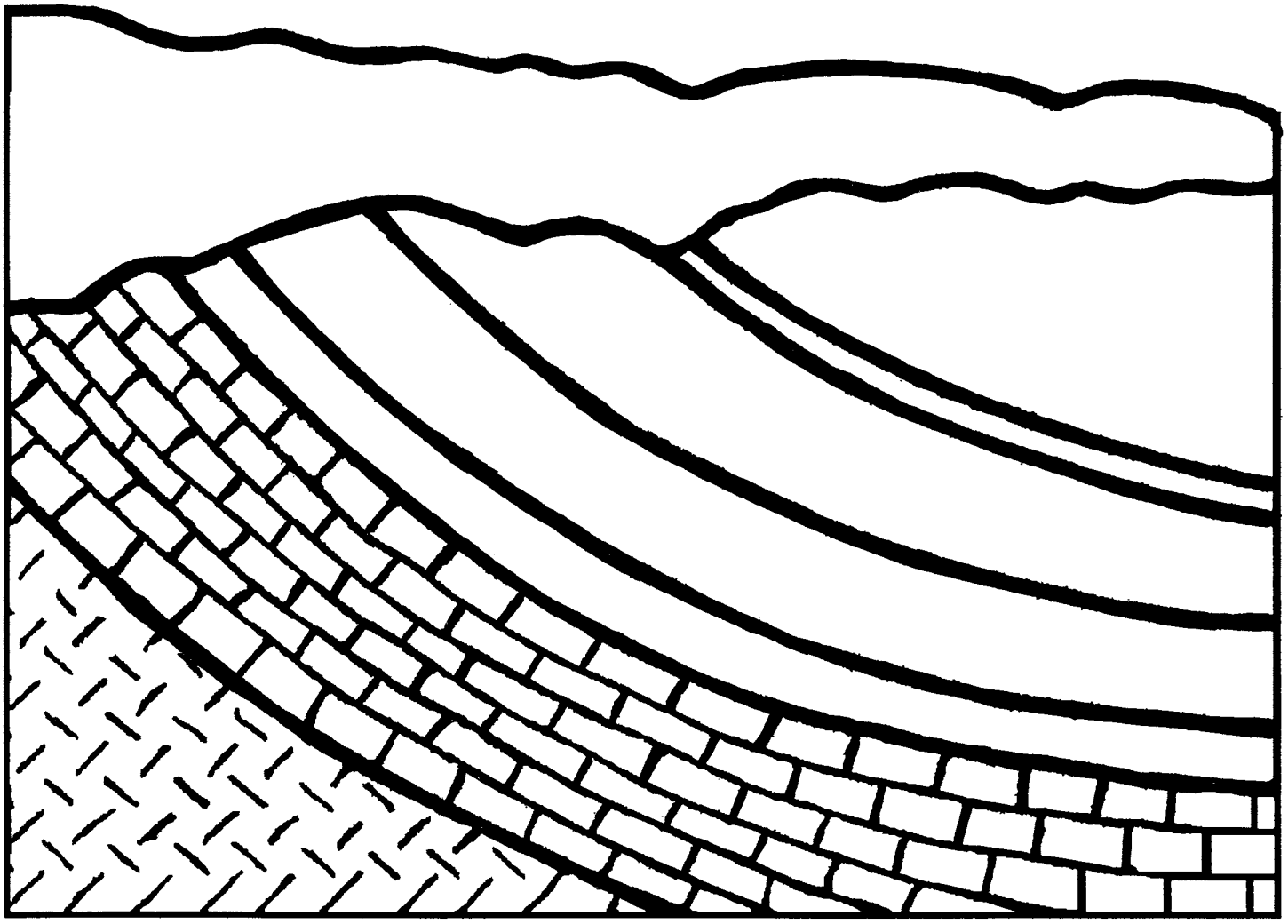
Michigan:
Its Geology & Geologic Resources



Program and Abstracts

March 18 & 19, 1993

Kellogg Conference Center, Michigan State University, East Lansing, Michigan

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Third Symposium

MICHIGAN:

ITS GEOLOGY AND GEOLOGIC RESOURCES

PROGRAM AND ABSTRACTS

March 18 and 19, 1993

at

The Kellogg Center
Michigan State University
East Lansing, Michigan

Hosted by:

Geological Survey Division
Michigan Department of Natural Resources

SCHEDULE OF PRESENTATIONS

Wednesday, March 17, 1993, Evening Program

6:00 to 8:00 pm - Registration in Big 10A Room, Kellogg Center

6:00 to 10:00 - Ice Breaker and Cocktails in Big 10A Room, Kellogg Center
Poster Presentations in Big 10A Room for the duration of the Symposium

Thursday, March 18, 1993, Morning Presentations

7:30 to 9:30 am - Registration and Coffee in Big 10A Room

TIME	LOCATION	SPEAKER	ORGANIZATION	TITLE	PAGE
8:45 am	Auditorium	Mike Moore and Tom Segall	Deputy Dir., DNR Chief, Geological Survey, DNR	Welcoming Remarks	
9:00 am	Auditorium	Bornhorst, T.J.	Michigan Technological University	Environmental and Resource Benefits of New and Revised Geologic Maps for Michigan	1
9:30 am	Auditorium	Decker, A. David	Advanced Resources International, Inc.	Gas Content and Log Derived Gas-in-place Calculations for the Antrim Shale, Michigan Basin	1
10:00 am	**BREAK - Coffee and Refreshments in Big 10A Room**				
10:30 am	Auditorium	Pyecroft, Jim	Halliburton Services	Multiple Stage Fracturing for Antrim Shale Completions	2
10:30 am	Big 10B Room	Rieck, Richard L.	Western Illinois University	Southern Michigan - The Largest Drift Repository in the Great Lakes Area	2
11:00 am	Auditorium	Garvin, Tom	Halliburton Services	Using Tiltmeter Technology to "Fracture Map" Antrim Shale Wells	3
11:00 am	Big 10B Room	Straw, Thomas W.	Western Michigan University	Conceptual Hydrogeologic Glacial Facies Models for Kalamazoo and Van Buren Counties	3
11:30 am	Auditorium	Peters, Jim B.	Halliburton Services	Effective Control of Iron Precipitation Damage During Stimulation of Michigan Basin Petroleum Wells	4
11:30 am	Big 10B Room	Seng, David	Western Michigan University	Ground Penetrating Radar and Shoreline Research: S.E. Lake Michigan	4
12:00 Noon	**LUNCH - Presentations Resume at 1:30 pm**				

SCHEDULE OF PRESENTATIONS

Thursday, March 18, 1993, Afternoon Presentations

TIME	LOCATION	SPEAKER	ORGANIZATION	TITLE	PAGE
1:30 pm	Auditorium	Hover, Victoria	University of Michigan	Shale Microstructure and Chemistry in Cratonic Basins: Comparison of Authigenesis in the Michigan and Illinois Basins and the Gulf Coast	5
1:30 pm	Big 10B Room	Keighly, Kelly	Western Michigan University	A Gravity Survey Over a Buried Valley in Barry County, Michigan	6
2:00 pm	Auditorium	Richards, J.A.	University of Michigan	Hydrochemistry of the Upper Devonian Antrim Shale, Michigan Basin: An Unconventional Gas Reservoir, a Complex Aquifer	6
2:00 pm	Big 10B Room	Chen, Jian	University of Toledo	The Discriminant Analysis for Contaminant Sources	7
2:30 pm	Auditorium	Wong, Mei Leng	Western Michigan University	Gravity Modeling of a Reef in Allegan County, Michigan	7
2:30 pm	Big 10B Room	Wiberg, Thomas	PRC Environmental Management, Inc.	Enhanced Differentiation of Late Wisconsinan Tills at a Superfund Site in Lansing, Michigan	8
3:00 pm	**BREAK - Coffee and Refreshments in Big 10A Room**				
3:30 pm	Auditorium	Prouty, C.E.	Michigan State University	Physical Evidence of Migratory Routes, Timing, and Potential Source(s) of Michigan Oil/Gas Accumulations	8
4:00 pm	Auditorium	Larchenkov, Evgeny	Odessa State University (Ukraine)/Eastern Washington University	Evolution and Petroleum Resources of Eastern European Platform Intracratonic Basins	9

Thursday Evening Symposium Banquet

Michigan State University, Kellogg Center, Big 10A Room

Cash Bar at 6:00 pm - Dinner at 7:00 pm

(Registration Desk Open 6:00 to 7:00 pm)

Speaker: Dr. Paul Hoffman, University of Victoria, Canada

"A Dessert Tray of Thoughts on Michigan Geology, as seen from the Outside World."

SCHEDULE OF PRESENTATIONS

Friday, March 19, 1993, Morning Presentations

7:30 - 9:30 am - Registration and Coffee in Big 10A Room

TIME	LOCATION	SPEAKER	ORGANIZATION	TITLE	PAGE
8:30 am	Auditorium	Basso, C. L.	Michigan State University	Preliminary Examination of a Suite of Chemically Weathered Staurolites From the Michigamme Slate Formation of Michigan's Upper Peninsula	10
8:30 am	Big 10B Room	Westjohn, D.B.	U.S. Geological Survey	Geological Controls of Distribution of Freshwater in Aquifers in the Michigan Basin	10
9:00 am	Auditorium	Weaver, Thomas L.	Michigan State University	Role of Volume Loss in Development of Deformation Fabrics in Proterozoic Metadiabase Dikes, Marquette County	11
9:00 am	Big 10B Room	Wilson, Timothy P.	Kent State University	The Origin and Evolution of $CaCl_2$ Brine in the Silurian Formations of the Michigan Basin, the Role of Mineralogic Reactions and Evaporite Diagenesis	12
9:30 am	Auditorium	North, Jon	University of Western Ontario	Riverton Formation Iron Ores: Keweenawan Oxidation and Iron Enrichment of a Pre-Penokean Superior Type Iron Formation	12
9:30 am	Big 10B Room	Meissner, Bruce D.	Michigan State University	Geochemical Evolution of Ground Water From Within the Marshall Sandstone Regional Aquifer, Michigan Basin	13
10:00 am	**BREAK - Coffee and Refreshments in Big 10A Room**				
10:30 am	Auditorium	Trow, Jim	Michigan State University	Gold Possibilities in Some Keweenawan Chalcocite	14
10:30 am	Big 10B Room	Wahrer, Marc A.	Michigan State University	Geochemistry of Ground Water from near Surface Bedrock and Glacial-Drift Regional Aquifers within the Michigan Basin	14

SCHEDULE OF PRESENTATIONS

Friday, March 19, 1993, Morning Presentations

TIME	LOCATION	SPEAKER	ORGANIZATION	TITLE	PAGE
11:00 am	Auditorium	Johnson, Alan M.	Michigan Technological University	Building and Decorative Stone in Michigan - An Underutilized High Value Mineral Resource	15
11:00 am	Big 10 Room	Kramer, Ruth	Michigan Technological University	Textures, & Chemical & Isotopic Compositions of Carbonates in Pennsylvanian Sandstones in the Michigan Basin	16
11:30 am	Auditorium	Bourne, H. Lyn	Consulting Geologist	Mining Construction Aggregates in Michigan - Problems and Solutions	16
11:30 am	Big 10 Room	Sibley, D.F.	Michigan State University	Burial Diagenesis and Pore-water Chemistry Evolution in the Marshall Sandstone Regional Aquifer, Michigan Basin	17
12:00 Noon	END OF SYMPOSIUM				

POSTER PRESENTATIONS

Posters are available for viewing in Big 10A Room throughout the entire Symposium

ABSTRACTS OF PRESENTATIONS BY APPEARANCE

ENVIRONMENTAL AND RESOURCE BENEFITS OF NEW AND REVISED GEOLOGIC MAPS FOR MICHIGAN

T. J. Bornhorst, Department of Geological Engineering, Geology, and Geophysics, Michigan Technological University, Houghton, MI

Geologic maps provide basic information that is a key input for a wide variety of complex decisions on issues such as the management and protection of the environment and management and utilization of mineral resources. Although geologic mapping is labor intensive and is not considered "high tech" science, geologic maps are vital for industry, government, and private citizens. It is often quite difficult to make an accurate analysis of the benefit/cost ratio of geologic mapping (forum, GSA 1992, Today, v. 2, no. 12). Benefit/cost ratio for environmental applications alone of geologic maps in two counties in Illinois ranged from 5.4 to 0.5 (Bhagwat and Berg, 1992, Environmental Geologic and Water Science, v. 19, no. 1, p. 33-40) and for mineral resource applications alone for geologic mapping in the entire state of Kentucky the benefit/cost ratio is in excess of 50 (McGrain, 1979, Kentucky Geological Survey Series XI, 12p.). Some benefits of geologic maps come in the form of cost avoidance e.g., proper siting of landfills. Michigan ranks in the bottom half of states in terms of total number of 1:24000 quadrangles mapped versus quadrangles available (about 8 percent mapped; American Association of Petroleum Geologists Explorer, December 1992), indicating a clear need for new geologic mapping in Michigan. The National Geologic Mapping Act of 1992 may provide new incentives for cost-effective geologic mapping through a partnership between federal and state governments and universities.

An example of a successful and cost-effective partnership between university and government is illustrated by geologic mapping by graduate students at Michigan Technological University. Partial funding was provided by the Geological Survey Division of Michigan, Department of Natural Resources and the COGEOMAP program of the U.S. Geological Survey. This graduate and faculty research has resulted in publication of new and revised geologic maps of several areas, highlighted by the recent release of the Negaunee NW 7½ minute bedrock geologic quadrangle map (Wilkin, Johnson, and Bornhorst, 1992, Contribution to Michigan Geology 92-2). The mapping effort has also resulted in several peer-reviewed publications including Johnson and Bornhorst (1991, U.S. Geological Survey Bulletin 1904-F) and Wilkin and Bornhorst (1992, Canadian Journal of Earth Sciences, v. 29, p. 1674-1685). The talk will highlight the components of a successful partnership with universities. A clear need exists for the acquisition of new and revised geologic maps as part of Michigan's infrastructure. Fulfilling this need requires a long term commitment of resources by government.

GAS CONTENT AND LOG DERIVED GAS-IN-PLACE CALCULATIONS FOR THE ANTRIM SHALE, MICHIGAN BASIN

A. David Decker, Tracy Lombardi, Advanced Resources International, Inc., Lakewood, CO; David Hill, Gas Research Institute, Chicago, IL

Gas-in-place calculations are an essential component for accurate reserve estimates. Furthermore, diffusion dependent reservoirs such as the Antrim shale require knowledge on gas content, langmuir volume and pressure and diffusivity coefficient for gas and water rate forecasting. Recognizing these important shortfalls in Antrim Shale reservoir characterizations, the Gas Research Institute initiated a program to measure desorption related parameters. Gas contents measured from five wells in Otsego, Osceola, Ogemaw and Livingston counties varied from 15 scf/ton (1.1 scf/cf)

to 166 scf/ton (12/scf/cf). Antrim shale gas content increases predictably with increasing organic richness. Gas-in-place calculations are based on the close mathematical relationship of gas content to open-hole log response. On the average, 16 bcf/mi^2 to over 35 bcf/mi^2 of gas is stored within the Antrim formation. An estimated 24-30 Tcf of gas resource underlies the current development trend. Basin wide, the Antrim contains 400-800 Tcf of gas. The focus of current research is to determine geologic factors controlling gas production from this vast resource.

MULTIPLE STAGE FRACTURING FOR ANTRIM SHALE COMPLETIONS

Jim Pyecroft, Halliburton Services, Mt. Pleasant, MI

This paper presents a comparison of techniques by which Antrim Shale wells are fractured in multiple zones and discusses advantages and disadvantages of each. Historically, a high percentage of completions have been single stage, open hole or cased hole, in either the Upper Antrim only or the Lower Antrim only. In instances where both zones were fractured simultaneously, the lower zone was often not stimulated (production increases were evident in refracts of Lower Antrim shale zones).

Completion techniques considered and compared in this presentation include the following:

1. Through tubing using retrievable bridge plugs and packers.
2. Through casing using either a retrievable or drillable bridge plug and ball and baffle technique.
3. Use of a wireline-set fracturing baffle that can be run in on wireline, slick line, sand line, or coiled tubing.
4. Use of a wireline-set, coiled tubing retrieved bridge plug.

Case histories detailing use of the above techniques on Antrim Shale fracture jobs are presented. Cost savings from elimination of workover rig requirements and implementation of several procedural improvements are identified.

SOUTHERN MICHIGAN
THE LARGEST DRIFT REPOSITORY IN THE GREAT LAKES AREA

Richard L. Rieck, Department of Geography and Department of Geology, Western Illinois University, Macomb, Illinois, and Harold A. Winters, Department of Geography and Environmental Engineering, United States Military Academy, West Point, NY, and Department of Geography, Michigan State University, East Lansing, MI

Multiple Pleistocene glaciations have affected the Southern Peninsula greatly modifying its topography. Drift thickness ranges from zero at a few points to >375 m. at a site south of Cadillac. Calculations from an original map based primarily on 100,000 well logs reveals that mean drift thickness for the peninsula is 85 m. Published estimates indicate this figure is almost twice the average for Iowa,nearly triple that for Illinois and "southern" Ontario, and five times more than Ohio and southeast Wisconsin. Volumetric data show that nearly 10,000 km^3 of drift cover southern Michigan -- an amount which exceeds the combined volume of Lakes Michigan, Huron, and Erie. Distribution is uneven, generally increasing from SE (Monroe County with 18 km^3) to NW (Otsego County 280 km^3). Drift volume per unit area north of Bay City is nearly triple that to the south. The peninsula's

preglacial topography (especially to the north) has been greatly modified resulting in the landscape we see today. It is by far the greatest repository for drift in the Great Lakes area.

USING TILTMETER TECHNOLOGY TO "FRACTURE MAP" ANTRIM SHALE WELLS

Tom Garvin and Frank Zamora, Halliburton Services, Dunan, OK

This presentation gives details of a case history in which a Michigan Antrim Shale well was (1) fractured in two zones, and (2) the fractures were mapped on the surface to determine their direction and extent. Mapping was done using tiltmeters placed on the earth's surface.

Tiltmeters record the changes that occur in the crust of the earth when fracture treatments are pumped into a formation. Signals recorded allow for analysis that shows fracture depth, shape, dimensions, and orientation. Sensitivity of tiltmeters allow them to resolve the daily range of the earth's tidal distortions that result from interactions of the gravity fields of the earth-moon-sun system. Such sensitivity also allows measurement of the earth's distortion resulting from hydraulic fracturing.

Presentation will include a thorough discussion of tiltmeter technology, practical applications, and field case history studies. Benefits of applying tiltmeter technology to oilfield use are presented.

CONCEPTUAL HYDROGEOLOGIC GLACIAL FACIES MODELS FOR KALAMAZOO AND VAN BUREN COUNTIES

Thomas W. Straw, Richard N. Passero, Alan E. Kehew, Department of Geology and Institute for Water Sciences, Western Michigan University, Kalamazoo, MI

Conceptual glaciogeologic facies models, developed from surface and well information, provide framework for understanding ground-water dynamics and contaminant transport in southwestern Michigan. The models are based on differences in glacial landform type and stratigraphy which characterize morainal, outwash, till plan and lacustrine facies. The Tekonsha, Kalamazoo, Valpariso and Lake Border Moraines are contrasting aquifer-aquitard systems developed in response to ice dynamics and drift provenance for the Lake Michigan ice lobe. Engineering borings, computerized water well records, gamma-ray logs, surface geophysics and aquifer tests depict unique and different Wisconsinan-Illinoisan stratigraphic sequences in the moraines comprised of glaciofluvial aquifers and diamicts with local lacustrine beds that are aquitards. Outwash includes large alluvial fan complexes heading in the Kalamazoo Moraine, enveloping the Tekonsha Moraine, but not associated with the Valpariso Moraine. One of these the Prairie Bonde Fan has been studied extensively and embodies classical marginal, proximal, medial, and distal facies over an older till-outwash sequence on the truncated Coldwater Shale.

The moraines are dominantly ground-water recharge areas with multiple aquifers. Ground-water flow in the morainal facies is strongly influenced by the heterogenous drift lithologies and stratigraphy. Tritium values and contaminant levels indicate ground-water flow downward through over 30 meters of till within the Tekonsha Moraine, but not across over 60 meters of till within the Kalamazoo Moraine. The Prairie Ronde Alluvial Fan forms a low relief, homogeneous sole-source aquifer. Ground-water is generally less than 5 meters below the surface resulting in

numerous small ponds and wetlands. Tritium data distinguish a shallow ground-water flow system comprised of many local systems sustaining flow-through ponds and wetlands. Beneath the fan is an older outwash aquifer recharged at the head of the fan and containing pre-1953 water. Both systems discharge at the distal end of the fan into a series of lakes and wetlands.

Ground-water throughout the region is of the calcium-magnesium-bicarbonate type. Only subtle changes in water chemistry have been observed along flow paths including the drift-bedrock interface although surficial tills appear to influence the concentrations of some chemical species. Nitrate concentrations in groundwater are relatively high and ubiquitous, but are generally limited to depths of less than 30 meters below the water table.

EFFECTIVE CONTROL OF IRON PRECIPITATION DAMAGE DURING STIMULATION OF MICHIGAN BASIN PETROLEUM WELLS

Jim B. Peters, Halliburton, Kalkaska, MI; Jim F. Pyecroft, Halliburton, Mt. Pleasant, MI;
Weldon M. Harms, Michael M. Brezinski, Halliburton, Duncan, OK;
Rick L. Middaugh, Halliburton, Oklahoma City, OK

Many of the Michigan Basin formations of interest to the petroleum industry are noted for containing problematical quantities of dissolved iron. The Antrim and Prairie du Chien formations can be highly damaged by premature precipitation of iron. A new chemical agent recently introduced offers better control of iron solubility and prevention of iron damage than is possible with commonly applied chemical complexing agents such as citric acid, EDTA, or erythorbic acid. This additive has proved to be highly compatible with most fracturing and acidizing stimulation fluids. In live acid fluids, the new additive promotes instant reduction of soluble ferric ion to ferrous ion, unlike most iron control chemicals which are only effective in spent acid. The new additive offers other advantages such as avoidance of precipitation of asphaltenes, reduced likelihood of forming oil external emulsions, and less tendency to cause phase separation of corrosion inhibitors that are often required as part of the treatment fluid. Test data to substantiate compatibilities as well as case histories of applications in the Michigan Basin are provided in this presentation.

GROUND PENETRATING RADAR AND SHORELINE RESEARCH; SE LAKE MICHIGAN

David Seng and William R. Laton, Dept. of Geology, Western Michigan University
William A. Sauck, Institute for Water Sciences, WMU

A conventional downward-looking pulse RADAR has been adapted for use in the littoral environment, with the antenna towed by a boat in a submerged sled along the bottom. In this configuration it has been used to investigate 3 to 4 meters into the bottom sediments using the 500 MHz antenna in water depths ranging from 0 to 6 meters along shore-perpendicular traverses. Onshore, the GPR has been used with 100 MHz antennae to extend the offshore lines across the beach to the base of the bluff.

In areas with shale or glacial clays within 4 m of the surface, the system is very useful in mapping sand thickness in this transitional environment where continuous seismic profiles are impossible. Where a thicker sand blanket is present, the GPR records often show internal details of primary depositional structures. Some of these prominent unconformities may be useful markers for referencing temporal changes of sand thickness after repeat surveys.

Onshore, the penetration is somewhat greater unless the beach sands contain significant clays derived from adjacent till bluffs. Shore-parallel profiles along the beach at Benton Harbor reveal stacked paleochannels in the drowned valley system entering the Lake at this location. Depths derived from coincident borings have been used to calibrate and confirm the radio-wave velocities appropriate for the saturated sands at this location. In the next field season, Vibracoring will be done to identify the internal RADAR reflectors encountered in the near-offshore. This will also serve as a means of calibration for the depth scale of the GPR records.

The system has proven to be a valuable adjunct to other methods for determining sand volume in this critical region where bluff erosion can be moderated by the presence of a significant sand wedge. The GPR also reveals internal structures which clarify the depositional history of the fluvial system which enters Lake Michigan at St. Joseph - Benton Harbor.

SHALE MICROSTRUCTURE AND CHEMISTRY IN CRATONIC BASINS: COMPARISON OF AUTHIGENESIS IN THE MICHIGAN AND ILLINOIS BASINS AND THE GULF COAST

Victoria C. Hover, Donald R. Peacor, and Lynn M. Walter,
University of Michigan, Ann Arbor, MI

The model for shale authigenesis during progressive burial has relied heavily on observations from the Gulf Coast Tertiary section. However, shale diagenesis in intracratonic basins are likely to be influenced by quite different hydrodynamic and geochemical regimes. In this study, we examined clay microstructures and compositions of Upper Devonian Antrim Shale (Michigan Basin) and New Albany Shale (Illinois Basin) by STEM/AEM methods in order to determine the extent and timing of water-rock interaction and to compare results with the Gulf Coast model.

The Antrim and New Albany shale matrix is composed of subparallel intergrowths of illite-rich crystals only 50-200 Angstroms thick some of which appear to have precipitated directly into pore space. Contrast in some lattice fringe images is consistent with ordered illite/smectite (I/S). Electron diffraction patterns indicate a partial disordered $1M_d$ stacking sequence with significant turbostratic stacking. The average composition is K-deficient and Si-rich relative to muscovite, and also contains significant octahedral Fe and Mg. Interlayer charge deficiencies of between 1.5 and 1.8 charges per 12 octahedral plus tetrahedral cations are typical. This immature illite is readily distinguished from detrital muscovite which contains more K, has interlayer charge deficiencies of 1.95 to 2.05 and an ordered 2M stacking sequence.

These relations are collectively consistent with a single event in which dissolution of detrital smectite was followed by precipitation of immature, authigenic, illite-rich I/S in a relatively open system. Preservation of this immature illite in these 360 Ma shales implies that subsequent to formation of immature illite, no further clay mineral reactions have taken place and these minerals have remained effectively closed to other tectonic overprints or fluid flow events. As such, the formation sequence mirrors that in Gulf Coast shales wherein such immature illite-rich I/S formed over a narrow depth interval, remained unchanged with further burial, and in which shale systems were open with respect to formation fluid up to the point of illite-rich I/S formation.

A GRAVITY SURVEY OVER A BURIED VALLEY IN BARRY COUNTY, MICHIGAN

Kelly Keighley, Western Michigan University, Geology Department, Kalamazoo, MI

A gravity survey was conducted over an area directly east of the Kavco Landfill site in Barry County, Michigan in the Spring of 1992. The purpose of the study was to determine the possible existence of a buried valley, the orientation, depth, and extent of the bedrock feature. Specifically, data collected along two survey lines adjacent to the landfill were used to create a subsurface profile of the area.

Preliminary interpretations of the data suggests the presence of a valley incised into the Coldwater Shale which is the bedrock formation in the study area. The bedrock valley is oriented NE to SW with a pronounced gravity low defining the extent of the valley. The gravity data correlates well with resistivity data that were collected within the Kavco Landfill region in 1982.

Based on the orientation and the thickness of this buried valley it is likely that it controls the local groundwater flow and may facilitate the transport of contaminants within the vicinity of the Kavco Landfill region. Further hydrological investigation of this site is required to characterize the groundwater flow and the potential for transportation of contaminants in the subsurface.

HYDROCHEMISTRY OF THE UPPER DEVONIAN ANTRIM SHALE, MICHIGAN BASIN: AN UNCONVENTIONAL GAS RESERVOIR, A COMPLEX AQUIFER

J. A. Richards, A. M. Martini, and L. M. Walter, Department of Geological Sciences, University of Michigan, Ann Arbor, MI; C. J. Kaiser, Shell Western Exploration and Production, Inc., Houston, TX

Recent extensive drilling for Antrim gas presents an unique opportunity to evaluate the utility of hydrogeochemistry to determine flow-patterns in a fractured-shale gas-reservoir. The trend is on the northern rim of the basin and production results from the combined occurrence of the organic-rich black shale facies and a regionally extensive fracture system. Co-produced water samples collected from wells in the Antrim Shale gas-producing trend were analyzed for chemical and isotopic composition to identify: 1) area of recharge, 2) source(s) of water and solutes; and, 3) relation of large-scale flow-patterns to regional fractures.

Formation waters from the Antrim are highly variable in salinity over small distances and isoconcentration maps over the producing trend show well-defined gradients. Solute concentrations increase with lateral distance away from the subcrop and with depth. In contrast, carbonate alkalinity and total inorganic carbon (TIC) decrease with increasing salinity. Although shallow ground-water samples from glacial deposits overlying the Antrim subcrop are depleted in TIC the most dilute endmember Antrim water has the highest TIC. This requires rapid and extensive organic carbon decomposition within the Antrim reservoir. Stable isotopic composition (O,D) also vary with salinity. Minor elements such as Ba exhibit locally centered enrichment, apparently unrelated to the regional flow system.

Chemical variations across the Antrim trend indicate that meteoric water recharges the Antrim at the subcrop. The source of salinity for Antrim waters is more complex; Cl-Na-Br systematics indicate that salinity is derived, in part, from local salt dissolution, and from mixing with Br-enriched Ca-Cl brines from subjacent formations. Geochemical gradients parallel the dominant northeast-southwest fracture trend in the Antrim.

Meteoric recharge, coupled with flow through fractures within the Antrim leads to the complex pattern in fluid chemistry. Better documentation of fluid chemistry variations and their sources may prove useful in identifying areas with potential production problems and, coupled with gas-production data, improve exploration and development of this unconventional gas resource.

THE DISCRIMINANT ANALYSIS FOR CONTAMINANT SOURCES

Jian Chen, Organic Carbon Facility, Department of Geology, University of Toledo, OH

This paper discusses the employment of discriminant analysis to distinguish contamination from different sources. It may provide reasonable solution to the following difficult question: Who is liable for specific ground water contamination incidents? The methods of pattern recognition are used to build mathematical models. Four discriminant procedures are considered: (1) Tanimoto Similarity which give a concise way to determine contaminant sources; (2) Discriminant Analysis using Fisher's criterion; (3) Bayesian Discriminant Analysis which is based on the calculation of a posteriori probability by means of known a priori probability; and (4) Factorial Discriminant Analysis which is related to dimensionality reduction and effectively describe the difference between M contaminant sources. Finally, an example is presented which involves discriminant analysis of mineralized springs in a salt basin in southwest China.

GRAVITY MODELING OF A REEF IN ALLEGAN COUNTY, MICHIGAN

Mei Leng Wong, William A. Smith and William B. Harrison III, Department of Geology, Western Michigan University, Kalamazoo, MI

The study of the Diamond Springs oil field in Allegan County focuses on the use of gravity to delineate individual reef buildups. The Diamond Springs oil field is a small patch reef located in northern Allegan County, Michigan. The reef, which is approximately 1400 feet deep, is found within the Middle Devonian Traverse Limestone and was deposited in an open shelf, carbonate platform and lagoonal environment. The reef covers an area of approximately one square mile and has a vertical relief of 30 to 80 feet.

A reef is a mound shaped feature that consists of the skeletal remains of corals, algae or similar shallow water organisms. Patch reefs are biohermal buildups formed in shallow waters in close proximity to shallow shelf margins. These porous reef materials are commonly buried by muds or evaporites resulting in ideal conditions for the generation and entrapment of hydrocarbons. Within the Michigan Basin, these reefs are major sources of oil and gas accumulations. The Traverse Limestone has produced over 100 million barrels of oil from these and other reservoir types. Current estimates of total recoverable reserves within Michigan reefs range from 500 to 800 million barrels of oil and 5 to 8 trillion cubic feet of gas. The principal means of exploration for these reefs are geophysical methods.

Gravity studies are primarily based on lateral variations in rock densities. Using data from cores and well logs available at the Michigan Basin Core Repository at Western Michigan University, the densities of the Diamond Springs patch reef and its surrounding rocks were determined. With this date, gravity models were constructed for the reef using a computer modeling program.

After these geophysical models were determined on the computer, field work was conducted. The gravity stations were located 200 feet apart, along a paved road and were surveyed in so as to determine their elevation and the location. As the

expected anomaly will be very small, repeat gravity measurements, using a Lacoste-Romberg gravimeter, were made in order to minimize the error, thus allowing us to discern the anomaly from the regional. The gravity models obtained from the reduced field data will then be compared with the theoretically determined models.

ENHANCED DIFFERENTIATION OF LATE WISCONSINAN TILLS AT A SUPERFUND SITE IN LANSING, MICHIGAN

Thomas Wiberg, Luda Voskov, and Ray Mastrolonardo, PRC Environmental Management, Inc., Chicago, IL

Subsurface data from a Superfund site in Lansing, Michigan, indicate the presence of at least two distinct till sheets emplaced during the Late Wisconsinan. The tills are separated by fluvial, lacustrine, and possibly deltaic sediments deposited during episodes of partial retreat of the Saginaw Ice Lobe.

The site lies between the Lansing Moraine to the south and the Grand Ledge Moraine to the north. The uppermost till is brown, sandy clay and is interpreted to be equivalent to the Bedford till. Below the Bedford till is a gray, silty clay which is interpreted to correlate with the Fulton till (Monaghan and Larson, 1986). These till sheets are separated by lacustrine and fluvial sediments, indicating a period of significant retreat of the Saginaw Ice Lobe. In places, lacustrine deposits are absent, and the contact between the till sheets is replaced by thin sands or an erosional unconformity. Underlying the Fulton till is an older, thick sequence of lacustrine and deltaic deposits. Lacustrine deposits are identified in the field by their millimeter-scale, rhythmic, silt and clay varves. The basal glacial deposits directly overlie the eroded surface of the Saginaw Formation.

The glaciofluvial sands are the major conduits for ground water in the glacial deposits and largely control contaminant migration at the site. Because of the thin nature and low yield of the sands, ground-water extraction through pumping does not appear to be a viable alternative for ground-water treatment.

PHYSICAL EVIDENCE OF MIGRATION ROUTES, TIMING AND POTENTIAL SOURCE(S) OF MICHIGAN OIL/GAS ACCUMULATIONS

C. E. Prouty, Emeritus, Department Of Geological Sciences, Michigan State University, East Lansing, MI

A number of organic geochemical studies have been made of the principle oil/gas producing horizons from Ordovician to Early Mississippian in the Michigan Basin. The presence of these several accumulations offers a challenge to the organic geochemists to fingerprint the horizons as to source(s), in situ accumulations and/or migrating oil mixtures. A review of the various analyses indicates a diversity of opinions. The nearest agreement centers around the observation that Ordovician and Dundee (Devonian) hydrocarbons are rather similar and that the stratigraphically intervening Niagara/Salina hydrocarbons differ from both and are considered in situ in origin. Other chemical analyses will be discussed.

The writer has reported heretofore on his concept of the tectonic history of the Michigan Basin and the likely accompanying movement of fluids within a shear model concept. He would attempt to relate this to the principle oil-bearing horizons. Though the above physical assessment may not in itself decipher the sources of in situ oil horizons and/or the possible migrational mixing of different oil

sources, these analyses need to be related to the physical history, feasible migratory routes and timing of tectonic events.

Evidence of rising (artesian) fluids will be discussed. These rising fluids are believed to have entered the shear faults at depth, after descending along the flanks of the Basin frame structures, and brought up, first, dolomitizing fluids followed sometime later by hydrocarbons, sulfide minerals and saddle dolomite. Unless oil was formed in situ in all the occurrences between the Ordovician and Mississippian, migration of the oil would have been (most likely upward) through the thick Upper Ordovician Utica carbonaceous shales (good potential source) and the Salina evaporites most logically along the shear faults which extend vertically from the Precambrian to the surface. Evidence indicates that this occurred in early Mississippian time coincident with the major development of shear faults and resulting shear folds accompanying the time of greatest stress applied to the Basin accompanying the Alleghenian Orogeny in the Appalachians.

EVOLUTION AND PETROLEUM RESOURCES OF EASTERN EUROPEAN PLATFORM INTRACRATONIC BASINS

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Intracratonic basins of Eastern European platforms are either supra-rift (supra-aulocogen) syneclises having buried branching rift systems (Baltic, Volyn'-Podol, Pre-Caspian and non-commercial Srednerussky basins), or supra-rift troughs with solitary paleorifts (Dnieper-Donets, Pripyat' basins).

There were two main stages in the evolution of these basins. Rifting occurred in Rephean time (with the exception of the Pripyat' basin). Syneclise formation began in Late Vendian time with intense subsidence in the Middle and Late Paleozoic resulting in thick accumulations of predominantly marine sediments. The basins were formed primarily by stretching with flexural predominating over fault-controlled subsidence.

Two of the basins are markedly different. The Dnieper-Donets basin is characterized by uplift from post-Riphean until Middle Devonian time and renewed rifting in the Middle and Late Devonian. In the Pre-Caspian basin, the crust thins to 22-30 kilometers, the sedimentary rocks reach a thickness of 20-23 kilometers, and Kungur age saline formation is widespread.

The Baltic and Srednerussky basins show many similarities in their development to the Michigan basin.

The Eastern European intracratonic basins listed above all contain considerable oil and gas resources. The most productive is the Pre-Caspian basin which hosts the giant Karachaganak (gas-condensate), Astrakhansk (gas-condensate), Tengiz (oil), and Zhanazhol (gas and oil) fields.

See table next page.

Basin	Baltic	Dnieper-Donets	Pre-Caspian	Pripyat'	Volyn-Podol
Age of hydrocarbon bearing sequences	ϵ_{1-2}	D_3-J_1	D_2-K_1	D_{2-3}	D_{1-2}
Number of:					
producing fields	26	118	108	28	2
hydrocarbon reservoirs	29	589	553	78	8
Sequences containing:					
main reserves	ϵ_{1-2}	C_1-C_3	C_{1-2}	D_{2-3}	D_{1-2}
main resources	ϵ_1-S_2	D_3-C_2	D_2-P_1	D_{2-3}	S_1-C_1

PRELIMINARY EXAMINATION OF A SUITE OF CHEMICALLY WEATHERED STAUROLITES FROM THE MICHIGAMME SLATE FORMATION OF MICHIGAN'S UPPER PENINSULA

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Weathering of high-grade metamorphic facies of the Michigamme Formation releases crystals of incipiently weathered staurolite. The small (0.5" and under), euhedral crystals occur loose, under a blanket of moss, where they are exposed to water and various organic acids in the moss layer. Scanning electron photomicrographs clearly depict crystallographically controlled dissolution voids (etch pits) aligned with the c-axis and penetrating the crystal parallel to {010}. The etch features exhibited by this suite of samples, although not as well developed, are similar to those found in heavily etched detrital staurolite and other heavy minerals. Under these conditions, the etching of staurolite is an interface-controlled reaction, as evidenced by surface etching and the lack of protective surface layers.

GEOLOGICAL CONTROLS OF DISTRIBUTION OF FRESHWATER IN AQUIFERS IN THE MICHIGAN BASIN

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Electrical-resistivity data from geophysical logs of hydrocarbon-exploration drill holes indicate that the most important control on the distribution of freshwater in sandstone aquifers is a direct hydraulic connection to glacial deposits. Brine (>100,000 mg/L dissolved solids) is present in Parma and Marshall Sandstones at distances as small as 10 miles down regional dip from areas where these aquifers are hydraulically connected to glacial drift and contain freshwater. The thickness of the transition from freshwater to brine in sandstones is relatively uniform and ranges from 200-300 feet in most of the central part of the Michigan basin. Freshwater in the Parma Sandstone is limited to areas where it subcrops beneath glacial drift, but mud invasion-profiles recorded on electrical-resistivity logs show the Parma Sandstone is permeable and constitutes the shallowest brine reservoir in the basin. This aquifer is stratigraphically continuous and may be a facies equivalent of the Bayport Limestone.

The Saginaw Lowlands is the only area of the State where saline water is common in glacial deposits. Saline water may have migrated from underlying bedrock aquifers, because the Saginaw Lowlands is a regional discharge area. The enigma is that glacial deposits in the Michigan Lowlands,

which is also a regional discharge area, contain freshwater. Saline-water-bearing glacial deposits in the Saginaw Lowlands have previously been interpreted to be lacustrine clays that were deposited in glacial Lake Saginaw (approximately 13,000 BP). Results of drilling along a 36-mile-long transect from eastern Gratiot to central Bay county shows that these deposits are primarily clay-rich basal-lodgement tills. Therefore, these glacial deposits are older than glacial Lake Saginaw, and they could be substantially older. The presence of saline water in glacial deposits may in part be related to the length of time that these dense-clay deposits have overlain bedrock in the Saginaw Lowlands. Additional geological controls of distribution of freshwater include the following: (1) Jurassic red beds and underlying bedrock units contain saline water, and apparently "Red Beds" act to impede recharge of fresh ground water from glacial deposits, and (2) hydraulic discontinuities are present in Marshall Sandstone where the vertical component of hydraulic conductivity is as much as three orders in magnitude less than the horizontal component, possibly explaining observed increases in dissolved solids with increasing depth.

ROLE OF VOLUME LOSS IN DEVELOPMENT OF DEFORMATION FABRICS IN PROTEROZOIC METADIABASE DIKES, MARQUETTE COUNTY

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Foliated Proterozoic metadiabase dikes cross-cut Archean granite-gneiss and greenstone terrains in several locations in Marquette County. These dikes were emplaced post-Algoman Orogeny (2.7 Ga.) and pre-Penokean Orogeny (1.9-1.85 Ga.), suggesting that much of the deformation of these dikes is related to the Penokean collisional event. Rotation of foliation increases from dike centers to margins indicating substantially higher shear strain at the country rock contacts than at dike centers. Shear strain may result in volume loss (solution transfer) rather than bulk-rock material transport. We anticipated that development of foliation was accompanied by solution transfer of silica and other mobile constituents out of the dikes.

If solution transfer is a major factor that produced the "apparent shortening" of the dikes, then bulk-rock and trace element concentrations should differ from low strain domains (dike interior) to high strain domains (dike margin).

To test the hypothesis, dikes were sampled along a linear transect from center to margin. Major and trace element concentrations were measured by X-ray Fluorescence. All dikes show a similar trend, of decreasing Na_2O and CaO, increasing K_2O and nearly constant silica, from dike interior to margin. Petrographic analysis showed higher modalpercentages of epidote and lower percentages of plagioclase in samples from margins (up to 12%); consistent with greenschist facies metamorphism of mafic rock in orogenic regimes. Linear counts (1,000 points) of felsic vs. mafic minerals of samples from the dike interior and margin show greater amounts (from 3.5 to 5.9%) of mafic minerals in margin samples.

Based on the chemical data, we suggest that shear strain-induced volume loss is not significant enough to account for the pervasive foliation seen in these dikes.

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THE ORIGIN AND EVOLUTION OF $CaCl_2$ BRINE IN THE SILURIAN FORMATIONS OF THE MICHIGAN BASIN, THE ROLE OF MINERALOGIC REACTIONS AND EVAPORITE DIAGENESIS

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Formation water from the Silurian aged reefs in the northern and southern trends of lower Michigan was collected and analyzed for major-minor ion and isotopic content. The results were combined with an analysis of an exceptionally concentrated (TDS > 640 g/l) brines reported by Case (1945) to demonstrate the origin and possible evolutionary pathways for the chemical and isotopic components of these brines. The waters are extremely concentrated (average TDS > 353 g/l), $CaCl_2$-rich brine. Brines produced from the northern reef trend appear to be slightly more concentrated in all components, and contain higher amounts of K and lower amounts of Na compared with brines from the southern reefs. Cl/Br and Na/Br ratios show the waters originated from seawater concentrated into the $MgSO_4$ and possibly KCl salt facies by evaporation. Although dolomitization appears to have been important in the evolution of the brine chemistry, it apparently does not explain all of the enrichment observed in Ca. Four scenarios may explain the evolution of the $CaCl_2$ chemistry: (1) modification of NaCl brine derived from the dissolution of the Silurian halite beds around the basin margin accompanied by cation-exchange, (2) reactions involving aluminosilicate minerals, carbonates and halite, (3) an input of $MgCl_2$ solutions released from the metamorphism of carnallite in the A-1 salts, and (4) a preexisting enrichment of $CaCl_2$ in the Paleozoic seawater that entered the basin, and which was subsequently evaporated. The isotopic composition of the water in the brines is consistent with evaporated seawater, although values may have been enriched by exchange with calcite and dolomite and by the input of hydration water from evaporite minerals.

RIVERTON FORMATION IRON ORES: KEWEENAWAN OXIDATION AND IRON ENRICHMENT OF A PRE-PENOKEAN SUPERIOR TYPE IRON FORMATION

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The Riverton Formation is chert-siderite facies Superior Type Iron Formation of the Paint River Group (PRG), Marquette Range Supergroup. It is 90 to 250 m thick, the main iron ore-bearing formation of the Menominee Range, underlain by 150 to 450 m of Dunn Creek Slate, and overlain respectively by 15 to 150 m of Hiawatha Greywacke, 30 to 60 m of Stambaugh Iron Formation and 1200 m of Fortune Lakes Slate. The Dunn, Hiawatha, Stambaugh, and Fortune Formations are complex grey to black slate, chert, siltstone, and greywacke formations that are variably pyritic and sideritic. The PRG overlies up to 4.5 km of Badwater Formation basalt which is probably correlative with the 1.95 Ga volcanic rocks of the Baraga Group Hemlock Formation, and was metamorphosed at 1.85 Ga, the age of syn to post-tectonic intrusive rocks of Penokean Orogeny. During the Penokean Orogeny the PRG was deformed into tight, northwest-plunging folds and open to tight, shallow-plunging folds. In the Riverton Iron Formation, siderite is oxidized to hematite and goethite, and chert is replaced by hematite and goethite, in high grade (> 50% Fe) porous, "soft" ore bodies. The iron ores contain minor quartz, kaolinite, and illite. The iron ores are only in the cores of upward opening structures (mostly synclines) with impermeable footwalls.

That is they are upward facing saddle reefs which collected descending rather than ascending mineralizing fluids. The formation of hematite-goethite iron ores is interpreted as a late oxidation event in the PRG, on the basis that: i) they are mostly in axial parts of plunging, Penokean synclines; ii) they do not have a structural fabric; iii) they have mineral assemblages of lower grade than the regional rank.

Ore formation occurred in two stages: i) widespread oxidation of siderite to hematite and/or goethite in envelopes much larger than orebodies; and, ii) dissolution and replacement of chert in ore bodies by hematite and/or goethite at stylolites and other pressure solution surfaces. Oxidation of siderite-chert iron formation to hematite-goethite iron ore is therefore a fossil supergene alteration of a carbonate formation, analogous to karstification with an iron oxide residue. It most likely occurred when the permanent water table was lowered during uplift of the PRG on the south ridge and flank of the Keweenawan Rift at about 1.1 Ga. Oxidation was oxygenated meteoric water ingress, and acid production from ferrolysis reactions in the pyrite-bearing slates supradjacent to the ore bodies, focused by footwall permeability barriers into cores of plunging, upward opening structures.

GEOCHEMICAL EVOLUTION OF GROUND WATER FROM WITHIN THE MARSHALL SANDSTONE REGIONAL AQUIFER, MICHIGAN BASIN

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Concentrations of dissolved solids in ground water from wells near the limits of the subcrop of the Marshall Sandstone of Mississippian age, a regional aquifer in the Michigan basin, are small [< 500 mg/L] and originate from meteoric-water/rock interactions. Concentrations of dissolved solids increase toward the center of the basin [> 300,000 mg/L] and are hypothesized to originate from evaporated seawater. This study examines the geochemistry of solutes in water from the Marshall Sandstone aquifer and compares these results to the geochemistry of solutes in water from Devonian formations that are separated from it by approximately 950 to 1,800 feet of shale. The analysis of geochemical data (300 geochemical and 120 stable-isotope samples) indicates that (1) hydrochemical facies range from Ca-HCO_3 in the subcrop area to Na-Cl and Ca-Cl in the basin center; (2) ion ternary diagrams and isotopic ratios indicate the mixing of meteoric water with brine; (3) Cl:Br, Cl:Na, and Carpenter Function:Cl ratios suggest that the brine in the Marshall Sandstone is similar to seawater evaporated beyond halite precipitation; (4) ion:Br ratios indicate that the Marshall brine is enriched in Ca and depleted in SO_4, Mg, and K with respect to equivalently evaporated seawater; and (5) most brines that were sampled are at, or near, equilibrium with respect to calcite, dolomite, and anhydrite, and less concentrated meteoric water samples are near equilibrium with respect to calcite. Brine-freshwater mixtures in the Marshall Sandstone are geochemically and isotopically similar to brines in the Devonian formations. Thus, the evolution of ground water in the Marshall Sandstone is hypothesized to be similar to that of the Devonian formations in which dilution of a marine brine by meteoric water is a dominant process and that other major geochemical processes, such as dolomitization, interaction with clays, and sulfate reduction occurred prior to dilution. Although the evolution of the brine is constrained from analysis of geochemical data, the source for the brine is unknown. Possible sources include upward migration of brine from Devonian formations, brines formed during Mississippian or Pennsylvanian time, and downward migration of brines from Jurassic red beds.

GOLD POSSIBILITIES IN SOME KEWEENAWAN CHALCOCITE

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Two years ago, when I spoke to this group on "inductive electrostatic gradiometry (IESG) explains Keweenawan native copper plumbing system", I indicated that the misnamed "dowsing, divining, and water witching" are not aspects of the occult, but rather are physical-physiological-neurological ways for the human sixth sense to indicate geophysical SP (self-potential) anomalies inductively, thanks to static electricity. Building on that concept today, I present a geophysical, geochemical, and geological leap across eastern Lake Superior from Mamainse Point, Ontario (where Keweenawan chalcocite-specularite ores in the Coppercorp mine contain as much as 2.50 oz/st of invisible gold in veins in the Upper Mamainse Group of basalts, correlated with Michigan's Portage Lake Lava Series), to the Keweenaw Peninsula, where similar chalcocite-specularite ores occur. They should be assayed for gold. In Ontario, invisible gold occurrence is localized as a consequence of appropriate depositional hydrothermal Eh, easily marked by conspicuous mineral zoning of abundant copper minerals, at the interface between common chalcopyrite and/or bornite with chalcocite and specularite -- a progressive oxidation boundary. The supporting data are given in greater detail in my 22 page Preprint 92-32 from the February 1992 AIME/SME Phoenix meeting, obtainable from the SME, Box 625002, Littleton, Colorado 80162-5002. Today, I add more information on what Frank Pardee called "the only genuine gold mining myth in Michigan" (Douglass Houghton's possible gold discovery which he is reported to have made shortly before his tragic drowning in 1845), and I suggest how we might relocate this deposit by IESG, stream sampling, soil sampling, etc.

GEOCHEMISTRY OF GROUND WATER FROM NEAR-SURFACE-BEDROCK AND GLACIAL-DRIFT REGIONAL AQUIFERS WITHIN THE MICHIGAN BASIN

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Ground water in Glacial-drift and two near-surface-bedrock aquifers (Pennsylvanian Grand River-Saginaw and Mississippian/Pennsylvanian Parma-Bayport) that are hydrologically connected on a regional scale contain dissolved-solids concentrations of up to 12,000 mg/L, 92,000, and 240,000 mg/L, respectively. The source for the large concentrations of dissolved solids in these aquifers is hypothesized to be similar to that for brine in the Marshall Sandstone of Mississippian age. To examine this hypothesis, the geochemistry of ground water from near-surface aquifers was compared to the geochemistry of ground water from the Marshall Sandstone. Analysis of geochemical data (900 geochemical and 400 stable-isotope samples) indicates that (1) the dominant hydrochemical facies in decreasing areal distribution, are Ca-HCO_3, Na-Cl, Ca-SO_4, and Na-HCO_3; (2) Na-Cl facies are present in all units within the Saginaw lowland, a regional ground-water-discharge area; (3) the Parma-Bayport aquifer has the most concentrated ground water followed by the Grand River-Saginaw and Glacial drift; (4) cation ternary diagrams indicate the principle process affecting water chemistry in the aquifers is mixing of Ca- and Na-rich solutions; (5) plots of anion ternary diagrams indicate that HCO_3- and SO_4-rich solutions mix at low concentrations, HCO_3-, SO_4-, and Cl-rich solutions mix at intermediate concentrations, and SO_4- and Cl-rich solutions mix at high concentrations; (6) isotopic ratios indicate that the water in the aquifers is meteoric; (7) ratios of selected ions to Br and Cl as well as Carpenter

Function:Cl ratios suggest that the solutes in the aquifers have resulted, in part, from dilution of a marine brine that was concentrated to near halite precipitation and enriched in Ca and depleted in SO_4, Mg, and K with respect to equivalently evaporated seawater; and (8) geochemical modeling indicates that the ground water in the aquifers is at or near equilibrium with respect to calcite and, possibly, to dolomite and gypsum. For each aquifer, ground-water compositions, except for the most dilute, plot along the seawater-evaporation curve if the Carpenter Function is plotted against Cl for dissolved-solids concentrations less than that of seawater to concentrations found in brine of the Marshall Sandstone, which plots well past halite precipitation. This composition continuum implies a common origin for solutes in near-surface aquifers and the Marshall Sandstone. The geochemistry of the ground water in the near-surface aquifers can be accounted for by a dilution of the brine in Pennsylvanian aquifers by recharge from overlying meteoric water and by discharge from underlying brines from Parma-Bayport aquifer (or upper Marshall Sandstone) into the Pennsylvanian aquifers.

BUILDING AND DECORATIVE STONE IN MICHIGAN -- AN UNDERUTLIZED HIGH VALUE INDUSTRIAL MINERAL RESOURCE

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Because of its geological diversity, Michigan has a wide variety of rock types that are ideal for building and decorative use. Nearly all of the types recognized by the stone industry can be found in Michigan including granite, sandstone, slate, limestone, marble, greenstone, quartzite, traprock plus miscellaneous types such as jaspilite. Rocks falling within most of these classifications are present in the Precambrian regions of the western Upper Peninsula.

An earlier study investigated the properties and suitability of 50 different Michigan stones for use in the decorative and building stone industry (Johnson et al, 1972; Johnson, 1982). In addition to chemical and physical properties, the project also solicited the opinions of architects regarding market appeal for these stones. The study also examined potential markets and transportation costs. It was determined that many stones could win market acceptance, but that the cost of transportation to distant markets would require the production of higher value stone. It was concluded that some crushed stone types, particularly marbles, would be economic to produce and could win market acceptance. Recent commercial development of the Randville dolomite (a marble) in Dickinson County demonstrates the accuracy of this conclusion.

Current efforts involving federal, state and university participation is directed toward more detailed investigation of some of the stones having greater promise for economic development. This market oriented effort involves closer examination of important technical and economic factors that must be known in order to attract stone producers to invest in Michigan. Chief among these factors are: 1) adequate resources of uniformly high quality stone, 2) good transportation, 3) skilled labor, 4) favorable tax structure, 5) reasonable environmental regulations and, 6) a market for the stone.

Although historically, Michigan was a major producer of building stone (Jacobsville sandstone), production of building and decorative stone in the state has not been significant for many years. Comparing Michigan's production with surrounding states and Canadian provinces which have thriving building and decorative stone industries bears this out. There is no apparent reason why Michigan cannot similarly develop and profit from its abundant and varied building and decorative stone resources.

TEXTURES, AND CHEMICAL AND ISOTOPIC COMPOSITIONS OF CARBONATES IN PENNSYLVANIAN SANDSTONES IN THE MICHIGAN BASIN

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Pennsylvanian sandstones in Michigan contain saline water or brine in most of the basin, but contain freshwater in some areas. We suggest that sandstone aquifers that currently produce freshwater once contained brine. To test this hypothesis, growth sequences and textures of authigenic carbonate minerals in Pennsylvanian sandstones were examined, and chemistries and isotopic compositions were determined. The sandstones studied are from shallow coal-exploration boreholes drilled in Jackson, Ingham, and Arenac counties. Sandstone aquifers in these areas contain fresh to slightly saline ground water (279 to 1,820 mg/L dissolved solids). The growth sequence of carbonate phases includes early siderite followed by magnesian-siderite overgrowth, ankerite, ferroan-dolomite, and late calcite. Dolomite, rhodocrosite, and witherite also are present but constitute minor phases. Carbon isotopic compositions (del ^{13}C) range from -12.1 to -2.6 PDB and oxygen isotopic compositions (del ^{18}O) range from -8.2 to +2.5 PDB. Mineral paragenetic sequences and carbonate phases are similar to those observed in Mississippian sandstones. Isotopic compositions of authigenic minerals have the same range of values in Mississippian and Pennsylvanian sandstones. These data support the conclusion that basinwide evolution of brine produced an authigenic mineral suite common in Carboniferous sandstones, and brine was present in Pennsylvanian units, perhaps as recently as Pleistocene time.

MINING CONSTRUCTION AGGREGATES IN MICHIGAN PROBLEMS AND SOLUTIONS

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Most construction aggregates in Michigan come from surface mining operations. The number of these operations has declined over the past 20 years, but the demand is still relatively high. The industry faces a number of problems including changing specifications from government users, obtaining permission to mine from local governments, and receiving the necessary permits from the State for mining.

Some recent changes in Michigan Department of Transportation (MDOT) specifications dealt with an aggregate wear index, a durability factor, and manufactured sand. At the local level, it can take two to five years to reach a decision for a new mining operation - and often permission is denied. If the company decides to press litigation, that process can take another two or three years - with no guarantee of success. Once the local permit question has been resolved, it isusually necessary to obtain permits from the State Department of Natural Resources (DNR). These include air quality permits and water discharge permits - the two that can prove the most difficult to get. The problems with permits are often due to changing standards and requirements.

The best prospect for the solution of these problems is education; education of regulators, education of legislators, education of local and county officials, and education of students who will be faced with some of the same questions as they become responsible citizens. There is a great deal of information available for the education process; all we need are the "teachers". It is our responsibility, as professionals whose background for the most part is geology, to become the teachers and reach these audiences.

BURIAL DIAGENESIS AND PORE-WATER CHEMISTRY EVOLUTION IN THE MARSHALL SANDSTONE REGIONAL AQUIFER, MICHIGAN BASIN

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Geochemical modeling of elemental compositions and stable isotopes of Marshall Sandstone pore waters indicate mixing between meteoric water and evaporated seawater. Authigenic cements in the Marshall Sandstone were analyzed to determine whether they reflect this mixture of brine and meteoric water.

Chlorite and dolomite-ankerite are cements precipitated during or after compaction. Kaolinite and illite are post-compaction cements. Kaolinite overlies, and therefore, post-dates carbonate cements. Illite overlies, and therefore, post-dates kaolinite. Compositions of dolomite-ankerite cements range from 4 to 24 mol % $FeCO_3$ and del ^{18}O between -6.0 and +0.5 per mil PDB. Del ^{18}O of chlorite cements range from +10.3 to +12.8 per mil SMOW and del ^{18}O of kaolinite cements range from +18.0 to +19.3 per mil SMOW.

Cements (chlorite, quartz, feldspar, carbonate, kaolinite, and illite) are present throughout the Marshall Sandstone, despite the wide range in chemistry of present day formation fluids. Secondary porosity related to feldspar and carbonate dissolution is present throughout the basin.

Cement stable isotopes and mineral paragenesis are consistent with carbonate and phyllosilicate precipitation during burial diagenesis at approximately 40-90°C in waters of progressively increasing del ^{18}O. The change is del ^{18}O of pore fluids probably reflects input of isotopically heavy water from the underlying Coldwater Shale and/or overlying Michigan Formation. The cements may have formed in brine similar to the isotopically heavy brines present in the formation today, but only at substantially higher temperatures.
Solid-phase and pore-water analyses indicate that mixing of meteoric water and brine may have influenced mineral paragenesis, and probably caused some dissolution of carbonate cement.

ABSTRACTS OF POSTERS ALPHABETICAL BY AUTHOR

MORPHOLOGIC, STRATIGRAPHIC, AND CHRONOLOGIC ASPECTS OF DEGLACIATION ALONG THE PORT HURON MORAINE IN NORTHWEST-SOUTHERN MICHIGAN

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Evidence based on an analysis of topographic maps, sediment facies, landform patterns, and field relationships indicates that the Port Huron moraine in northwest-southern Michigan formed along successive marginally stagnant glacial termini as the ice margin pivoted clockwise to the northwest during final deglaciation. Landform and sediment relationships show that the final deglaciation was characterized by long intervals of quasi-stable ice-marginal conditions favoring thick outwash deposition, punctuated by brief transitional periods of rapid meltwater incision due to ice-marginal retreat. A radiocarbon age from lacustrine sediments immediately proximal to the Inner Port Huron moraine suggests that deglaciation commenced approximately 12,960 +/-350 yr. B.P.

SOME POTENTIAL SOURCES OF SOIL AND GROUNDWATER CONTAMINATION ASSOCIATED WITH OIL AND GAS DRILLING AND PRODUCTION SITES IN MICHIGAN

Robert V. Brady, Geologist, Jackson, MI

There are a number of potential sources of soil and groundwater contamination associated with oil and gas drilling and production sites in Michigan. Potential contaminants range from drilling fluid additives to components of natural gas and petroleum and other natural formation fluids. Other contaminants can include refined petroleum products from drilling and completion operations, as well as chemicals used in completion and work-over programs. While the vast majority of oil and gas operators in Michigan have not been grossly negligent in their activities, government regulations have gradually reduced the potential for even the unintentional introduction of contaminants into soil and groundwater, though at a significant cost to the industry. This presentation focuses on the potential contaminants and the possible points of their introduction into the soil or groundwater.

REACTIVATED ARCHEAN STRUCTURES, PROTEROZOIC STRATIGRAPHY AND MINERAL DEPOSITS; WESTERN UPPER MICHIGAN

William F. Cambray, Michigan State University, East Lansing, MI; Robert W. Hodder, University of Western Ontario, London, Ontario; Glenn W. Scott, Consulting Geologist, Marquette, MI

Basement structures related to the late Archean continental collision along the Great Lakes Tectonic Zone appear to have been reactivated during the Proterozoic. Evidence for this reactivation includes: isopach and facies variation in Proterozoic stratigraphy, location of intrusions and the formation of mineral deposits. The sequence of proposed events is:

1. Formation of fabrics trending east-west and northwest during the suturing of the Archean cratons at approximately 2.5 Ga.
2. Rifting and sedimentation associated with basins that were localized by these fabrics during the development of a passive margin prior to the Penokean Orogeny.

3. Folding and thrusting during collision associated with the Penokean Orogeny.

The Proterozoic basins in the Marquette, Gwinn and Republic areas formed parallel to the underlying Archean fabric and acted as hosts for the banded iron formations, Kona copper deposits and other base and precious metal occurrences. There is some indication that the areas in which these mineral deposits are most concentrated lie at the intersection of the east-west and northwest trends found in the basement. We propose that continued reactivation of these basement structures focused the deep iron formation basins and acted as conduits for igneous intrusions and fluid flow associated with other mineral deposits, perhaps including Keweenawan copper and Mesozoic kimberlites.

INVENTORY OF THE GEOLOGICAL SURVEY DIVISION'S UPPER PENINSULA SIGNIFICANT WATER WELL CUTTINGS LIBRARY AT ESCANABA

Frank Chenier, Department of Natural Resources, Geological Survey Division, Escanaba, MI

Nearly 500 selected water wells are represented by drill cuttings in the collection maintained in the Geological Survey Division, Michigan DNR office at Escanaba, Michigan. The cuttings collection is available for study and review, as are copies of water well logs for the entire Upper Peninsula. For an appointment, contact Frank Chenier at 906-786-2351.

LOWER MIDDLE SILURIAN WITHIN THE MICHIGAN BASIN

Ronald C. Elowski, Department of Natural Resources, Geological Survey Division, Lansing, MI

The terms Burnt Bluff and Manistique have been used for many years as group names for lower Middle Silurian outcrops in the Northern Peninsula of Michigan. I am proposing the use of Burnt Bluff and Manistique as group names in the subsurface of the Michigan Basin. My poster is meant to show the vertical and lateral extent of these groups and to propose limits for the use of the term Clinton group in the subsurface of the Michigan Basin.

BEDROCK TOPOGRAPHY AND GLACIAL DRIFT THICKNESS MAPS OF THE SOUTHERN PENINSULA OF MICHIGAN

John M. Esch, Department of Natural Resources, Environmental Response Division, Geological Services Section, Lansing, MI

The most detailed glacial drift thickness and bedrock topography maps for the southern peninsula of Michigan have been assembled. These maps (Aangstrom Precision Corporation) were originally constructed to aid in seismic data processing for oil and gas exploration in Michigan.

A true drift thickness map is the difference in elevation between two different surfaces; the bedrock elevation surface and the land elevation surface. Most drift thickness maps are constructed by contouring the depth to bedrock from well logs. This does not take into account the lateral variation in drift thickness that occurs between these two surfaces.

A new technique in drift thickness mapping was used. The drift thickness map was constructed by subtracting a bedrock topography contour map of the southern peninsula from the land surface contour map of the southern peninsula. Using this technique the drift thickness map consists

of the available downhole data (depth to bedrock from well logs) but incorporates present land surface elevations from topographic maps.

The bedrock topography map of the southern peninsula of Michigan was constructed using data from a Michigan petroleum well database, with additional data from other well logs (geological tests, core tests, mineral tests, coal borings, disposal wells, water wells) and supplemented with published and unpublished bedrock topography and bedrock outcrop maps. The present land elevation surface map was constructed by digitizing elevations from USGS 7.5 and 15 minute topographic maps.

The new bedrock topographic map shows a very irregular bedrock surface with deep bedrock valleys, cuestas, locally smoothed surfaces, and an occasional fault valley. The Marshall Sandstone Cuesta is evident as a distinct west sloping bluff at the Marshall Sandstone/Coldwater Shale subcrop contact extending from the northwest corner of Muskegon County in a northeasterly arc to north-central Wexford County. A combined Marshall Sandstone-Coldwater Shale Cuesta is evident as a pronounced bedrock high extending from western Branch County northeasterly to the tip of the thumb.

Drift up to 1250 feet thick occurs in the southern peninsula. It changes thickness and lithology abruptly and is locally thicker overlying bedrock valleys and is non-existent over widely scattered outcrop areas. The drift thickness map is similar to the present land surface topography map. Higher land surface elevations generally correspond to thicker drift, especially in northern Michigan. However, in parts of southern Michigan the opposite is true, especially in Jackson, Hillsdale and Branch Counties where the Marshall Sandstone and Coldwater Shale outcrops and subcrops. In parts of this area higher land surface is associated with thinner drift and higher bedrock elevations.

A GEOPHYSICAL INVESTIGATION OF THE MID-CONTINENT RIFT, BRANCH COUNTY, MICHIGAN

Mitchell J. Gutaj and William A. Smith, Department of Geology, Western Michigan University, Kalamazoo, MI

Branch County is located on the southwestern margin of the mid-Michigan geophysical anomaly which is believed to represent an extension of the Mid-Continent Rift. The existing gravity data for the area is widely spaced with intervals ranging from 5 to 15 kilometers. Interpretation of this data indicates a broad NW-SE trending feature, but detailed basement structures are not discernible.

In order to determine what structures may exist, a detailed gravity survey was acquired. The station spacing intervals were approximately 0.5 to 1.5 kilometers. A total of twelve 7 1/2-minute quadrangles were surveyed with 80-140 gravity stations per quadrangle. Gravity contour maps were constructed and with the assessment of existing well-logs and aeromagnetic data, several cross-sections were chosen for computer modeling. To further constrain the subsurface models, data from oil company seismic lines, detailed ground magnetic surveys, and physical examinations of available rock cores were studied and interpreted.

Delineation of these trends would be of importance for (1) oil and gas production in southwest Michigan, and (2) the eventual interpretation of the Mid-Michigan Rift. The Albion-Scipio field, located in Hillsdale, Jackson, and Calhoun counties and immediately to the northeast of the field study area, is an oil reservoir found along a narrow, linear, NW-SE trending fault zone. Other fields of this type may occur in adjacent areas such as Branch County, but because some of these fields can be as small as one square kilometer in area, their locations cannot be inferred without a detailed gravity survey.

The geophysical maps constructed for this purpose, consisting of gravity maps of Branch County and detailed ground magnetic maps of selected areas, show trends of interpreted fault zones or basement lithological boundaries. The subsurface models produced from the available data across these trends delineate areas which could be favorable for hydrocarbon exploration and production. In the least, this may provide an insight into the role basement tectonics has on hydrocarbon producing areas in the overlying Paleozoic section.

CHARACTERIZATION OF MEGASCOPIC FOSSILS AND THEIR HOST, THE 2.1 BILLION-YEAR-OLD NEGAUNEE IRON-FORMATION, MARQUETTE DISTRICT, MICHIGAN

T. M. Han, Consulting Applied Mineralogist, Ishpeming, MI

Megascopic fossil remains resembling Grypania spirals have been found in the 2,100 million-year-old early Proterozoic Negaunee Iron-Formation at the Empire Mine, in the Upper Peninsula of Michigan. These fossil remains are about 700 million years older than those previously known from Montana and China, and 100 million years older than those reported from India.

The posters show the sedimentological and mineralogical characteristics in the fossiliferous zone of the iron-formation; and feature the size, morphology, distribution, and arrangement of the fossil remains and their relation to the sedimentary structures in the fossiliferous zone.

The objective is to establish evidence relative to the physical and chemical conditions under which these fossils were deposited and preserved.

GEOLOGIC MAP PORTFOLIO OF CHIPPEWA COUNTY, MICHIGAN

Sean McCann and Lewis M. Brown, Lake Superior State University, Sault Ste. Marie, MI;
Michelle Ribant and Suzanne Lieurance, Chippewa County Environmental Health, Sault Ste. Marie, MI;
Frank J. Chenier and Milton A. Gere, Jr., Geological Survey Division, Michigan
Department of Natural Resources, Gladstone, MI, and Marquette, MI, respectively.

The purpose of this study is to produce a geologic map portfolio of Chippewa County in the northeastern Upper Peninsula of Michigan. The portfolio includes: a geologic map showing stratigraphic relationships from the Jacobsville Sandstone of Keweenawan Age to the Engadine Dolomite of Silurian Age; a three-dimensional bedrock contour map; and a set of cross-sections to depict stratigraphy and bedrock surface variations. The maps and cross-sections were computer generated from about 1400 water well logs and a number of oil well logs.

The portfolio will have many uses: assisting in analysis of groundwater conditions and the development of groundwater supplies; helping to identify areas subject to groundwater contamination, i.e., shallow limestone bedrock, open aquifers, etc. Homeowners, planners, governmental agencies, such as health departments, drillers, geologic consulting and engineering firms should find the portfolio useful. The portfolio is one example of a use of information stored on the Statewide Groundwater Data Base.

UNDERGRADUATE STUDENT PROJECTS PORTRAYING THE DEVELOPMENT OF THE MICHIGAN BASIN: FROM PALEOTIMES NEWSPAPER TO COMPUTER GRAPHICS POSTERS TO GEO/BIO TIME LINES

Marian M. Smith, Department of Geology, Western Michigan University, Kalamazoo, MI

The details of the geologic and biological evolution of the Michigan Basin is a lot to test upon in standard examining situations. Students are more likely to truly understand the information if they can first be told the information and then present it in their own fashion in a take-home test or class project. When students share these projects with each other in a peer grading situation, they come to see the wide range of efforts and imaginations. Projects such as these also give the professor an appreciation of the students as individuals.

Students often use desk top publishing and poster making programs in their presentations. Group projects also provide the opportunity to learn how to work with peers and be graded for the project as a whole. Geologic time lines showing the biological and geological development of the Michigan Basin made by university students for middle school classes also provide a unique learning and sharing experience.

These projects are meant to show many of the new themes in improving science education: group learning, communication skills, mathematical skills, and thematic teaching.

PRIMARY AND SECONDARY BOUGUER GRAVITY TREND ANALYSES OF THE KIERNAN SILLS AREA, IRON COUNTY, MICHIGAN: IMPLICATIONS FOR EARLY PENOKEAN TECTONICS

Stephen D. Stahl, and Michael J. Cogan, Department of Geology,
Central Michigan University, Mt. Pleasant, MI

-NO ABSTRACT-

GEOPHYSICAL MAPPING OF THE SAUBLE ANOMALY, LAKE AND MASON COUNTIES, MICHIGAN: EVIDENCE FOR WRENCH TECTONICS IN THE MICHIGAN BASIN

Stephen D. Stahl, David A. Pavlick, Russell A. Smith, and
Mark A. Waters, Department of Geology, Central Michigan University,
Mt. Pleasant, MI

-NO ABSTRACT-

GEOLOGICAL CORE & SAMPLE REPOSITORY, MARQUETTE, MICHIGAN AN UPDATE

William T. Swenor and Milton A. Gere, Jr., Department of Natural Resources,
Geological Survey Division, Marquette, MI

The Geological Core and Sample Repository of the Geological Survey Division, Michigan Department of Natural Resources is located near Marquette, Michigan. This "Rock Library" includes materials from across the state. However, most of the more than 15,000 boxes of material consist of mineral exploration drill core and samples from Upper Peninsula locations.

The Repository is open to the public, by appointment, to allow study of the materials. Numerous geologists from industry, universities and state and federal

agencies have used our materials to further their research. It is hoped that the use of this collection will help in interpreting Michigan's complex geology and mineralogy and will ultimately lead to new mines, industry and jobs in Michigan.
The core and sample collection continues to expand. Several large donations of core have been received recently from industry. Additional donations are encouraged.

To make an appointment to visit the Repository, please call either Bill Swenor or Milt Gere at 906-228-6561. The most recent update of the inventory of the facility is available as "Inventory of the Geological Core and Sample Repository, Marquette, Michigan," Open File Report 93-02, (50 pages), and may be purchased from Geological Survey Division, P.O. Box 30256, Lansing, Michigan 48909, or call Greg Wilson at 517-334-6943.

SYMPOSIUM BRIEF SYNOPSIS OF ACTIVITIES

Wednesday

Poster Setup	3:00 - 6:00 p.m.	Big 10A Room
Registration	6:00 - 8:00 p.m.	Big 10A Room
Posters	6:00 - 10:00 p.m.	Big 10A Room
EVENING RECEPTION	6:00 - 10:00 p.m.	Big 10A Room

Thursday

Registration	7:30 - 9:30 a.m.	Big 10A Room
Morning Coffee	7:30 - 9:00 a.m.	Big 10A Room
Posters	All day	Big 10A Room
PRESENTATIONS	8:30 a.m. - 12:00	Auditorium and Big 10B Room
Slide Preview	All day	Room 108, prep. room for Speakers
Morning Break	10:00 - 10:30 a.m.	Big 10A Room
Lunch	12:00 - 1:30 p.m.	On your own
PRESENTATIONS	1:30 - 4:30 p.m.	Auditorium and Big 10B Room
Afternoon Coffee	3:00 - 3:30 p.m.	Big 10A Room
Registration	6:00 - 7:00 p.m.	Big 10A Room
Cocktail Hour	6:00 - 7:00 p.m.	Big 10A Room
BANQUET	7:00 - 10:00 p.m.	Big 10A Room
Speaker	Dr. Paul Hoffman	Big 10A Room

Friday

Registration	7:30 - 9:30 a.m.	Big 10A Room
Morning Coffee	7:30 - 9:00 a.m.	Big 10A Room
Posters	All morning	Big 10A Room
PRESENTATIONS	8:30 a.m. - 12:00	Auditorium and Big 10B Room
Slide Preview	All morning	Room 108, prep. room for Speakers
Morning Break	10:00 - 10:30 a.m.	Big 10A Room
Poster Break-down	12:00 - 5:00 p.m.	Big 10A Room

General

Parking is available next to the Kellogg Center.
Parking is free for hotel guests, with a pass from the front desk.
A coat check is available in the hotel lobby.
Hotel cafeteria and lounge are located on the lower level.
The State Room Restaurant is located on the first floor.
The Corniche Room is located on the second floor.
Harrison Roadhouse restaurant is within walking distance.
Downtown East Lansing is one mile from the Kellogg Center.

Kellogg Center

First Floor Plan