

**KECK GEOLOGY CONSORTIUM
PROCEEDINGS OF THE TWENTY-THIRD
ANNUAL KECK RESEARCH SYMPOSIUM IN GEOLOGY
ISSN# 1528-7491**

April 2010

Andrew P. de Wet
Editor & Keck Director
Franklin & Marshall College

Keck Geology Consortium
Franklin & Marshall College
PO Box 3003, Lanc. Pa, 17604

Lara Heister
Symposium Convenor
ExxonMobil Corp.

Keck Geology Consortium Member Institutions:

Amherst College, Beloit College, Carleton College, Colgate University, The College of Wooster, The Colorado College
Franklin & Marshall College, Macalester College, Mt Holyoke College, Oberlin College, Pomona College, Smith College, Trinity University
Union College, Washington & Lee University, Wesleyan University, Whitman College, Williams College

2009-2010 PROJECTS

SE ALASKA - EXHUMATION OF THE COAST MOUNTAINS BATHOLITH DURING THE GREENHOUSE TO ICEHOUSE TRANSITION IN SOUTHEAST ALASKA: A MULTIDISCIPLINARY STUDY OF THE PALEOGENE KOOTZNAHOO FM.

Faculty: Cameron Davidson (Carleton College), Karl Wirth (Macalester College), Tim White (Penn State University)

Students: Lenny Ancuta, Jordan Epstein, Nathan Evenson, Samantha Falcon, Alexander Gonzalez, Tiffany Henderson, Conor McNally, Julia Nave, Maria Princen

COLORADO – INTERDISCIPLINARY STUDIES IN THE CRITICAL ZONE, BOULDER CREEK CATCHMENT, FRONT RANGE, COLORADO.

Faculty: David Dethier (Williams) Students: Elizabeth Dengler, Evan Riddle, James Trotta

WISCONSIN - THE GEOLOGY AND ECOHYDROLOGY OF SPRINGS IN THE DRIFTLESS AREA OF SOUTHWEST WISCONSIN.

Faculty: Sue Swanson (Beloit) and Maureen Muldoon (UW-Oshkosh)

Students: Hannah Doherty, Elizabeth Forbes, Ashley Krutko, Mary Liang, Ethan Mamer, Miles Reed

OREGON - SOURCE TO SINK – WEATHERING OF VOLCANIC ROCKS AND THEIR INFLUENCE ON SOIL AND WATER CHEMISTRY IN CENTRAL OREGON.

Faculty: Holli Frey (Union) and Kathryn Szramek (Drake U.)

Students: Livia Capaldi, Matthew Harward, Matthew Kissane, Ashley Melendez, Julia Schwarz, Lauren Werckenthien

MONGOLIA - PALEOZOIC PALEOENVIRONMENTAL RECONSTRUCTION OF THE GOBI-ALTAI TERRANE, MONGOLIA.

Faculty: Connie Soja (Colgate), Paul Myrow (Colorado College), Jeff Over (SUNY-Geneseo), Chuluun Minjin (Mongolian University of Science and Technology)

Students: Uyanga Bold, Bilguun Dalaibaatar, Timothy Gibson, Badral Khurelbaatar, Madelyn Mette, Sara Oser, Adam Pellegrini, Jennifer Peteya, Munkh-Od Purevtseren, Nadine Reitman, Nicholas Sullivan, Zoe Vulgaropulos

KENAI - THE GEOMORPHOLOGY AND DATING OF HOLOCENE HIGH-WATER LEVELS ON THE KENAI PENINSULA, ALASKA

Faculty: Greg Wiles (The College of Wooster), Tom Lowell, (U. Cincinnati), Ed Berg (Kenai National Wildlife Refuge, Soldotna AK)

Students: Alena Giesche, Jessa Moser, Terry Workman

SVALBARD - HOLOCENE AND MODERN CLIMATE CHANGE IN THE HIGH ARCTIC, SVALBARD, NORWAY.

Faculty: Al Werner (Mount Holyoke College), Steve Roof (Hampshire College), Mike Retelle (Bates College)

Students: Travis Brown, Chris Coleman, Franklin Dekker, Jacalyn Gorczynski, Alice Nelson, Alexander Nereson, David Vallencourt

UNALASKA - LATE CENOZOIC VOLCANISM IN THE ALEUTIAN ARC: EXAMINING THE PRE-HOLOCENE RECORD ON UNALASKA ISLAND, AK.

Faculty: Kirsten Nicolaysen (Whitman College) and Rick Hazlett (Pomona College)

Students: Adam Curry, Allison Goldberg, Lauren Idleman, Allan Lerner, Max Siegrist, Clare Tochilin

**Funding Provided by: Keck Geology Consortium Member Institutions and NSF (NSF-REU: 0648782)
and ExxonMobil**

**Keck Geology Consortium: Projects 2009-2010
Short Contributions – WISCONSIN**

**THE GEOLOGY AND ECOHYDROLOGY OF SPRINGS IN THE DRIFTLESS
AREA OF SOUTHWEST WISCONSIN**

Project Faculty: *SUSAN K. SWANSON*: Beloit College
MAUREEN A. MULDOON: University of Wisconsin – Oshkosh

**LITHOSTRATIGRAPHIC CONTROLS ON GROUNDWATER FLOW AND
SPRING LOCATION IN THE DRIFTLESS AREA OF SOUTHWEST WISCONSIN**

HANNAH DOHERTY: Mount Holyoke College
Research Advisor: Al Werner

**ESTABLISHING PALEOCLIMATE VARIATION FROM MAJOR AND TRACE
ELEMENTS AND STABLE ISOTOPES IN A TUFAL DEPOSIT, WISCONSIN**

ELIZABETH FORBES: Whitman College
Research Advisor: Kirsten Nicolaysen

**A COMPARISON OF TECHNIQUES FOR DETERMINING SPRING SOURCE
AREAS: CRAWFORD COUNTY, WISCONSIN**

ASHLEY KRUTKO: Capital University
Research Advisor: Terry Lahm

**WATER GEOCHEMISTRY OF TUFAL-DEPOSITING SPRINGS IN THE
DRIFTLESS AREA, WISCONSIN**

MARY LIANG: Franklin and Marshall College
Research Advisor: Dorothy Merritts

**A CLIMATIC STUDY OF SPRING TUFAL DEPOSITS USING STABLE ISOTOPES
AND MAJOR AND TRACE ELEMENT CONCENTRATIONS, SOUTHWESTERN
WISCONSIN**

ETHAN MAMER: Beloit College
Research Advisor: Susan Swanson

TEMPERATURE PROFILE MODELING OF A SMALL SPRING-FED STREAM

MILES REED: DePauw University

Research Advisor: Tim Cope

Funding provided by: Keck Geology Consortium Member Institutions and NSF (NSF-REU: 0648782)

Keck Geology Consortium
Franklin & Marshall College
PO Box 3003, Lancaster Pa, 17603
Keckgeology.org

LITHOSTRATIGRAPHIC CONTROLS ON GROUNDWATER FLOW AND SPRING LOCATION IN THE DRIFTLESS AREA OF SOUTHWEST WISCONSIN

HANNAH DOHERTY

Mount Holyoke College

Research Advisor: Al Werner

INTRODUCTION

The relationship between springs and groundwater flow within the Driftless Area is poorly understood. Outcrop analog studies have helped better characterize portions of the Driftless Area's Cambrian-Ordovician aquifer in southern Wisconsin. An abundance of discrete contact springs associated with the aquifer's upper Sinnipee Group is evidence that heterogeneity exists in the subsurface (Swanson, 2007; Tipping et al., 2006; Swanson et al., 2009). Groundwater is believed to flow preferentially along high permeability features such as bedding plane fractures or lithological contacts. Where stream valleys intersect these features, groundwater is discharged as contact springs.

This study seeks to better understand how the Sinnipee Group's sedimentary strata control preferential groundwater flow and thus the stratigraphic location of springs within its members. Having located hydraulically significant springs within the Sinnipee Group, this study was able to conduct outcrop analog studies and identify hydraulically significant features such as bedding planes that could control groundwater flow. These outcrop analog data were then correlated with geophysical data from nearby borehole wells and road outcrops.

The Ordovician aquifer system is used extensively for water supply within the Upper Midwest and detailed stratigraphic information could help water resource management, as well as assist in successful conservation and restoration strategies, particularly pollution remediation. Additionally, in light of the 2003 WI Act 310, which sets out to protect spring resources in the state of Wisconsin, the more re-

source managers understand the geologic controls on spring positions, the better spring resources can be protected.

BACKGROUND

The Sinnipee Group dominates the shallow bedrock in Grant County and the Driftless Area in southwest Wisconsin. The Sinnipee, composed of the Platteville, the Decorah and the Galena Formations, is in the upper part of the Cambrian-Ordovician aquifer and has high heterogeneity with abundant dissolution features, vertical and horizontal fractures, and a zone of shaley layers. De Geoffroy et al. (1967; 1970) report that many springs in southwest Wisconsin emanate from fractures and along zones of contrasting permeability in the Platteville, Decorah, and Galena Formations (Fig. 1).

The Platteville Formation includes the Pecatonica Dolomite, McGregor Limestone, and Quimbys Mill Limestone Members. It is overlain disconformably by the Spechts Ferry Shale Member of the Decorah Formation (Ostrom, 1987). The Decorah Formation, which is the primary focus of this study, is subdivided in ascending order into the Spechts Ferry and Guttenburg Members. The Spechts Ferry Member contains interbedded fossiliferous gray-brown limestone, and thick gray-green shale layers. It is conformably overlain and transitional with the Guttenburg Limestone Member, which consists of fine crystalline, thin bedded, fossiliferous light brown limestone with brown petroliferous shale partings and interbeds (Ostrom, 1987). The Ion Member of the Galena Formation overlays the Guttenburg Member. It is composed of gray to blue dolomite with concentrated dissolution, and is overlain by the

rest of the Galena Formation, a cherty, thick-bedded, vuggy dolomite with medium to coarse sugary texture (Fig. 1).

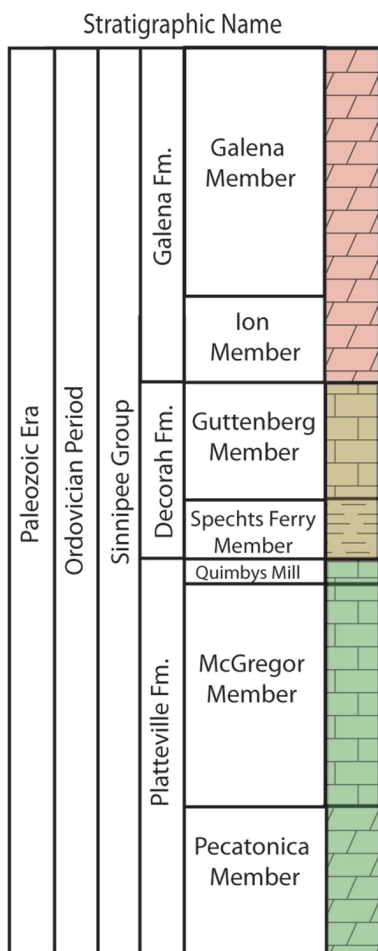


Figure 1. Generalized stratigraphic section of the Sinnipee Group, found in the upper part of the Cambrian-Ordovician aquifer system in Wisconsin.

METHODS

The Potosi and Platteville spring sites are both stratigraphically positioned within the Sinnipee Group. They were chosen based on hydraulic significance, and their influence on groundwater flow. Based on the initial field visit, it was evident that the springs discharged from zones of high permeability and additional springs were identified and included in this analysis. The Platteville site had two additional springs (#2 and #3) that discharged from the same stratigraphic zone as the principle tufa depositing spring, and the Potosi site had a second spring (#2)

with a 25 m exposure of Sinnipee Group rocks. The 25 m Potosi spring exposure is referred to as the Potosi Spring exposure. The backwalls of each spring orifice were described, noting composition, texture, grain size and Munsell color.

Outcrop Studies

Outcrop-analog studies of the Sinnipee Group were conducted to better understand how the rocks' geologic features would affect groundwater flow in the saturated subsurface. Three exposures on Potosi Hill along the east side of Highway 61 were selected for study (Fig. 2). The outcrops were measured and described, noting composition, texture, grain size and Munsell color, and these data were used to construct a stratigraphic column. The location of any seepage and/or plants growing out of the exposure was also noted.

Natural gamma was measured and logged every 0.9 m at the Potosi Hill exposure using a GF Instruments GRM-260 hand-held gamma-ray spectrometer. For better correlation purposes additional gamma measurements were taken every 0.3 m at the identified Spechts Ferry and Guttenberg Members. At the Potosi Spring Exposure, natural gamma was measured every 1.5 m. Natural gamma was also measured at the backwalls of each spring orifice. Natural gamma measurements improve facies characterization, and are a useful tool in correlating surface outcrops to subsurface geological data (Aigner et al., 1995). This study compares the rock exposures' natural gamma measurements, which reflect specific features that might have potential to influence discrete flow, with natural gamma measurements from southwest Wisconsin boreholes.

Borehole Studies

Natural gamma data and hydrogeophysical data, provided by the Wisconsin Geological and Natural History Survey, were collected from boreholes at the University of Wisconsin Pioneer Farm (LF467) and the University of Wisconsin-Platteville (GR172 and GR173) (Fig. 2). Geophysical data in all boreholes included natural gamma radiation, caliper,

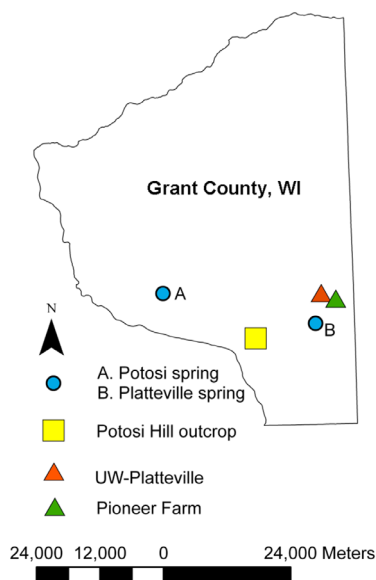


Figure 2. Study site locations and borehole locations in Grant County, WI.

and spontaneous potential. These data were compared, with specific attention given to identifying concentrations of high natural gamma occurrence to recognize the Spechts Ferry Member in the subsurface, and secondly, to determine the units' lateral continuity across the region. Video logs from UW-Platteville's GR172 and GR173 boreholes enhanced these comparisons, providing visuals of the subsurface lithology at specific stratigraphic locations of interest.

Groundwater data from these boreholes were analyzed to determine if changes in fluid flow were correlated to stratigraphic features. Specific attention was given to identifying changes in fluid flow along bedding planes within the Decorah Formation. Groundwater conductivity and temperature measurements were collected in GR172 and GR173 and examined to better understand fluid transport through the aquifer. In LF465, a spinner flowmeter measured vertical flow and these data were also used to evaluate the hydraulic characteristics of the aquifer.

RESULTS

The lithology found at each spring orifice is comprised of fine crystalline, thin irregularly bedded,

fossiliferous light brown limestone with brown shale partings. At the Platteville tufa spring, Platteville spring #3, and Potosi spring #2, green shale bedding is visible beneath the spring orifices, ranging in thickness from 10 to 30 cm.

In Potosi Hill outcrop, the Platteville Formation's Pecatonica Dolomite and McGregor Limestone Members are heavily weathered, with thin irregular bedding. The Quimbys Mill Limestone Member measures 0.6 m, is fine crystalline, purplish gray-brown, and thickly bedded. Above, the Spechts Ferry Member is 2.5 m thick, highly recessed, and interbedded with gray-green shale layers and thin fine-grained limestone layers. The Guttenberg Limestone Member is roughly 4.6 m, and has abundant horizontal fractures along fossiliferous zones with brown shale drapes. Approximately 0.5 m of the Ion Dolomite Member of the Galena Formation overlay the Guttenberg Member.

The Potosi Hill outcrop's natural gamma intensity remains generally constant throughout the exposure until the Spechts Ferry Member, where counts per second (cps) of natural gamma have the highest frequency for approximately 2 m of the unit and the lowest 0.75 m of the Guttenberg (Fig. 3). The Potosi Spring exposure's natural gamma frequencies followed the same trend as the Potosi Hill outcrop.

Borehole Studies

Natural gamma logs from LF465, GR172, and GR173 demonstrate that the rocks in the subsurface can confidently be correlated to those in exposure (Fig. 3). Therefore, rocks at the Potosi Hill outcrop can be used as an analog for those in the subsurface at the Pioneer Farm and the UW-Platteville campus. As in outcrop, the stratigraphic thickness for highest natural gamma counts in the subsurface was also approximately 3 m, and followed similar patterns of natural gamma intensity in all boreholes.

The caliper and spontaneous potential measurements of LF465, GR172, and GR173 also reflected changes in the subsurface lithology. GR172's measurements are representative of each borehole and

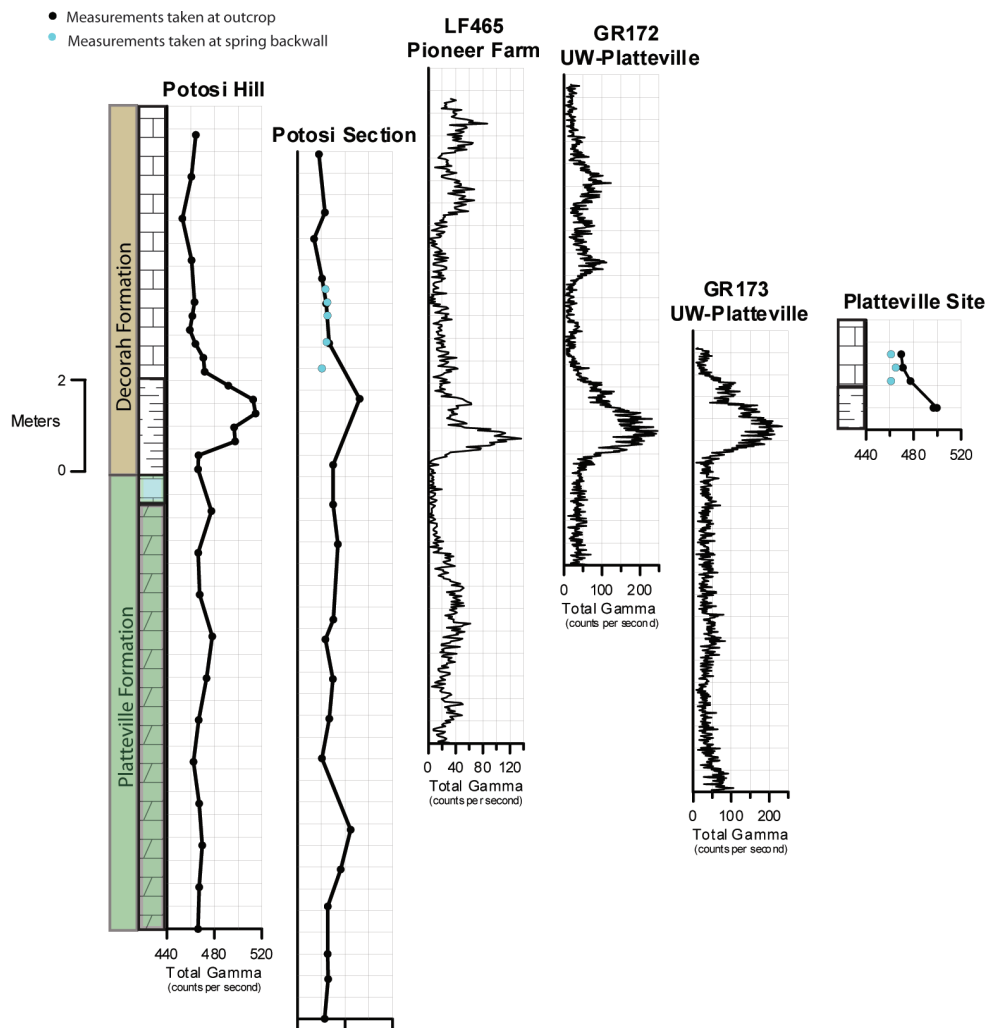


Figure 3. Correlated natural gamma logs of the Potosi Hill outcrop with stratigraphic section, Potosi Spring Exposure and Potosi spring backwall, Potosi Spring backwall, LF465, GR172, GR173, and Platteville site and spring backwalls. Note that natural gamma begins to increase before the Spechts Ferry.

are shown in Figure 4. When aligned with the stratigraphic column from the Potosi Hill exposure, spontaneous potential increases within the Spechts Ferry Member. Borehole diameter increases of 5 cm at both Pioneer Farm and UW-Platteville occur directly above or within the Spechts Ferry (Fig. 4). Video logs from this borehole provide evidence of a 1.5 m thick interval of increased concentration of thin brown shale partings within the Guttenberg Member and above the Spechts Ferry (Fig. 4). GR173's video log also showed similar concentrations of shale partings just above the Spechts Ferry.

Groundwater data indicate that groundwater flow changes in response to the subsurface stratigraphic features. Conductivity measured in GR172 and

GR173 increases dramatically just above the Spechts Ferry. Other changes in groundwater that occur just above the Spechts Ferry include a decrease in temperature (Fig. 4). Vertical fluid flow, measured in LF465, is highest within the Guttenberg Member, most likely due its well developed secondary porosity (Fig. 5). Average fluid flow decreases within the Spechts Ferry and then increases again at the Quimbys Mill Member of the Platteville Formation, thus indicating that the Spechts Ferry is a hydraulically important feature.

DISCUSSION

Results suggest that the tufa depositing springs originate from lateral flow at the upper contact of

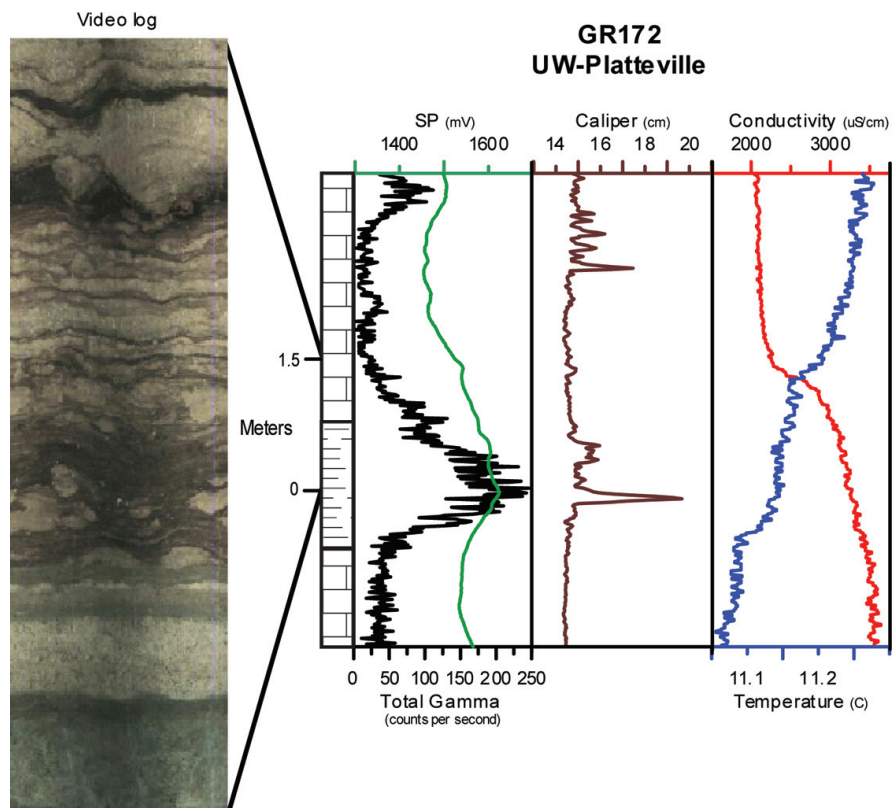


Figure 4. Log of GR172 including video log, stratigraphic characterization, lithostratigraphic data; natural gamma, spontaneous potential, caliper, and hydraulic data; temperature and conductivity. Lithostratigraphic and hydraulic data were collected by the Wisconsin Geologic and Natural History Survey.

the Spechts Ferry Member of the Decorah Formation. The correlatable nature of the borehole natural gamma logs support that this feature is laterally extensive and hydraulically significant within the subsurface. Changes in caliper log and hydraulic logs coincide with the high natural gamma frequency of the Spechts Ferry measured in outcrop (Figs. 4, 5). The caliper measurement also reflects the Spechts Ferry's recessed shale layer, erosion easily seen in outcrop. Temperature decreased while conductivity increased, indicating that water of differing chemistry enters from this transmissive zone.

The hydrologic logs tie these significant features recognized in the subsurface to specific stratigraphic positions within the Sinnipee Group. The abundance of horizontal fractures and vertical fractures seen within the Guttenberg, particularly near its lower bedding plane, provides a geologic explanation for the groundwater flow in the subsurface. Horizontal fractures have been shown to develop at contacts between contrasting lithologies and where

the rock is weak (Muldoon et al., 2001). In addition, very thin clay partings, as seen in the video logs of the Guttenberg-Spechts Ferry contact, are potentially weaker than the surrounding limestone and would facilitate the development of horizontal fractures within the member (Swanson, 2007). As fluid travels downward through the Guttenberg's fractures, the less permeable Spechts Ferry Shale impedes flow, acting as an aquitard and directs fluid within the Guttenberg to flow laterally along its upper bedding plane. When these features are exposed at the land surface, water discharges discretely above the Spechts Ferry as an expression of the same geologic features in deeper subsurface.

Hydrology data demonstrate that the Quimbys Mill Limestone Member, located beneath the Spechts Ferry, is transporting water from a different zone than the Guttenberg. Temperature in GR172 decreases in correspondence with lithological changes (Fig. 4). In addition, the Quimbys Mill has a higher conductivity, which explains the increase in fluid flow below

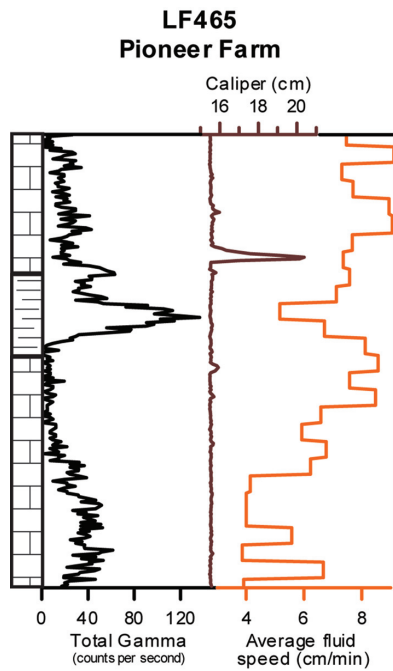


Figure 5. Log of LF465 including stratigraphic characterization, natural gamma, caliper, and average fluid speed.

the shale layer.

CONCLUSION

The tufa depositing springs discharge at the bedding plane between the Guttenburg and Spechts Ferry Members of the Decorah Formation. Horizontal and vertical fractures within the Guttenburg member facilitate discrete flow particularly along the lithological contact. The less permeable shale layers of the Spechts Ferry member produce an aquitard, causing water to flow laterally as evidenced in the groundwater data and the zone of high permeability from which multiple contact springs were discharging.

The detailed lithostratigraphic data of spring backwalls and outcrop provide a more accurate interpretation of the borehole geophysical and hydraulic logs, and provide evidence that discrete lateral flow within the Decorah Formation is continuous over large spatial scales. This hydrostratigraphic study improves the understanding of groundwater flow in the upper portion of the Ordovician-Cambrian aquifer and could facilitate better water management and pollution remediation.

ACKNOWLEDGEMENTS

I thank my Keck directors Sue Swanson and Moe Muldoon. I thank Al Werner, my advisor. I thank Ken Bradbury of the Wisconsin Geologic and Natural History Survey for supplying the borehole data, and Miles Reed, Ethan Mamer, Liz Forbes, Mary Liang and Ashley Krutko for helping me collect data.

REFERENCES

- Aigner, T., Schauer, M., Junghans, W.D., Reinhardt, L., 1995, Outcrop gamma-ray logging and its applications: examples from the German Triassic: *Sedimentary Geology*, v.100, p.47-61.
- De Geoffroy, J., Wu, S.M., Heins, R.W., 1967, Geochemical coverage by spring sampling method in the southwest Wisconsin zinc area; *Economic Geology*, v. 67, p. 679-697.
- De Geoffroy, J., Wu, S.M., Heins, R.W., 1970, Some observations on spring in southwest Wisconsin: *Water Resources Research*, v. 6(4), p. 1235-1238
- Muldoon, M.A., Simo J.A., Bradbury, K.R., 2001, Correlation of hydraulic conductivity with stratigraphy in a fractured-dolomite aquifer, northeastern Wisconsin, USA: *Hydrogeology*, v. 9, p. 570-583.
- Ostrom, M.E., 1987, Middle Ordovician rocks at Potosi Hill, Wisconsin, in Biggs, D.L. ed., *Geological Society of America Centennial Field Guide – North-Central Section*, p. 201-204.
- Swanson, S.K., Bradbury, K.R., Hart, D.J., 2009, Assessing the vulnerability of spring systems to groundwater withdrawals in southern Wisconsin: *Geoscience Wisconsin*, v. 20, p.1-13.
- Swanson, S.K., 2007, Lithostratigraphic controls on bedding-plane fractures and the potential for discrete groundwater flow through a siliclastic sandstone aquifer, southern Wisconsin: *Sedimentary Geology*, v.197, p. 65-78.

Tipping, R.G., Runkel, A.C., Alexander Jr., E.C.,
Alexander, S.C., Green, J.A., 2006, Evidence
for hydraulic heterogeneity and anisotropy in
the mostly carbonate Prairie du Chien Group,
Southeastern Minnesota, USA: *Sedimentary
Geology*, v. 184, p. 221-342.