Michigan: Its Geology and Geologic Resources

Fourth Symposium
Thursday March 14, 1996 and
Friday March 15, 1996

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Michigan Department of Environmental Quality
Michigan Geological Survey Division

and

Michigan Basin Geological Society

Michigan: Its Geology and Geologic Resources - Table of Contents

Abstracts of Papers

listed in order of presentation

Thursday, March 14 Morning Session

Contributing Areas of Water-Supply Wells in Elkton and Pigeon, Huron County, Michigan

by G. J. Barton, U. S. Geological Survey, Columbus, Ohio

The villages of Elkton and Pigeon in Huron County, Michigan, depend on wells completed in the Marshall aquifer to provide a reliable source of potable water. To protect the quality of water pumped from these wells, these municipalities need to ensure that potentially harmful contaminants do not enter the Marshall aquifer within the contributing areas of these wells. The Well Head Protection Plan for the State of Michigan requires the delineation of a contributing area based on a 10-year time of travel.

The Marshall aquifer, composed of permeable sandstone, is the principal bedrock aquifer in the Elkton-Pigeon area and in the Michigan Basin. In the Elkton-Pigeon area, the top of the Marshall aquifer is roughly 90 to 150 feet below land surface, and the aquifer is about 80 feet thick. Transmissivity ranges from 40 to 1,300 ft^2/day, effective porosity is estimated to be about 10 percent and hydraulic gradient ranges from 0.0013 to 0.0025. The recharge area of the aquifer is several miles southeast of Elkton and Pigeon, where the aquifer is a subcrop beneath the permeable Port Huron End Moraine.

Water from wells at Elkton and Pigeon has tritium concentrations of less than 0.8 tritium unit, indicating that (1) the water is more than 40 years old; and, (2) the aquifer is highly confined. On the basis of average Darcian flow rates, the uniform-flow equation, and the semianalytical Well Head Protection Area model, the contributing areas for a 10-year time of travel for water supply wells are almost entirely within each village boundary; contributing areas for a 40-year time of travel encompass areas within approximately 1 mile of each village and are several miles from the recharge area of the aquifer.

Control of land use activities within the contributing areas will not ensure that water pumped from these supply wells will remain potable. The Marshall aquifer overlies the Coldwater Shale, which contains brine that could migrate toward the pumped wells.

Pleistocene Geology of Metropolitan Detroit

by D. T. Rogers, Clayton Environmental Consultants, Novi, Michigan

Pleistocene sediments in Michigan consist of complex unconsolidated glacial drift and lacustrine deposits that may be as thick as 1,000 feet. In metropolitan Detroit, Pleistocene sediments range in thickness from approximately 50 to 200 feet. The Pleistocene sediments in metropolitan Detroit were first studied and mapped for potential mining and agricultural purposes more than 150 years ago. Many geological researchers have since contributed significantly in evaluating Pleistocene geology in the region.

Stratigraphic analysis of Pleistocene sediments in metropolitan Detroit has generally not been possible because (1) of the lack of subsurface data; and,(2) the complexity of deposition. Other difficulties in studying Pleistocene sediments in metropolitan Detroit have included removing or obscuring original depositional features through (1) erosion and reworking of sediments; and, (2) urbanization.

Geologic information obtained from (1) historical geological researchers; (2) water and oil and gas drilling logs; and, (3) recent investigations at sites of environmental contamination were used to map the surface geology and conduct a preliminary analysis of Pleistocene stratigraphy in metropolitan Detroit.

The findings have revealed a more detailed geologic understanding of near-surface sediments and have also revealed the impact of recent human activities on near-surface soils and aquifers. In addition, the findings underscore the need for a comprehensive and thorough understanding of the surficial geologic and hydro-geologic environment in urban regions. The significance of this understanding is far reaching. Without it, the accuracy of current studies in numerous related disciplines (e.g., urban planning, ecosystem management) is fundamentally limited.

GIS Evaluation of the Interactions Among Formation Brine, Near-Surface Ground Water and Large Lakes

by J. K. Kolak, D. T. Long, G. J. Larson, D. F. Sibley, Department of Geological Sciences, Michigan State University, East Lansing, Michigan, and J. M. Matty, Department of Geology, Central Michigan University, Mt. Pleasant, Michigan.

The Saginaw Lowland Area (SLA) of east-central Michigan lies directly atop the Michigan basin. Portions of near-surface ground water in the SLA are saline (> 10,000 mg/L chloride) as a result of interaction with formation brine from the Michigan basin. Elevated chloride levels have also been detected in a number of streams within the Saginaw Bay watershed. We hypothesized that discharge from the saline, near-surface ground water was responsible for the affected streams. To test this hypothesis, arrays of nearly 200 river (and lake) samples were collected from the Saginaw Bay watershed. The arrays collected also enabled an evaluation of the watershed's response to varying flow conditions. Each sampling array was completed within two days, and the spatial data were evaluated using GIS (IDRISI). There are a number of anthropogenic sources for chloride (e.g., road salt), hence, chloride/bromide ratios were used to identify the source for chloride. Initial chloride sources considered were road salt (chloride/bromide ~ 1,000) and formation brine (chloride/bromide ranges from 250-300).

In general, the spatial distribution of chloride in surface water is consistent with the regional distribution of chloride in the near-surface ground water. This positive correlation persists through changing flow conditions. There are localized areas where elevated chloride levels in streams are unrelated to the regional distribution of chloride in ground water, indicating that anthropogenic inputs have overprinted the system. Chloride/bromide ratios are unexpectedly low (~ 100-150) throughout the region. We conclude that surface waters in the Saginaw Bay watershed are impacted by saline, near-surface ground water, however, there are significant anthropogenic interferences. Furthermore, the depressed chloride/bromide ratios may be an indicator of anthropogenic release of bromide (e.g., agricultural runoff and auto emissions).

Six-Phase Deglaciation of Pictured Rocks National Lakeshore

by W. L. Blewett, Department of Geography-Earth Science, Shippensburg University of Pennsylvania, Shippensburg, Pennsylvania

Deglaciation within Pictured Rocks National Lakeshore (PRNL) commenced approximately 9,800 yr. B.P., as a retreating ice margin confined eastward-flowing meltwater streams against the Munising moraine to the south. During recession a complicated assemblage of coalescing outwash aprons, kame terraces and incised channels formed as progressively lower outlets were uncovered along a bedrock highland west of Grand Marais. Radiocarbon age estimates from the correlative Marquette moraine and detailed chronologies documenting Lake Agassiz overflow to Lake Superior indicate that most glacial terrain within PRNL formed within 300-500 years. Spatial and temporal differences in glacier dynamics likely produced the significant variations in surficial sediment characteristics and landform assemblages present within the park. The Munising moraine - not a bedrock high thinly mantled by drift as proposed by others - represents a significant ice-marginal accumulation containing abundant ice-contact and proglacial stratified drift formed along a stagnant glacial margin.

The Geology and Depositional History of a Pleistocene Beach Sand in Southeastern Michigan

by D. T. Rogers, Clayton Environmental Consultants, Novi, Michigan

Pleistocene geology in southeastern Michigan is dominated by glacial lacustrine deposits. The sediments were deposited as Wisconsinan-age glaciers retreated. The glacial ice did not retreat uniformly; as many as 20 distinct stages of retreat and occasionally a re-advance of ice have been identified. The resulting terminal and lateral moraines became effective natural dams which were ideal for the development of glacial lakes. Several significant lake stages have been identified in southeastern Michigan. A sand unit deposited from the Arkona, Warren and Wayne glacial lake stages from approximately 13,500 to 12,000 years ago is the subject of this study.

The sand unit is located along the western margin of metropolitan Detroit. The unit trends in a north-south direction for approximately 30 kilometers, is 7.5 meters wide at its widest point and is a maximum 11 meters thick. The western margin generally follows the 235.5 meter (710 feet) contour line. The eastern margin follows the 211 meter (640 foot) contour line. At most locations, the sand unit is encountered less than 0.5 meters beneath the surface of the ground.

The unit encountered beneath the sand is a clay deposit. The clay unit is older than the sand unit and was deposited during an earlier glacial lake stage which is most likely the Maumee. The contact between the clay unit and the sand is non-gradational and sharp. Clay rip-up clasts are present in the lower 0.5 meters of the sand. The presence of the rip-up and the non-gradational boundary between the clay and the sand indicate that the boundary between the two units is an erosional contact.

The sand unit coarsens upward which indicates that the glacial lake was generally in a regressive state. In addition, the lower portion of the sand unit (lower 5 meters) can be differentiated from the upper portion (upper 6 meters). The lower portion of the sand unit is light olive gray, fine-to-medium-grained quartz sand. The lower portion shows limited evidence of stratification and ripple marks. When stratification is present, the layers are generally greater than 5 centimeters thick. The upper portion of the sand unit is as a moderate yellowish brown, medium-to-course-grained quartz sand. The upper portion is also well stratified and has well developed cross-bedding, ripple marks and scour and fill features. In addition, there is also localized evidence of reworking and eolian deposition within the uppermost 2 meters.

The observed depositional features of the sand unit indicate that the lower portion was deposited under a stable, lower energy, deeper water environment compared to the upper portion. The upper portion of the sand unit was deposited under considerably higher energy conditions and at times was eroded and reworked most likely by extensive wave action.

Contaminant Migration in the Pleistocene Glacial Deposits of Metropolitan Detroit

by D. T. Rogers, Clayton Environmental Consultants, Novi, Michigan

Sites of environmental contamination are not uncommon in metropolitan Detroit. Nearly 3,000 sites of environmental contamination have been identified by the Michigan Department of Environmental Quality in metropolitan Detroit. Pleistocene geology in metropolitan Detroit is dominated by glacial lacustrine deposits. The sediments were deposited as the Pleistocene glaciers retreated and several significant lake stages have been identified in southeastern Michigan. Four distinct lithologic units are present: a moraine unit, a sand unit, a sandy and silty clay unit and a clay unit. The clay unit is the easternmost unit and the moraine unit is the westernmost unit.

The lower portion of the sand is water-saturated. Ground water flow within the lower portion of the sand unit generally mirrors the surface-water drainage pattern of the River Rouge, which is toward the east-southeast.

Volatile organic compounds (VOCs) are the dominant types of contaminants at sites of environmental contamination in metropolitan Detroit. VOCs typically include degreasing solvents and petroleum products such as gasoline. Many of the VOCs are considered carcinogens or suspected carcinogens. The solubility, viscosity, ability to absorb to soil grains, biodegradability and density of VOCs are important factors when evaluating their migration through the subsurface environment. In general, VOCs (1) have low surface tension; (2) adsorb strongly to clayey soil particles and adsorb weakly to sandy soil particles; and, (3) have low capillary action which may inhibit VOCs from being retained between soil grains.

When released into the subsurface environment in a sandy substrate, VOCs typically migrate vertically in unsaturated soil from the source or release point. In addition, high concentrations of VOCs are not generally detected in very sandy soils because VOCs do not adsorb strongly to sandy soil particles. Once the VOCs reach the piezometric surface (if present), the transport mechanism for migration is ground water flow and dispersion. Therefore, VOCs released within the sand unit have a high potential to migrate a considerable distance from the point of release.

The presence of the sand unit represents an area that is sensitive to industrial and commercial development because ground water present within this sand unit is a pathway for contaminants to migrate to surface water bodies within the River Rouge drainage basin.

Contaminated sites in the eastern portion of the study are located within the clay unit and near surface ground water is not present. When contaminants (the majority being VOCs) are released within the boundaries of the clay unit, they are generally detected at high concentrations because they adsorb strongly to clayey soil particles. The migration of the contaminants is impeded in the clay unit because of the (1) low permeability of the clay; and, (2) the tendency of the contaminants to strongly adsorb to clayey soil particles. Therefore, sites within the clay unit are not located in an area that is as geologically sensitive as those sites located within the sand unit.

Although the majority of the residents within the study area obtain potable water from the Detroit River to the north and east of the study area, the contaminants detected in ground water will generally migrate in the direction of ground water flow to surface water bodies, if they are not controlled or captured. The surface water bodies within the study area used for recreational purposes and by wildlife (which include fish and waterfowl) and ultimately discharge into the Detroit River and Lake Erie.

Keynote Presentation

Improved Recovery Using Horizontal Drilling in the Dundee Formation of the Michigan Basin

W. B. Harrison, III, Department of Geology, Western Michigan University, Kalamazoo, Michigan

The goal of this project is to demonstrate that oil production from selected fields in the Dundee Formation (Dev.) of Michigan can be substantially increased, perhaps restored to near-original production levels, by utilizing horizontal drain wells. Devonian rocks have been the most prolific hydrocarbon producers of any system in the Michigan Basin. The Dundee Formation is Michigan's all-time production leader with 352 million barrels of oil and 42 billion cubic feet of gas. Because most of Michigan's Dundee Formation reservoirs were developed with only "primary" production techniques and most were discovered before 1960, recovery factors are thought to be only 10-15 percent. Many fields were badly mismanaged during initial development, especially in the early 1930s and 1940s, with the net result that much producible oil was bypassed as the development wells were pumped at such high rates that they watered out prematurely. Crystal Field in Montcalm County, Michigan, which has been selected as a field trial for this project, is such a field. Analysis of production data for Crystal Field suggests that an additional 400,000 bbls of oil per well can be produced using this horizontal technology. Total additional production from the Crystal Field could be as much as 6-8 MMbbls. Spin-offs from this technology could increase Dundee production in Michigan up to 35 percent, adding 80-100 MMbbls to the cumulative production.

The project will benefit small-to-medium sized independent oil field operators by demonstrating how to design and implement horizontal drains and manage efficient recovery programs. The approach combines proven, cost-effective horizontal drilling technology with modern reservoir characterization and management. A total of 30 Dundee fields are characterized in this study.

Well logs, other well data, drilling, and production data and rock samples from the Dundee Fm. will be obtained, assembled, analyzed, and input into TERRASCIENCES(s), a commercial database manager specifically designed for gas and oil operations. Petrographic and petrophysical measurements made on samples will be used to calibrate well logs. These data sets will be used to correlate log responses with geologic and engineering parameters. Rock properties will be quantified and used to predict the reservoir response. Computer models describing the diagenetic, stratigraphic and thermal evolution of the Michigan Basin will be developed and applied to the Crystal Field reservoir. A post-mortem study will monitor the effect of the horizontal well on Crystal Field production.

The initial test well in Crystal Field was completed in early October, 1995. Only about 100 feet of horizontal borehole was drilled due to engineering problems. The well has maintained a flowing oil rate of 100 Bbls per day with no water since completion.

Thursday, March 14 Afternoon Session

Petrologic Constraint of Possible Reactions of Saline Formation Water with Sediments at Equilibrium with Fresh Pore Water, Saginaw Bay

by J. A. Wilson, Department of Geological Sciences, Michigan State University, East Lansing Michigan

The mixing of different types of waters has long been recognized as an important component of carbonate diagenesis. At Saginaw Bay there exists an unparalleled opportunity to study if the mixing of fresh water and saline formation water affects the diagenesis of siliceous sediments. The sediments are modern lacustrine clays and Wisconsinan tills and are in the zone of mixing between the fresh water of Lake Huron and the formation brines of the Michigan basin. In the Saginaw Bay area these brines are very concentrated, even near the surface, with dissolved solids commonly exceeding 1,000 mg/L. This study also attempts to provide a mineralogic constraint for the mineral-water interactions that influence the pore-water chemistry in the sediments. A number of possible combinations of mineral dissolution and precipitation and iron exchange reactions may result in a given pore water chemistry.

Intergranular Pressure Solution Controls Permeability in the Marshall-Michigan Stray Sandstone

by R. Sturn and D. Sibley, Department Geological Sciences, Michigan State University, East Lansing, Michigan

The purpose of this study was to determine whether or not permeability variations within the Marhshall-Michigan Stray sandstones correlate with petrographic evidence of pressure solution. Samples were analyzed from the Austin and Six Lakes gas storage fields in Mecosta and Montcalm counties. The sandstones studied are quartz arenites with small amounts (<5 percent) of quartz, ferroan dolomite and/or kaolinite cement. Porosity of the sandstones ranges from 6 to 26 percent with a mean of 17.5 percent and permeability ranges from 1 to 4700 md with a mean of 190 md. The correlation between porosity and log permeability is quite poor (r^2=0.08) for 58 samples analyzed but much better when taken by field r^2= 0.47 for Six Lakes samples and 0.39 for the Austin samples. Because of the importance many sedimentary petrologists place on secondary porosity, we point counted secondary porosity in 16 samples but found no correlation with permeability.

Because pressure solution can have a dramatic effect on pore throat geometry while having little effect on porosity, we examined the relationship between **tight packing index** and log permeability. The tight packing index is the *number of log + concavo-convex + sutured intergranular contacts/no. of grains.* The tight packing indices for the sandstones range from 1.12 to 4.30. Good correlation's were found between tight packing indices and log permeability: r^2= 0.81 and 0.77 for Six Lakes and Austin samples respectively.

Permeability can be higher on-structure than off. We examined one off-structure core and three on-structure cores from the Austin field. The samples off-structure had a lower permeability and higher TPI than the samples on-structure.

The Jurassic "Red Beds" of Michigan: Source, Age Correlation and Flora

by A. T. Cross, Department of Geological Sciences, Michigan State University, East Lansing Michigan

The "Red Beds" are comprised of gypsiferous, red, red-brown, gray and green shales, siltstones, sandstones and pod-like beds of gypsum in the central part of the Michigan Basin. They uncon-formably overlie Pennsylvanian strata on a beveled surface of low relief and are unconformably overlain by Quaternary glacial deposits of from a few meters to more than 200m in thickness. These beds have been identified to be of mid-Jurassic age (Bajocian-Bathonian) on the basis of a rich palynoflora. The sediments probably accumulated in the vicinity of a large inland playa or possibly a lake with internal drainage on a structurally controlled, reactivated, shallow depression. However, an alternative scenario is the possible transgression of an epeiric sea through a restricted channel from the west or northwest for a limited time and the development of a sabkha-like environment on a broad coastal plain of very low relief. The deposits are non-marine as is evidenced by lack of any dinoflagellates in the palynoflora.

The pollen and spores compare closely with those of the palynoflora of the "Mistuskwia Beds", encountered in two drill holes in the Moose River Basin of the James Bay Lowland, Ontario. The "Mistuskwia Beds" have also been identified by palynology as mid-Jurassic in age. The flora is distinctly older than that of the Mattagami Formation and the Onakawana lignites, which overlie the "Mistuskwia Beds" and appears to be older than the "Fort Dodge Beds" in Webster County, Iowa, just east of the Manson impact center. The flora of the Fort Dodge gypsum and associated redbeds seems to be more closely allied with non-marine, late Jurassic floras (Kimmeridgian or Portlandian) than with that of the Michigan "Red Beds". The palynofloras of all other Mesozoic rocks of the eastern interior area, including the Windrow Formation (upper Mississippi valley), the Ohio River Formation (southeastern Indiana) and the Bayliss Formation (southern Illinois) are of Cretaceous age.

The palynoflora of the Michigan "Red Beds" is more diverse than that of the "Mistuskwia Beds" but contains nearly all of the 65 species reported from that palynoflora, and many more. The principal stratigraphic indicators of early to mid-Jurassic age for both palynofloras are species of the genera ***Spheripollenites, Leptolepidites, Callialasporites, Classopollis, Cerebropollenites*** and ***Podocarpidites***. Another distinctive genus with at least four species is ***Eucommiidites***. It is very abundant in the "Red Beds" but not recorded yet in the Ontario sediments. ***Classopollis*** is the predominant genus in the Michigan "Red Beds", with several species. In some samples these are in excess of fifty percent of the total number of spores or pollen. This palynoflora is compared with several palynofloras from Jurassic rocks of central and western Canada including the Gravelbourg, Shaunavon and Sawtooth Formations and with several Jurassic sections in the United States.

On the Recent Discovery of a Fish Jaw in the Mississippian Michigan Formation, Grand Rapids, Michigan

by S. G. Kenaga, and S. M. Sellepack, Geology Department, Grand Valley State University, Allendale, Michigan

A dentigerous, partial lower jaw of a rhipidistian crossopterygian fish was recently found in rocks of the Mississippian Michigan Formation. The specimen consists of the anterior portion of a tooth-bearing dentary six centimeters long. Six of the twenty-one tooth sockets contain the remains of teeth, and this tooth row is accompanied by a denticle row along the exterior margin. The bone was compressed dorsoventrally, slightly crushing the larger teeth. Teeth with broken tips reveal an open pulp cavity indicative of polyplocodont dentition. The external surface of the bone is ornamented with conical tubercles approximately 1mm in diameter with flattened, polished crowns and radial grooves on the sides. Identified as ***Onychodus sigmoides,*** the specimen is only the third fossil found in Michigan to be referred to the genus ***Onychodus***.

Associated fossils from the Grand Rapids gypsum mines include the well documented specimens of cladodont-type shark teeth, fin spines of ctenacanth sharks and fish coprolites (Dorr and Moser, 1964). In addition to the jaw, a variety of paleoniscoid and acanthodian fish scales have been collected and fragments of ***Calamites and Lepidodendron*** are exposed in the mine ceiling. It is evident that the much ignored Michigan Formation contains evidence of a rich Late Mississippian flora and fauna despite the singular circumstances that produced evaporite deposition.

Stratigraphic Relations of the Parma Sandstone and Saginaw Formation: Basal Pennsylvanian Sandstones in the Michigan Basin Revisited

by D. B. Westjohn, U. S. Geological Survey, Lansing, Michigan

The Parma Sandstone was named by Alexander Winchell in 1861 for outcrops that are considered to be the type section in northeastern Jackson County, Michigan. Subsequent geologic investigations concluded that the Parma Sandstone forms the basal part of the Pennsylvanian Saginaw Formation. Isopach and structure-contour maps of Mississippian and Pennsylvanian rock units were constructed as part of a U.S. Geological Survey regional assessment of ground water resources in the central Michigan Basin. These maps show that correlation of the Parma Sandstone with the basal section of the Saginaw Formation is questionable.

Analysis of geophysical logs indicate that a sheet sandstone rests on the Bayport Limestone or the Michigan Formation (Mississippian units) in the west-central part of the basin. This sheet sandstone is in the correct stratigraphic position to be the Parma Sandstone. Up regional dip from the basin center, the Parma Sandstone seems to interfinger with carbonate rocks of Bayport Limestone. If Bayport Limestone/Parma Sandstone interfinger, the Parma Sandstone must be Late Mississippian rather than Early Pennsylvanian in age, because the Bayport Limestone is known to be Mississippian on the basis of fossil evidence. Regardless of whether this alternative interpretation of age is correct, the Parma Sandstone in the central part of the basin has a distinct geophysical-log signature, and it forms an easily identifiable stratigraphic unit with an areal extent that exceeds 4,000 square miles. Such stratigraphic continuity is atypical of strata of the Saginaw Formation, which consists of strata that are laterally discontinuous at the scale of a few miles. However, it is not possible to correlate the Parma Sandstone in the central part of the basin with type-locality outcrops in the southern part of the state. The Parma Sandstone seems to be truncated and overstepped by typical Pennsylvanian strata along the northern parts of Eaton and Ingham counties.

Because the Parma Sandstone is a laterally continuous, mappable stratigraphic unit and is atypical of cyclothem strata of the Saginaw Formation, additional consideration should be given to stratigraphic relations of these units. Although the Parma Sandstone resembles Mississippian Formations in terms of stratigraphic continuity and it appears to interfinger with the Bayport Limestone, assignment of a Mississippian age (or Pennsylvanian age) remains conjectural.

Causes of Some Sedimentary and Structural Anomalies of Coals and Associated Rocks of the Michigan Basin

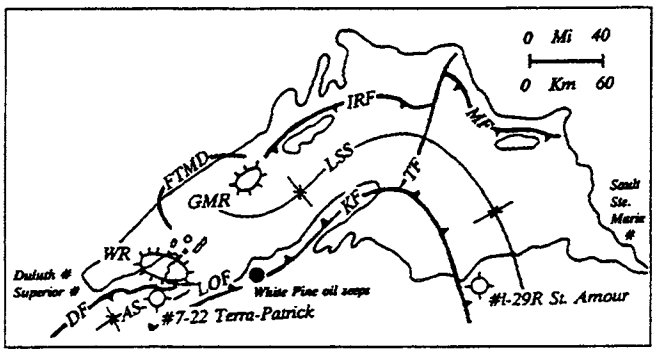
by A. T. Cross, Department of Geological Sciences, Michigan State University, East Lansing, Michigan

The earliest Pennsylvanian sediments (Morrowan) were deposited by a prograding deltaic system that essentially filled the erosional and structural lows of an irregular erosion surface previously developed on Mississippian strata. The succeeding strata of Atokan and Desmoinesian age are interbedded alluvial plain sediments deposited on a low, westward paleoslope that was occasionally irregularly inundated during short periods of marine transgression. Post-Desmoinesian erosion resulted in an irregular surface on which Jurassic coastal plains sediments accumulated. The tectonic deformation and displacement, identified in subjacent Paleozoic strata, does not appear to have continued into the Pennsylvanian. Some sediment deformation and displacement have been observed in local quarries and strip pits. These anomalies appear to have resulted from gravitational readjustment of poorly consolidated sediments or deformation during unequal compaction and dewatering caused by anomalous distribution of less-compactable sediments in channels, bars or banks in proximal subjacent or superjacent strata. Many shaley siltstones (mudstones) were deposited on low-angle, seaward sloping plains and in marginal bays or shelves, or along levees and channelside lowlands. Oversteepening of cutbacks of shifting channels, changes of hydrostatic pressure or baselevel, or slight earth tremors could cause gravitational sliding, deformation and faulting of poorly consolidated organic and inorganic sediment accumulations.

Friday, March 15 Morning Session

New Structural and Stratigraphic Interpretations of Lake Superior Basin Derived from Hydrocarbon Exploration Geophysics and Geology

by A. B. Dickas, Department of Geology, University of Wisconsin-Superior, Superior Wisconsin



FTMD:	Finland Tectono-Magnetic Discontinuity
LSS:	Lake Superior Syncline
GMR:	Grand Marais Ridge
MF:	Michipicoten Fault
IRF:	Isle Royal Fault
AS:	Ashland Syncline
LOF:	Lake Owen Fault
KF:	Keweenaw Fault
WR:	White's Ridge
DR:	Douglas Fault
TF:	Thiel Fault

Between October 1987, and April, 1992, two significant, deep boreholes were drilled along the south shore of Lake Superior in a test of the hydrocarbon potential of the conglomerate, sandstone and shale of the Middle Proterozoic Oronto Group. These drilling ventures were preceded by geophysical programs which yielded hundreds of km. of reflection seismology. Combined with wireline and core information, these data support new interpretations of the structural and stratigraphic geology associated with the development of the Midcontinent Rift in the Lake Superior district.

#7-22 Terra-Patrick: A stratigraphic, but not a structural fit.

This borehole, located in Section 22, T47N, R6W, Bayfield County, Wisconsin, drilled an expected sequence of Oronto Group clastic red-beds (see stratigraphic column). No viable hydrocarbon shows were encountered. Six section reflection seismology profiles collected in northwestern Wisconsin prior to drilling indicates the Douglas Fault decreases in throw in an easterly direction, changing to a fold northeast of the borehole. This termination is associated with the south flank of White's Ridge, a pre-rift residual high. White's Ridge is identified by modeling studies and seismic interpretations indicating local absence of Mid-continent Rift volcanics and overlying strata. To the southwest of Isle Royal, the pre-rift Grand Marais Ridge exhibits similar characteristics. These ridges prevented linkage of the Isle Royal Fault with the Douglas Fault during rifting and formed accommodation zones which divide the western Lake Superior Basin into separate sub-basins (see structural map).

Terra-Patrick Section

Unit	Thick	Lithology
Pleistocene	290	Drift
Freda Formation	3442	Sandstone
Nonesuch Formation	436	Silt/Shale
Copper Harbor Cong.	798	Conglomerate
Total Depth	4966	

#1-29 St. Amour: A structural, but not a stratigraphic, fit.

Drilled in Section 29, T46N, R18W, Alger County, Michigan, the St. Amour well appears to bottom in pre-rift metamorphic basement rocks. This hole was 100% cored. No hydrocarbon shows were reported. Reflection seismology profile analysis verifies a change in strike, from northeast to southeast, of the Keweenaw Fault in the eastern Lake Superior Basin (see map). The drilled section includes 6,000 feet of pre-Paleozoic red-beds containing cross-bedding, ripple marks and multiple fining-upward strata. The basal 673 feet of this sequence is suggestive of Copper Harbor stratigraphy. Below these strata, and above the basement, lies a section composed of four volcanic units separating three interflow sedimentary sequences. Two of the latter units are made up of red beds, while the central interflow unit is composed of gray to black siltstone and shale, a rock-stratigraphic equivalent to the Oronto group Nonesuch Formation.

St. Amour Section

Unit	Thick	Lithology
Paleozoic	523	Dolomitic/gray ss
Jacobsville Undif.	6000	Arkosic clastics
Volcanic #4	50	Altered basalt
Interflow	72	Red-beds
Volcanic #3	46	Dense basalt
Interflow	182	Organic clastics
Volcanic #2	51	Gray basalt
Interflow	9	Red-beds
Volcanic #1(?)	149	Rhyolitic
Metamorphosed	156	"Fe formation"
Total Depth	7238	

Surface Geophysical Studies On the WSW Flank of the Amasa Oval, Iron County, Michigan

by M. Nash, W. Sauck and D. Werkema, Department of Geology, Western Michigan University, Kalamazoo, Michigan

Coincident aeromagnetic and airborne electromagnetic (INPUT) anomalies were selected for ground follow-up during three intensive geophysics field courses held in Iron County in the Upper Peninsula in 1980, 1981 and 1982. The magnetic and conductivity anomaly chosen for the detail work reported here was in Section 29 of T44N, R32W. This is located off the WSW flank of the elliptical gneiss-cored uplift known as the Amasa Oval. The specific site is within the area previously mapped as Hemlock Formation, consisting mainly of metabasalt, pyroclastics, volcanic breccia, tuff and slaty greenstone dipping WSW away from the gneissic core. Outcrops in Section 29 and adjacent sections are rare and small, occupying at most only a couple percent of the area. Many geophysical methods were used to delineate the magnetic and conductive structures. The magnetic response appeared to be greatest over a pillow basalt, so the magnetic anomaly served as a stratigraphic marker. Ground surveys showed the conductive unit to be WSW of the magnetic unit, or stratigraphically higher in section. It responded strongly to the Spontaneous Potential (SP), Very Low Frequency (VLF) electromagnetic method (both In-phase and Quadrature) and Horizontal Loop Electromagnetic (HLEM) method (In-phase and Quadrature at 200 foot coil separation). Contour maps of all the measured geophysical parameters were made, covering an area 3,000 feet along strike by 1,000 feet across strike. The linear conductive zone produced SP anomalies in excess of -300mv, HLEM anomalies greater than -40ppt and very large VLF anomalies. A central line repeated with HLEM coil separations of 100, 200, 300 and 400 feet allowed estimates to be made of the depth to the top of the conductive zone and inferences about its depth extent. A gravity profile over the central conductive zone however showed no appreciable excess mass, thus ruling out the presence of a massive sulfide deposit. The feature, totally concealed by glacial drift, is apparently due to graphite or very thin zones of sulfides, such as fracture coatings of pyrite. This and similar areas nearby are excellent training sites for teaching the synergistic use of multiple geophysical methods for geologic mapping and the evaluation of potential mineral deposits in terrain almost completely covered by glacial drift.

Stone Sentinels Along Michigan's Railroads-Dimension Stone Use in Railroad Architecture

by M. J. Camp, Department of Geology, University of Toledo, Toledo, Ohio

Until the 1870's, Michigan was serviced by only a few railroad lines, either built by the state or constructed as part of federal land grants. Depots, buildings erected at certain points or stations along the lines, were usually wood frame structures or open air shelters. As communities grew in population and importance, railroad companies often replaced original depots with larger and better designed structures. Many remained of wood construction, but native stone, brick or combinations of the two, became favored for county seats, resort towns and more influential communities.

The Michigan Central Railroad, headquartered in Detroit, constructed some of the more attractive stone depots in the state. With the exception of quarries in the Mississippian Marshall Formation, the Michigan Central lines ran through mainly glaciated terrain with few bedrock exposures. In the 1880's the company commissioned the office of F.H. Spier, a Detroit architectural firm, to design a number of replacement depots, many to be made of fieldstone. Gearing and Sons, also of Detroit, supplied the stone masons and other contractors. The railroad opened a pit at Fosters near Ann Arbor to supply glacial erratics for the stonework. Dressed fieldstone depots were built at Ann Arbor, Bay City, Grass Lake, Standish and Wyandotte and a natural surface fieldstone depot was erected at Lawton. Although the Marshall Formation is now quarried in Napoleon for use as flagstone or facing stone, it was not widely used by the Michigan Central. A more favored dimension stone was the Cambrian, Jacobsville Sandstone, quarried in the Hancock, L'Anse and Jacobsville region and then shipped by railroad or schooner to sites in the Lower Peninsula. It formed the trim of brick depots at Battle Creek, Detroit, Kalamazoo and Saginaw. The 1892 depot at Niles is unique for it is composed of brown sandstone of the Mississippian Cuyahoga Formation from the Carroll-Lithopolis area of central Ohio. Other depots at Charlotte, Dowagiac, Grand Rapids, Jackson, Lansing and Ypsilanti have foundations of Silurian-Devonian carbonates from quarries in southeastern Michigan and elsewhere. Michigan Central Terminal at Detroit contains a facade of Mississippian Salem Limestone from the Bloomington-Bedford, Indiana, stone belt.

The Lake Shore and Michigan Southern Railroad erected an attractive stone depot at Hudson in 1886. F.H. Spier was again the architect. A quarry at Stony Point reportedly supplied the stone, probably a dolostone of the Silurian Bass Islands Group. The foundation was Mississippian Berea Sandstone from north central Ohio. A number of LS&MS depots were replaced with new brick and sandstone (Berea Sandstone) structures in the 1890's, including Jonesville, Lenawee Jct., Sturgis and White Pigeon.

The Pere Marquette Railroad built depots at Bad Axe and Petoskey made of local Devonian limestones, erected a brick and sandstone depot at Muskegon and used dressed limestone blocks in the foundations of depots at Bay City, Flint and Saginaw. The Grand Trunk Western depots at Battle Creek, Durand, Flint, Grand Rapids, Ionia, Lansing, Owosso, Pontiac and St. Johns; Detroit & Mackinac depot at Alpena; and, the Ann Arbor Railroad depot at Cadillac exhibit foundations of dressed limestone blocks. The Detroit & Mackinac Railroad which ran through the Devonian terrain of northern Lower Michigan had a dressed limestone depot at Harrisville and concrete block depots at Millersburg, Omer, Ossineke and Rogers City.

The Duluth South Shore and Atlantic depot at Houghton is composed of blocks of Cambrian Jacobsville Sandstone from the nearby Portage Entry area. The DSS&A used local Jacobsville Sandstone for their Sault Ste. Marie depot and Bayfield Group sandstone from Port Wing, Wisconsin, for their Marquette depot. Jacobsville Sandstone also found use as trim in a number of depots including the Grand Rapids and Indiana depot at Cadillac and the Copper Range's depot at Houghton.

A number of these stone depots still stand, a tribute to their architects and contractors of turn of the century Michigan and to the dimension stone industry of the Midwest.

Preliminary Petrographic Description and Classification of the Coleman, Michigan, Meteorite

by M. Velbel, Department of Geological Sciences, Michigan State University, East Lansing, Michigan, and D. J. Matty, Department of Geology, Central Michigan University, Mt. Pleasant, Michigan

The Coleman, Michigan, meteorite fell at 1:51 a.m. (local time) 20 October, 1994, penetrating the kitchen roof of a private home. Although the fireball was widely seen, and observed to break up in flight, only the one roof-penetrating object was recovered.

A polished slice reveals a light gray stony object with flecks of metal, transected by distinct and abundant black shock-veining. Petrographic model analyses of two thin sections prepared by NASA permit classification of the meteorite. Preliminary electron microprobe analyses indicate the presence of various silicate minerals (olivine, diopside, orthopyroxene, and minor sodic plagioclase), Fe-Ni alloys, and Fe-sulfides (all common constituents of ordinary chondrites). Silicate matrix, mineral fragments, and chondrules, together with glassy shock veins, constitute 85.9 percent of the meteorite; opaque primary phases (Fe-Ni alloys, and Fe-sulfides) constitute 14.1 percent. Chondrules indicate Coleman is a chondrite; the composition of the matrix and overall texture are those of an ordinary chondrite; and the modal opaque content suggests Coleman belongs to the H-chondrite group. Boundaries between chondrules and matrix are indistinct and difficult to define; this degree of chondrule-matrix integration suggests assignment to petrologic type 6. Coleman is provisionally classified as an H6 chondrite, veined (shocked).

Coleman is Michigan's third documented fall, and third stony meteorite; all other Michigan meteorites are finds, not observed falls, and are irons. Like Michigan's two previous falls, Allegan (H5; fell 1899) and Rose City (H5, brecciated, black [dark matrix]; fell 1921) Coleman belongs to the common and abundant H-chondrite group; approximately one-fourth of all known meteorites are H-chondrites. Coleman has a much lighter matrix than Rose City, and is probably more extensively thermally and shock-metamorphosed, than either previous Michigan H-chondrite fall. The main mass of Coleman is in the hands of a private collector.

Laboratory Investigation of Air Sparging: An Experimental Technique For Identifying Air Flow Pathways in a Saturated Porous Medium

by J. W. Peterson and B. A. Vandenheuvel, Department of Geological and Environmental Sciences, Hope College, Holland, Michigan

Air sparging is a popular new technology used to remediate ground water contaminated with volatile organic compounds. This technology is currently being employed at many petroleum contaminated sites in Michigan. One of the outstanding questions related to air sparging is the nature of air flow in the subsurface. A specific unknown is the geometry of air flow as it travels from the injection point in the saturated subsurface to the vadose zone. Very little laboratory experimentation has been performed on air sparing systems. The few experiments have been performed using clear glass beads as porous media within visualization tanks. Until now, the opacity of natural sediments precluded their use in laboratory visualization experiments.

We have established a new technique for determining the location and geometry of airflow pathways in natural sediment air flow visualization experiments. The technique involves the use of iron filings as a reactive indicator of the presence of oxygen. Natural sediments, ranging from 1.19 to 2.38mm diameter, were spiked with iron filings, and then were loaded into a transparent plexiglass tank (1m x 1m x 2.54cm) to form a well-mixed sediment column possessing a sediment to iron filing ratio of 6:1. The iron-spiked porous medium was loaded simultaneously with deoxygenated water to form a saturated experimental aquifer. Standard breathing air was delivered to the aquifer via a diffuser at the base of the tank which simulated an air sparge well. Air delivery pressure was regulated from 0.55 to 0.70psi and airflow was regulated from 0.4 to 0.6l/minute. Delivery pressure was regulated slightly above the entry pressure required to overcome the hydrostatic head and capillary pressures of the aquifer. The locations of air pathways in the sediment column were indicated by a color change in the iron filings from black to orangish-brown. Slight visible oxidation was observable after 4 hours of run time, with extensive oxidation present after 15 hours. The color change is likely due to the chemical reaction of iron to the iron hydroxide, limonite ($Fe+O_2+H_2O=Fe\text{-}OH\text{-}nH_2O$), and occurred only in those areas in contact with an air pathway. A similar experiment with spiked sediments was performed with nitrogen, instead of breathing air. No oxidation of the iron filings was observed in this experiment until after 24 hours.

This technique will facilitate laboratory investigations of air sparging remediation systems. It is anticipated that further experimentation will help develop qualitative, and possibly quantitative, relationships between radius of influence, angle of distribution, subsurface geology and site criteria for air sparging systems in particular geologic settings.

Extreme Over-Balanced Perforating Proves Non-Damaging with Limited Frac Height in Glenwood / St. Peter Formations

by J. Guoynes, Halliburton Energy Services, Kalkaska, Michigan

A new completion method has been tested for water sensitive formations allowing radial extension past damage without vertical growth into adjacent zones. This process was evaluated for the Glenwood formation in Clare County, Michigan. This paper documents the process and analysis results. The process is known as extreme over-balanced perforating, or Perf-Stim, which involves perforating at pressures above the frac gradient of the formation. Several technologies are incorporated with the process which allow the perforation tunnels to be extended radially past damage without the vertical height associated with fracturing.

The Glenwood formation has not been routinely completed due to extensive damage from water invasion and drilling fluids that restrict production. Further introduction of water or water based fluids during completion can result in additional damage, limiting gas production. The test case results clearly show that the Glenwood can be an economically productive formation. The case history includes the initial completion using the Perf-Stim technique, whereby nitrogen was used to extend the perforation tunnels past damage without vertical growth into water bearing zones.

The paper documents the process using Tracer-Scan logs after the extreme over-balanced perforating to show vertical growth of the perforation tunnels. Additional post-test buildup analysis shows the process achieved penetration well past the damage region and quantifies the reservoir flow characteristics and skin damage following the initial completion. Further technical information is quantified to diagnose radial length of the Perf-Stim extension.

Salt Weathering and Honeycomb Weathering of Carboniferous Sandstones in the Mid-Western United States

by J. B. Sallman, III, Department of Geological Sciences, Michigan State University, East Lansing, Michigan

Outcrops exhibiting honeycomb weathering in Carboniferous sandstones of the temperate, mid-continental Midwest were studied to evaluate what outcrop characteristics may control the development of honeycomb weathering. Salt weathering of sandstone has long been hypothesized to control honeycomb formation. Field and laboratory observations suggest that salt weathering may be a precursor to honeycomb weathering in some cases. However, in the areas studied, the ubiquity of iron oxyhydroxide case-hardening and other characteristic iron structures in the outcrops suggest that the distribution/ mobilization of iron in the rocks controls honeycomb development.

Iron diffusion is invoked as the basis for a new geochemical model for the development of honeycomb. Organic acids from plants, lichens and other biota reduce and dissolve the ferric oxyhydroxide case-hardening on the sandstone surface, mobilizing the reduced ferrous iron. The organic acids then transport iron away from newly formed honeycomb cavities to honeycomb walls where the iron reprecipitates as ferric oxyhydroxides, strengthening the walls and making them more resistant to further weathering

POSTERS DISPLAYED DURING SYMPOSIUM

Geologic Map Portfolio of Mackinac County, Michigan
by M. A. Leach, et al., Lake Superior State University, Sault Ste. Marie, Michigan

Chitinozoans from The Hungry Hollow Formation, Hungry Hollow, Ontario, Canada
by J. Agnew, Department of Geology, Central Michigan University, Mt. Pleasant, Michigan

Mercury and Other Trace Elements in the Michigamme River System
by M. Crook, Department of Geology, Central Michigan University, Mt. Pleasant, Michigan

A Tectonic Origin For the Peavy Node
by M. Emilio, Department of Geology, Central Michigan University, Mt. Pleasant, Michigan

Geophysical Investigations Above a Purported Cavern System in Northwestern Alpena County
by C. Kaminski, Department of Geology, Central Michigan University, Mt. Pleasant, Michigan

Bouguer Gravity Maps of the Sauble Anomaly Region, Lake and Mason Counties
by A. Kanouse, Department of Geology, Central Michigan University, Mt. Pleasant, Michigan

Comparison of the Kiernan Sills Granophyres To the Hemlock Formation Rhyolites
by T. Purdy, Boise State University, Boise, Idaho

Baseflow Concentrations of Sr, Rb and Ba in Streams in the Saginaw Bay Watershed; Indicators of Brine Influx
by J. B. Stinson, Department of Geology, Central Michigan University, Mt. Pleasant, Michigan

Hydrogeologic Investigations in a Karst Terrane (Trenton Formation), Delta County
by M. Petrie, MI Department of Environmental Quality, Environmental Response Division, Marquette, MI

Update On the Geological Core and Sample Repository -Marquette, Michigan
by W. Swenor, MI Department of Environmental Quality, Geological Survey Division, Marquette, MI

Developing a Computerized Data Base For Abandoned Underground Mines in Michigan
by A. M. Johnson, Michigan Technological University and M. A. Gere, Jr., MI DNR, Real Estate Division, Marquette, MI

Exploration Data Available from Lapsed Michigan Metallic Mineral Leases -
by M. A. Gere, Jr., MI Department of Natural Resources, Real Estate Division, Marquette, MI