MICHIGAN: ITS GEOLOGY & GEOLOGIC RESOURCES

THE FIFTH SYMPOSIUM

Thursday April 9 and
Friday April 10, 1998

The Kellogg Center
Michigan State University, East Lansing, Michigan

Sponsored by the

Geological Survey Division
Michigan Department of Environmental Quality
&
Michigan Basin Geological Society

Michigan: Its Geology and Geologic Resources Fifth Symposium

Thursday, April 9, Morning Session

	AUDITORIUM	ROOM 103
8:00	**Opening remarks**	
8:30	**Wildcelery Tubers at Grassy Island, Shiawassee National Wildlife Refuge,Wyandotte Unit, Wyandotte, Michigan** - Bruce A. Manny, U.S. Geological Survey,	**Improving Production by Identifying and Characterizing Fractures and Porosity Heterogeneity in Interwell Areas Using Borehole Gravimetry ("BHGM")** - James W. Bradley, Diana Morton-Thompson and Paul A. Daniels, Earth Resources International
9:00	**Investigation of Sediment and Water Chemistry at Grassy Island,Shiawassee National Wildlife Refuge, Wyandotte Unit, Wyandotte, Michigan** - Michael J. Sweat, U.S. Geological Survey	**The Effect of Land Use Change on Flow Patterns and Chemistry in the Grand Traverse Bay Watershed** - David F. Boutt, David W. Hyndman, Bryan C. Pijanowski, David T. Long and Andrew W. Olds, Michigan State University, Sheridan K. Haack, U.S. Geological Survey
9:30	**Investigating Heavy Metal Partitioning in Sediments from Differing Redox Environments** - Robert J. Ellis, Gary A. Icopini, and David T. Long, Michigan State University	**Arsenic in Ground Water in the "Thumb Area" of Michigan: the Mississippian Marshall Sandstone Revisited** - David B. Westjohn, Allan Kolker and William F. Cannon, U.S. Geological Survey, Duncan. F. Sibley, Michigan State University
10:00	**MORNING BREAK**	**MORNING BREAK**
10:30	**Chromium Speciation and Mobility in a Wetland Environment** - Gary A. Icopini, Robert J. Ellis and David T. Long, Michigan State University, Larry. J. Forney, University of Groningen	**Quality of Shallow Ground Water in Residential Areas, Greater Metropolitan Detroit, Michigan** - Erin A. Lynch, U.S. Geological Survey
11:00	**A Closer Look at Diagenetic Quartz and Dolomite with Atomic Force Microscopy** - Duncan F. Sibley, Michigan State University	**Recharge to Discharge Groundwater Travel Times in the Michigan Basin and the Effect of Glacial Ice Loading** - John R. Hoaglund III., GeoLogic Solutions
11:30	**Fate of Hydrocarbon Constituents During Land Treatment** - Stephen. J. Rouse, Shell Noreast Company, Chris. A. Caico and Ann. Saterbak, Shell Development Company	**Vulnerability of Groundwater to Atrazine Leaching in Kent County, Michigan** - David J. Holtschlag and Carol Luukonen, U.S. Geological Survey
12:00	**LUNCH, BIG 10 ROOM C**	

Origin and Transport of Methane at Kingsford, Michigan, and Their Relation to Geology, Hydrology, Geochemistry and Microbiology

David B. Westjohn, U. S. Geological Survey

Michigan: Its Geology and Geologic Resources Fifth Symposium

Thursday, April 9, Afternoon Session

	Auditorium	Room 103
1:30	**The Role of Science in Public Policy Decisions: the Potential Use of Michigan's Salt Formations for Hazardous Waste Management** - Julie Gales, Legislative Services Bureau	**Temporal Heterogeneity in Aqueous Geochemistry and Microbiology of a Contaminated Aquifer** - Sheridan K. Haack, U.S. Geological Survey, Larry. J. Forney, University of Groningen, Peter Adriaens, Francis H. Chapelle, U.S. Geological Survey
2:00	**The Use of Seismic Data and Attributes for Reservoir Characterization in Crystal Field, Michigan** - Terra E. Bulloch and Wayne D. Pennington, Michigan Technological University	**Applying Geologic Sensitivity Analysis in the Rouge River Watershed** - Daniel T. Rogers, Clayton Environmental Consultants
2:30	**AFTERNOON BREAK**	**AFTERNOON BREAK**
3:00	**Horizontal Drilling for Oil and Gas in the Michigan Basin** - William B. Harrison, III, Western Michigan University	**An Evaluation of Heavy Metals in Soil in the Rouge River Watershed** - Daniel T. Rogers and Douglas E. McVey, Clayton Environmental Consultants
3:30	**Implications of the 1994 Central Michigan Earthquake on Hazard Assessment in Southern Michigan** - Kazuya Fujita, Kevin G. Mackey, and Trent H. Faust, Michigan State University	**Water Resources of the Keweenaw Bay Indian Community** - Michael J. Sweat, U.S. Geological Survey

4:00

AUDITORIUM
Geological Society of America John Birdsall/Shirley Dreiss Distinguished Lecture

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Origin and Migration of Saline Fluids in Sedimentary Basins

Jeffrey S. Hanor, Department of Geology and Geophysics, Louisiana State University

Michigan: Its Geology and Geologic Resources - Fifth Sympposium

Friday, April 10, Morning Session

	AUDITORIUM	ROOM 103
8:00	**Soils and Soil Sequences in the Leelanau Drumlin Field, Michigan** - Paul Rindfleisch, Michigan State University	**The Collection of Structural Data in an Area containing Magnetic Rocks using the Total Station, Tilden and Empire Mines, Michigan. Some Preliminary Results** - Cheryl Webster, E. Wilson and William F. Cambray, Michigan State University, G. Scott and P. Nordstrom, Cleveland Cliffs Mining Company
8:30	**New Views on the Pleistocene History of Northeastern Lower Michigan** - Randy Schaetzl, Michigan State University	**A New Method of Measuring the A-axis in Quartz Using Fluid Inclusion Morphology** - Susan M. Rosin and Eric Johnson, Central Michigan University
9:00	**Paleoenvironmental Implications of Interior Dune Fields in Michigan**.- Alan F. Arbogast, Michigan State University	
9:30	**Mega Crevasse Fillings at Sleeping Bear Dunes National Lakeshore and their Relationship to the Manistee Moraine** - Todd Erick Wallbom and Grahame J. Larson, Michigan State University	
10:00	**MORNING BREAK**	**MORNING BREAK**
10:30	**Terrace Elevation and Lake Level Relationships in the Lower St. Joseph River Valley** - Kevin A. Kincare, Michigan Geological Survey	
11:00	**Panel Discussion: Suggested Revisions of "The Stratigraphic Succession Chart in Michigan"** - Stratigraphic Nomenclature Committee of the Michigan Basin Geological Society: Mark Wollensak and Paul Catacosinos, chairs **Mississippian through Quaternary** David B. Westjohn, U.S. Geological Survey, , **Antrim** Don Baily **Devonian** William B. Harrison, Western Michigan University **Silurian** Bob Reynolds **Ordovician and Cambrian** Paul Catacosinos and Paul A. Daniels	
11:45	**CLOSING REMARKS**	

The Geological Society of America John Birdsall/Shirley Dreiss Distinguished Lecture

Delivered by

Professor Jeffrey S. Hanor, Department of Geology and Geophysics, Louisiana State University, Baton Rouge, Louisiana 70803-4101

Professor Hanor is the Charles L. Jones Professor of Geology and Geophysics at Louisiana State University. He received his B.S. in Geology from Carleton College and his M.S. and Ph.D. in Geology from Harvard University. He was then a NSF Postdoctoral Fellow at the Scripps Institution of Oceanography. Professor Hanor joined the faculty at Louisiana State University in 1970. He has served as Chairman of the Department of Geology and Director of the School of Geoscience and has directed over 40 M.S. and Ph.D. students in thesis and dissertation research projects. He is the author of numerous published research papers on fluids in sedimentary environments.

ORIGIN AND MIGRATION OF SALINE FLUIDS IN SEDIMENTARY BASINS

Most sedimentary basins contain large volumes of pore water having salinities far in excess of that of normal sea water. The properties of these saline fluids provide important information on the geochemical, hydrologic, and tectonic evolution of the shallow crust and insight into important applied problems related to the generation of ore deposits, migration of hydrocarbons, distribution of potable water, and disposal of hazardous wastes.

The talk will document the complex and fascinating interplay which exists between the geological, chemical, and physical processes involved in the generation and large-scale migration of these fluids. The presentation will begin with a very brief review of the history of thought on the origin of subsurface brines, a history which parallels the general development of thought on groundwater hydrology itself. Examples from recent studies in the U.S. Gulf Coast will be used to evaluate subaerial evaporation, subsurface dissolution of evaporites, and membrane filtration as potential mechanisms for generating waters of high salinity. It will be shown that variations in cation composition of saline waters world-wide are far more systematic than often supposed and reflect fluid buffering by silicate-carbonate mineral assemblages, even at temperatures well below 100°C. High concentrations of chloride appear to be the key factor in determining whether or not a subsurface brine can act as an effective solvent for heavy metals, such as Pb and Zn, and hence become a potential ore-forming fluid.

The formation and presence of brines also plays an important role in the physical hydrogeology of sedimentary basins. For example, the dissolution of salt domes at shallow depth creates fluid density inversions capable of driving km-scale vertical and 10 to 100 km-scale lateral fluid flow. The dynamic nature of this solute transport has

important consequences for the distribution of fresh water resources and for the fate of injected wastes.

Some Recent Publication Related to the Lecture:

Hanor, J.S., 1994, Physical and chemical controls on the composition of waters in sedimentary basins: Marine and Petroleum Geology, v. 11, p. 31-45.
Hanor, J.S., 1994, Origin of saline fluids in sedimentary basins: in Parnell, J., (ed.), Geofluids: Origin and migration of fluids in sedimentary basins: Geological Society of London Special Publication No. 78, p. 151-174.
Hanor, J.S., 1996, Variations in chloride as a driving force in siliciclastic diagenesis: in Crossey, L.J., Loucks, R., and Totten, M.W. (eds.), Siliciclastic diagenesis and fluid flow: concepts and applications: SEPM Special Publication, n. 55, p. 3-12.
Hanor, J.S., 1997, Controls on the solubilization of lead and zinc in basinal brines: in Sangster, D.F. (ed.), Carbonate-hosted lead-zinc deposits: Society of Economic Geologists Special Publication 4.

PALEOENVIRONMENTAL IMPLICATIONS OF INTERIOR DUNE FIELDS IN MICHIGAN.

Alan F. Arbogast, Michigan State University, Department of Geography, 315 Natural Science Building, East Lansing, MI, 48824-1115

Geomorphological research at Michigan State University has recently focused on determining the age and paleoclimatic implications of stabilized dune fields that exist far (> 50 km) from the modern Great Lakes shorelines. The dunes are common in both upper and lower Michigan where they overlie a variety of glaciolacustrine sediments. In general, these dunes have been assumed to be beach ridges that developed in association with the myriad of proglacial lakes that existed at the end of the Pleistocene. Rather than being linear features, however, they are parabolic in form with northwesterly-oriented limbs. Thus, they must have formed since the lakes receded, either during the very late Pleistocene or Holocene, when northwesterly winds prevailed. In order to partially reconstruct the eolian chronology, surface soils in many of these dunes have been analyzed and a limited number of radiocarbon ages of buried wood and charcoal have been
obtained.

Results thus far suggest that several periods of eolian mobilization have occurred. Basal radiocarbon ages indicate mobilization both during the late Pleistocene and middle Holocene. Analysis of surface soils in the Saginaw lowland suggest most dunes stabilized concurrently, possibly during the early to middle Holocene, following a period of regional mobilization. In addition to the basal and surficial data, several buried soils have been recognized in several dunes. Radiocarbon ages have been recovered from charcoal in each of these soils and indicate that localized eolian activity has transpired, probably due to fire, in the late. Overall, the record suggests that individual dunes and dune fields have episodically mobilized in time and space, with destabilization hypothetically linked to climate change, fluctuations in the level of Lakes Michigan/Superior/Huron, and fire.

THE EFFECT OF LAND USE CHANGE ON GROUNDWATER FLOW PATTERNS AND CHEMISTRY IN THE GRAND TRAVERSE BAY WATERSHED

David F. Boutt and David W. Hyndman, Michigan State University, Department of Geological Sciences, 206 Natural Science Building, East Lansing, Michigan 48824-1115
Bryan C. Pijanowski, Michigan State University, Department of Entomology, East Lansing, Michigan 48824
David T. Long and Andrew W. Olds, Michigan State University, Department of Geological Sciences, 206 Natural Science Building, East Lansing, Michigan 48824-1115
Sheridan K. Haack, U.S. Geological Survey, Water Resources Division, 6520 Mercantile Way, Suite 5, Lansing, Michigan 48911-5971

Michigan's Grand Traverse Bay Watershed (GTBW) has some of the highest rates of development in the United States. This development is likely causing significant changes to the hydrobiogeochemical

dynamics of the watershed. We will use our Land Transformation Model to predict the effects of development on watershed hydrobiogeochemical dynamics. A relationship between recharge/evapotranspiration rates and land use patterns will be estimated based on historical data. The model will predict the seasonal flux of groundwater to the bay and will provide estimated flowpaths through the regional aquifer. In addition, information from our water quality sampling will be used to model the relationship between land use/cover and biogeochemical parameters in groundwater. This study builds upon a 1986 report by the U.S.G.S., which catalogued biogeochemical parameters, land use, and hydrologic parameters for a subset of the GTBW, Grand Traverse County, MI, in 1984-86. With much of the State of Michigan experiencing land transformation, the findings of this study will provide insight into similar effects throughout the Great Lakes Basin.

IMPROVING PRODUCTION BY IDENTIFING AND CHARACTERIZING FRACTURES AND POROSITY HETEROGENEITY IN INTERWELL AREAS USING BOREHOLE GRAVIMETRY ("BHGM")

James W. Bradley, Diana Morton-Thompson and Paul A. Daniels, Earth Resources International, L.C., P.O. Box 20245, Kalamazoo, Michigan, 49019-1245

Fractures and high porosity/permeability zones can contribute in excess of 95% of the total fluid flow to a wellbore. Therefore, the identification and management of such zones is critical to maximizing well/field life and ultimate recovery. Reservoirs with these types of high porosity/permeability zones include, but are not limited to: fractured sandstones, carbonates, and shales; dolomitized collapse features; and heterogeneous carbonates, such as reefs.

Because the Borehole Gravimeter provides detailed, in-situ, bulk density information, that is not available from other downhole evaluation devices, the Borehole Gravimeter has proven extremely successful in evaluating interwell areas. Results of various reservoir examples will be presented, including specific examples from the Michigan Basin.

The Borehole Gravimeter has three strengths over conventional tools:

1. The ability to observe bulk density variations resulting from fractured- and/or facies-controlled porosity that may exist at a distance from the wellbore, but that are not necessarily present (or not visible) in the wellbore.
2. The ability to observe bulk density variations at distances of up to 500 feet from the wellbore.
3. The ability to quantify porosity values down to approximately one-fourth (0.25) to one-half (0.5) of a percent.

In addition, the improved accuracy in bulk density and porosity measurements can result in:

1. Rapid identification of by-passed reserves.
2. Identification of fluid type and fluid contacts.

3. More accurate volumetric calculations (with the consequent possibility of additions to booked reserves).
4. A clearer understanding of the structural fabric(s) and facies relationships that control the three dimensional (3-D) porosity/permeability distributions.
5. Improved calibration of 3-D seismic modeling/mapping and reservoir simulation.

THE USE OF SEISMIC DATA AND ATTRIBUTES FOR RESERVOIR CHARACTERIZATION IN CRYSTAL FIELD, MICHIGAN

Terra E. Bulloch and Wayne D. Pennington, Michigan Technological University, Department of Geological Engineering, Geology and Geophysics, 1400 Townsend Drive, Houghton, Michigan 49931-1295

The Dundee Formation (Devonian) is of particular interest because it has yielded more oil than any other producing interval in the Michigan Basin. Crystal Field is one of the more prolific oil fields in the Dundee Formation. Recent drilling activity has shown that a large amount of by-passed oil has been left between many wells in the Dundee Fields, including Crystal Field. A recent experiment involved drilling a horizontal well in Crystal Field, the Tow 1-3. This well was very successful with a production rate of 100 bbls of oil per day and over 60,000 bbls in less than 3 years, leading to increased interest in new production techniques. While the geology of some Dundee fields in the Michigan Basin is reasonably well known, many old fields generally lack modern well logs and seismic studies.

The objective of this project is to interpret seismic attributes, such as instantaneous frequency and amplitude, in terms of lithology and reservoir properties, and use that information for reservoir characterization. More specifically, the seismic travel time and simple seismic attributes will be evaluated and compared with known structure and geology within the Crystal Field. Four seismic lines across Crystal Field have been loaded into GeoGraphix SeisVision and are currently being evaluated. Future work includes obtaining the preprocessed (prestack) seismic data and processing it (partially in-house). A particular goal is to enhance faults or karstic features based on seismic attributes. The reflection character will also be studied to determine if it changes with the presence of a limestone cap or with dolomitization. If successful, this project should provide oil producers with a new interpretation tool to evaluate reservoirs and monitor the overall performance of a field.

INVESTIGATING HEAVY METAL PARTITIONING IN SEDIMENTS FROM DIFFERING REDOX ENVIRONMENTS

Robert J. Ellis, Gary A. Icopini, and David T. Long, Michigan State University, Department of Geological Sciences, 206 Natural Science Building, East Lansing, Michigan 48824-1115

The fates of heavy metals (e.g., Cr, Fe, Cu, Pb and Zn) are being studied in sediments at a former tannery site. The sediments vary in degree of water saturation, redox state and organic matter content

and have metal concentrations ranging from background to elevated. These conditions afford the opportunity to study the biogeochemical fate of heavy metals under diverse sediment environments and microbiological processes. Selective chemical extractions and porewater chemistry are being used to determine metal partitioning within sediments and between solid and liquid phases, respectively. Information gained from sequential chemical extractions, developed for oxic systems, is being evaluated for anoxic systems.

In oxic sediments, the easily reducible (ER - Mn oxides and reactive Fe oxides), moderately reducible (MR - Fe oxides) and basic oxidizable (BOX - organic matter) are the most important sequestering phases. In anoxic soils the three phases are also important, but the substrates comprising the ER and MR phases are unclear. Thermodynamic modeling of anoxic pore water chemistry indicates near or supersaturation with respect to FeS, $FeCO_3$, and Fe_3O_4. Experiments involving acid volatile sulfides, simultaneously extracted metals (AVS/SEM) and magnetic separation all show the presence of FeS and Fe_3O_4. However the masses of these minerals cannot account for all the Fe in the ER and MR phases. Thus, $FeCO_3$ and/or resistant Fe oxides may be present in these soils. This is a subject of ongoing investigation.

Our results show that sequential extractions can be used in more anoxic systems, but more work is needed to determine what substrates are being attacked. Multiple substrates may comprise operationally defined extraction phases and these substrates may be metal-specific. The importance of characterizing pore water chemistry when applying sequential chemical extractions to anoxic sediments is evident. Microbial processes may play a key role in determining the nature of substrates available to immobilize metals under anoxic conditions.

IMPLICATIONS OF THE 1994 CENTRAL MICHIGAN EARTHQUAKE ON HAZARD ASSESSMENT IN SOUTHERN MICHIGAN

Kazuya Fujita, Kevin G. Mackey, and Trent H. Faust, Michigan State University, Department of Geological Sciences, 206 Natural Science Building, East Lansing, Michigan 48824-1115

On September 2, 1994, a magnitude 3.4 (USGS) earthquake occurred near Lansing, Michigan, as 21:23:10 UTC (5:23:10 local time). Based on isoseismal data and records from nearby stations, the epicenter was located 4-5 km north of Eaton Rapids and the focal depth is estimated to be 10-15 km. This event was the first felt natural earthquake centered in southern Michigan in nearly 50 years and provides some preliminary insights on the level of seismic risk from local earthquakes.

Very few faults have been mapped in southern Michigan and no active faults are visible at the surface. Based on isopach and structure contour data, Fisher (1981) identified several faults, notably the northwest-southeast striking Howell Fault in Livingston County. Geophysically, the Mid-Michigan gravity high trends generally in a northwest-southeast direction, although its strike changes locally by a few tens of degrees. There is also a discontinuity in the magnetic field extending from South Haven to north of Coldwater that has been suggested to reflect a basement fault.

In examining the 1994 Central Michigan earthquake, we noted that the few P-wave first motions were consistent with a compressional quadrant to the southeast, similar to solutions obtained for earthquakes in Ohio and northern Kentucky. We suggested, therefore, that the 1994 event occurred on a roughly northwest-southeast striking left-lateral strike-slip fault that branched off the Lucas-Monroe Fault and included a short fault along the Ingham-Jackson county line proposed by Fisher (1981).

The isoseismals of the magnitude 4.7 Coldwater earthquake of 1947 have the same trend as the geophysically inferred South Haven-Coldwater Fault. Schwartz and Christensen (1988) suggested that the magnitude 4.5 1986 St. Mary's Ohio earthquake was also generated along a northwest striking fault. Thus, there is extensive evidence for nearly parallel northwest-striking faults spaced about 75-100 km apart throughout southern Michigan northwest Ohio; this pattern likely extends across northern Indiana as well. These faults appear to generate earthquakes with magnitudes up to about 5 with intensities up to VI. Although recurrence rates are not known, the northwest Ohio zone is quite active with 7 events with intensities greater than IV in the past century and there are 2 or 3 events with intensities greater than III or IV in southern Michigan since the 1870's. Thus a recurrence time of about 50 years in southern Michigan for a magnitude 3 to 5 event (maximum intensity of III to VI) is a reasonable estimate.

Based on empirical relationships, these events should yield horizontal accelerations not exceeding 0.05**g** in river valleys and 0.035**g** on bedrock. Vertical accelerations are generally expected to be 25-50% lower. However, strong events from the New Madrid seismic zone of Missouri are expected to generate much higher accelerations, perhaps as high as 0.07**g** in river valleys. Given the estimated recurrence rates for New Madrid events, a reasonable estimate for the maximum horizontal acceleration in southern Michigan is likely to be 0.05**g** on a 50-100 year time scale and 0.07**g** on a 1000 year time scale.

THE ROLE OF SCIENCE IN PUBLIC POLICY DECISIONS: THE POTENTIAL USE OF MICHIGAN'S SALT FORMATIONS FOR HAZARDOUS WASTE MANAGEMENT

Julie Gales, Legislative Services Bureau, P.O. Box 30036, Lansing, Michigan 48909

The Role of Science in Public Policy Decisions: The Potential Use of Michigan's Salt Formations for Hazardous Waste Management

State legislation addressing science, engineering, and technology issues has increased over 30% in the last 20 years. Ideally, legislative debate on these issues is extensive and fueled by accurate information. However, most state legislators and their staff do not have the scientific expertise necessary to grasp many of these complex technical issues on their own. Therefore, they are left with the question "Where do I turn for useful scientific and technical information and analysis?"

Michigan began providing in-house scientific and technical expertise to its state legislators in 1979

through a pilot program with the National Science Foundation. The pilot project proved to be so successful that, when the grant expired, the Michigan Legislature appropriated funding to support a science office as part of their nonpartisan central staffing agency, the Legislative Service Bureau (LSB). Today, the LSB's Science and Technology (S&T) Division is comprised of six research staff and two support staff. The S&T Division provides unbiased, objective scientific, engineering, and technical information to the Michigan Legislature.

In 1987, the S&T Division was asked to identify issues related to the state's limited amount of hazardous waste disposal capacity and to provide options for legislative action. Michigan faced an estimated five years of capacity at the state's only commercial hazardous waste landfill. Also at this time, new federal regulations provided for the use of a range of nontraditional waste disposal facilities, including subsurface salt mines. The option was particularly appealing to some policy makers and industry representatives because there is abandoned salt mine below the city of Detroit. However, room and pillar salt mines had never been used for hazardous waste disposal in North America. Therefore, other legislators and members of the public opposed this use, claiming that regulatory agencies did not have the appropriate technical experience or regulations in place to permit hazardous waste disposal in salt mines.

In this politically charged environment, the S&T Division was requested to provide objective information on the pertinent scientific, regulatory, and policy issues regarding the use of Michigan's salt formations for hazardous waste disposal. Specifically, we provided information on Michigan's geology and mine engineering research; theoretical, technical, and regulatory issues related to the hazardous waste disposal; policy issues related to subsurface waste disposal; room and pillar mine closure options; and the use of a pre-existing facility. The research was used extensively by both proponents and opponents of the salt mine disposal option and continues to be in demand as geologic and waste management policy issues arise in the Michigan Legislature. While the intense political debate has died down in recent years, there are policy issues outstanding that would have to be addressed before Michigan sited a disposal facility in a subsurface mined space. The potential use of Michigan's salt formations for hazardous waste disposal will be presented as a case study of how scientists serve state policy makers.

TEMPORAL HETEROGENEITY IN AQUEOUS GEOCHEMISTRY AND MICROBIOLOGY OF A CONTAMINATED AQUIFER

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Larry. J. Forney, University of Groningen, Department of Microbiology, Kerklaan 30, PO Box 14, 9750 AA Haren, The Netherlands
Peter Adriaens, University of Michigan, Department of Civil and Environmental Engineering, Ann Arbor, Michigan 48109
Francis H. Chapelle, U.S. Geological Survey, Water Resources Division, tephenson Center, Suite 129, Columbia, South Carolina 29210

The goal of this interdisciplinary study is to better understand how spatial and temporal variation in aqueous geochemistry and microbial community structure affects the intrinsic bioremediation of fuel and chlorinated solvents. Our sampling program is designed to 1) determine the dominant terminal electron accepting process (TEAP) by measuring the H_2 gas concentration of ground water; 2) determine patterns of microbial community DNA composition in sediments taken from each TEAP zone, by using amplified ribosomal DNA restriction analysis (ARDRA) and denaturing gradient gel electrophoresis (DGGE); and 3) determine patterns in the distribution and abundance of TEAP-specific microbial populations (e.g., methanogens, sulfate-reducers) by using hybridization to 16S rRNA extracted from aquifer sediments.

On three dates, we sampled ground water in a shallow, sandy aquifer contaminated with jet fuel and chlorinated solvents. Samples taken from five multi-level wells and 2 single-depth wells were analyzed for redox chemistry (NO_3, NH_4, Fe(II), SO_4, and CH_4), and nucleic acids were extracted from aquifer sediments taken from each TEAP zone. For the last two sample sets, we also determined major ions and contaminant chemistry. Preliminary results suggest that there are dramatic (but logical and predictable) spatial and temporal changes in TEAP's at this site, and that microbial community DNA composition (ARDRA and DGGE patterns) for a given location in the aquifer changes with the TEAP. Preliminary 16S rRNA hybridization data suggest that methanogens (or other Archaea) are most abundant in sediments where the TEAP indicates methanogenesis during some part of the year. Once determined and accounted for, knowledge of site geochemical and microbiological heterogeneity can be used to refine sampling strategies and monitoring programs, improve the reproducibility of field and laboratory tests for biodegradation, and develop more accurate models.

HORIZONTAL DRILLING FOR OIL AND GAS IN THE MICHIGAN BASIN

William B. Harrison, III, Michigan Basin Core Research Laboratory, Department of Geology
Western Michigan University, Kalamazoo, Michigan 49008

The first horizontal well was drilled in Michigan in 1985. As of December 1, 1997 there have been 214 horizontal wells drilled and completed. Another 140 wells are pending, having been permitted and are in various stages of planning, drilling, or waiting on completion. All horizontal wells have been drilled in known fields in previously productive reservoir zones. Most of these fields were considered to be depleted or approaching an economic productivity limit with respect to their existing vertical wells. About 93% of the completed horizontal are considered to be successful. Only about 7% have been declared dry holes.

Horizontal drilling in Michigan began slowly with only 66 wells completed between 1985 and 1994. In 1995, 1996, and 1997 there were nearly 50 wells completed each year. Improvements in horizontal drilling technology and successful wells in Michigan have contributed to the increased horizontal drilling activity.

Horizontal wells in Michigan are mainly being used as a secondary recovery technology to improve productivity in Michigan's aging fields. A few horizontal wells have also been drilled in gas storage reservoirs to greatly enhance injection or withdrawal rates.

Twelve different Michigan reservoirs have, thus far, been targets of horizontal wells. They range in age from Ordovician to Mississippian and include sandstone, carbonate, and shale lithologies. The most prolifically drilled horizon is the Niagaran pinnacle reefs . Approximately 60% of currently completed horizontal wells are in this formation. The Antrim Shale, Dundee Formation, Trenton/Black River Formations, and St. Peter Sandstone (aka. Prairie du Chien) all have at least 10 completed wells. Other horizons with at least one horizontal completion include the Salina A1-Carbonate, Berea Sandstone, Detroit River "sour zone", Michigan "stray" Sandstone, Reed City Formation, Richfield Member of the Lucas Formation, and Traverse Limestone.

Productivity of these horizontal wells has been variable. Few of the wells have a long history of production by which to evaluate their performance. Using initial production potential (IP) it appears that horizontal wells can perform about the same as vertical wells in the same field. Because the current set of horizontal wells are drilled in existing and supposedly depleted fields, it is unclear what level of production should be expected. Any additional production from these aging fields may be considered beneficial, representing reserves that would have otherwise not have been recovered. Horizontal drilling in Michigan appears to provide the opportunity for recovery of additional hydrocarbon reserves from Michigan's aging oil and gas reservoirs.

RECHARGE TO DISCHARGE GROUNDWATER TRAVEL TIMES IN THE MICHIGAN BASIN AND THE EFFECT OF GLACIAL ICE LOADING

John R. Hoaglund III, GeoLogic Solutions, 1111 E. Hazel St., Lansing, Michigan 48912

Numerical modeling of regional recharge to discharge advective groundwater travel times in the Michigan basin indicates that groundwater residence times are generally much less than 10,000 years for the glacial drift aquifer and greater than 20,000 years for bedrock aquifers. The RAND3D particle tracking solute transport model uses the steady-state U.S. Geological Survey Regional Aquifer Systems Analysis (RASA) Modflow flow model. The flow model shows groundwater heads and flows in the glacial aquifer are controlled by local stream stages and discharges, resulting in localized flow cells accounting for over 90% of the overall model water budget. As a result, the number and extent of flowpaths from the water table of more than 10,000 years is insufficient to transport isotopically changing recharge of the Younger Dryas and subsequent warming climatic events to produce isotopically light groundwater anomalies observed in the Saginaw lowlands. Since the Younger Dryas was the last climatic event cold enough to produce the lightest isotopes from recharge, another mechanism is implied. Given the short residence times of shallow groundwater, deep penetration for long duration is required for the emplacement of the light isotopic groundwater mass if the mass is to endure 10,000 years of subsequent discharge. An alternative hypothesis is the reversing of

groundwater flow by the loading of glacial meltwater, either directly by the ice or indirectly from high proglacial lake stands. Groundwater modeling of the Port Huron glacial advance using Modflow and the existing RASA model showed that the effect of ice loading is localized to the region of the ice sheet where groundwater flow is reversed and affects the bedrock aquifers, with a strong downward component of flow beneath the icesheet and an upward component of flow into a large proglacial lake. The modeling shows that given the assumptions in the model, ice loading is a very effective mechanism for introducing light isotopic water from the icesheet deep into the aquifer systems

VULNERABILITY OF GROUND WATER TO ATRAZINE LEACHING IN KENT COUNTY, MICHIGAN

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A steady-state model of pesticide leaching through the unsaturated zone was used with readily available hydrologic, lithologic and pesticide characteristics to estimate the vulnerability of the near-surface aquifer to atrazine contamination from non-point sources in Kent County, Michigan. The model-computed fraction of atrazine remaining at the water table was used as the vulnerability criterion; time of travel to the water table was also computed. Model results indicate the average fraction of atrazine remaining at the water table was 0.039%; the fraction ranged from 0% to 3.6%. Time of travel of atrazine from the soil surface to the water table averaged 17.7 years and ranged from 2.2 years to 118 years.

Aquifer vulnerability estimates were used with a steady-state, uniform atrazine application rate to compute a potential concentration of atrazine in leachate reaching the water table. The average estimated potential atrazine concentration in leachate at the water table was 0.16 µg/l in the model area; estimated potential concentrations ranged from 0 µg/l to 26 µg/l. About 2 per cent of the model area had estimated potential atrazine concentrations in leachate at the water table that exceeded the U.S. Environmental Protection Agency maximum contaminant level of 3µg/l.

Uncertainty analyses were used to assess effects of parameter uncertainty and spatial interpolation error on the variability of estimated fractions of atrazine remaining at the water table. Results of Monte Carlo simulations indicate parameter uncertainty is associated with a standard error of 0.0875 in the computed fractions. Results of kriging analysis indicate that errors in spatial interpolation are associated with a standard error of 0.146. Thus, uncertainty in fractions remaining is primarily associated with spatial-interpolation error, which can be reduced by increasing the density of points where the leaching model is applied. A sensitivity analysis indicated that fractions remaining are most sensitive to unit changes in pesticide half-life and in organic-carbon content in soils and unweathered rocks, and least sensitive to infiltration rates, among the 13 parameters investigated.

CHROMIUM SPECIATION AND MOBILITY IN A WETLAND ENVIRONMENT

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Here we report data from studies to understand the fate and transport of chromium at a former leather tannery site. The studies are being done to assess the potential use of biogeochemical processes to limit Cr mobility (biostabilization). High Cr levels (up to 200,000 mg/kg) are found in surface soils at the site that range from sandy and oxic to peaty and anoxic. Sequential chemical extractions (SCE's) were used to identify substrates that sequester Cr in six operationally defined phases of the soils. In both anoxic and oxic soils, Cr was primarily associated with an acidic, moderately reducible (MR) phase and a basic, oxidizable (BOX) phase. In anoxic soils a significant amount of Cr was also associated with an acidic, easily-reducible (ER) phase. A positive linear correlation was observed between the concentration of Cr in the BOX phase and total organic matter. The data suggest there are multiple sequestering mechanisms for Cr in these soils. In oxic soils, sequestering most likely occurs through sorption to or coprecipitation with Fe oxyhydroxides in the MR phase and organic matter in the BOX phase. Other than sorption to organic matter, the most likely mechanism for Cr immobilization in anoxic soils is the formation of a Cr-hydroxide precipitate.

Pore-water samples were also collected at this site and modeled using PHREEQC. No quantifiable aqueous Cr(VI) was detected. However, pore-water concentrations of Cr are higher than predicted by equilibrium with the most soluble Cr minerals in the data base used for the modeling. This indicates that Cr solubility is being influenced by factors that are not incorporated in the thermodynamic modeling. These factors include non-equilibrium conditions, Cr-organic complexation and colloidal transport. A positive linear correlation was observed between total aqueous Cr and neutrally/negatively charged Cr species, which indicates that the aqueous Cr is neutrally or negatively charged. This suggests that the elevated aqueous Cr concentrations are a result of colloidal transport or Cr-organic complexation.

TERRACE ELEVATION AND LAKE LEVEL RELATIONSHIPS IN THE LOWER ST. JOSEPH RIVER VALLEY

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The Wymer site is a multi-component archeological site on the St. Joseph River floodplain about one mile north of Berrien Springs, Michigan. Early and Middle Archaic cultural phases were found at the site. These sites are unusual in that their occurrence corresponds to the extreme low lake levels associated with Lake Chippewa and the people were assumed to have occupied those now submerged

shoreline areas. A geologic evaluation of the site was undertaken to examine the sediments and depositional structures. Trenches, grain-size analysis, radiocarbon samples and valley topography were used to determine that the site was a point bar situated on a terrace 2.5 meters above the modern floodplain. The deposit was probably associated with headward erosion during a time of higher energy at a lower base level. Organic sediments at the assumed position of the river channel during deposition of the point bar yielded radiocarbon dates of 6,920 and 5,550 years B.P. Comparison of site data to published lake level fluctuations over the last 14,000 years yielded an early Algonquin/Chippewa regression time frame to match the energy requirements for point-bar deposition associated with headward erosion of the river into the inside edge of the Valporaiso Moraine. The radiocarbon dated samples indicate a subsequent period of aggradation that preceded the Nipissing high stand by at least 1,900 years.

QUALITY OF SHALLOW GROUND WATER IN RESIDENTIAL AREAS, GREATER METROPOLITAN DETROIT, MICHIGAN

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Water samples were collected from a network of 30 shallow monitoring wells in areas of residential land use in greater metropolitan Detroit to assess the quality of recently recharged shallow ground water in a residential setting. The wells, which were screened just below the water table, were installed by the U.S. Geological Survey in areas of Pleistocene outwash underlain by interbedded sandstone and shale bedrock of Mississippian age. Water samples were analyzed for major and trace elements, nutrients, radon and pesticides. Arsenic was detected in 7 of the samples at concentrations below the U.S. Environmental Protection Agency Maximum Contaminant Levels for drinking water. The Maximum Contaminant Level was exceeded for nitrate in 1 of the samples. Samples from 21 of the 30 wells were collected and analyzed for radon and detectable concentrations were found in all 21 samples. Pesticides were not commonly detected in samples, and no pesticide was present at a concentration exceeding its Maximum Contaminant Level. Simazine was detected in 1 of the samples. Desethyl atrazine was detected in 1 of the samples.

This study was conducted as part of the U.S. Geological Survey's National Water Quality Assessment program in the Lake Erie-Lake St. Clair drainage basin.

INVESTIGATION OF PCB'S, PAH'S AND HEAVY METALS IN SEDIMENTS AND WILDCELERY TUBERS AT GRASSY ISLAND, SHIAWASSEE NATIONAL WILDLIFE REFUGE, WYANDOTTE UNIT, WYANDOTTE, MICHIGAN

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Grassy Island is a diked confined disposal facility (CDF) on a national wildlife refuge in the Detroit River that was used by the Army Corps of Engineers for sediments dredged from the Rouge River between 1961 and 1983. Previous studies have shown that the sediments in the CDF contained heavy metals and chlorinated organic compounds and that wildlife using the island were exposed on site to these contaminants. In 1995 Grassy Island was designated a Hazardous Materials Management (HAZMAT) demonstration site by the Department of the Interior. Because it is located near municipal water intakes for the cities of Detroit and Wyandotte, and because large numbers of migratory diving ducks feed on wildcelery tubers in shoal sediments around the island, concern was raised about whether contaminants are adequately contained in the CDF and if wildlife using the refuge are being exposed to measurable contamination.

This study addressed the distribution of heavy metals, polychlorinated biphenyls (PCB's) and polycyclic aromatic hydrocarbons (PCA's) in surface soils collected at 40 locations that were selected systematically in a stratified-random manner over the entire island by application of a grid overlay, and in wildcelery tubers and river bottom sediments collected at four stations along a transect immediately upstream and downstream of the island where tuber densities in the river sediments were known to be high. Soil samples were collected on the island in March, 1997. Tubers and river sediments were collected near the island in October, 1997. All island soil samples were screened for PCB's and PAH's within 1 day of collection using enzyme immunoassays and analyzed for metals within 3 days of collection with appropriate quality assurance and control by an EPA-certified contract laboratory near Ann Arbor, Michigan.

Preliminary results showed the highest concentrations of PCB's, PAH's and selected heavy metals in island soils, river sediments and wildcelery tubers were (in mg per dry kg):

Sample Matrix	Variable									
	PCB	PAH	As	Cd	Cr	Cu	Hg	Ni	Pb	Zn
Island soils	12	68	20	19	370	360	1	100	2000	2000
River Sediments	ND	13	4	ND	10	21	0.1	12	18	47
Wildcelery Tubers	ND	ND	2	0.9	1.1	4.4	ND	ND	ND	22

CONCLUSION: Contaminant levels are higher inside than immediately outside the CDF. Waterfowl

inhabiting ponds on the island are potentially exposed to higher levels of these contaminants than waterfowl feeding on wildcelery tubers that grow near the island. Because river sediments adhere to tubers consumed by waterfowl, waterfowl are exposed not only to metals in tubers but also to all of the above variables in river sediments.

SOILS AND SOIL SEQUENCES IN THE LEELANAU DRUMLIN FIELD, MICHIGAN

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The examination of soils and the surficial deposits in which they have formed is often a useful means to establish the Quaternary history of an area. This study's goals were twofold: 1) to establish whether a fine sandy loam cap found on drumlins in northeastern lower Michigan exists on drumlins in Leelanau County, Michigan, and 2) to characterize the caternary relationships of the soils and the surficial deposits found there. Drumlins were identified on topographic and county soil survey maps, and transects were established roughly perpendicular to the axes of the drumlins. Soil samples were gathered from summit, backslope, footslope, and toeslope areas. Preliminary particle size analyses indicate that if a fine sandy loam cap is present, it is subdued by the presence of fairly high (on average about 25% of the sample) and consistent fine sand content throughout the profiles sampled. In general, summit and backslope profiles have an upper sandy loam layer that is virtually stone free, over a thin gravelly layer, which is underlain by sandy loam till. Upland soils usually key out asTypic Eutroboralfs. Foot and toeslope areas are more variable with a wide range in both fine sand content and parent materials. Lowland soils key out across a wide variety of taxonomic classes, including Mollic Epiaquepts and Terric Borosaprists. Stonelines in many of the upland soils, the presence of stratified clays at a lowland (between drumlins) site, and new evidence suggesting much higher lake stands in this region, all seem to indicate that this region may have experienced subaqueous deposition in the Late Pleistocene.

APPLYING GEOLOGIC SENSITIVITY ANALYSIS IN THE ROUGE RIVER WATERSHED

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The financial risks associated with environmental contamination can be staggering and are often difficult to identify and accurately assess. Geologic sensitivity analysis is gaining recognition as a significant and useful tool that can empower the user with crucial information concerning environmental risk management. It is particularly useful when (1) evaluating the potential risks associated with redevelopment of historical industrial facilities and (2) planning for future development, especially in areas of rapid development because the number of potential contaminating sources often increases with an increase in economic development.

The first step in conducting an analysis of geologic sensitivity to environmental contamination was to

revise and update the surface geologic map of the Rouge River Watershed. The revised geologic map was, in large part, based on previous maps and geologic and hydrogeologic information collected from subsurface investigations conducted at more than 3000 sites of environmental contamination. Once the revised surface geologic map was completed a sensitivity map was prepared by integrating information from known soil and groundwater contamination, environmental risks and environmental cleanup costs with the revised geologic map. To evaluate geologic sensitivity and risk at a specific location, a geologic sensitivity model was developed that used information on (1) the soil type, (2) the depth to groundwater, (3) the abundance of groundwater, (4) the position of specific geologic units, (5) the potential potable use of groundwater, (6) the groundwater migration rate and (7) the potential groundwater/surface water interaction. The map uses information unique to the Rouge River Watershed to evaluate potential environmental risk posed by a site.

An examination of the financial implications relating to geologic sensitivity analysis in the Rouge River Watershed from numerous case studies indicates that the environmental cost of contamination may be more than 100 times greater at a geologically sensitive location compared to the least sensitive location. Geologic sensitivity analysis has demonstrated that near-surface geology may influence the environmental impact of a contaminated site to a far greater extent than the amount and type of industrial development.

The geologic sensitivity map that has been developed for the Rouge River Watershed, a rapidly developing region of several million people where industrial development has existed for more than 100 years, has implications for most other urbanized areas of the country.

AN EVALUATION OF HEAVY METALS IN SOIL IN THE ROUGE RIVER WATERSHED

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To evaluate heavy metals within the Rouge River Watershed, more than 3000 project files from subsurface investigations conducted at sites of environmental contamination were reviewed at the Michigan Department of Environmental Quality (MDEQ) district headquarters in Livonia, Michigan. At approximately 250 of the more than 3000 sites, soil samples were analyzed for heavy metals. From the 250 sites, 5340 soil samples were analyzed for metals. Typically, the metals of concern included arsenic, barium, cadmium, chromium, copper, lead, mercury, nickel, selenium, silver and zinc.

Each soil sample analyzed for heavy metals was segregated into categories according to soil type and geologic unit. Surface soil (defined as that portion of the soil column within 2 feet of the ground surface) was treated as a separate category. Nine different categories were identified and included: moraine, outwash, sandy clay, sandy and silty clay, upper clay, lower clay, sand and fill material.

Statistical analysis of the data reveals that heavy metals from suspected anthropogenic sources within the Watershed are most prevalent in the surface soil and least prevalent in the lower clay unit. Elevated

concentrations of heavy metals from suspected anthropogenic sources including barium, cadmium, chromium, copper, lead, nickel and zinc are observed in each of the nine categories. Elevated concentrations of arsenic, mercury, silver and selenium from suspected anthropogenic sources are not observed. However, elevated concentrations of arsenic may not be observed potentially because of arsenic's solubility. Elevated concentrations of mercury may not be observed because of sample collection methods (i.e. sample dilution). The absence of observed anthropogenic impact from silver and selenium is most likely due to the lack of significant anthropogenic sources for these specific metals.

In addition, the statistical evaluation of the data reveals that lead represents the most significant anthropogenic impact of the 11 heavy metals evaluated. In addition, it appears that more than two populations of lead are present in surface soil within the Watershed. The lead populations within the data are suspected to originate from (1) naturally occurring lead concentrations, (2) anthropogenic airborne sources (e.g., automobile exhaust) and (3) anthropogenic point sources (e.g., lead shot, lead paint, slag).

The results of this study suggest that accumulation of heavy metals in the urban environments of the Rouge River Watershed from anthropogenic sources primarily occurs at or near the surface of the ground. In addition, this study has also revealed that evaluating naturally occurring concentrations of heavy metals in an urban environment may not be possible because anthropogenic concentrations of heavy metals dramatically distort and mask the naturally occurring concentrations.

A NEW METHOD OF MEASURING THE A-AXIS IN QUARTZ USING FLUID INCLUSION MORPHOLOGY

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To understand the processes at work in the deformation of rock, focus is placed upon the microstructures within the rock; mainly the orientations of the axes of the minerals. In cases where the deformation results from a low strain rate and temperature, measuring the axis is an uncomplicated procedure. However, with higher strain and temperature, measurements can become complicated and costly. Therefore, development of a new procedure for obtaining orientation of minerals in rocks would greatly benefit microstructural studies.

This project endeavors to develop a new procedure using fluid inclusion morphology to measure the a-axis in quartz crystals of rocks sampled from the Simpson Fault Zone in Switzerland. Preliminary work has shown promise in successfully locating the a-axis in deformed aggregates of quartz. Completed measurements from this study will be compared to measurements derived by an X-ray texture goniometer of the same rock. A successful match of the two sets of measurements will bring to the world of microstructure studies a new method that will save time and money.

FATE OF HYDROCARBON CONSTITUENTS DURING LAND TREATMENT

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Land treatment is a low-cost option for hydrocarbon-contaminated soils. Crude oil (3 wt% TPH) was incorporated into a pilot land treatment unit (2500 ft^2) without a subsurface liner or surficial cover. The fate of TPH, VOC constituents and BTEX was monitored as a function of time. Emission rates of benzene and VOC's were measured using an Isolation Flux Chamber. Leaching of BTEX was detected using subsurface lysimieters to 7 feet beneath the treatment unit in a one-time event following a heavy rainfall event three days into the project. Hydrocarbon concentrations in the soil were also monitored. Biodegradation was the primary fate pathway for TPH ($\cong$ 85%); volatilization and sorption accounted for the balance. Volatilization was the primary fate pathway for benzene ($\cong$ 70%); biodegradation and leaching accounted for the balance ($\cong$ 30 % and < 0.5%, respectively). Environmental impact assessments have been completed to estimate appropriate loadings of hydrocarbon material into units to be protective of ambient air and groundwater standards.

NEW VIEWS ON THE PLEISTOCENE HISTORY OF NORTHEASTERN LOWER MICHIGAN.

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This study will present new data on the geomorphic history of NE lower Michigan, based on interpretations of surficial data and soils, geomorphic features, landscape "linearity", and till fabrics. These new data suggest:

1. The Port Huron advance, circa 13 ka, was the last major advance to enter this part of Michigan, i.e., the Greatlakean ice was much more areally restricted than was previously thought and may not have advanced much farther south or east than Mullett Lake.
2. The Port Huron ice advanced into the area from the northwest, largely out of the Lake Michigan basin, rather than approaching from the northeast as previously thought.
3. As the Port Huron ice advanced into northeastern lower Michigan, it "turned" and changed direction, from a NW-SE orientation to a due south orientation, essentially paralleling its large end moraine in Otsego, Montmorency and Oscoda Counties.
4. During the Port Huron retreat a large lake developed across most of Presque Isle, Montmorency and Alpena Counties, the elevation of which was tens of meters higher than that of Main Lake Algonquin, some 1000 years later.
5. The lake, dammed by the highlands of the Port Huron moraine on the west and south, and (probably) by large ice blocks on the east and north, is responsible for scattered deposits of pink, stratified clays on the uplands throughout northeastern lower Michigan. Many of these clays are now

overlain by dune sand.

A CLOSER LOOK AT DIAGENETIC QUARTZ AND DOLOMITE WITH ATOMIC FORCE MICROSCOPY

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Atomic Force Microscopy (AFM) provides petrologists with nanometer (10^{-9} meter) scale resolution. Smooth surfaces observed with light and scanning electron microscopes are not smooth at all. Instead they have:

1. Round to polygonal topographic highs (referred to here as islands).
2. Flat terraces with steep edges.
3. Growth spirals.

The different topographies reflect different growth mechanisms. Growth spirals and flat terraces with steep edges are the expected nanotopography for crystals which grow by layer growth initiated at defects. The island nanotopography is the expected microtopography for growth by polynuclear birth and spread mechanism. AFM analyses of synthetic and natural quartz and dolomite provides evidence of more complex diagenetic histories than previously recognized, suggesting that previous models of diagenesis have been too simplistic in design.

Quartz overgrowths from the Galesville Sandstone (Cambrian, Wisconsin), Marshall Sandstone (Mississippian, Michigan basin), Guadalupe Group (Cretaceous, Venezuela), an agate from Brazil, intraparticle dolomite cement from the Seroe Domi Fm. (Miocene, Netherlands Antilles), a Niagaran reef (Silurian, Michigan basin) and the Trenton Fm. (Ordovician, Michigan basin) have been analyzed. In addition we have examined synthetic dolomite and quartz. The same features found on synthetic mineral surfaces have been observed on natural samples hundreds of millions of years after their formation.

Prism faces of quartz overgrowths commonly are striated. The striations are generally formed by broad flat ridges 10-30 nanometers high and hundreds of nm wide. These features are consistent with a model of layer growth initiated at face boundaries. Pyramid faces on quartz overgrowths are generally characterized by small islands, <1 nm high and approximately 100 nm wide. Similar islands, 2-10 nm high, were observed on quartz crystals from a geode. Growth spirals have been observed on a specimen from the Marshall Sandstone and the Guadalupe Gp. Galesville Sandstone overgrowths have islands superimposed on growth spirals indicating two fundamentally different growth mechanisms.

The surface of dolomite is often characterized by irregular depressions interpreted to be the result of dissolution. However some surfaces are composed of coalescing islands similar to those seen on some of the quartz surfaces. Island topography is apparent on dolomite cement from the Seroe Domi Fm.

and nonplanar dolomite cement from the Trenton Fm. Layer growth features are found on surfaces of deep sea Holocene dolomite and dolomite cement from a Niagaran reef.

WATER RESOURCES OF THE KEEWENAW BAY INDIAN COMMUNITY

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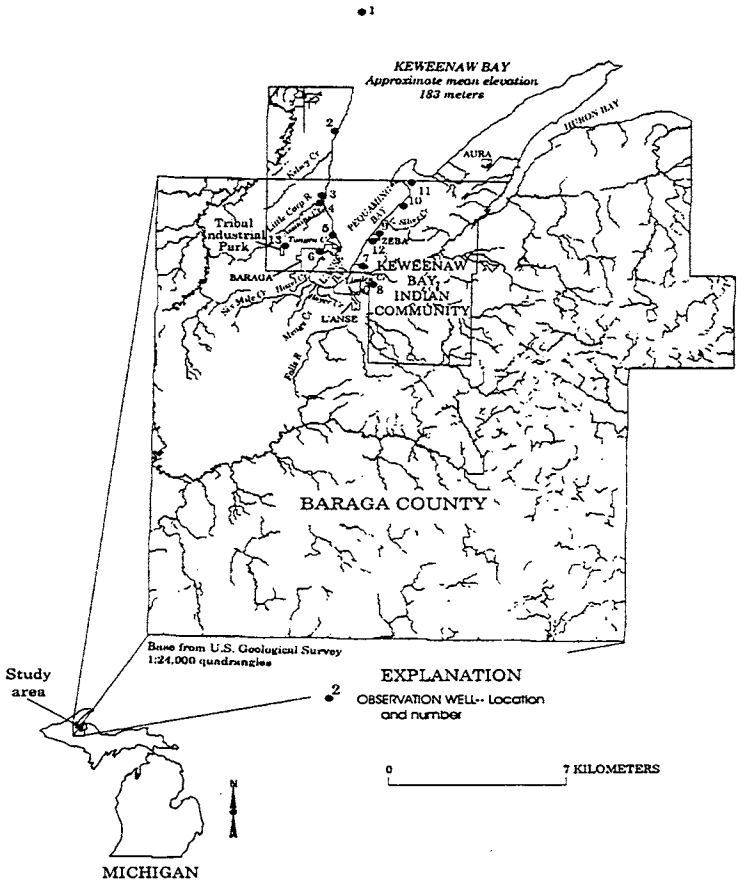

Figure 1. Location of the Keweenaw Bay Indian Community study area and location of ground-water sampling sites.

The Keweenaw Bay Indian Community (figure 1) depends on ground water for most domestic, commercial, and industrial supplies, although the communities of Baraga and L'Anse obtain their water supply from Keweenaw Bay. Plans for additional capacity and development of a Tribal industrial park are being considered, and ground-water sources could be threatened by spills of any contaminants at the park. Information on water resources is needed to make sound decisions about future activities at the industrial park.

Thick, water-bearing surficial deposits are absent from much of the Tribal lands, and bedrock aquifers, principally the Jacobsville Sandstone and the Michigamme Slate, are the primary sources of public water supplies for the community. Aquifer tests and historic water levels indicate that these bedrock aquifers are hydraulically connected, and are confined throughout most of the Tribal lands. Hydraulic conductivities in these formations range from 10^{-4} to 10^{1} meters per day. Near the shores of Keweenaw Bay, Huron Bays, and locally throughout the Tribal lands, water levels in wells are above land surface.

Ground water flows from Tribal lands toward Keweenaw Bay, Huron Bay, and Silver River. Between the Tribal industrial park and Keweenaw Bay, ground water flows to the southeast, toward Keweenaw Bay. Along this flow path, surficial deposits are generally thicker than 26 meters, and contain thick

lenses of clay and clay mixed with sand. The average depth to ground water along this flow path is greater than 26 meters. Wells in this area completed in the underlying bedrock have sustainable yields of 1 liter per second.

The quality of ground water and surface water is suitable for most domestic, commercial, and industrial uses. Locally, however, concentrations of dissolved iron (35,000 µg/l) and manganese (560 µg/liter) in ground water make the water undesirable for some uses.

INVESTIGATION OF SEDIMENT AND WATER CHEMISTRY AT GRASSY ISLAND, SHIAWASSEE NATIONAL WILDLIFE REFUGE, WYANDOTTE UNIT, WYANDOTTE MICHIGAN

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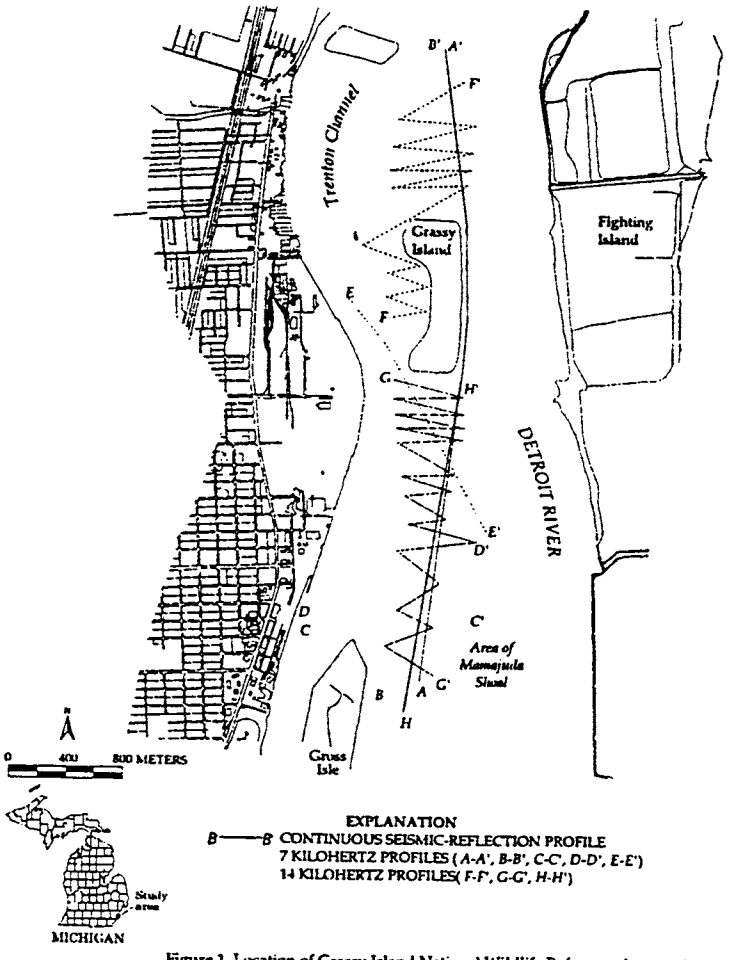

Figure 1. Location of Grassy Island National Wildlife Refuge and approximate location of continuous seismic-reflection profiles.

Grassy Island lies in the Detroit River, 1 kilometer (km) east of Wyandotte. The island has an area of 29 hectares (h) surrounded by 93 h of shoal. A population of five million people lives near the island. The U.S. Army Corps of Engineers (USACOE) used Grassy Island as a confined disposal facility (CDF) for sediment dredged from the Rouge River between 1961 and 1983. The CDF is comprised of 2 tiers of dikes composed of riprap and rubble that contain the dredged sediments. As the first CDF constructed on the Detroit River, it lacks the confinement technology required in more recent CDFs.

In 1961, the island became part of the Wyandotte National Wildlife Refuge because of the large population of migratory waterfowl that feed on wild celery in the shoals near the western and southern shores. Previous investigations by USACOE, Michigan Department of Environmental Quality (MDEQ), U.S. Environmental Protection Agency (USEPA), and the Detroit River Remedial

Action Plan (RAP) have found the sediments and soils deposited on the island to contain concentrations of metals and organic compounds that exceed USEPA limits.

From November 18 through 20, 1996, continuous seismic-reflection profiles (CSP) were collected along the shoals of Grassy Island to determine general lithologic properties, the thickness of riverine sediments, and depth to underlying bedrock. Profiles were collected using both 7 kilohertz (kHz) and 14 kHz energy sources to obtain adequate depth penetration and profile resolution. Profiles were collected in both upstream and downstream directions (north-south), as well as normal to the flow direction (east-west). Sediments are generally glacio-lacustrine clays, and range in thickness from about 1 to 6 meters (m), although they are locally absent.

Between May 20 and June 9, 1997, 16 piezometers were installed. Water levels indicate ground-water flow is radial, from the center of the island toward the perimeter. Water and sediment samples were collected at 10 sites on Grassy Island and in the Detroit River, both north and south of the island, and analyzed for selected volatile organic compounds, semi-volatile organic compounds, pesticides, inorganics, and physical characteristics. Of the 37 samples collected, including blanks and duplicates, 6 were water matrix and 31 were sediment matrix.

Iron was the most frequently detected inorganic analyte, and was present in all water samples and in all but one sediment sample. Calcium, magnesium, sodium and zinc were also detected in all water samples, but only zinc was detected in sediment samples. Manganese was detected in all but one sediment sample and in all but one water sample. Other frequently detected inorganic materials include lead, aluminum and mercury. Few organic analytes were detected in water samples aside from methylene chloride and acetone; both were also present in most sediment samples. Numerous semivolatile organics and pesticides were present at detectable levels in sediments.

MEGA CREVASSE FILLINGS AT SLEEPING BEAR DUNES NATIONAL LAKESHORE AND THEIR RELATIONSHIP TO THE MANISTEE MORAINE

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Leverett and Taylor first described and mapped the glacial geology of Manistee County, Michigan in 1915 and associated the large transverse ridges at Sleeping Bear Dunes National Lakeshore with the Manistee Moraine. Recent inspection of well-exposed 70m-high bluffs at Sleeping Bear and Pyramid Points has revealed that the ridges are underlain almost exclusively by stratified sand locally >70m thick. The sand shows well developed trough cross stratification, climbing ripples, and drapes and locally includes lenses of gravel <0.5m thick as well as beds of fine grained diamict 1-5m thick. The sedimentology exposed in the bluffs indicates that the sand was deposited in a subaqueous environment and most likely represents subaqueous fan deposits associated with water-filled mega crevasses developed when the ice margin stood near the Manistee Moraine. The diamict beds within the sand are probably rainout till deposited when supply of sand to the crevasses was temporarily restricted. This

probably rainout till deposited when supply of sand to the crevasses was temporarily restricted. This interpretation for the origin of the sand and diamict beds means that the transverse ridges at Sleeping Bear Dunes National Lakeshore are actually landforms associated with mega crevasse fillings and should not be associated with a stable ice edge position.

THE COLLECTION OF STRUCTURAL DATA IN AN AREA CONTAINING MAGNETIC ROCKS USING THE TOTAL STATION, TILDEN AND EMPIRE MINES, MICHIGAN. SOME PRELIMINARY RESULTS.

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The ability to make structural measurements in the Banded Iron Formations has been limited to using a sun compass or to surveying methods that are time consuming to perform with precision. The Total Station is an laser surveying instrument with a precision of 5 mm in a km. This allows one to make three measurement on a planes (no larger than one needed for a Brunton compass), such as bedding, cleavage, faults or joints and solve the three point problem to determine dip and dip direction. The same can be done with two measurements for any linear feature such as a fold hinge or a slickenside lineation. The data can be collected rapidly with one person operating the station and another the reflector. The data collected in this study was reduced using a simple routine written on Excel. In the Tilden mine the most significant part of the study delineated the geometry of a large dip-slip reverse shear zone on the southern margin of the Marquette Trough. Shear bands are widely used kinematic indicators, usually occurring with spacings of a few millimeters to a few centimeters. At this location a steep NNE-dipping foliation is cut by shallow NNE shear bands with approximately 3 meter spacing, indicating reverse dip-slip with the principal shortening direction being NNE-SSW. This conforms with previous studies of foliations in sheared mafic dikes adjacent to the Marquette Trough. Folds measured in the hanging wall adjacent to the shear zone plunge gently to the WNW and are overturned towards the SSW, suggesting that the shear zone and the folds formed under the same stress conditions. In the Empire Mine most of the folds also plunge gently to the WNW and the axial surfaces vary from steep NNE to steep WNW dips. There is however a complexity in the Empire Mine that resembles the superimposed folding seen at Jasper Knob, but on a much larger scale. This may be due to a combination of NNE compression and left lateral slip parallel to the Marquette Trough.

ORIGIN AND TRANSPORT OF METHANE AT KINGSFORD, MICHIGAN, AND THEIR RELATION TO GEOLOGY, HYDROLOGY, GEOCHEMISTRY AND MICROBIOLOGY

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On July 12, 1995, accumulation of methane gas in near-surface glacial deposits in Kingsford, Michigan, led to the explosion of a residence. The areal and vertical distribution of methane and the relation of methane to geology, hydrology, ground-water geochemistry and microbiology are subjects of an ongoing investigation by the U.S. Geological Survey, in cooperation with the U.S. Environmental Protection Agency. Interpretations on the origin and transport mechanism of methane are formulated on the basis of existing data.

Stable isotopic composition of methane (stable isotopes of carbon and hydrogen) indicates that it is the product of microbial degradation of organic compounds. Radiogenic carbon dates of methane gas sampled from soils and gas vents, and from methane gas exsolved from ground water show that the methane is modern in age. Acetic acid, formic acid and propionic acid are present in large concentrations in ground water in areas where concentrations of dissolved methane are near or at saturation limits; these organic acids are likely progenitors of methane. Methane is generated and transported in stacked, compartmentalized confined aquifers that are interbedded with silts and clays of eolian or lacustrine origin. Ground water that contains large concentrations of dissolved methane flows toward discharge areas along the Menominee River and enters unconfined conditions where methane appears to be released to the unsaturated zone.

ARSENIC IN GROUND WATER IN THE "THUMB AREA" OF MICHIGAN: THE MISSISSIPPIAN MARSHALL SANDSTONE REVISITED

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In many parts of the "Thumb Area" of Michigan, arsenic is present in ground water at concentrations that exceed the U.S. Environmental Protection Agency's maximujm contaminant level (MCL) which is 50 micrograms per liter. Typically, groundwater that exceeds the MCL for arsenic is from the Mississippian Marshall Sandstone, although there are isolated cases where water from the glacial or Pennsylvanian aquifers approaches or exceeds the MCL.

The Marshall Sandstone commonly has concentrations of arsenic that are about 10 parts per million (ppm) which is about five times larger than the world-wide average for sandstones. Concentrations as

large as 350 ppm have been measured in Marshall Sandstone sampled from areas of the Thumb. Pyrite is the only arsenic-bearing mineral known to be present in the Marshall Sandstone. Pyrite is ubiquitous in trace concentrations in the formation; in some sandstones pyrite constitutes a few to as much as 20 per cent, typically as pore-occluding cement. Microprobe analyses of arsenic-bearing pyrite grains show that arsenic is distributed heterogeneously, and arsenic concentrations larger than 5 weight percent have been measured. Large concentrations of arsenic are commonly associated with framboidal pyrite, but large concentrations of arsenic are also dispersed within massive pyrite cement.

Authigenic pyrite formed during early- mid- and late-stages of mineral diagenesis. Early diagenetic pyrite forms coatings on detrital grains. Framboidal pyrite formed in the intermediate stages of diagenesis and precipitated on authigenic carbonate and chlorite, or on authigenic quartz overgrowths. Late-stage pyrite encapsulates earlier framboidal pyrite grains. The possible relation of anomalous concentrations of arsenic in the Marshall Sandstone and in ground water from the aquifer is currently being investigated.

POSTER AND DISPLAY ABSTRACTS

THE EFFECTIVENESS OF THE GEOPROBE™ CONDUCTIVITY PROBE IN CONJUNCTION WITH TERRAIN CONDUCTIVITY TO DEFINE THE HORIZONTAL AND VERTICAL EXTENT OF BRINE CONTAMINATION IN AN OIL FIELD IN GLADWIN COUNTY, MICHIGAN

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The Buckeye Oil Field, located in Buckeye Township, Gladwin County, was discovered and developed in the 1930's and has been producing oil and coincident brined since that time. It was suspected that annular and pit disposal of brines and significant flowline losses had contributed to considerable chloride contamination of the unconfined aquifer. The aquifer consists of 25 to 30 feet of fine- to medium-grained sand underlain by a massive clay unit. The water table is encountered 1 to 4 feet below ground surface, and wetlands are present in portions of the oil field. Groundwater flow direction is to the southeast.

The intent of this limited investigation was to determine in a cost-effective manner the horizontal and vertical extent of any brine contamination for assessment of the risk to public health, safety and welfare and the environment. The budget for the project was approximately $65,000. The area of interest was approximately 1.5 square miles.

The first task was to perform a terrain conductivity survey over the area of interest. A Geonics model EM 34-3 with a data logger was used at 20-meter spacing in both the horizontal and vertical dipole modes. Stations were spaced at 20 meters and traverses were primarily oriented east-west, although several traverses were oriented north-south. The survey was completed in 9 days in September, 1995. The terrain conductivity survey indicated 6 anomalies of varying size, oriented northwest to southeast.

The results of the terrain conductivity survey were used to direct the second task of the investigation, which was to determine the vertical distribution of the brine contamination throughout the aquifer, utilizing the GeoProbe™ Conductivity Probe. The conductivity probe is an electrical probe installed on a standard GeoProbe™ unit that measures soil and groundwater conductivity with depth. The conductivity probe was pushed through the unconfined aquifer into underlying clay aquitard, measuring continuously. Four samples were located outside of anomalous areas, and sixteen samples were located within the anomalous areas. The GeoProbe™ was also used to collect groundwater sampled at the depths of highest conductivity at all twenty locations. These samples were analyzed for chlorides, sodium and total dissolved solids. This task was completed in two phases due to GeoProbe™ scheduling conflicts, in October and December, 1995, for a total of 7 days field work.

GeoProbe™ measurements outside anomalous areas showed small conductivity differences. These differences are attributed to changes in soil type. The four groundwater samples from locations outside anomalous areas contained concentrations of chloride from 80 mg/l to aa64 mg/l, and were interpreted as upgradient or unaffected areas. GeoProbe™ measurements within anomalous areas were two to three orders of magnitude greater than measurements outside anomalous areas. The conductivity increases were detected approximately two to ten feet above the clay aquitard. This was interpreted as the interface of the brine plume(s) within the aquifer. The sixteen samples documented elevated chloride concentrations in groundwater ranging from 5,510 mg/l to 33,400 mg/l.

The limited investigation did confirm significant degradation of the unconfined aquifer. The geophysical anomalies related well with probable source areas and known brine releases. The terrain conductivity survey, GeoProbe™ Conductivity Probe measurements and groundwater quality results correlated well, although the correlation was not linear. The conductivity probe used in conjunction with terrain conductivity was effective in determining the vertical and horizontal extent of brine contamination in a timely, cost-effective manner.

RESULTS OF A PILOT STUDY TO DETERMINE THE EFFECTIVENESS OF SURFACTANT SOIL WASHING TO REMEDIATE CRUDE OIL CONTAMINATION

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The need for economically efficient remediation methods increases as budgets for environmental cleanup decrease. The pilot project for the Michigan Department of Environmental Quality (MDEQ) was to conduct *ex situ* surfactant-enhanced soil washing at a former oil field tank battery site near Gladwin, Michigan. Since there are many surfactants that could be used in soil washing, a soil washing protocol developed at the University of Oklahoma was used for surfactant selection. The first objective of this project was to conduct bench-scale laboratory testing and analysis to screen surfactants for bench-scale flow-through testing. The model consisted of a miniature trommel and sand screw. The results of the model demonstrated that DOWFAX*8390 could remove 88% of the crude oil contaminant at a 0.25x micellar concentration (CMC). Based on the bench-scale testing and engineering design a field-scale soil washing apparatus was designed and built. The system was operated on site and processed a total of 2700 yd^3 of soil. During on-site operation samples were taken and analyzed to determine the level of contaminant removed. The results of that analysis showed that 96-97% of the crude oil was removed. The soil washing method used in this study proved to be efficient at removing the crude oil contamination as well as being cost effective when compared to other technologies. In addition overall costs are predicted to be similar to dig and haul costs for remediation of similar soils and contaminants.

GRAPHICAL CROSS-SECTIONS OF FOUR MICHIGAN AQUIFER UNITS WITH EDXSXN

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EDXSXN graphically displays gridded strata top elevations in cross-section. EDXSXN uses the Win32 API for graphics, and was compiled with ABSOFT Pro Fortran for the 32-bit Windows 3.1 (enhanced with Win32s), 95, and NT operating systems. The input requires for each layer one grid (real array) of top elevations, one grid (real array) of bottom elevations, and one grid (integer array) that defines the map extent of the strata, corresponding to an equally-spaced raster covering the map domain. The program was written to display and edit the TOP, BOT, and IBOUND variables respectively of the U.S. Geological Survey Michigan Regional Aquifer System Analysis (RASA) MODFLOW flow model. The Michigan basin RASA domain consists areally of 1 kilometer pixels equally-spaced in 361 columns and 470 rows corresponding to the MSU Center for Remote Sensing ERDAS database, and consists stratally of 4 aquifer and 3 confining units. The top and bottom arrays were defined by interpolating hand-drawn structure contour and isopach maps for the Glacial aquifer, the Jurassic red beds confining unit, the Saginaw aquifer, the Saginaw confining unit, the Parma aquifer, the Michigan confining unit, the Marshall aquifer, and the Coldwater confining unit. The domain completely and accurately (!?!) defines the geology above the Coldwater shale for the entire Lower Peninsula of Michigan. The program user can switch between complete row (W-E) and column (N-S) cross sections displayed in color, and can zoom changing the vertical exaggeration. The user can also sweep the cross section through the domain with arrow keys, which the author jokingly refers to as MODFLOW Tomography or MODFLOW MRI.

GEOLOGIST OUTREACH - DEPARTMENT OF ENVIRONMENTAL QUALITY/DEPARTMENT OF NATURAL RESOURCES GEOLOGISTS NETWORKING FOR THE FUTURE

Geologist Outreach Committee

The Geologist Outreach Committee (GOC) was formed in 1990 by State Geologist R. Thomas Segall in an effort to assure timely and efficient training for geologists employed in the DEQ/DNR. While the programs worked by DEQ/DNR geologists are quite varied, there are numerous specialty areas in common. Contaminant hydrogeology, contaminate fate and transport, and hydrogeology in glacial terranes are just a few of the areas of common training needs between programs.

This Outreach effort continues to be an important element in meeting the training needs of DEQ/DNR geologists and helping to utilize the individual geologist's areas of specialization. Besides it's normal training forums, the GOC is currently involved with an effort to assemble and publish general geological information of public interest. This information will be in the form of pamphlets, brochures, and posters, and will be specific to the State of Michigan.

CONTRIBUTING AREAS TO PUBLIC-SUPPLY WELLS WITHIN THE TRI-COUNTY REGION SURROUNDING LANSING, MICHIGAN

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The U.S. Geological Survey, in cooperation with the Tri-County Regional Planning Commission, developed a numerical model to simulate ground-water flow in the Saginaw Aquifer within the Tri-County region. This region, which consists of Clinton, Eaton and Ingham Counties, includes a nine-township area surrounding Lansing, Michigan. Ground-water withdrawals from wells within the nine-township area account for almost 80 percent of the public-supply withdrawals within the region. Contributing areas to public-supply wells in the nine-township area were delineated by a particle-tracking analysis. Results indicate that about 121 square miles within the Tri-County region ultimately contribute to public-supply wells within the nine-township area. Contributing areas for particles having travel times of 10 years or less cover about 4 square miles. The 10-year zone of transport areas was also determined. These areas correspond to that part of the aquifer through which water travels from the land surface to the well.

The model was developed to simulate the regional response of the Saginaw Aquifer to major ground-water withdrawals associated with public-supply wells. The Saginaw Aquifer, which is in the Grand River Formation and Saginaw Formation of Pennsylvanian age, is the primary source of water for about 290,000 Tri-County residents. The Saginaw Aquifer is overlain by glacial deposits, which are also important ground-water sources in some locations.

Flow in the Saginaw Aquifer and the glacial deposits is simulated by discretizing the flow system into two corresponding layers of model cells. Each square cell, which corresponds to a land area of 0.0625 square mile, represents the locally averaged properties of the system. The spatial variation of hydraulic properties controlling ground-water flow was estimated by geostatistical analysis of 4947 well logs. Parameter estimation, a form of nonlinear regression, was used to calibrate the flow model.

RARE EARTH ELEMENTS IN STREAM SEDIMENTS, UPPER MICHIGAN

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The rare earth elements (REE) are a useful geochemical tool. The unique chemical behavior of this group of elements allows them to be used as tracers for a wide variety of geochemical processes. REE have been extensively studied and widely used in the field of petrology, but have only recently been applied to the study of aquatic systems. Nonetheless, the REE represent a potentially useful tool for interpreting the environmental record preserved in stream sediments.

For this project REE concentrations were measured in the labile fraction of sediments collected from the Escanaba and Michigamme Rivers in upper Michigan. Both rivers flow across iron-ore exposures and a variety of lithologies. The labile fraction of sediments includes those phases, such as iron and manganese oxy-hydroxides, that are capable of exchanging trace elements with water. These phases may adsorb elements that are added to the river from sources such as weathering of bedrock or leaching of mine tailings. Conversely, changes in water chemistry--such as varying pH or redox potential--may lead to desorption of trace elements. Thus examining the REE content of the labile fraction should provide useful information about sources and geochemical controls on REE in river systems.

Sediments were collected from stream channels and from reservoirs that have been constructed along the two rivers. Samples were processed using an acid extraction procedure which leaches metals from the labile fractions of sediments. Extracts were analyzed by inductively-coupled plasma mass spectrometry. Concentration data were normalized to North American Shale Composite.

In most cases, REE patterns are similar to reported values for average river particulate matter, but display some interesting deviations from this pattern. Abundances and shale-normalized patterns of REE do reflect adjacent lithology. For example, stream sediments collected from sites near exposures of banded iron formation have distinguishing characteristics, including relatively high abundances, distinctive shale-normalized REE patterns, and lack of any europium anomaly. Many of the other sediments display a slight negative europium anomaly. Additional controls on REE geochemistry can be discerned from variations among the reservoir sediments. For instance, in lakes with high concentrations of iron in the sediments, the REE are influenced by iron redox chemistry. In other cases lake water pH and sediment organic carbon content appear to affect REE geochemistry.

GLACIAL MAPPING IN BERRIEN COUNTY, MICHIGAN

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No abstract submitted.

GLACIAL SCOUR MAP

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This isopach map shows the relationship between the base of the glacial drift (BOD) and the top of the Lachine Member of the Antrim Shale Formation. The main feature of this map is the presence of long linear scours in the bedrock. The scours have caused problems for oil and gas operators attempting to develop natural gas reserves from the Antrim Shale. Several of these scours have actually eliminated

some or all of the productive members (Lachine and Norwood) of the Antrim Shale, thereby rendering that productive acreage worthless. Therefore accurate delineation of the scours is essential for the successful development of Antrim gas projects. Seismic interpretations combined with existing water well and oil and gas well data have helped to illuminate them. The geologic mechanism responsible for the features and their approximate age is open for debate.

NATURALLY OCCURRING ARSENIC IN GROUND-WATER SUPPLIES OF SOUTHEASTERN MICHIGAN

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Recent studies of ground-water resources in southeastern Michigan by the Michigan Department of Community Health (MDCH), the Michigan Department of Environmental Quality (MDEQ) and the U.S. Geological Survey (USGS) show that local arsenic concentrations in ground water may exceed the U.S. Environmental Protection Agency's (USEPA) minimum contaminant level (MCL) of 50 µg/l in several counties. The USGS in cooperation with nine county Public Health Departments (Genesee, Huron, Lapeer, Livingston, Oakland, Sanilac, Shiawassee, Tuscola and Washtenaw) and the MDEQ is conducting a two-year study on the natural occurrence of arsenic in southeastern Michigan ground water. This study is interdisciplinary, interdivisional within the USGS, and conducted in collaboration with the University of Michigan.

Wells with detectable arsenic concentrations are often completed in the Mississippian Marshall Sandstone. However, the specific stratigraphic and/or mineralogic sources of arsenic and the geologic, hydrologic and biogeochemical conditions which favor arsenic release to ground water are largely unknown. Goals of the project are:

1) To determine if arsenic concentration is a function of depth, lithology and/or mineralogy in a specific stratigraphic unit.

2) To determine the biogeochemical factors involved in arsenic mobilization.

Sixty-seven private and public wells were sampled and analyzed for pH, temperature, dissolved oxygen, Eh, specific conductance, major ions, dissolved and suspended organic carbon, nutrients, bacterial numbers and arsenic. Bedrock core and depth-specific water samples were collected from a newly-drilled well to compare lithology and mineralogy to the associated water chemistry. Preliminary results indicate 1) detectable arsenic concentrations occur in ground water from several different geologic units, 2) arsenic is correlated with major ion chemistry, and
3) arsenic (III) is the predominant species. Results of the analyses may indicate stratigraphic, mineralogic and biogeochemical controls on the release of arsenic to ground water in southeastern Michigan, and practices which could affect arsenic concentrations in drinking water.

Maps showing the aerial distribution of arsenic, the relationship of arsenic concentration to bedrock and the distribution of any biogeochemical or mineralogical indicators will be provided to counties to help them identify problem areas and possible sources, develop protocols to avoid or remediate high arsenic concentrations and ways to avoid contamination of water supplies. Information gained from this study will also be important to other arsenic health studies taking place in Michigan, including a health education project by the Agency for Toxic Substances and Disease Registry (ATSDR) and an arsenic-toxicity study by the MDCH and local physicians. Data on the naturally-occurring arsenic concentrations will also assist the USEPA in its reevaluation of the 50 µg/l MCL.

PANEL DISCUSSION

SUGGESTED REVISIONS OF THE "STRATIGRAPHIC SUCCESSION CHART IN MICHIGAN": AN OPEN FORUM

Stratigraphic Nomenclature Committee of the Michigan Basin Geological Society:

Mark Wollensak and Paul Catacosinos, chairs
Mississippian through Quaternary David B. Westjohn, U.S. Geological Survey, Water Resources Division, 6520 Mercantile Way, Suite 5, Lansing, Michigan 48911-5971
Antrim Donald J. Bailey, 12724 Mutiny Lane, Tomball, Texas 77375
Devonian William B. Harrison, III, Michigan Basin Core Research Laboratory, Department of Geology Western Michigan University, Kalamazoo, Michigan 49008
Silurian Robert F. Reynolds, Reynolds Geological, L.L.C., 509 Hall Boulevard, Mason, Michigan 48854
Ordovician and Cambrian Paul Catacosinos, 100 Martingale Lane SE, Albuquerque, New Mexico 87123-4305, and Paul A. Daniels, R.P.G., Earth Resources International, L.C. (ERI-SA), P.O. Box 20245, Kalamazoo, Michigan, 49019-1245.

The Stratigraphic Nomenclature Committee of the Michigan Basin Geological Society (MBGS) plans to revise the graphic column depicting the stratigraphic succession in Michigan, published by the Michigan Geological Survey in 1964. Substantial new geological data have become available since the column was published and members of the MBGS believe that the current symposium is an appropriate forum to stimulate open discussion of changes the Committee believes to be appropriate.

Members of the Committee invite all interested and concerned individuals to attend the forum. Contributors will present a short summary emphasizing suggested changes in the stratigraphic column. Open discussion of the potential changes is strongly encouraged.

MISSISSIPPIAN TO QUATERNARY: NOMENCLATURE OF GEOLOGIC UNITS IN THE MICHIGAN BASIN

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The U.S. Geological Survey (USGS) Regional Aquifer-Systems Analysis (RASA) program completed a 10-year study of ground-water resources in the central part of the Michigan Basin in 1994. Thickness and surface configuration maps of Mississippian and younger geologic units were prepared by use of geophysical and geological logs of oil, gas and water wells as part of this hydrogeologic investigation. This mapping led to some concerns regarding stratigraphic names and stratigraphic position of certain geological

units in the basin, as they are depicted on the "Stratigraphic Succession in Michigan" chart (Michigan Department of Conservation, 1964).

The Stratigraphic Nomenclature Committee of the Michigan Basin Geological Society plans to revise the stratigraphic nomenclature and publish a new version of the "Stratigraphic Succession in Michigan". The following additions/deletions/changes in the updated stratigraphic chart should be considered:

1) Graphic patterns should be added to the revised stratigraphic chart to depict lithologic differences within Pleistocene glacial deposits.

2) Jurassic "red beds" (informal stratigraphic name) form a distinct mappable unit of significant areal extent, and assignment of formal stratigraphic nomenclature is suggested.

3) member names for subunits of the Grand River Formation (Ionia, Eaton and Woodville Sandstones) refer to single outcrop localities; consideration should be given to dropping these obscure names.

4) There is no indication that the Verne Limestone Member of the Saginaw Formation forms a mappable stratigraphic unit. In fact there are multiple limestone horizons within the Saginaw Formation, all of which are laterally discontinuous. The obscure term "Verne Limestone" should be deleted from the column.

5) No evidence was found for an unconformity between the Bayport Limestone and Parma Sandstone. The unconformity depicted on the chart should be deleted or at least queried.

SILURIAN SYSTEM STRATIGRAPHIC NOMENCLATURE

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Silurian age rocks in the Michigan Basin are found below an unconformity between the Bass Island Formation and the Devonian System. The Silurian formations were marine, deposited within a subsiding basin in either a shallow sea floor environment or in hypersaline evaporative conditions.

The Silurian System as referenced in the "Stratigraphic Succession in Michigan" chart - 1964 - printed by the Michigan Department of Natural Resources Geological Survey Division, requires only minor updates to make it current. From a stratigraphic nomenclature point of view, the Bass Island Series in subcrop is undifferentiated and referred to as the Bass Island Formation and in more recent years the Salina H unit.

The Salina A-0 Carbonate, although a time-honored nomenclature, was not in general use until authors in the 1960's began using the formation name in their papers. The Salina A-0 Carbonate is a shallow water marine carbonate and stone-planar stromatolite located between the Salina A-1 Evaporite and the Niagaran Group.

Several authors in the 1960's suggested nomenclature and formation unit changes for the entire Salina Group but the changes were not generally accepted by the geologic profession.