platform and undercuts shoreward cliffs. When the lake stand changes these steps and terraces are abandoned and a new set formed at the new elevation of the lake surface. Thus, a set of geomorphic features resembling the tread and riser system of a staircase records previous lake levels. Subsequent erosion, deposition, and burial by hydrothermal-explosion deposits helps obscure these shorelines. Regardless, a terrace cut at some specific time is available for human occupation after it is abandoned by generally decreasing lake levels.

The ancient shoreline terraces around Yellowstone Lake provide a superb history of postglacial surface deformation. Richmond (1973) first mapped these shorelines but earlier observers also noted them (see history in Locke and Meyer, 1994). Early observation is not a big surprise as the ancient terraces are obvious to any casual observer near the current shores of Yellowstone Lake. Better detail came about when Pelton and Smith (1982) contributed precise geodetic measurements of deformation by resurveying USGS benchmarks along Yellowstone Park’s roads. At a more detailed scale, Meyer and Locke (1986) measured, mapped, and correlated shorelines around the northern part of Yellowstone Lake. More recent work continues to add detail to our knowledge of terrace ages, their formation, and subsequent deformation (e.g. Hofmann and Hendrix 2011).

Meyer and Locke (1994) conducted a thorough survey between 1984 and 1988 that encompassed the entire perimeter of Yellowstone Lake. Using automatic levels, rods, and tapes with centimeter scale resolution of topography they surveyed 230 topographic profiles perpendicular to the shorelines and identified 11 recognizable terraces. Out of these 11 terraces, five were continuous around the lake basin and were used to identify deformation patterns. These were identified as the S3, S4, S5, S7, and S9 shorelines.

In the northern region of the lake the elevation of the S3 was approximately 5.7 m above the modern lake level as derived from a USGS digital elevation model (DEM) which puts the modern lake elevation at 2,356.74 meters above sea level. The S4, S5, S7 and S9 shorelines are approximately at 8.7 m, 12.2 m, 17 m and 23.7 m above lake elevation. In the central portions along the east shore near Clear Creek and Columbine Meadows the paleo-shorelines above DEM elevation were; S3, 1.2 m; S4, 3.7 m; S5, 5.7 m; S7, 13.7 m and S9 at 20.7 m above the modern lake elevation. In the southern region near Beaver Dam Creek paleo-shoreline elevations were recorded at; S3, 2.2 m; S4, 3.7 m; S5, 8.7 m; S7, 15.7 m and S9 at 23.7 m above the modern lake elevation. The ages of these shorelines are interpreted by Locke and Meyer as; S3, 2 ka; S4, 3 ka; S5, 4.5 ka; S7, 9 ka and S9 at 11.5 ka.

Pierce et al. (2007) performed a similar study around the northern shores of the lake and identified six abandoned terraces. Both studies of Meyer and Locke (1994) and Pierce et al. (2007) used carbon-isotopic analysis to date shoreline features. However, Pierce et al. (2007) also incorporated archaeological evidence to better constrain the shoreline chronology. Their new dating and archeological studies showed that the lower shorelines are much older than previously thought in the northern region of Yellowstone Lake. Pierce et al.’s 2007 shoreline sequence starts at the modern shoreline (S1) at 1.9 +/- 0.3 m above their datum and then extends from S2 through S6. S2, the lowest generally recognizable shoreline, was cut at 8 ka and is about 5 meters above datum. S6, cut at approximately 14.4 ka is about 20 meters above their datum. There are some submerged
shorelines, but the lake has been at or near its present level for about 8 thousand years; successively higher shorelines are also older. Of note for our analysis, Locke and Meyer (1994) observed that most shorelines are subhorizontal and the highest, oldest postglacial shorelines are at similar elevations inside and outside of the caldera (± 8 meters at most).

In recent geomorphological studies of the eastern and southern shores, Hofmann and Hendrix (2012) found considerable evidence that substantiates Locke and Meyer’s (1994) shoreline chronology. During their field season surveys in 2010 and 2011, Hofmann and Hendrix (2012) conducted geomorphological field studies on several formational terraces along the eastern and southeastern shores of Yellowstone Lake. During these studies they obtained dates from three carbon samples. The lowest elevation sample, from three to four meters above datum in an abandoned stream channel of Columbine Creek, yielded an age of 2,795 ±55 cal. B.P. About seven meters above datum they recovered a second carbon sample (4,150 ± 80 cal. B.P) above the nearby Clear Creek streambed. Finally, Hofmann and Hendrix (2012) recovered a carbon sample (10,390 ± 150 cal. B.P) 23m above datum in coarse gravels that form of the Alluvium Creek Gilbert-style delta. Though known to be sporadic, the average rise of these terraces is on the order of 2-3 mm/year.

Hofmann and Hendrix (2012) infer from the ages and stratigraphic positions of their carbon samples two periods of differing rates of relative terrace uplift. The first period indicates a rate of uplift of about 2.6m/kyr between 10,390 B.P. and 2,795 B.P. The last period from 2,795 B.P. to modern times shows a decrease in rate to about 1.3m/kyr. While carbon samples were few in number to achieve more accurate interpretations in their shoreline model, the rates of lake level decline are similar to Lock and Meyer’s (1994) interpretation. Hofmann and Hendrix (2012) also note that a Gilbert-style delta near Trail Creek in the Southeast Arm of Yellowstone Lake shares very similar geomorphic characteristics to the Alluvium Creek Gilbert-style delta further north. Thus, they infer that the lake level histories between these two deltas situated in the central and southern regions of the eastern shore were the same and that the abandonment of terraces coincided at the same times and elevations.

This indicates that the shoreline models proposed by Locke and Meyer (1994) and Hofmann and Hendrix (2012) are appropriate for the central and southern regions of the Yellowstone Lake where caldera-related processes are not as high amplitude as at the northern end of the lake. Conversely, the model proposed by Pierce et al. (2007) best reflects the deformational process leading to uplift and tilting of shorelines in the northern regions of Yellowstone Lake. At the north end, subaerial shorelines incur greater deformation due to their close proximity to the Sour Creek resurgent dome which lies just to the northeast of Fishing Bridge. As a result, the northern shorelines exhibit higher amplitude changes in elevation due to cyclic caldera breathing (Christiansen 2002; Pierce et al. 2007). As one proceeds south along the eastern shore the caldera breathing component of deformation is greatly attenuated. Along the central and southern lake shores isostatic and climatic forces dominate the relative uplift of terraces.

Given that Locke and Meyer’s (1994) shoreline models are appropriate as indicated by Hofmann and Hendrix (2012) we use their terrace designations and ages to suggest likely areas for concentrated surface surveys along the eastern and southeastern shores of Yellowstone Lake (Figure 1). Our expectation is that there should be a good correlation between the age of human occupations and the age of ancient wave-cut terraces. Sites of seasonal habitation should be younger than the age of terrace formation. And we should find the oldest most deeply buried sites of occupation on the oldest, highest elevation terraces where water covered soon to be younger terraces. Of course, redistribution of individual artifacts due to erosion and recycling will move older items onto levels that were submerged while the original sites were occupied. We also note that camp sites must be accessible. At higher lake stands some travel paths between the lake shores and wintering grounds for sheep and elk herds are submerged and those sites of potential occupation would be difficult to access. Thus, to predict likely sites of occupation, we seek those that are accessible at the appropriate times, have sufficient level ground for camping, provide nearby access to streams or the lake, and offer adequate provision for security and food supply.
Methods

To predict likely sites of occupation we used the shoreline elevations and ages of Locke and Meyer (1994) as discussed above. To map those shoreline elevations and predict likely sites of human occupation we used 1/3 arc-second USGS digital elevation models (DEM) from the USGS Seamless Server. We do that in three simple steps. First, we assume we can map ancient shorelines around the lake using the previously established terrace designations and elevations. The errors in the shorelines elevations (Locke and Meyer 1994) are generally small relative to the difference between designated shoreline terrace elevations. Second, we determine suitable
camping locales by limiting areas on those terraces to slopes of less than 5%, a slope which yields suitable flat camping for groups. Though 5% would be steep for camping, given 1/3 arc-second DEM, areas of suitable lesser slope may well exist with 5% patches. Third, we consider access to suitable sites as restricted by lake levels at the probable time of occupation. We do this by simulating the backfilling of the lake to the low elevation contour rising to a particular terrace.

We used the Pierce et al. (2007) datum elevation for their work as 2356.48 m since no elevation was given for Lock and Meyer’s (1994) datum at Fishing Bridge. Datum elevations between the two studies must be very similar with an error of ±3 meters given fluctuations in seasonal lake levels and episodic uplift or contraction of caldera breathing. The USGS DEM has the open water of Yellowstone Lake at an elevation of about 2,356.74 meters. This equals Pierce’s datum level of 2,356.48 m plus 0.26 meters which is a reasonable range in variability in lake level due to seasonal lake level fluctuations that have nominal amplitude of one meter depending on annual precipitation.

To accommodate accumulated uncertainties in DEM, tectonics, terrace estimates, and the like we use a generalized model of terraces and their ages and broke the group into three periods: Early, Middle and Late. We also allowed a one meter overlap at the transitions between periods to account for variability in shoreline elevations. The earliest period includes the highest lake shores between 2,369 m to 2,379 m (13 m to 23 m above datum; S7-S9) and reflects the Paleo-Indian cultural period beginning around 12,000 B.P. and ending at 8,000 B.P. The Middle period has lake shore elevations between 2,361 to 2,370 meters (5 to 14 m above datum; S4-S6) comprised of the Middle and Early Archaic periods from 8,000 to 3,000 B.P. The Late Period, with lake shore elevations from 2,356.48 meters to 2,362 meters (0-6 m above datum; S1-S3), spans the last 3,000 years and includes the Late Archaic and Late Prehistoric cultural periods.

Having designated elevation bounds for the three age groups, we used ESRI® ArcMap to calculate and predict potential ancient campsites on lakeshore terraces along the eastern and southeastern shores of Yellowstone Lake. We limited areas of interest to those with sufficiently flat areas for group camping (<5% slope) and predict their ages based on shoreline elevation by binning them into elevations reflecting the Early, Middle and Late periods of lake level history (Figure 2). MYAP field crews investigated the east shores of Yellowstone Lake in the summers of 2010 and 2011; here, we compare those results with the predictions.

Results/Discussion

Our GIS analysis revealed four main areas along the eastern shores with slopes of less than 5% that would seem ideal for hunter-gatherers to exploit (Figure 2). First, the Clear Creek Area, along the northeastern section of the study area, includes two stream drainages (Cub Creek and Clear Creek) flowing westward from the Absaroka Mountain Ranges. The Clear Creek area is comprised of erosional step terraces (Hofmann and Hendrix 2012) that extend eastward a kilometer with the oldest subaerial shorelines further away from the lake and obviously at higher elevations. The second potential habitation area is approximately 2.5 km further south at Meadow Creek and was a small protected harbor until at least 3,000 B.P. after which lake levels dropped enough to expose its surfaces. The third habitable area is further south in the vicinity of Columbine Meadows and the Alluvium Creek Delta and extends approximately 3 km north from Alluvium Creek to 800 meters past the mouth of Columbine Creek. The final area that may reflect habitable living spaces is adjacent to the northern most edge of Yellowstone Lake’s delta foot near Beaver Dam Creek. However, this area is primarily made up of the delta’s flood plain on which bugs and floods likely decrement the attraction of this area for hunter-gatherers seeking temporary occupations.

The Clear Creek habitation area, subject to considerable archaeological survey in 2011 and 2012 (Livers et al. 2012), yielded a wealth of artifacts from several sites with dates as expected from our GIS analysis. For example, site 48YE678 yielded multiple hearth features at approximately 1,500 B.P. which lie on terraces S1-S3 within 5 meters of the current lake level (Figure 2). In addition, the carbon samples dated to 4,150 ± 80 cal B.P. recovered by Hofmann and Hendrix (2012) come from terraces about 7 meters above datum (site 48YE2080) just as expected in our Middle and Early Archaic zone (8,000 to 3,000 B.P.). The 2011 field work of the Montana Yellowstone Archaeological Project (MYAP)
identified additional projectile points distinctive to the Middle Archaic Period (5,000 to 3,000 B.P.) on the same terrace exposed at about 8,000 B.P. as predicted in our analysis. These points were found among the same terraces where Hofmann and Hendrix (2012) recovered their carbon samples and verify that lake levels were at the predicted elevations. The oldest artifacts recovered in 48YE2080 are Middle Archaic. Unfortunately, MYAP’s
2010 and 2011 field season failed to recover archaeological material or C\textsuperscript{14} samples older than Middle Archaic. Thus, we have neither positive nor negative confirmation of much older sites on the highest terraces in Clear Creek. Given the wealth of artifacts (nearly 6,000) from six Clear Creek sites (Livers et al. 2012) the higher terraces are ripe for exploration for Paleo-Indian era sites. Regardless, the archaeological discoveries and C\textsuperscript{14} dates confirm the GIS predictions for the Clear Creek habitation area.

In the Meadow Creek area our GIS analysis indicates the region was a small protected bay prior to 8,000 years ago. Based upon C\textsuperscript{14} dating analyses of samples recovered by Hofmann and Hendrix (2012) near Clear Creek, much of the bottom surfaces of this bay were exposed by 4.1 ka during the Middle Archaic Period (5,000-3,000 B.P.). By the transition into our Late Period (less than 3,000 years), lake levels had receded far enough to expose the entire bottom of this bay, thus creating new living surfaces for prehistoric occupations. Unfortunately, during 2010 MYAP field crews identified only one datable prehistoric site, culturally distinct to the Late Archaic Period (3,000 to 1,500 B.P.). That site, 48YE2092, was on a lower terrace within the expected elevation range for lake levels during this period in time (Figure 2). Revisiting the area in 2011, MYAP crews excavated 48YE2090 and discovered a probable Late Archaic or Late Prehistoric occupation at 2,360 meters (4 meters above datum) as predicted. During the 2010 investigations, field crews surveyed the higher elevated terraces for older sites but found insufficient surface scatter to warrant excavation. Thus, as with the Clear Creek area, we have no archaeological evidence from the higher terraces. Note that the Meadow Creek-Park Point area is somewhat isolated and may have experienced less use than the Clear Creek site. Travel up Meadow Creek does not lead to a pass; rather it leads to a tributary of Clear Creek. During higher lake stands, arriving at Meadow Creek and Pack point requires travel from Clear Creek two miles to the north. During those high stands, access is less easy from the south as the lake lapped against cliffy terrain.

Our third habitable area, the Columbine Creek habitation area, is about seven kilometers south of Meadow Creek. It can be accessed either along the eastern shoreline during all but the highest lake stands or from a pass ten kilometers to the northeast. However, the MYAP 2010 and 2011 field season surveys did not identify any prehistoric sites even though terraces from all three of our age/elevation groups exist in the area. Hofmann and Hendrix’s (2012) geomorphologic field analyses confirms lake levels in this region at approximately 2,379 m at 10.4 ka and 2,359 m at 2.8 ka. Thus, though we have good available living surfaces in all age groups we have no archaeological confirmation of their use.

The last area from this study exhibiting slopes gentle enough to support comfortable living surfaces is at the mouth of Beaver Dam Creek where it meets the Yellowstone River delta (Figure 2). Again, our GIS analysis shows suitable living surfaces in all three age groups in terms of slope and access. However, this region would have been wet, marshy, and subject to seasonal flooding. Such conditions are not desirable for modern camping, nor would they be so in the past. This would have restricted occupations onto the higher more stable terraces that were away from the flood plain. In 2010, two culturally distinct sites were identified in this region and one of these is likely to reflect a secondary deposition. 48YE2106 rests on a low-lying erosional terrace within the predicted elevation bounds and is culturally associated with the Middle Archaic McKean Complex (5,000 to 3,000 B.P.). Another 2010 site, 48YE250 was identified on the edge of the delta foot and is culturally distinct to the Late Prehistoric Period. It too is within the expected elevation range. However, 48YE250 likely reflects the redistribution of archaeological material transported by natural erosional mechanisms in a fluvial environmental context (Livers and MacDonald 2011). Site 48YE1499, excavated in 2011, yielded a Pelican Lake projectile point and a radiocarbon date of 1,260-1,060 Cal B.P. at an elevation of 2,365 meters (8.6 m above datum). Thus, as expected, the site is younger than the exposure of the terrace.

Conclusions
We suggest that the shoreline designations of Locke and Meyer (1994) are more appropriate for the east and southeast shores of Yellowstone Lake, that portion outside the seismically active caldera, than those of Pierce et al. (2007) as also noted by Hofmann and Hendrix (2012). We separate these shorelines into three...
general groups: 1) the earliest period (13 m to 23 m above datum) reflects the Paleo-Indian cultural period from 12,000 B.P. to 8,000 B.P., 2) the middle period (5 to 14 m above datum) comprised of the Middle and Early Archaic periods from 8,000 to 3,000 B.P., and 3) the Late Period (0-6 m above datum) from Late Archaic to historic. After separating the shorelines into these age groups we calculated topographic slopes based on 1/3 arc-second DEMs and masked those results for areas with slope less than 5%. Thus, we find areas in designated age bands with surface slopes suitable for group camping and use that as a basis for predictive modeling of occupation sites. The Montana Yellowstone Archaeological Project’s 2010 and 2011 archaeological results from the east and southeast shores of Yellowstone Lake corroborate our predictions from GIS analysis of ancient shoreline levels.

Unfortunately, there is a very limited sample range of datable archaeological sites along the eastern and southeastern shores. Livers and MacDonald (2011; Livers et al. 2012) and there are no sites earlier than Middle Archaic. Regardless, the spatial distribution of the discovered sites is in agreement with our predicted ranges. Prehistoric sites dating to the Late Archaic and Late Prehistoric cultural periods are found on terraces associated with Late Period lake levels (2,356.48 m to 2,362 m) that have been gradually receding over the last 3,000 years. Occupations dating to the Middle Archaic cultural period are associated with lake levels (2,361 to 2,370 m) during the Middle Period of the lake shore model. MYAP did not discover any Early Archaic cultural period (8,000 to 5,000 B.P.) or Paleo-Indian era (12,000 to 8,000 B.P.) occupations even though there is previous evidence of those cultures in the Yellowstone Lake area. For example, there are more Paleoindian points are found around Yellowstone Lake than in any other area of the park (Johnson, 2002). Included here is the nearby Late Paleoindian Osprey Beach locality (Shortt 2003) on the West Thumb portion of the southern shore of Yellowstone Lake. Further, Pitblado (2010) has 92 Paleoindian sites less than 300 kilometers to the southwest in Idaho and Utah, sites that include Clovis, Folsom, and Angostura artifacts. Similar, yet fewer, such sites are distributed around Yellowstone in the adjacent areas of Montana and Wyoming. As Livers et al. (2012) note, it is our earliest period with the highest terraces that should hold records Paleoindian and Early Archaic.

Two explanations come to mind. Perhaps there was less occupation in those times or there is insufficient surface scatter from more deeply buried sites to reliably discover them using pedestrian surface surveys.

Our predictive modeling identifies many suitable occupational living surfaces on successively higher and older lake shores. Yet, there appears to be fewer sites on the eastern and southeastern than on the northern or western shores (e.g. Livers et al. 2012). It is possible that hunter-gatherers avoided much of the east shore as the frequency of site counts dramatically diminishes south of Clear Creek (Livers and MacDonald 2011) where higher lake stands encroached on cliffy areas. One can travel easily from Clear Creek to Meadow Creek at all lake levels. At higher stands, travel further south to Colombine Creek is impeded by cliffy shores at the foot of the Absaroka Range. Both Clear Creek and Colombine Creek lead east to passes out of the Yellowstone ecosystem but Sylvan Pass at the head of Clear Creek provides somewhat easier travel. This route leads to the Shoshone River and the big game wintering grounds around Cody, WY. There is much easier travel to Yellowstone Lake from the north and southwest so perhaps those shores were simply more popular and hunter-gatherers avoided the eastern areas because the invested energy costs outweighed the caloric energy to be gained from the resources. There is also a paucity of sites demonstrating prehistoric occupations at the south of our study area in the Beaver Dam Creek region this could easily stems from the fact that the vicinity is in the flood plain with its attendant wet, marshy, buggy conditions and frequent spring flooding. Even occupations that did exist would be subject to the erosive and depositional processes of the Yellowstone River; local ecological conditions must be part of the prediction.

Alternatively, perhaps Paleoindian and Early Archaic sites exist on the higher terraces and have yet to be discovered; searching for and documenting such resources is central to the Montana Yellowstone Archaeological Project. It is easy to imagine effective burial of archaeological evidence in the current ecological conditions of Yellowstone. Clear Creek, Meadow Creek, Colombine Creek, and the Yellowstone River deliver vast quantities of sediment to their fan and delta systems each year. Lodgepole forests grow fast and
burn frequently; duff builds rapidly, and grasses are tall. Clearly Clear Creek has been well used for millennia; yielding nearly 6,000 artifacts from the Middle Archaic forward (Livers and MacDonald 2011). Due to that artifact frequency, its large area, and easy access from the north and from Sylvan Pass to the east the higher older terraces of Clear Creek seem to be the most likely on the eastern shore to hold evidence of earlier occupation. Geophysical exploration using total field magnetic observations has proved very successful on the northwestern shores of Yellowstone Lake (Sheriff and MacDonald 2011; Sheriff 2012). In some of those investigated areas 40% of test units excavated hearth features. Given the success of the GIS predictions, combining geophysical exploration and further archaeological investigation may yield older sites on higher terraces and help establish archaeological resources in Yellowstone National Park as well as the document the change in use and technologies from Paleoindian through historic times.

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