PROCEEDINGS OF THE TWENTY-SIXTH ANNUAL KECK RESEARCH SYMPOSIUM IN GEOLOGY

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Pomona College, Claremont, CA

Dr. Robert J. Varga, Editor
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Pomona College

Dr. Jade Star Lackey
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Pomona College

Carol Morgan
Keck Geology Consortium Administrative Assistant

Christina Kelly
Symposium Proceedings Layout & Design
Office of Communication & Marketing
Scripps College

Keck Geology Consortium
Geology Department, Pomona College
185 E. 6th St., Claremont, CA 91711
(909) 607-0651, keckgeology@pomona.edu, keckgeology.org

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Robert J. Varga
Editor and Keck Director
Pomona College

Keck Geology Consortium
Pomona College
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Christina Kelly
Proceedings Layout & Design
Scripps College

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Keck Geology Consortium: Projects 2012-2013
Short Contributions— Clear Lake, Wisconsin Project

Keck Geology Consortium
Pomona College
185 E. 6th St., Claremont, CA 91711
Keckgeology.org

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THREE DIMENSIONAL ANALYSIS OF THE HYDROSTRATIGRAPHY NEAR CLEAR LAKE, WISCONSIN

H. LEIGH HONOROF, Mount Holyoke College
Research Advisor: Alan Werner

ABSTRACT

This research involves geospatial modeling around four groundwater fed lakes in Milton, Wisconsin. Devastating floodwaters associated with heavy 2008 precipitation began receding from Clear Lake, Mud Lake, Grass Lake and Duck Lake only in recent months (Fitzpatrick et al., 2008; Joachim et al., 2011). Data from private well construction logs and water table measurements were entered into ArcGIS for hydrostratigraphic analysis. Three large, semi-continuous intervals rich in clay were mapped in the study near the lakes and the Rock River. Their influence, which may be impeding and redirecting groundwater flow, may explain the slow drainage of lake floodwaters.

INTRODUCTION

Flooding in the Clear Lake area has submerged and destroyed valuable lakefront property. It has also occurred in tandem with significant eutrophication. The residents and property owners of the area are personally invested in knowing why this has happened, when it will end, and if it will reoccur. Understanding lacustrine flooding in the studied region and other regions with similar kettle lakes may also become regionally significant in the near future, as climate researchers expect that soil moisture, mean precipitation, and the number of extreme precipitation events increase in the upper American Midwest (Lorenz et al., 2009; Vavrus and Van Dorn, 2010).

The purpose of this project is to determine the potential influence of hydrostratigraphy on groundwater flow and therefore the flooding of groundwater fed lakes in the Clear Lake region. The hypothesis driving the analysis is that the local stratigraphy contains intervals of low hydraulic conductivity that may be obstructing the timely draining of local floodwaters. The cause of these intervals' low hydraulic conductivity would be compositions rich in fine-grained sediments such as clay. The study area in Milton, Wisconsin is approximately 4.67 by 5.95 kilometers. The study focus is the hydrostratigraphy surrounding Clear Lake, Duck Lake, Grass Lake, and Mud Lake. GIS techniques are used to evaluate the reported well-log stratigraphy in order to determine the thickness, lateral extent and depth of three semi-continuous clay-rich intervals. Additionally, the study analyzes the local water table in greater resolution than the regional water table modeled by Gaffield et al. (2002).

METHODS

The primary source of data is one hundred and nineteen local private well construction logs, each with reliable location information, a water table elevation, and stratigraphic descriptions. Data from these well construction logs were coded and entered into ArcMap version 10.1. Street addresses or section locations were matched to local GIS address points and property lists, and water table elevations were determined by subtracting static water levels from regional elevation data as mapped by the U.S. Geological Survey on the Milton, Wisconsin 7.5 series topographic quadrangle. Clay-rich stratigraphic intervals are assigned to one of three categories: shallow, intermediate, or deep. If three apparent clay-rich intervals are not touching, but are separated by sandy or gravelly intervals, they are assigned based on their relative depth. Where wells have fewer than three distinct clay-rich intervals, intervals are categorized by depth. Clay rich intervals less than 9.14 meters are considered shallow, intervals between 9.14 and 30.17 meters are considered intermediate, and intervals greater than or surrounding 30.48 meters are considered deep. The final three intervals vary in elevation between 271 and 216 meters for the shallow interval, 265 and 167 meters for the intermediate interval, and 235 and162 meters for the deep interval. Surface elevation, year of construction, and well depth are also added as metadata for each well.

Additional well information included four wells drilled during Keck Wisconsin 2012 fieldwork. A deeper piezometer well and a shallower water table well were drilled beside each other at two sites, one north and the other south of Clear Lake. Split spoon samples were collected at .0696 meter increments in the shallow monitoring wells to a depth of 10.67 to 11.89 meters. Detailed descriptions of these samples were taken, including grain size, sorting, Munsell color, and relative moisture, density, consistency, and carbonate content. The 2012 Keck Wisconsin team also collected eleven water table data points using either a Solinst flat tape water level meter or sonic water level meter.

All well data were entered into ArcGIS for geo-spatial analysis. Well data corresponding to the thickness, lateral extent, and elevation in meters of clay intervals were transformed into raster files composed of continuous pixel units, each with an assigned value. These assigned values were generated for each pixel by the Inverse Distance Weighting interpolation process. The raster files were then used to create maps showing the thickness, lateral extent, and elevation in meters of the three clay intervals. A raster of water table elevations was also created to show the regional direction of groundwater flow. The two-dimensional maps of clay interval thickness and lateral extent combine raster images with dots color-coded to reveal elevation. The two-dimensional map of water table elevation includes similar dots color-coded to reveal the year of elevation measurement. The two-dimensional maps include a base map of the Milton, Wisconsin 7.5-minute series U.S.G.S. topographic quadrangle. ArcScene version 10.1 was used to transform the rasters of clay interval thickness and elevation and water table elevation into a three-dimensional map. This map reveals where the clay intervals intersect, as well as the flow of the water table within or around the clay intervals.

RESULTS

Figure 1 shows a two dimensional GIS representation of the regional water table surface by elevation. An interpolation search radius of 20 is used, meaning that at least 20 wells are used to calculate the value for each raster cell. This interpolation search radius is relatively large. For example, the default interpolation search radius for ArcGIS 10.1 is 12. The larger interpolation search radius helps smooth extreme peaks and valleys in water table elevation data that might have arisen from changes in water table elevation over time. A gently sloping water table without extreme variations is a more realistic interpretation. The water table appears much higher to the south and east of Clear Lake. Overall, groundwater flows south to north. Using the water table raster, a shallow horizontal gradient of -.0019 was calculated. This gradient runs 2, 650 meters from the south to the north of the study area, intersecting Mud Lake, Clear Lake, and Grass Lake.

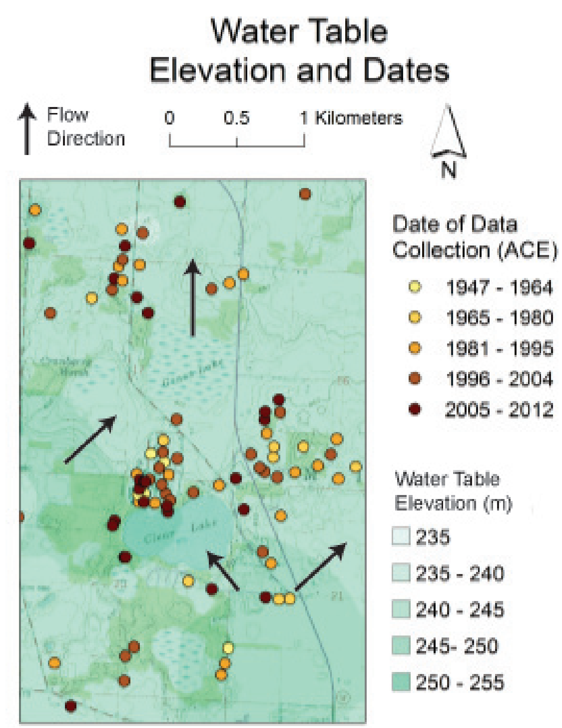

Figure 1: Map of the water table near Clear Lake, zoomed to focus on the four lake chain.

Figure 2, Figure 3, and Figure 4 show the thicknesses and elevations of the shallow, intermediate and deep clay rich intervals. All express thickness using an interpolation search radius of 15, intermediate between the 20 used in the water table map and the default of 12. This choice was made because subsurface clay intervals, unlike water tables, are generally static and may realistically undulate. Unusual peaks and valleys may still appear and require smoothing to integrate them into the image. However, the interpolation search radius of 15 allows for variations. All three clay-rich intervals are thickest to the north of Clear Lake. Only eleven well sites lack clay, but they are scattered and generally shallow, with a maximum depth of 37 meters. Perhaps clay rich material is indeed absent in these locations, but it is also possible that the drillers failed to document clay accurately or the wells were not deep enough to penetrate a clay interval.

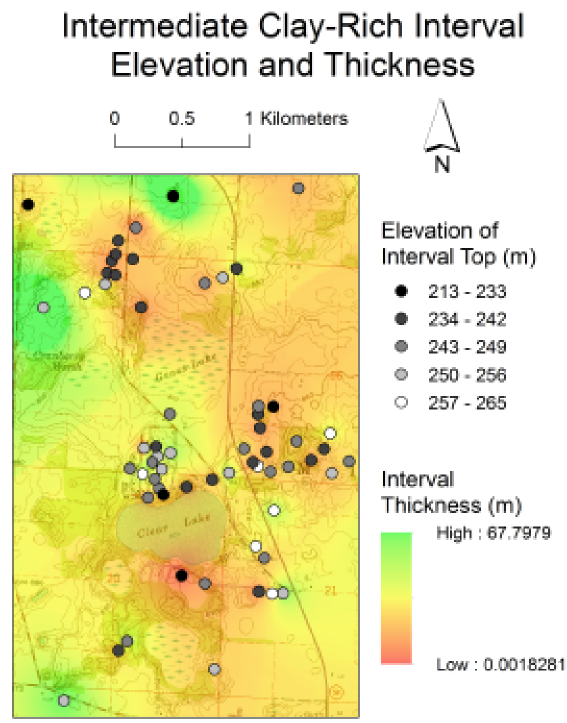

Figure 3: Map of the intermediate clay-rich interval near Clear Lake, zoomed to focus on the four lake chain.

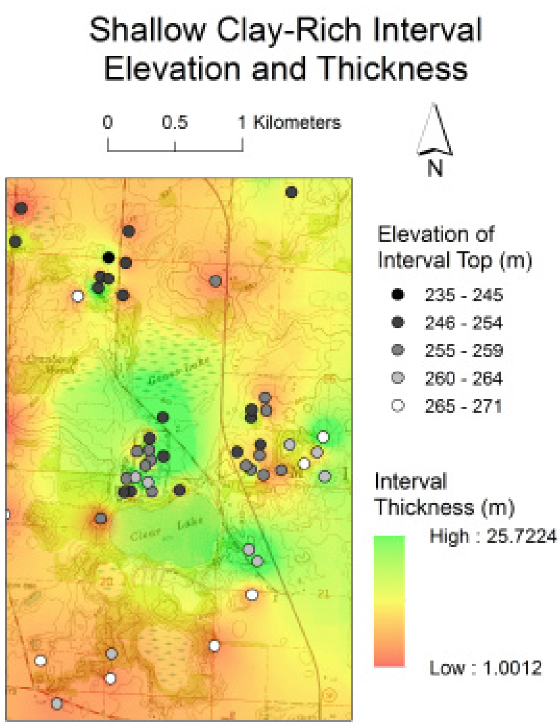

Figure 2: Map of the shallow clay-rich interval near Clear Lake, zoomed to focus on the four lake chain.

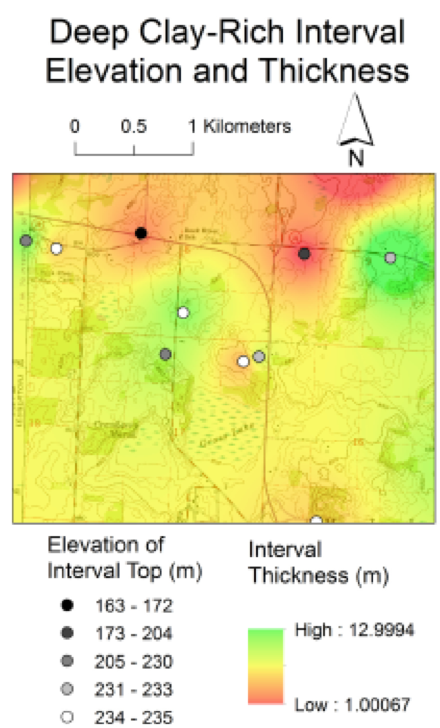

Figure 4: Map of the deep clay-rich interval near Clear Lake, zoomed to focus around Grass Lake, where this layer is most present.

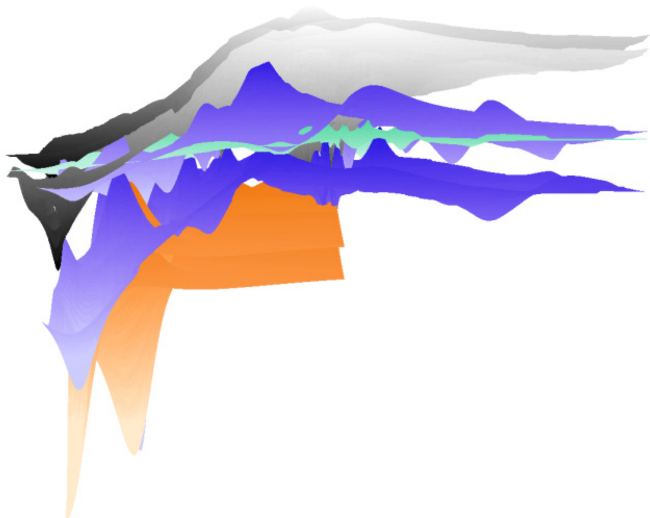

Figure 5: A three dimensional interpretation of the images in Figures 1 - 4, with a vertical exaggeration of 50. The two grey intervals are the top and bottom of the shallow clay-rich interval. The same applies to the two purple intervals and the intermediate clay-rich interval, as well as the two orange intervals and the deep clay-rich interval. The areas between two different clay-rich intervals represent more coarse-grained materials with higher hydraulic conductivity.

Figure 5 represents the three clay intervals and the water table in three dimensions. Grey surfaces represent the top and bottom of the shallow interval, purple the intermediate interval, and orange the deep interval. The single blue surface represents the water table. Note that this image has a vertical exaggeration of 50. In the south of the study area, the three clay intervals are stratigraphically distinct, separated by sand and gravel intervals. However, the clay intervals appear to thicken and merge to the north. Throughout the study area the water table appears to intersect the clay intervals rather than occurring only in sand and gravel. Unusually extreme peaks and dips in this figure probably reflect the assignment by depth method for wells with fewer than three distinct clay intervals. Although the study area is relatively flat, these dips and peaks might be reduced if elevation rather than depth categorized certain clay locations.

DISCUSSION

The water table map uses data taken over a span of 65 years, during which the water table is likely to have changed. However, the large search radius of the raster interpolation method and the wide dispersion of the older wells mean that the resulting map should not be strongly affected by the age of data points and therefore is a reliable representation. The lowering of the water table from the south to the north of this region agrees with the water table contours of Gaffield et al. (2002). However, the map also shows irregular increases in water table elevations to the northwest and southeast of Clear Lake, which are not described by Gaffield et al. (2002). Perhaps this reflects the smaller scale of this study.

The fact that the water table intersects clay intervals as well as sand and gravel suggests an environment of complex groundwater flow, despite the high hydraulic conductivity of the sand and gravel aquifer. This heterogeneity may help explain the long-term flooding of Clear Lake, Duck Lake, Grass Lake, and Mud Lake.

Challenges faced in the interpretation of the well construction reports include the merging of perceived intervals, variations in the detail of stratigraphic descriptions, and data point clumping. The division of the clay-rich material into three distinct intervals is a concept with strengths and weaknesses, as shown in Figure 5. Although these intervals are clearly divided by more permeable intervals of sand and gravel in the south, there are locations where the intervals appear to merge, particularly in the north. The intermediate and deep intervals seem more connected than separate in the most northern fifth of the study area. The shallow and intermediate intervals also merge at locations in the middle and far north of the study area. More well data would help to determine the accuracy of these interpretations. The geologic quality of driller's logs can be highly variable. While some logs differentiate between "sandy clay," "blue clay," and "red sandy clay," others simply mention "clay" or "clay and gravel." Similarly, while one log describes "fine sand" and "red sand," another only describes "sand." While it is clear from the more detailed logs that both the coarse-grained and fine-grained materials are compositionally and perhaps hydraulically complicated, there are not enough logs to fully describe that complexity throughout the Clear Lake region. The distribution of private well locations is also uneven, due to the uneven distribution of residences. Well data points are clustered overall to the north of Clear Lake. This means that map interpretations may be more accurate in that region.

Although this is helpful in addressing questions about the flooding of Clear Lake, more data points would be useful in promoting accurate regional interpretations.

CONCLUSIONS

The results support the hypothesis that an abundance of clay-rich subsurface material has promoted the flooding and sustained high water conditions of the study area. Clay-rich intervals are widespread, especially in northern locations, and their low hydraulic conductivity is likely inhibiting the northward drainage of groundwater throughout the region. The subsurface near Clear Lake shows this trend in detail, with clay rich areas immediately to the north of areas with unusually high groundwater table elevations. Three dimensional modeling shows that groundwater tends to flow through areas of primarily low hydraulic conductivity rather than flowing more easily through sandy or gravelly stratigraphic intervals. Analysis of more well construction logs and recent water table measurements might increase the accuracy and detail of the interpretations.

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