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FRACTURE-TRACE ANALYSIS FOR WATER-WELL SITE LOCATIONS IN PRECAMBRIAN IGNEOUS AND METAMORPHIC ROCK IN CENTRAL WISCONSIN

by B.J.Socha

available from
Geological and Natural History Survey
University of Wisconsin-Extension
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ABSTRACT

Aerial photographs, hydrologic data, and field observations, including geophysical investigations and test drilling were used to identify and characterize zones of higher permeability in igneous and metamorphic rock in central Wisconsin. These zones of higher permeability exist primarily because of fracturing and weathering and may be expressed on the ground surface by features such as shallow sags, vegetation changes, and differences in soil moisture and texture. Color-infrared aerial photographs were found to be especially useful in identifying subtle moisture changes associated with fine-textured soils and other features resulting from weathering of igneous and metamorphic rock. Low electrical resistivity and magnetic field anomalies were found to be associated with a fracture trace identified from field observations and interpretation of aerial photographs. Test drilling on the fracture trace produced fractured and weathered rock. Off the fracture trace, less fractured and weathered rock was encountered. Zones of vertical weathering are present and may be indicative of extensive fracturing at depth.

INTRODUCTION

Regional Background

In parts of central Wisconsin obtaining an adequate groundwater supply can be difficult because of the geologic nature of the area. A thin, discontinuous layer of glacial deposits, colluvium, alluvium and Paleozoic sedimentary rock overlies Precambrian granitic, gneissic, and volcanic rock. Except for in the Central Sand Plain region, the surficial sediment and the sedimentary rock are generally inadequate as aquifers because they are too thin to provide the volume or quality of water needed for agricultural, municipal, or even domestic uses. Because the Precambrian rock has very low hydraulic conductivity and permeability, wells in this aquifer frequently have very low specific capacities and dry test holes are not uncommon. However, a few wells in the area have high specific capacities, presumably because they have penetrated fault or fracture zones in the Precambrian rock.

Terminology

Linear features, visible on aerial photographs and on the ground surface, that are faults or concentrations of fractures and are less than one mile [1.6 km] long are called fracture traces. The term lineament is used for such linear features that are at least one mile [1.6 km] long (Lattman 1958). Both fracture traces and lineaments consist of aligned changes in vegetation and soil types, tones, or moisture conditions, and aligned topographic features such as straight stream segments. Except in regions of bare rock, fracture traces are the indirect expression of joints, fractures and faults propagated through the overlying residuum and transported material, and are enhanced by subtle differences in vegetation, moisture conditions and soil tones that are visible on aerial photographs.

Purpose of Study

This study is an investigation of the use of aerial photographs along with field observations and hydrogeologic data as a method of identifying Precambrian terrane characteristics presumably associated with fault and fracture zones in igneous and metamorphic rock that have potential of serving as sites for high capacity water wells.

Scope of Study

Landsat imagery for a five county region in central Wisconsin was examined for lineaments coincident with the location or orientation of mapped faults or geophysical lineaments. Results of this study are compared with a more extensive Landsat lineament study by Dutch (1981) that included this area in central Wisconsin. Regional structural features were studied because of their possible relationship to the distribution and pattern of features such as joints and faults that directly affect groundwater distribution.

A brief description of the Precambrian rock and surficial sediment is given as an understanding of the geologic complexity of the area is essential to the interpretation of fracture traces and other terrane elements evident on satellite imagery, aerial photographs or the ground surface.

A map of fracture traces and lineaments was produced for Wood County from various scales and types of aerial photographs and well log information from wells with high yields. Topographic expression, drainage conditions, and soil and vegetation types associated with fracture traces and existing wells with high yields were observed in the field. Based on these observations, aerial photographs and ground surface characteristics were identified as possible indicators of subsurface fracture zones.

At a site near Pittsville in Wood County, a shallow electrical resistivity and total magnetic field survey was conducted in an area of possibly fractured rock as identified from fracture-trace analysis and from field observation. Limited test drilling on and off the fracture trace yielded fractured and unfractured rock, respectively.

Report Format

The following three sections describe methods and results of investigations in the five county region, in Wood County, and in the Pittsville area and include an evaluation of the methods employed. The last section consists of conclusions and recommendations for well site locations and suggestions for further research.

Geologic well logs prepared by the Wisconsin Geological and Natural History Survey for wells in central Wisconsin that have high yields from igneous or metamorphic rock are included in an appendix to this report.

CENTRAL WISCONSIN

Study Area

Five counties in central Wisconsin were selected on the basis of having significant land areas with shallow depths to rock and subsequently numerous low yield wells in igneous and metamorphic rock and having a climate and soils supporting an agricultural industry. The location of the five counties--Marathon, Clark, Wood, Portage and Waupaca Counties--is shown in figure 1.

Depths to Rock and Aquifer Potentials

Depths to rock in Marathon, Clark and Wood Counties are generally less than 50 ft [15 m]. Areas of thicker surficial sediment include the early or pre-Wisconsinan Marshfield moraine in northwestern Wood and southeastern Clark Counties, late Wisconsinan fluvial deposits in the Wisconsin River valley and deposits of glacial Lake Wisconsin in southern Wood County.

Probable yields from wells in the sandstone and thin sand and gravel deposits are less than 100 gallons per minute (gpm) [378 litres per minute (lpm)] (Devaul, 1975); and probable yields from wells in the Precambrian aquifer are less than 20 gpm [76 lpm] in Marathon, Clark and Wood Counties (Lippelt and Hennings, 1981).

In Portage and Waupaca Counties surficial sediment is more than 100 feet [30 m] thick except for areas in the northwestern parts of these two counties where depth to rock is less than 50 feet [15 m] (Trotta and Cotter, 1973).

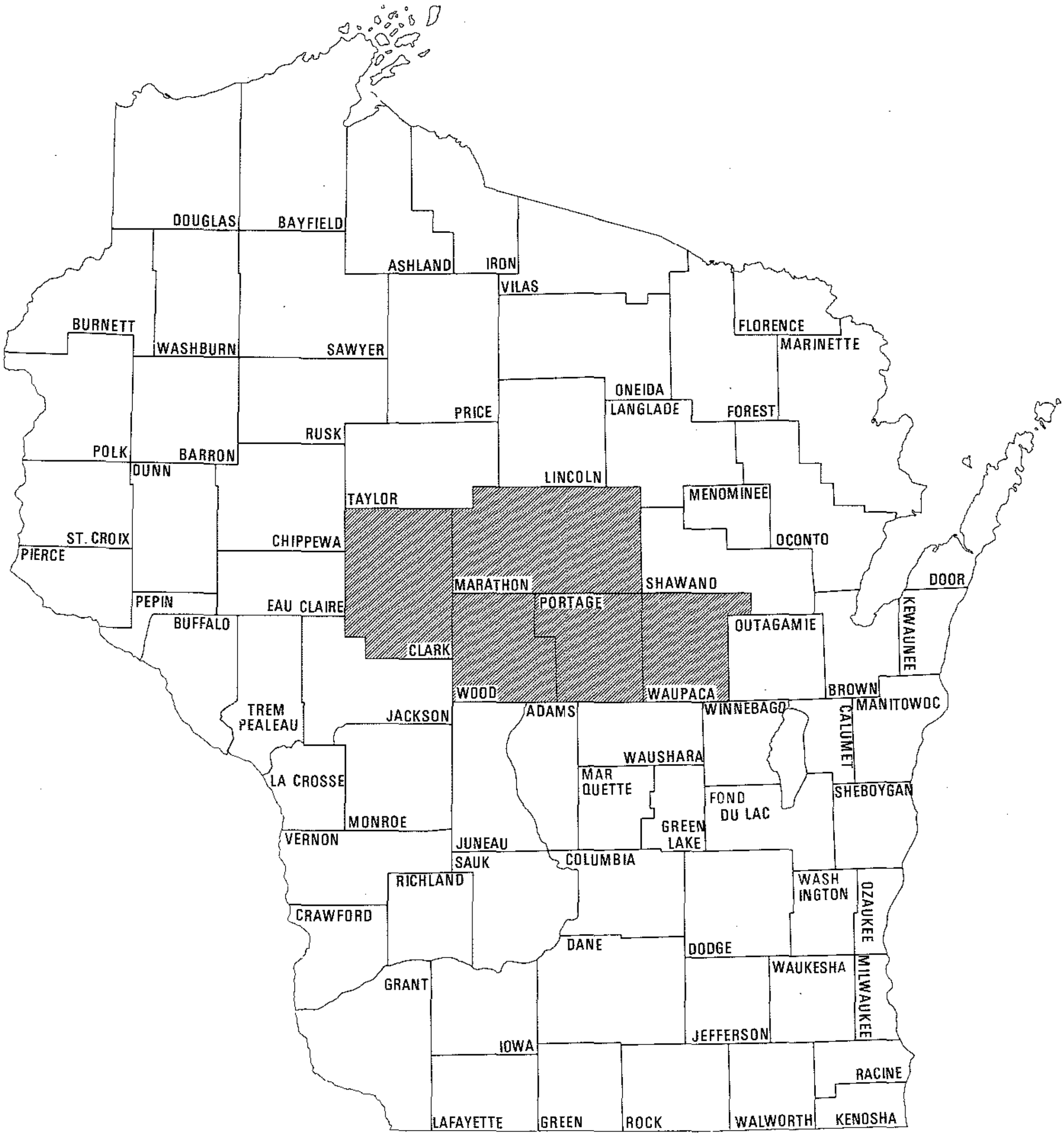

FIGURE 1.--Location of the regional study site in central Wisconsin, including Marathon, Clark, Wood, Portage, and Waupaca Counties.

Probable yields for wells in the sandstone aquifer in these two counties are generally less than 100 gpm [378 lpm]. Yields for wells in the sand and gravel aquifer in northwestern Portage and southeastern Waupaca Counties are also less than 100 gpm [378 lpm] (Devaul 1975). The rest of the area has a high probable well yield (in excess of 1000 gpm [3785 lpm] in the sand plain in Portage County); but yields for wells in isolated areas of igneous and metamorphic rock are less than 20 gpm [76 lpm] (Lippelt and Hennings, 1981).

Precambrian Geology

The Precambrian rock in the study area ranges in age from about 3000 to 1500 million years old (fig. 2). During this time, three major periods of tectonism occurred in the region. Fracture zones or faults may be some of the deformational features produced by tectonism; or they may be inherited from structural zones of weakness resulting from tectonic activity.

The oldest rock in the area is Archean in age and occurs in an isolated block in Wood, Portage and Clark Counties. An approximate age of 2800 million years is indicated by whole-rock Rb-Sr and zircon U-Pb analysis for the migmatite and gneiss in Portage and Wood Counties (Van Schmus and Anderson, 1977). Indication of an elevated initial $^{87}Sr/^{86}Sr$ ratio implies that the migmatite and gneiss were formed from 3000 million year old crustal rock of granitic to intermediate composition (Van Schmus and Anderson, 1977).

During the Early Proterozoic, about 1900 million years ago, sedimentary and volcanic rocks were deposited south of the craton and were subsequently metamorphosed, intruded and deformed as part of the Penokean Orogeny about 1850 million years ago (Goldich and others, 1961). During this second period of tectonism, the volcanic terrane in Marathon, northeastern Wood, and northwestern Portage Counties was produced. These Early Proterozoic rocks probably underwent several stages of deformation and intrusion during the Penokean Orogeny, resulting in complex deformational structures (Brown and Greenberg, 1981).

The Penokean tectonic structures were probably modified by the third major period of tectonism, during which the 1500 million year old Wolf River granitic complex was emplaced. Related to the Wolf River complex are the Wausau and Stettin syenite bodies in Marathon County (Myers, 1976). Locally intense deformation and thermal metamorphism is associated with this major plutonic event. Aeromagnetic trends indicate tectonic reorientation in Marathon and Portage Counties (Brown and Greenberg, 1981). In eastern Marathon County, intense deformation is observed in metavolcanic rock adjacent to the Wolf River complex (LaBerge, 1980). LaBerge (1980) describes a zone of cataclastic rock that extends southwest along the north edge of the Proterozoic volcanic-plutonic terrane that composes most of Marathon County. Another zone of cataclastic rock borders the volcanic-plutonic terrane on the south. The zone is 0.6 to 3.1 miles (1 to 5 km) wide and extends southwest for more than 37 miles (60 km) along the Eau Claire and Little Eau Claire River valleys to Lake Du Bay, where it curves up the Eau Pleine River valley to Stratford and then southwest toward Neillsville in Clark County. In southwestern Clark County the two cataclastic zones may join but Paleozoic and Pleistocene deposits obscure the Precambrian rock (LaBerge, 1980).

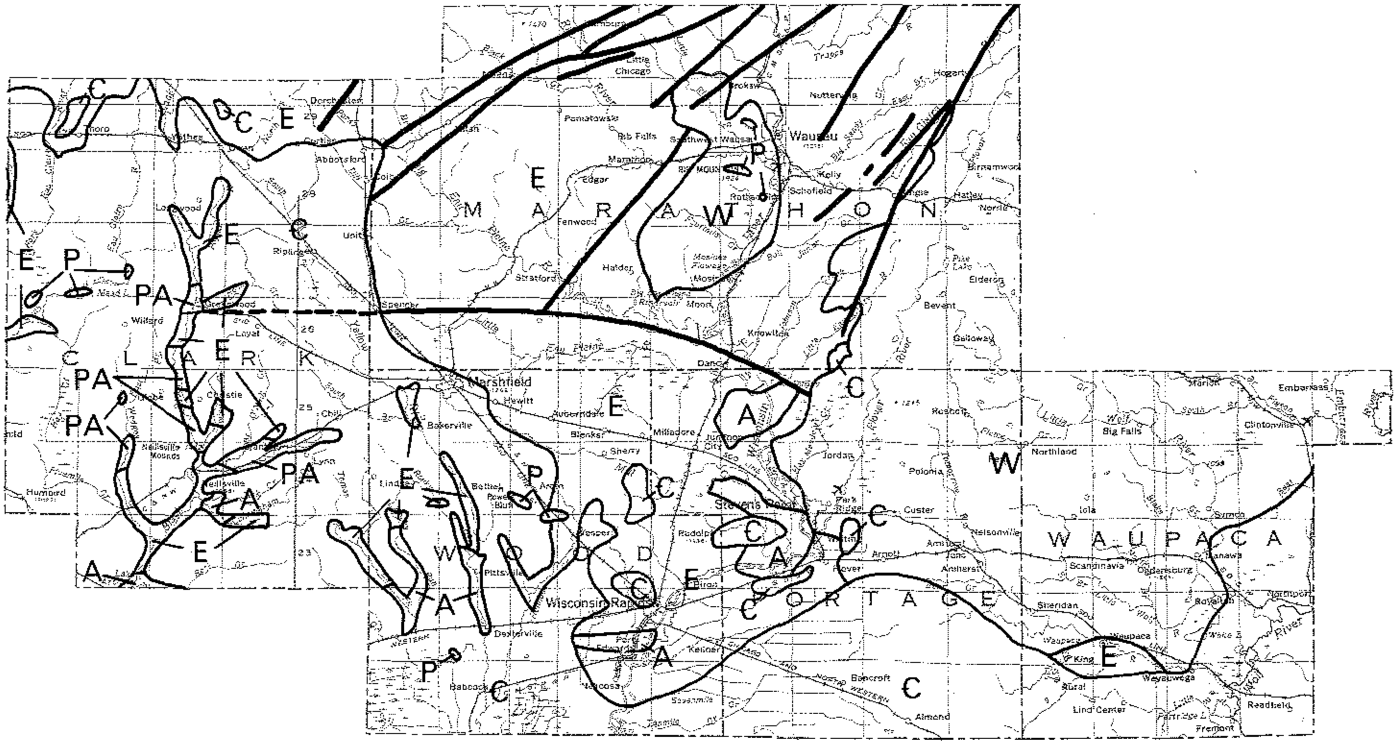

FIGURE 2.--Generalized geologic map of central Wisconsin. Scale 1:1 000 000. (Adapted from Mudrey, Brown, and Greenberg, 1982.)

C — Cambrian sandstone with some dolomite and shale.

W — Middle Proterozoic (1500 m.y. old) Wolf River granitic complex includes granite, syenite and quartz monzonite.

P — Early Proterozoic (1710 to 1640 m.y. old) quartzite and other metasedimentary rock.

E — Early Proterozoic (1830 to 1950 m.y. old) intrusive rock including granitic and tonalitic to granodioritic rock; metamorphosed ultramafic to mafic rock; and metavolcanic rock of mafic, intermediate and felsic composition with subordinant metasedimentary rock.

PA — Proterozoic or Archean (1850? to 3000? m.y. old) quartzo-feldsparthic and migmatitic gneiss with amphibolite and biotite schist.

A — Late Archean (2800 to 3000 m.y. old) rock including gneiss, migmatite and amphibolite.

Fault, dashed where projected.

North of the study area, amphibolite-grade metamorphism, intense folding, recrystallization, refoliation, and other deformational and metamorphic features occur in association with the Wolf River plutonic event (Brown and Greenberg, 1981).

The complex Precambrian terrane is overlain by nearly flat-lying, generally undisturbed, Cambrian sedimentary rock, consisting predominantly of sandstone with some shale and dolomite. Cambrian rock covers extensive areas of Clark, Portage, Wood, and Waupaca Counties, but is nearly absent in Marathon County.

Surficial Sediments

Glacial and proglacial fluvial deposits, loess, dune sand, offshore sediment, residuum, and fluvial and colluvial deposits are present in the study area.

Four tills have been identified in Marathon County and parts of Clark and Wood Counties (Mode, 1976; Stewart, 1973; LaBerge and Myers, 1971). The till of the early or pre-Wisconsinan Merrill and Bakerville Members of the Lincoln Formation is sandy loam. The till of the pre-Wisconsinan Edgar and Wausau Members of the Marathon Formation has a loam texture. The till of the Wausau and Merrill Members has a large amount of vermiculite and smectite, presumably as a result of weathering and not incorporation of preglacial soil (Mode, 1976). However, the origin of some of the material in the Wausau Member is controversial. The sandy loam in the Wausau Member may not be till but rather colluvium and/or residuum.

Proglacial fluvial deposits cover large areas of Portage and Wood Counties and merge with deposits of glacial Lake Wisconsin to the southwest. The offshore sediment is mostly fine to medium sand with some interbedded, thin clay layers. The contact with the proglacial fluvial sediment is indistinct because the offshore sediment and fluvial sediment are texturally similar and were deposited concurrently. The level of Lake Wisconsin is generally assumed to be about 1000 feet [300 m].

The surficial sediment has an irregular distribution over the area. The Marshfield moraine in northwestern Wood and southeastern Clark Counties is a major constructional glacial feature. The moraine is composed of up to 120 feet [37 m] of till over rock. From the moraine, south and east to the Wisconsin River, the surficial sediment decreases in thickness and averages about 20 to 30 feet [6 to 9 m]. A thin, 1.3 to 2.0 feet [0.4 to 0.6 m] thick layer of loess covers most of the landscape (Mode, 1976).

In Portage and Waupaca Counties, surficial sediment is thicker than in the rest of the study area. Several moraines, including the Arnott moraine and two late Wisconsinan moraines, are present. The moraines rise 50 to 150 feet [15 to 45 m] above the proglacial fluvial plain and till surface. Till and fluvial sediment may be as thick as 300 feet [90 m] in the moraine area (Weeks and Stangland, 1971).

Familiarity with the glacial history of the area is important because features resulting from ice flow and glacial deposition must be distinguished from patterns related to rock structures and joints or fractures.

Landsat Lineaments

Black and white transparencies of Landsat multispectral bands 4 and 6, at a scale of 1:1 000 000 were manually analyzed for lineaments. The lineaments were transferred by overlay to a base map at the same scale (fig. 3). Coverage was not available for Waupaca County.

The trend of most conspicuous lineaments noted is southwest-northeast or northwest-southeast and several lineaments are coincident with lineaments mapped by Dutch (1981) and with mapped and published faults, cataclastic zones, physiographic features, and pre-Pleistocene valleys compiled by Dutch (1981).

The major cataclastic zones in Marathon County are evident as lineaments on Landsat images and also from aeromagnetic (Zeitz and others, 1978) and gravity surveys (Ervin and Hammer, 1974). This includes the cataclastic zone in northwestern Marathon County and the Eau Claire Dells mylonite zone in the eastern part of the county.

A lineament along the Little Eau Claire River is coincident with a mapped and published fault (LaBerge, 1976). A physiographic lineament is apparent along the Big Eau Pleine River in Marathon County and part of the Wisconsin River in Portage County. A filled pre-Pleistocene valley in central Marathon County is apparent as a lineament.

Evaluation of Method

Although suitable for recognition of regional structural trends that are important insofar as they effect lithologic distribution, fault zones and joint systems, the resolution of Landsat imagery is insufficient for the purpose of providing information directly useful in delineating fracture traces for well-site locations. Large scale imagery such as aerial photographs is more suitable for this purpose.

WOOD COUNTY

Precambrian Rock Aquifer

Precambrian rock is a major aquifer in Wood County. Igneous and metamorphic rock types present include granite, granodiorite, tonalite, metamorphosed ultramafic rock and mafic, intermediate and felsic metavolcanic rock. Hydrologic characteristics of these rock types are described by various authors in studies from other parts of the country and are summarized here.

General Hydrologic Characteristics of Igneous and Metamorphic Rock

Igneous and metamorphic rock is characterized by porosity of less than 1% and commonly permeability so low as to be called impermeable in most groundwater studies (Davis and Turk, 1964). Fracturing can produce porosity up to 10% (Freeze and Cherry, 1979); and weathering can produce porosity up to 50% (Stewart, 1962) in igneous and metamorphic rock. The permeability of weathered rock is dependent on original texture, mineralogy, and degree of weathering. In unweathered rock, permeability is dependent on size, spacing, orientation and interconnectedness of fractures.

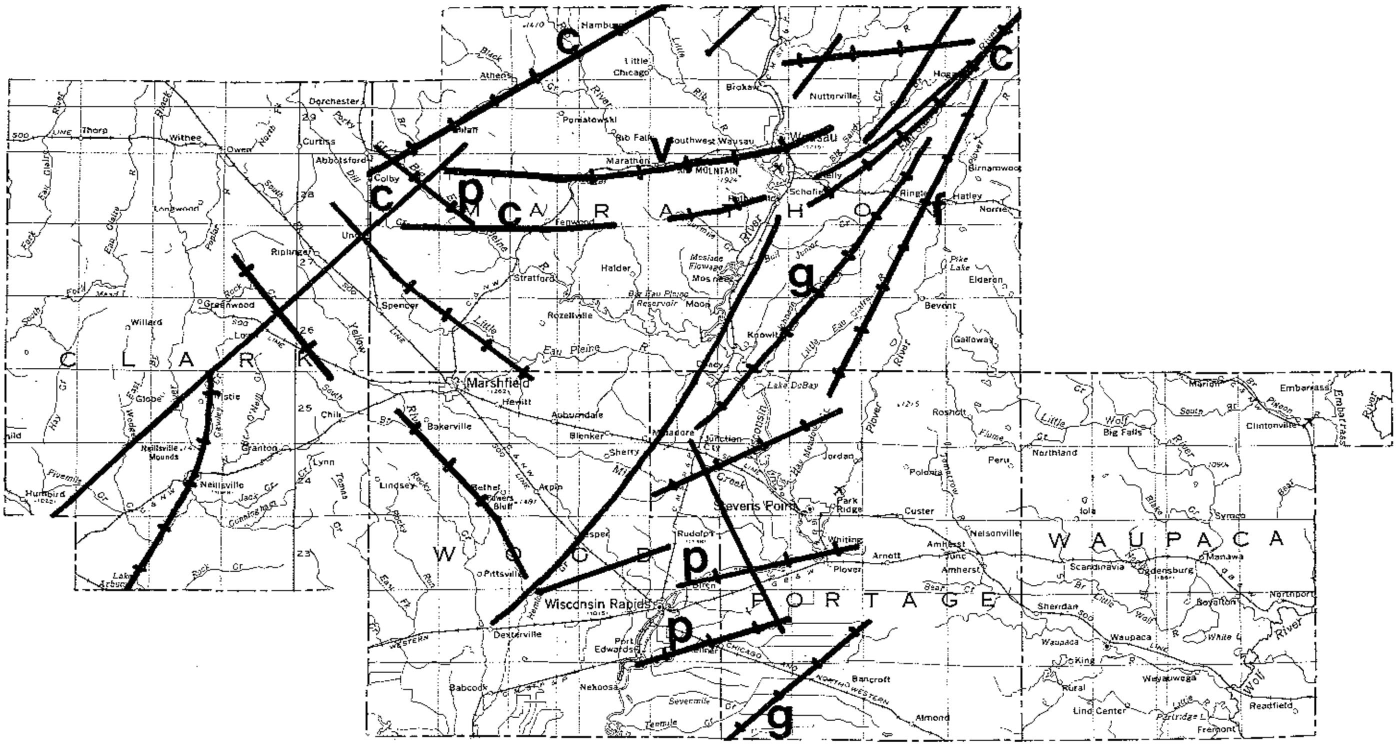

FIGURE 3.--Landsat lineaments in central Wisconsin. Scale 1:1 000 000. (MSS 4 and 6 NASA ERTS E-1577-16163 20Feb74)

———	Landsat lineaments.
—+—+—+—	Landsat lineaments that are coincident with those found by Dutch; mapped and published faults; cataclastic zones; physiographic lineaments; or pre-Pleistocene valleys compiled by Dutch (1981).
g	Lineament coincident with gravity lineament.
c	Lineament coincident with cataclastic zones.
f	Lineament coincident with mapped and published fault.
v	Lineament coincident with filled valley.
p	Lineament coincident with physiographic feature.

Groundwater yields from igneous and metamorphic rock average 10 to 25 gpm [38 to 95 lpm] with median yields being much smaller because variations within an area are large and the number of actual high capacity wells is very small (Davis and De Wiest, 1966). The measure of a well's capacity to produce water is subjective because of a number of variables involved in testing the well including, among others, pumping rate, well construction and boundary conditions within the aquifer. Not uncommonly, wells in fractured igneous and metamorphic rock will have a relatively high initial yield but because of low storage capacity and insufficient recharge, drawdown is extensive, and the well can be easily pumped dry.

A relationship between topographic position and well yield has been suggested by LeGrand (1954) who for 520 wells in igneous and metamorphic rock in the Statesville area, North Carolina, found that yields of wells located on hills were one half of that in all other locations and several times less than wells in small valley bottoms.

The explanation offered is that valleys have developed over areas of less physically or chemically resistant rock. Also, wells in the Statesville area that penetrated more basic rock types such as hornblende gneiss, gabbro and diorite had slightly higher average yields than wells in other rock types such as granite.

Yield per foot of well was found to decrease with depth. It is generally assumed that the permeability of igneous and metamorphic rock decreases with depth because the stress variations that cause fracturing are larger near the ground surface and that vertical and lateral stresses associated with overburden loading cause fractures to close at depth.

Horizontal joint surfaces whose formation is probably related to erosional unloading and consequent rock expansion are concentrated near the surface (Jahns, 1943) and become unimportant as contributors to permeability below about 300 feet [100 m] in depth (Davis and De Wiest, 1966).

Permeable zones at depths of several thousands of feet [a few thousands of meters] have been encountered in mining and tunneling operations and their existence has been attributed to vertical fault zones. However, theoretically rock creep should tend to close even vertical faults (Davis and Turk, 1964).

Frost and root wedging are effective only in the top 6 or 7 feet [2 m] of rock. Chemical weathering is usually confined to the depths of 300 feet [100 m] or less (Davis and De Wiest, 1966) although exceptions are known (Table 4).

All these evidences imply expected decreases in yields per foot with increasing depth and suggest optimum well depths of less than 250 to 300 feet [75 to 100 m].

Well Yields in Wood County

In Wood County, wells in igneous and metamorphic rock have maximum potential yields of generally less than 20 gpm [76 lpm]. In some areas maximum potential yields are less than 5 gpm [20 lpm] (Lippelt and Hennings, 1981).

Records of 370 wells were consulted for a correlation between topographic position and well yield. This included all wells penetrating rock other than sandstone, as reported by the Wisconsin Geological and Natural History Survey (WGNHS) geologic well logs and well constructors' reports. Well sites previously located on topographic maps (Golden Sands Resource Maps, WGNHS open-file report) were categorized according to their topographic position as determined from the maps. Wells with ambiguous locations, that is, located in an area having more than one topographic setting, were not included.

The available data, however, was inadequate for determination of a relationship between topographic position and well productivity as suggested by LeGrand for an area of North Carolina. The main problem in using data from Wood County is that enough data points were not available on the Golden Sands Resource Maps to determine the configuration of the rock surface. The relationship between topographic position and well yield is valid only if the topographic position can accurately be described. In Wood County the relief may be due to glacial constructional features, or stream valleys may be cut in surficial sediment or sandstone. Because only one well location per section was plotted, it was not possible to come to any conclusions about the suggested relationship between topographic position and well productivity.

The validity of the relationship as demonstrated by LeGrand is questionable because conclusions were based on <u>well yield</u>, defined as the quantity of water that a well is known to be capable of producing. This quantity does not take drawdown, or length of open hole above the water table into consideration. LeGrand compared <u>average yields</u> which may have little or no meaning if the data is not normally distributed. The specific capacity data from Wood County has a log-normal distribution.

<u>Fracture Traces and High Yielding Wells</u>

The association of high yielding wells and fracture traces was investigated. A map of fracture traces at a scale of 1:100 000 was compiled from various types and scales of aerial photographs for Wood County (Pl. 1). The intent of the map is to illustrate the general trends and distribution of fracture traces and high yielding wells and not to provide specific locations of individual fracture traces and wells. For specific locations the original aerial photographs and well logs must be consulted. For the purpose of this study high yielding wells are those wells with reported pumping rates and drawdowns yielding specific capacities of 0.95 gallons per minute per foot of drawdown (g/m/ft) [12 litres per minute per metre of drawdown (l/m/m)] or greater. The specific capacity values for 370 wells in Wood County have a log-normal distribution and most values are less than 0.10 g/m/ft [1.2 l/m/m] (Table 1). Only 13% of the 370 wells noted had specific capacities greater than 0.95 g/m/ft [12 l/m/m]. The range of specific capacities is 0.0 to 14.5 g/m/ft [0.0 to 180 l/m/m] with only a few wells having high yields.

The location of 47 wells with specific capacities greater than or equal to 0.95 g/m/ft [12 l/m/m] were plotted on the fracture trace map. Of these, nine wells were found to lie on the fracture trace or within 1000 feet [300 m] of a fracture trace as determined from interpretation of aerial photographs and recorded well locations. Because no attempt was made to check the location of these nine wells or fracture traces in the field, the correlations are approximate.

Table 1. Specific capacities of igneous and metamorphic rock wells in Wood County.

Specific Capacity g/m/ft	1/m/m	% of total (370)
0.05	0.6	24
0.10	1.2	36
>0.95	12.0	13

Fracture-Trace Analysis

Aerial Photography

The fracture-trace map (Pl. 1) was compiled from various types and scales of photographs (Table 2). The color-infrared photographs (National High Altitude Photography--NHAP) were most useful in compiling the map because the scale allowed observation of the continuity and regional trend of fracture traces. Color-infrared film has a wider range of spectral sensitivity (0.3 to 0.9 μm wavelengths) than panchromatic film (0.3 to 0.7 μm wavelengths). Because of atmospheric scatter of ultraviolet (0.0 to 0.4 μm) and blue wavelengths (0.4 to 0.5 μm), filters are usually used with aerial cameras so that the wavelengths actually recorded are green, red, and reflected infrared (0.5 to 0.9 μm) for color-infrared film and green and red (0.5 to 0.7 μm) for panchromatic film. Color-infrared film therefore has the advantage of recording wavelengths over a wider spectral range including reflected infrared. Infrared film is very helpful in distinguishing between subtle soil moisture differences because water strongly absorbs the reflected infrared wavelengths resulting in strong tonal contrasts. Subtle differences in vegetation type or vigor are also conspicuous on color-infrared photographs because plant cell structures reflect infrared wavelengths strongly.

In addition to information being recorded over a wider spectral range with color-infrared film, a greater degree of sophistication in interpretation is possible with color film as the human eye-brain system can detect millions of different colors but only about 200 different shades of gray.

Black-and-white infrared film records light over the same wavelengths as color infrared but is more limited in interpretation possibilities because it is reproduced in shades of gray. However, one advantage of using the black and white infrared photography was that its larger scale made it more useful than the color-infrared 1:56 000 photographs for locating fracture traces and landmarks in the field.

For fracture-trace analysis, the black-and-white 1:40 000 photographs were least suitable because of limited spectral sensitivity and relatively small scale. Very few fracture traces were visible on these photographs. From Vesper, north to the Marathon County line and east to the Portage County line, only black-and-white 1:40 000 photographs were used. Relatively few fracture traces were recorded for this area probably because of the photographs used and not because of terrane differences.

TABLE 2.--Aerial photography parameters

Source	Scale	Film type	Reproduction type	Date	Description
Wisconsin Department of Transportation Madison, Wis.	1:20 000	Black and white infrared	Black and white contact paper prints	9-22-78 6-24-79 9-17-79	Unified aerial photography
ASCS-USDA Salt Lake City Utah	1:40 000	Black and white panchromatic	Black and white contact paper prints	9-23-78	Mapping photography
ASCS-USDA Salt Lake City Utah	1:56 000	Color infrared	Ilford Cibachrome (color contact paper prints)	10-28-80 10-29-80 4-22-82 4-24-82 4-27-82	NHAP-80 NHAP-82
EROS Data Center Sioux Falls S. Dak.	1:80 000	Black and white panchromatic	Black-and-white contact paper prints	10-28-80	NHAP-80

Parts of southern Wood County are covered by thick, proglacial fluvial and offshore sediment, areas of which have been extensively ditched for cranberry production and other uses. The ditches divert the drainage from the natural drainage pattern that is presumably related to fractured or weathered zones to an artificial rectilinear pattern and thereby obscure the presence of fracture traces. Because of the artificial ditches and reservoirs, extensive marshes and thicker surficial deposits, only a few fracture traces were apparent.

Method of Compilation

Frosted acetate was laid over one photograph in each stereo pair and fracture trace end points were marked on the acetate with arrows. Photographs were viewed using a mirror stereoscope and natural or artificial transmitted and reflected light. Because the study area has little relief and topographic maps were available for recognition of topographic and cultural features such as rock ridges, moraine fronts, railroad grades and gas pipe line routes, monoscopic viewing was sufficient for most areas. Viewing the photograph from various oblique angles also proved helpful.

All photographs were marked in this manner and then the fracture trace locations were transferred to the base map by reference to landmarks. Some positioning error is likely but should be less than 500 feet [150 m]. For more precise locations of fracture traces the original photographs must be referred to.

Characteristics of Fracture Traces on Aerial Photographs

Fracture traces consist of aligned changes in vegetation and soil types and tones and straight segments of topographic features such as stream segments and gullies. Along their length, fracture traces can be expressed by a combination of these features.

Figure 4 shows some examples of fracture traces in Wood County as seen on black-and-white infrared photographs at a scale of 1:20 000. Fracture traces A and C are composed of an alignment of dark soil tones continuous through a number of cultivated fields. On infrared film, increased soil moisture results in darker photograph tones. Presumably the increased soil moisture is due to increased permeability and clay content from weathering along fractured zones in the rock. In B and F, trends of offset segments of streams are continuous with dark soil tones in fields. Along fracture trace D, tonal differences are apparent through a wooded area and are probably related to a slight gully continuous with the gully observed in adjoining cultivated fields. Fracture trace E is a conspicuous feature consisting of the alignment of a major offset of the Yellow River, a prominent gully, and soil tonal differences.

In addition to these characteristics, fracture traces on color-infrared photographs may be represented by color changes related to soil moisture and vegetation vigor. Extensive areas in Wood County have poorly or very poorly drained soils developed in residuum from shaley sandstone or igneous and metamorphic rock such as granite and schist. Shallow ditches or furrows that are usually cropped over are common. Excessive moisture in these drainageways causes the vegetation to turn yellow or die. Natural slight depressions developed over fracture traces can have this same effect on vegetation; or in

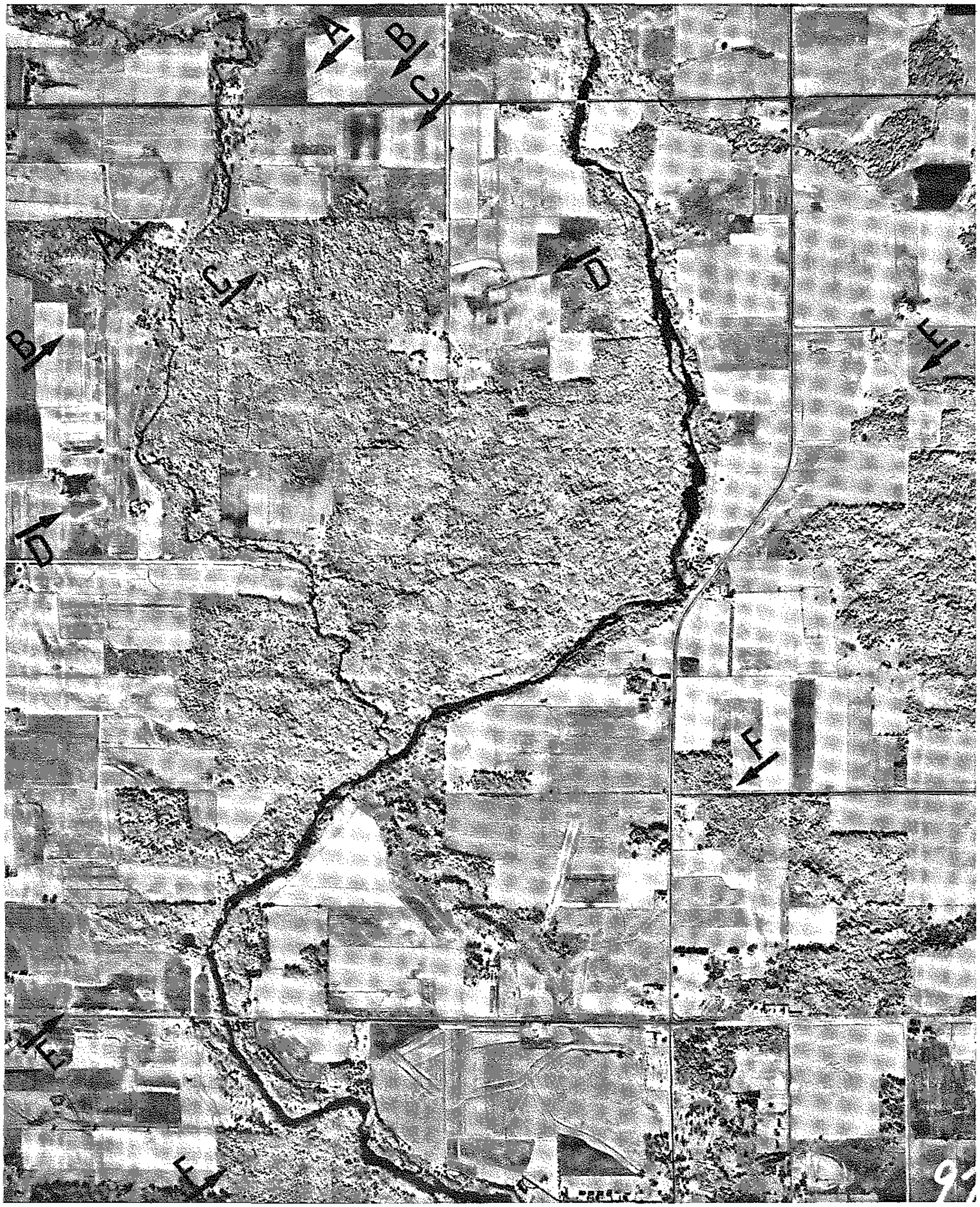

FIGURE 4.--Fracture traces in Wood County (Department of Transportation photograph 2303E15) (Sections 15, 16, 21, 22, T. 23 N., R. 03 E.)

A,C - Alignment of dark soil tones in cultivated fields.
B,F - Alignment of dark soil tones and offset stream segments.
D - Tonal differences in a wooded area aligned with a small gully.
E - Alignment of major offset of the Yellow River, gully and soil tonal differences.

uncultivated areas, excess moisture may promote the growth of marsh vegetation along the length of the fracture trace. Not uncommonly, the artificial drainage is at an angle to the trend of the fracture traces and has the effect of smearing out the linear trend. Plowing at an angle to the fracture trace also diffuses the linear feature.

On color-infrared photography, yellow or dead vegetation will appear very light greenish blue, whereas the healthy vegetation adjacent to it will be pink or red. Therefore, decreased plant vigor, due to excessive moisture along fracture traces, is marked by a color change on color-infrared photographs.

Bare soil generally appears very pale blue. However, in wet areas, the high absorption of infrared wavelengths results in very dark blue or blackish blue tones. Increased moisture in a slight depression along a fracture trace or weathered zone will therefore result in tonal changes particularly apparent on color-infrared photography.

A number of cultural and natural linear features can have appearances very similar to fracture traces. These include geologic features such as soil changes associated with geologic contacts, for example, glacial deposits over sandstone or crystalline rocks or sandstone over crystalline rocks. Glacial features such as flutes or drumlins or crevasse fillings have linear trends that could resemble fracture traces. Cultural features such as artificial drainageways, tertiary roads, railroad grades, gas pipelines, utility line clearings and fence lines all have linear trends similar to fracture traces. Deer and cattle trails are often prominent enough to be visible on aerial photographs. All of these features can be eliminated as fracture traces by reference to topographic and geologic maps, ground checking or consulting local landowners.

Ground Characteristics of Fracture Traces

Field checking of selected fracture traces resulted in verification of ground-surface expression of about 25 fracture traces in Wood County. Ground characteristics of fracture traces observed include the following features or a combination of these features.

Elongate, shallow, linear depressions or alignments of discontinuous slight depressions, conspicuous because of darker soil tones resulting from higher moisture and/or organic content, are presumed to form because of the differential settlement of surface material or weathered residuum into rock fissures. A depression forms because of groundwater leaching and seepage forces causing settlement of the unconsolidated material. An actual depression may not be noticeable but a slight difference in soil tone or moisture may be evident.

Increased moisture content along the fracture may result in vegetation changes. For example, marsh vegetation may be present in a linear trend through a pasture or woodland. In a cultivated field, crops such as corn turn yellow because of excess moisture along a fracture trace. In other areas vegetation growth may be more vigorous over fracture traces. Lattman and Parizek (1964) report, from an area of carbonate rock in Pennsylvania, taller, thicker, darker-colored grain over a fracture trace than in adjacent areas with lower moisture and organic content. In Wood County, however, because of a near-surface water table throughout much of the year, low spots tend to be excessively wet and detrimental to plant vigor.

In uncultivated areas, such as woodlands, gullies and incipient drainage are developing along fracture traces. Fracture traces consisting of straight stream segments coincident with the trend of foliation, jointing, or rock contacts visible in outcrop along stream banks suggest the stream course has been influenced by zones of weakness resulting from stresses associated with deformation or implacement of the Precambrian rocks.

Rock Weathering

Zones of joints or fractures increase the permeability and porosity of massive igneous rocks otherwise lacking intergranular porosity, allowing water to enter and facilitate chemical weathering and removal of materials.

The presence of a weathered clay zone along the Precambrian and Upper Cambrian contact in west-central, southern and eastern parts of Wisconsin has been attributed to the action of groundwater leaching (Bultz, 1981). Others, including Weidman (1907), Morey (1972), and Cummings and Scrivner (1981), suggest extensive, subaerial weathering resulted in the clayey saprolitic surface on the Precambrian rock.

This weathering presumably took place in a tropical or subtropical climate as paleomagnetic data (Dott, 1974) indicate a latitude of 10° to 20° south for the study area during the Cambrian.

Evidence for either interpretation is inconclusive but observations made during this study suggest that extensive deep weathering is characteristic of much of the Precambrian terrane in central Wisconsin.

Vertical weathering zones have been observed at a number of sites in Wood County. In a quarry at Cary Bluff (SE¼ sec. 25, T. 24 N., R. 2 E.) about 25 feet [8 m] of saprolitic rock is in vertical contact with fractured unweathered rock (fig. 5). In another quarry about 1.25 miles [2 km] southwest of this site (NE¼ sec. 1, T. 23 N., R. 2 E.), unweathered sandstone is in low angle contact over a saprolite of igneous rock (fig. 6). Along the Yellow River near Pittsville (SW¼ sec. 27, T. 23 N., R. 3 E.) about 25 feet [8 m] of saprolite is in contact with unweathered gneiss. A test hole augered on a fracture trace for this study, about 0.3 miles [0.5 km] west of the outcrop along the Yellow River, penetrated 24 feet [7.3 m] of sandy clay saprolite. Numerous shallow exposures of saprolitic rock have been observed elsewhere in Wood and adjacent counties.

The vertical and lateral extents of these saprolitic zones suggest a more complex weathering history than groundwater leaching after Mt. Simon (Cambrian) time.

An objection raised by Bultz (1981) to the idea of regional saprolitization is based on the fact that the sequence of weathering product clays present in a relatively small area--Rusk, Chippewa, Clark, Jackson and Wood Counties--do not have a homogeneous lateral extent. However, erosion of a topography with relief to a nearly flat or broadly undulating plain would result in lateral inhomogeneity as the erosional surface would truncate the

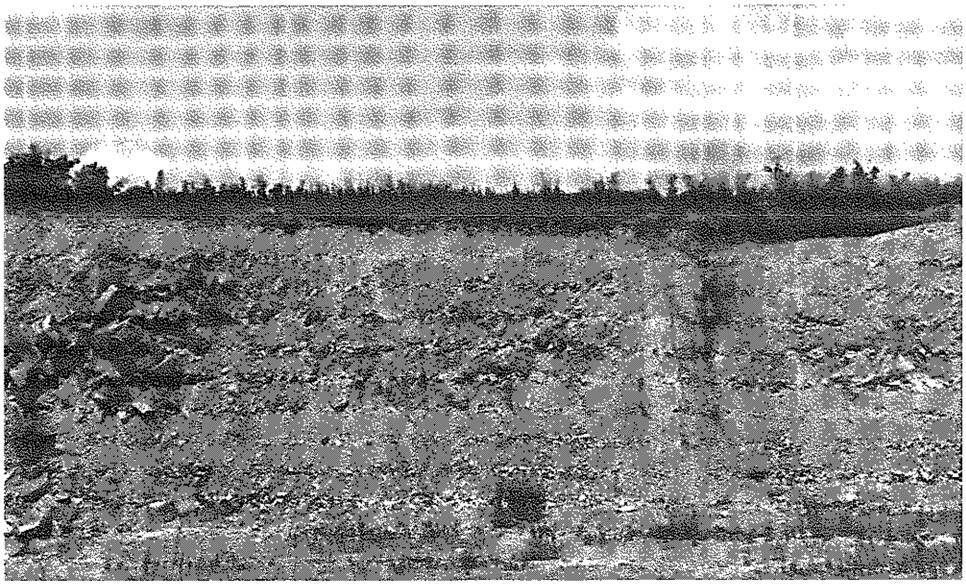

FIGURE 5.--Vertical weathering zone in igneous rock at Cary Bluff, Wood County. Relatively unweathered, fractured granite (left side of photograph) adjacent to chemically weathered, fractured granite. Height of the outcrop is about 25 feet [8 m].

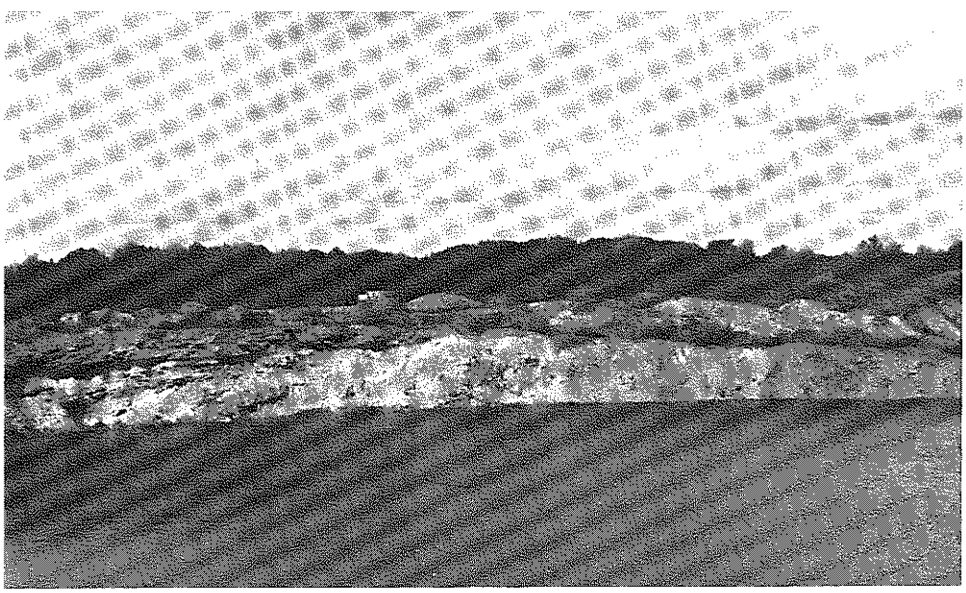

FIGURE 6.--Weathering zone below Cambrian sandstone at Cary Bluff, Wood County. Jointed sandstone over weathered igneous rock. Height of the outcrop is about 16 feet [5 m].

weathering sequences. Erosion by Precambrian streams, the Cambrian sea and the Pleistocene glacier would remove much of the easily eroded saprolite, leaving shallow irregular weathering profiles.

Because of the wave activity necessary to deposit the Cambrian sandstone, Bultz stated that a Precambrian saprolite would not be preserved and therefore the saprolite present must have formed after the Mt. Simon Formation was deposited. However, the saprolite present might represent an erosional remanent of a much thicker sequence eroded by the Cambrian sea. Numerous descriptions of thick saprolitic zones have been described in the literature (Table 3). The Precambrian weathered zone could have been hundreds of feet [tens of metres] thick and later eroded to a few tens of feet [metres] by the Cambrian sea or the Pleistocene glacier. Since weathering can only take place along fractures in massive igneous and metamorphic rock, intensely fractured zones would be most susceptible to weathering and have the greatest thicknesses of saprolitic material above them. Because of greater thicknesses, saprolitic material above fracture traces would have a better chance of being preserved and evident in the modern topography. Modern drainage would be expected to exploit this area of weakness. Bultz (1981) may have observed only moderately altered rock because the intensely altered part of the sequences have been stripped off.

TABLE 3.--References to deep weathered zones

Depth feet	Depth metres	Location	Rock type	Author, date
120	37	W. Australia	granite	Ollier, 1965
148	45	Queensland	granite	Ollier, 1965
260	80	Victoria	granite	Ollier, 1965
300	91	Nigeria	Undifferentiated	Thomas, 1965
300	91	Uganda	igneous and	Ollier, 1960
330	100	Czechoslovakia	metamorphic rock	Demek, 1964
400	122	Victoria	mylonite	Ollier, 1975
550	168	Victoria	granodiorite	Ollier, 1975
600	183	Victoria	schist	Ollier, 1975
1150	350	Victoria	gneiss	Ollier, 1975
1312	400			Vageler, 1930
305-	1000-			
458	1500			Razumova and Kheraskov, 1963

Whereas the Cambrian rock is characteristically quartz arenite, the basal sandstone in many places is pebbly or conglomeritic, with weathered Precambrian clasts. Shaley layers are also common in the lower sandstone units. These conglomeritic and shaley units suggest formation by erosion and reworking of a weathered Precambrian surface.

For these reasons, Precambrian weathering along fractured zones probably occurs in Wood County.

Though groundwater leaching is no doubt part of the weathering history and probably has been in progress since the Precambrian, other types of weathering and fracturing are potentially involved. These include surface weathering such as chemical alteration during soil formation and physical weathering due to modern frost action. In addition to freeze-thaw cycles of the modern climate, ice-wedge casts in a sandstone quarry in Portage County (NW¼ sec. 6, T. 23 N., R. 6 E.) indicate a cold paleoclimate during which much physical weathering probably occurred.

Unloading, an expansion within rock due to pressure release by erosion of the overlying load, has probably been active since Pleistocene deglaciation along with expansion due to external forces such as chemical decay of minerals.

These forces, along with Precambrian igneous and metamorphic activity and deformation, have acted on the crystalline rocks producing a very complex history of fracturing and rock weathering. This complex history should be considered when attempting to characterize the Precambrian terrane in central Wisconsin and recognize fractured and weathered zones with potential for water well sites.

In contrast, the sedimentary rock in Wisconsin has had a relatively uncomplicated fracturing history. Fractures consist mainly of joints resulting from loss of volume due to dehydration. The Cambrian sediment is undeformed, nearly flat lying and is predominately sandstone that is chemically unaltered because of the abundance of quartz.

Precambrian Terrane in Central Wisconsin

Figure 7 is a diagramatic representation of fracturing and associated weathering in Precambrian igneous and metamorphic rock in central Wisconsin.

PITTSVILLE SITE

A site, 1300 by 3000 feet [400 by 900 m] about 0.3 miles [0.5 km] west of Pittsville in Wood County, was selected because of proximity to a known high-yield well, prominent fracture traces, and near-surface igneous and metamorphic rock, to test a method of locating fractured rock through use of fracture-trace analysis and surface geophysical methods. Six shallow test holes provided partial confirmation of the method.

Hydrogeology

Pittsville municipal well number 4, drilled to 353 feet (107.6 m) in igneous and metamorphic rock, is an exceptionally productive well in Wood County. It has been pumped for 12 hours at 200 gpm [757 lpm] with 134 ft

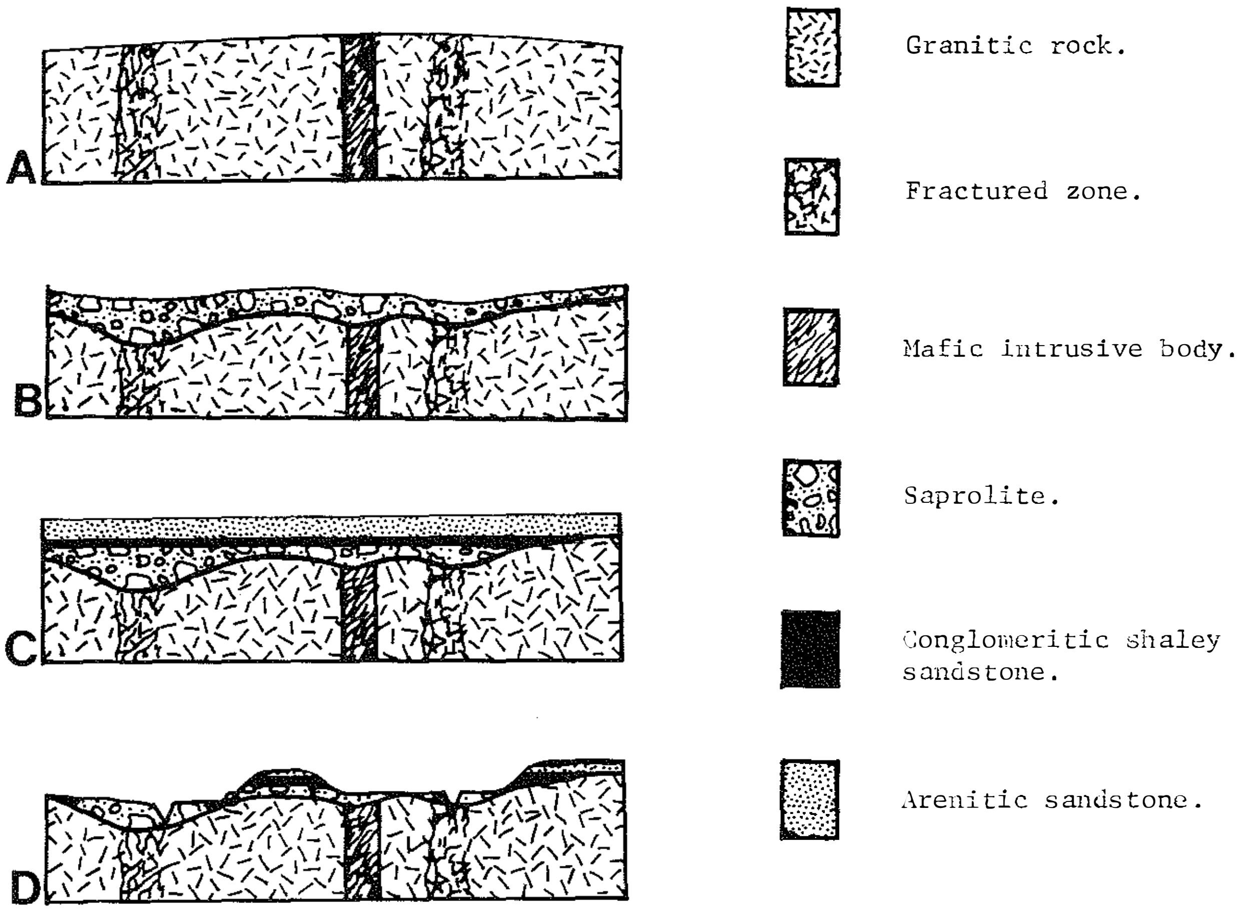

FIGURE 7.--Generalized sequence of development of Precambrian terrane in central Wisconsin from oldest to youngest.

A. Granitic rock is intruded by mafic dikes, and zones of fractures result from regional deformation.

B. Subaerial weathering in a tropical climate results in a surficial saprolite which is locally thicker over the more easily decomposed mafic rock and fracture zones.

C. Cambrian sea erodes and reworks the saprolitic surface and deposits a conglomeritic, shaley sandstone followed by clean quartz sandstone.

D. Post-Cambrian erosion by Pleistocene glaciers and Holocene rivers results in the present landscape with small outliers of sandstone over granitic rock. Stream valleys and small gullies develop in the less resistant material overlying fractured and weathered zones. Springs may be present where the land surface intersects the contact between the saprolite and the granitic rock. Exfoliation, frost action, soil formation, and groundwater leaching contribute to the complexity of the terrane's weathering history.

(40.8 m) of drawdown and has a specific capacity of 1.49 g/m/ft [18.6 l/m/m] (See appendix).

Well-construction reports for domestic wells in the area show wells with a range of specific capacities of 0.0 to 0.2 g/m/ft [0.0 to 3.0 l/m/m]. A well on the study site, located on a fracture trace, is reported by the owner to produce sufficient water for domestic use. The owner also reported that two wells drilled in the area were dry holes. These wells were off of a fracture trace.

Fracture Traces

Two prominent fracture traces trend approximately N 130° E through the study site. This is approximately parallel to a major offset in the course of the Yellow River flowing along the east side of the site and parallel to strike of foliation and joints in gneiss outcropping along the Yellow River at the bridge on County Road E. In addition to linear trends visible on black-and-white infrared photographs and color-infrared photographs, an area of anomalously dark soil tones about 720 by 1280 feet [220 by 390 metres] in size is apparent on the color-infrared photographs.

A gully running from this area to the Yellow River exposes about 25 feet [7.6 m] of weathered gneiss. The more felsic bands of the gneiss have weathered to red clay and the more mafic bands to blue clay. Outcrops along the main channel of the river show little weathering.

Soil substrata range from quartz sand to sandy clay in the area previously mentioned. Residuum from granitic rock is prevalent in the topsoil above a saprolitic granite substratum. Fracture traces were visible on the ground as shallow wet spots and dark soil areas. The area of dark tones on the color-infrared photograph coincide with uncultivated areas of clayey soil, marsh vegetation, and granitic residuum in the topsoil in an otherwise cultivated area.

Geophysical Investigations

Electrical Resistivity

A Soiltest R-40C Strata Scout resistivity meter with a Schlumberger electrode configuration was used to make vertical electrical soundings to a depth of about 90 feet [27 m] at sites on and off fracture traces. The survey was too limited in extent to yield quantitative results but did indicate an area of anomalously low resistivity (23 to 100 ohm/ft [7-30 ohm/m]) coincident with the fracture trace and probably indicates a clay layer over decomposing gneiss (Costello, 1980).

Magnetic Survey

A survey of the total magnetic field intensity was made using a Geometrics G-816 proton magnetometer. Transects were made through the area of presumed deep weathering on the fracture traces and in an area where no fractures or weathering were apparent from aerial photographs or ground observations. A base magnetometer was not available to monitor temporal magnetic field drift independent of position. Instead, a base station was reoccupied every 15 to 20 minutes and the raw data was corrected for temperal change. Variations were less than 20 gamma over the total survey and less than 10 gamma for individual transects. Readings of 58,350 to 58,450 gammas were obtained in areas of presumed fractured and weathered rock. Off fracture trace, readings ranged from 58,550 to 58,700 gammas. Low magnetic anomalies in the range of 100 to 350 gammas appear to be associated with fractured and weathered granitic rock in the study area.

This is contrary to the results of Wagner (1979) who found positive magnetic anomalies associated with fractures in igneous and metamorphic rock in Vermont. High anomalies are possibly associated with fractures because a residual concentration of magnetic minerals forms along this zone. Low magnetic anomalies may be associated with fractured and weathered zones in igneous and metamorphic rock in central Wisconsin because the degree of weathering is much greater and the magnetic minerals have been altered to hematite or clay. In a simplified weathering sequence (Table 4), magnetite is one of the first common minerals to be altered.

TABLE 4.--Weathering sequence (Ollier, 1975)

most resistant	zircon, quartz
	tourmaline
	epidote
	muscovite
	biotite, magnetite
least resistant	feldspar

Similar low anomalies were obtained from transects made over a fracture trace near Greenwood in Clark County indicating some degree of predictability in magnetic-field variations associated with weathered and fractured igneous and metamorphic rock.

Test Drilling

A hole augered on the fracture trace penetrated 12 feet [3.8 m] of coarse sand and 12 feet [3.8 m] of granitic saprolite below which a 12 inch [30 cm] core of weathered granitic rock was retrieved. South of the fracture trace, a drill hole encountered rock at 18 feet [4.2 m]. Fourteen inches [35 cm] of core were retrieved. The top 6 inches [15 cm] of the core showed alteration similar to the core taken on the fracture trace, but the lower 4 inches [10 cm] consisted of fresh though fractured granitic rock. Iron staining was prevalent on fracture surfaces from both cores. Off the fracture trace, rock was reached at a shallower depth and was less weathered and fractured than the rock on the fracture trace or in the weathered zone. Two holes augered in the weathered zone to depths of 24 and 11 feet [7.3 and 3.4 m] penetrated red and blue-green sandy clay, saprolitic material. Rock was not reached in either hole.

Evaluation of Method

Because of drilling difficulties only shallow rock cores were retrieved. The samples retrieved do, however, show weathering and fracturing and agree with observations made through fracture-trace analysis, field observations, and geophysical methods.

Recognition of fracture traces on aerial photographs and on the ground is relatively simple and is helpful in identifying weathered and fractured zones suitable for well site locations. Acquisition of electrical resistivity and magnetic data is a simple field procedure. Quantitative interpretation of the data can be very complex but if qualitatively interpreted, that is for anomaly detection, the process is fairly uncomplicated and useful.

CONCLUSIONS

Recommendations for Well-Site Locations

It is suggested that wells drilled in topographically low positions in the landscape have a better chance of penetrating fractured rock and having higher yields than wells on the uplands. This is presumably because erosion has been greater along areas of weakness associated wtih fractured and weathered rock.

Aerial photographs, and particularly infrared photographs, should be used to identify fracture traces present in the area of interest. Recognition of shallow sags, vegetation changes, soil type, and moisture differences as related to fracture zones can be an aid in selecting sites in fractured and weathered rock zones with potential for higher well yields. Wells located on fracture traces should have higher yields.

Geophysical methods such as electrical resistivity and magnetic surveys can identify anomalous areas. Low resistivities and low magnetic readings appear to be associated with fractured and weathered zones. Qualitative interpretation of geophysical data can be helpful in locating fracture zones but interpretations should be made with reference to available geologic information, such as nearby outcrops, geologic logs and maps, and well constructors' reports.

Suggestions for Further Research

The preliminary findings of this study indicate fracture-trace analysis is potentially useful in locating fracture zones in igneous and metamorphic rock for use as high-capacity well sites.

Essential to the identification of fracture zones is the characterization of the Precambrian terrane. An understanding of the geology, including lithologic distribution, structural trends, and weathering characteristics through detailed field mapping, is needed.

Well drillers' construction reports can be used to verify if a relationship exists between topographic position, rock type and well productivity. In addition, a number of construction reports mention the presence of a layer of weathered or fractured rock above solid rock and the location of these wells could be checked to determine if they lie on a fracture trace or are more productive than adjacent wells that are not reported to penetrate weathered or fractured rock and do not lie on a fracture trace. A large number of well records need to be analyzed in order to determine the Precambrian rock topography and distinguish it from topography on the Cambrian and Pleistocene deposits. The distribution of the specific capacity data should be log-normalized if necessary and the data should be analyzed statistically to determine the significance of a correlation between rock type, topographic position, presence of fractured or weathered rock and well productivity.

Further observation of terrane characteristics associated with areas of high yielding wells is needed. A number of municipal wells including those of Pittsville and Vesper in Wood County, Edgar in Marathon County, Granton in Clark County, and Gresham in Shawano County, have high specific capacities and these sites could be examined in more detail. (See appendix for geologic well logs.) Domestic well logs could be checked to identify additional high-yielding wells. Aerial-photograph characteristics and ground-surface characteristics of these areas could be examined for terrane elements indicative of fractured and weathered zones.

A better understanding of the prevalent types of rock weathering present in the area is needed to characterize the dimensions and hydrologic properties of more permeable rock zones. Weathering may persist at considerable depths or be associated with fractures and faults at considerable depths.

The advent of rotary and down-hole hammer drilling has allowed the construction of wells to greater depths than traditionally considered optimal in igneous and metamorphic rock. Depths of 330 feet [100 m] or less are usually considered optimal and few wells in central Wisconsin have been drilled to more than 215 feet [65 m]. Recently however a number of deep, igneous and metamorphic rock wells with high yields have been drilled in the area. These include the municipal wells of Edgar, drilled to 360 feet [110 m], the Pittsville village well at 353 feet [108 m] and the Gresham city well at 401 feet [122 m]. A well drilled at Granton was reported by the driller (Haupt Well Co., Auburndale) to be dry at 456 feet [139 m]. Further drilling to a depth of 426 feet [145 m] produced water that rose to the ground surface (Clark County Press, Neillsville 7-26-79). Haupt also reports that in a well in Stevens Point water entered from a broken zone at 344 to 349 feet [105 to 106 m]. These wells evidently are penetrating fractured zones, and drilling to greater depths may be advantageous.

The practical aspect of well drilling tends to keep some drillers away from fracture zones. Difficulties associated with drilling in weathered and fractured rocks include flowing sand, caving zones, broken rock, and loss of water circulation or drilling mud. Surface conditions tend to be wetter and more clayey above fractured and weathered zones and drillers may tend to choose other sites for these reasons.

The use of geophysical methods should continue to be investigated as means of detecting more permeable zones in igneous and metamorphic rock.

To improve well yields, sites should be chosen on the basis of observable terrane characteristics related to more permeable zones in the rock. The research suggested may result in better identification of these parameters.

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APPENDIX

Wisconsin Geological and Natural History Survey Geologic Well Logs for Wells in Igneous and Metamorphic Rock in Central Wisconsin with High Yields.

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Edgar Village Test Hole #3 29
Gresham Village Test Hole and Well #2 31
Sentry Insurance Co., Inc. Test Hole and Final Well 33
Vesper Village Well #2 35
Pittsville City Test Hole and Well #4 36

UNIVERSITY OF WISCONSIN GEOLOGICAL & NATURAL HISTORY SURVEY
1815 University Avenue, Madison, Wisconsin 53706

Log No. K133-Mr-857

Well name Edgar Village Test Hole #3

County: Marathon

Owner.... Village of Edgar
Address.. Village Hall
Edgar, WI 54426
Driller.. Haupt Well & Pump Co., Inc.
Engineer.

Completed...
Field check.
Altitude.... 1240' ETM
Use......... Test
Static w.l..
Spec. cap...

R. 4E.
T. 28 N.
Sec. 12

Quad. Edgar 7½'

Drill Hole						Casing & Liner Pipe or Curbing							
Dia.	from	to	Dia.	from	to	Dia.	Wgt.& Kind	from	to	Dia.	Wgt.& Kind	from	to

Drilling method:
Samples from 0 to 360' Rec'd: 6/27/80

Grout	from	to

Studied by: Mary J. Hartman

Issued: 5/20/83

Formations: Drift, Precambrian

Remarks: The basalt is recrystallized and metamorphosed.

LOG OF WELL:

	Depths	Graphic Section	Rock Type	Color	Grain Size Mode	Grain Size Range	Miscellaneous Characteristics
	0-5		Sand	Dk yl bn	M	Vfn/VC	Little gravel. Trace silt, clay.
D	5-10		"	"	"	"	Same.
	10-15		"	"	"	"	"
R	15-20		"	"	"	"	"
I	20-25		"	"	"	"	"
	25-30		"	"	"	"	"
F	30-35	Mag	"	"	"	"	Much gravel. Little Fn magnetite. Trace silt, clay.
T	35-40	Mag	"	"	"	"	Little gravel, Fn magnetite. Trace silt, clay.
	40-45		"	"	"	"	Same.
	45-50	Mag	"	"	"	"	"
55'	50-55		Gravel	Black	S peb	Gran/M peb	Basalt,granite,chert. Ltl sand. Tr silt,clay. Tr hem. Wea.
	55-60		Basalt	"	Fn	Mssv/Fn	Hbld 50%,plag 40%,magn 5%,biot 3%,chlor 2%. Ltl snd&gvl fr abv.
P	60-65		"	"	"	"	Hbld 50%,plag 40%,magn 5%,biot 3%,chlor 2%. Tr orthoc,hem,chlor,
	65-70		"	"	"	"	Hbld 42%,plag 35%,magn 15%,biot 3%,orthoc cvd snd&gvl. Wea.
R	70-75		"	"	"	Mssv/M	Same but ltl cvd snd&gvl. 5%. Tr chlor,hem,cvd snd&gvl. Wea.
E	75-80		"	"	"	Mssv/Fn	Hbld 50%,plag 35%,magn 7%,biot 3%,orthoc 3%,chlor 2%. Tr cvd snd
	80-85		"	"	"	"	Hbld 50%,plag 30%,magn 12%,biot 5%,chlor 3%. Tr &gvl. Wea.
C	85-90		"	"	"	"	Same but ltl cvd snd & gvl. hem,orthoc,cvd snd&gvl. Wea.
A	90-95		"	"	"	"	Same but no orthoclase. snd & gvl. Wea.
M	95-100		"	"	"	"	Hbld 50%,plag 30%,magn 10%,biot 5%,chlor 3%. Tr hem,orthoc,cvd
	100-105		"	"	"	"	Same. V wea.
B	105-110		"	"	"	"	Hbld 50%,plag 30%,magn 7%,biot 5%,chlor 8%. Tr hem,cvd snd&gvl.
R	110-115		"	"	"	"	Hbld 50%,plag 30%,magn 10%,biot 5%,chlor 3%,hem 2%. Tr cvd snd&
I	115-120		"	"	"	"	Same. gvl. Wea.
	120-125		"	"	"	"	Hbld 50%,plag 35%,magn 7%,biot 3%,chlor 3%,hem 2%. Ltl cvd snd&
A	125-130		"	"	"	"	Hbld 50%,plag 35%,magn 8%,biot 4%,chlor 3%. Tr hem, gvl. Wea.
N	130-135		"	"	"	"	Hbld 50%,plag 35%,magn 7%,biot 3%, orthoc,cvd snd&gvl. Wea.
	135-140		"	"	"	"	See end of log. chlor 3%,orthoc 2%. Tr hem,cvd snd&gvl. Wea.
	140-145		"	"	"	"	Hbld 45%,plag 38%,magn 10%,chlor 5%,biot 2%. Tr hem,orthoc,cvd
	145-150		"	"	"	"	Hbld 45%,plag 35%,magn 10%,biot 5%,chlor 3%,hem snd&gvl. Wea.
	150-155		"	"	"	"	Same. 2%. Tr pyr,cvd snd&gvl. V wea.
	155-160		"	"	"	"	Hornblende 45%, plagioclase 40%, magnetite 8%, biotite 4%,
							chlorite 3%. Trace hematite, caved sand and gravel. Weathered

Page 1 of 2

Well name: Edgar Village Test Hole #3

PRECAMBRIAN

	Depths	Graphic Section	Rock Type	Color	Grain Size Mode	Grain Size Range	Miscellaneous Characteristics
	160-165		Basalt	Black	Fn	Mssv/Fn	Plag 43%.hbld 40%.magn 10%.biot 5%.chlor 2%. Tr cvd snd & gvl.
	165-170		"	"	"	"	Same plus trace orthoclase. pyrite. Wea.
	170-175		"	"	"	"	Same but no orthoclase, pyrite.
	175-180		"	"	"	"	Plag 50%,hbld 40%,magn 8%,biot 2%. Tr chlor,orthoc,pyr,hem.
	180-185		"	"	"	"	Same but no pyrite. Slgtly wea.
	185-190		"	"	"	"	Same.
	190-195		"	"	"	"	Hbld 40%,plag 40%,magn 12%,biot 5%,chlor 3%. Tr pyrite. Wea.
	195-200		"	"	"	"	Plag 45%,hbld 38%,magn 10%,biot 4%,chlor 3%. Tr hem,cvd snd&gvl.
	200-205		"	"	"	"	Plag 45%.hbld 38%.magn 10%.biot 4%.hem 3%. Tr chlor,cvd snd&gvl.
	205-210		"	"	"	"	Same but more weathered. Slgtly wea.
	210-215		"	"	"	"	Plag 45%, hbld 35%. magn 13%. biot 5%. chlor 2%. Slgtly wea.
	215-220		"	"	"	"	Plag 45%,hbld 35%,magn 15%,biot 5%. Tr chlor,hem. Slgtly wea.
	220-225		"	"	"	"	Plag 45%, hbld 35%, magn 13%, biot 5%, chlor 2%. Slgtly wea.
	225-230		"	"	"	"	Same. snd&gvl. Wea.
	230-235		"	"	"	"	Plag 40%,hbld 35%,orthoc 10%,magn 8%,biot 4%,chlor 3%. Tr cvd
	235-240		"	"	"	"	Plag 45%,hbld 35%,magn 10%,biot 5%,orthoc 3%,chlor 2%. Wea.
	240-245		"	"	"	"	Plag 48%,hbld 35%,magn 10%,biot 5%,chlor 2%. Tr pyr,orthoc,hem.
	245-250		"	"	"	"	Plag 45%,hbld 35%,magn 15%,biot 3%,chlor 2%. Tr cvd snd. Wea.
	250-255		"	"	"	"	Same. Weathered.
	255-260		"	"	"	"	Same plus trace hematite.
	260-265		"	"	"	"	Plag 45%,hbld 35%,magn 15%,biot 3%,chlor 2%. Tr pyr,cvd sand.
	265-270		"	"	"	"	Same but no pyrite. Wea.
	270-275		"	"	"	"	Plag 45%,hbld 40%,magn 7%,chlor 5%,biot 3%. Tr pyrite. Wea.
	275-280		"	"	"	"	Same.
	280-285		"	"	"	"	"
	285-290		"	"	"	"	Plag 45%,hbld 35%,magn 10%,biot 5%,chlor 5%. Tr pyrite. Wea.
	290-295		"	"	"	"	Same.
	295-300		"	"	"	"	"
	300-305		"	"	"	"	Plag 48%,hbld 35%,magn 8%,chlor 5%,biot 4%. Tr pyr,cvd snd. Wea.
	305-310		"	"	"	"	Plag 50%,hbld 25%,magn 15%,biot 5%,chlor 5%. Tr pyrite. Wea.
	310-315		"	"	"	"	Same plus trace caved sand.
	315-320		"	"	"	"	Same.
	320-325		"	"	"	"	Plag 45%,hbld 35%,magn 10%,biot 5%,chlor 5%. Tr pyrite. Wea.
	325-330		"	"	"	"	Same plus trace caved sand. Wea.
	330-335		"	"	"	"	Plag 45%,hbld 35%,magn 13%,biot 4%,chlor 3%. Tr pyr,cvd sand.
	335-340		"	"	"	"	Plag 35%,hbld 30%,magn 25%,biot 7%,chlor 3%. Tr pyrite. Wea.
	340-345		"	"	"	"	Magnetite 35%, plagioclase 35%, hornblende 20%, biotite 10%.
	345-350		"	"	"	"	Plagioclase 40%. magnetite 30%. hornblende 20%. biotite 10%.
	350-355		"	"	"	"	Plag 45%,magn 25%,hbld 20%,biot 10%. Tr chlor,cvd snd. Slgtly
305'	355-360		"	"	"	"	Same but more weathered. Wea.

END OF LOG

Depths	Graphic Section	Rock Type	Color	Grain Size Mode	Grain Size Range	Miscellaneous Characteristics
135-140		Basalt	Black	Fn	Mssv/Fn	Hornblende 45%, plagioclase 37%, magnetite 7%, hematite 5%, biotite 3%, chlorite 3%. Trace pyrite, caved sand and gravel. Weathered.

UNIVERSITY OF WISCONSIN GEOLOGICAL & NATURAL HISTORY SURVEY
1815 University Avenue, Madison, Wisconsin 53706

Log No. F79-Sh-30
Sample Nos. All Retained

Well name	Gresham Village Test Hole and Well #2 Herman Township	County:	Shawano
		Completed...	8/10/76
Owner....	Village of Gresham	Field check.	
Address..	Box 6 Gresham, WI 54128	Altitude....	930' ETM
		Use.........	Municipal
Driller..	Haupt Well & Pump Co., Inc.	Static w.l..	40'
Engineer.	R. W. Pedersen Shawano, Wisconsin	Spec. cap...	.5 GPM/ft

R.14E.
T. 27 N.
Sec. 3

Quad. Gresham 15'

Drill Hole						Casing & Liner Pipe or Curbing							
Dia.	from	to	Dia.	from	to	Dia.	Wgt.& Kind	from	to	Dia.	Wgt.& Kind	from	to
12"	0	13'				6"	New blk stee P.E. welded jts.x .280" ASTM A 53	+3.5'	40'				
10"	13'	40'											
6"	40'	401'											

Grout: Kind	from	to
Neat cement	0	40'

Samples from 0 to 401' Rec'd: 12/8/75 Studied by: R. M. Peters Issued: 7/11/79

Formations: Drift, Precambrian.

Remarks: Well tested for 40 hours at 80 GPM with 173 feet of drawdown.
Well drilled by rotary method.

LOG OF WELL:

	Depths	Graphic Section	Rock Type	Color	Grain Size Mode	Grain Size Range	Miscellaneous Characteristics
Dft. 17'	0-8		NO SAMPLE	Driller reports		lay.	
	8-17		NO SAMPLE	Driller reports		unny sandy	lay.
PRECAMBRIAN	17-17.5		NO SAMPLE	Driller reports		ranite.	
	17.5-24		Granite	Blk,gy & pk	M	—	—
	24-29		"	"	"	—	—
	29-34		"	"	"	M/C	—
	34-39		"	"	"	M/C	—
	39-44		"	"	"	—	—
	44-49		"	"	"	—	—
	49-54		"	"	"	M/C	—
	54-59		"	"	"	—	—
	59-64		"	"	"	—	—
	64-69		"	"	"	—	—
	69-74		"	"	"	—	—
	74-79		"	"	"	—	—
	79-84		"	"	"	—	—
	84-89		"	"	"	—	—
	89-94		"	Pink & blk	"	—	—
	94-99		"	Blk,gy&pnk	"	M/C	—
	99-104		"	"	"	—	—
	104-109		"	"	"	—	—
	109-114		"	"	"	—	—
	114-119		"	"	"	—	—
	119-124		"	"	"	—	—
	124-129		"	"	"	—	—
	129-134		"	"	"	—	—
	134-139		"	"	"	—	—
	139-144		"	"	"	—	—
	144-149		"	"	"	—	—
	149-154		"	"	"	—	—
	154-159		"	"	"	—	—

Page 1 of 2

Log No. F79-Sh-30
Sample Nos. All Retained

Well name: Gresham Village Test Hole and Well #2

PRECAMBRIAN

384

Depths	Graphic Section	Rock Type	Color	Grain Size Mode	Grain Size Range	Miscellaneous Characteristics
159-164	x x x x x x	Granite	Bk,gy&pk	M	—	—
164-169	x x x x x x	"	"	"	—	—
169-174	x x x x x x	"	"	"	—	—
174-179	x x x x x x	"	"	"	—	—
179-184	x x x x x x	"	"	"	—	—
184-189	x x x x x	"	"	"	—	—
189-194	x x x x X X X	"	"	"	M/C	Trace weathering.
194-199	x x x x X X X	"	"	"	"	Same.
199-204	x x x x x x x	"	Blk,gy&red	"	—	"
204-209	x x x x x x x	"	"	"	—	—
209-214	x x x X X X X	"	"	"	M/C	—
214-219	x x x x x x x	"	Blk,gy & pk	"	—	—
219-224	x x x x X X X	"	"	"	M/C	—
224-229	x x x x x x x	"	"	"	—	—
229-234	x x x X X X X	"	Blk,gy&rd	"	M/C	Trace weathering.
234-239	x x x x x x x	"	"	"	—	Same.
239-244	x x x X X X X	"	"	"	M/C	"
244-249	x x x x X X X	"	Blk,gy & pk	"	"	"
249-254	x x x x X X X	"	"	"	"	"
254-259	x x x X X X X	"	"	"	"	—
259-264	x x x x x x x	"	"	"	—	—
264-269	x x x x x x	"	"	"	—	—
269-274	x x x x x x	"	"	"	—	—
274-279	x x x x x x	"	"	"	—	—
279-284	x x x x x x	"	"	"	—	—
284-289	x x x x x x	"	"	"	—	—
289-294	x x x x x x	"	"	"	—	—
294-299	x x x x x x	"	"	"	—	—
299-304	x x x x x x	"	"	"	—	—
304-309	x x x x x x	"	"	"	—	—
309-314	x x x x x x	"	"	"	—	—
314-319	x x x x X X X	"	"	"	M/C	—
319-324	x x x x x x	"	"	"	—	—
324-329	x x x x x x	"	"	"	—	—
329-334	x x x x x x	"	"	"	—	—
334-339	x x x x x x	"	"	"	—	—
339-344	+ x + x + x	Qtz diorite	Blk & gray	"	—	—
344-349	x + x + x +	"	"	"	—	—
349-354	+ x + x + x	"	"	"	—	—
354-359	x x x x x x	Granite	Blk,gy& pk	"	—	—
359-364	x x x x x x	"	"	"	—	—
364-369	x x x x x	"	"	"	—	—
369-374	x x x x x x	"	"	"	—	—
374-379	x x x x x	"	"	"	—	—
379-384	x x x x x x	"	"	"	—	—
384-389	x x x x x	"	"	"	—	—
389-394	x x x x x x	"	"	"	—	—
394-401	x x x x x	"	"	"	—	—

END OF LOG

UNIVERSITY OF WISCONSIN GEOLOGICAL & NATURAL HISTORY SURVEY
1815 University Avenue, Madison, Wisconsin 53706

Log No H102-Pt-924

Well name Sentry Insurance Co., Inc. Test Hole & Final Well
Hull Township
Owner.... Sentry Insurance Co., Inc.
Address.. 1421 Strongs Avenue
Stevens Point, WI 54481
Driller.. Haupt Well & Pump Co., Inc.
Engineer. Flad & Associates

County: Portage
Completed... 4/25/77
Field check.
Altitude....
Use.........
Static w.l.. 11.5'
Spec. cap... .57 GPM/ft

T. 24 N. R. 8E. Sec. 20

Quad.

Drill Hole						Casing & Liner Pipe or Curbing							
Dia.	from	to	Dia.	from	to	Dia.	Wgt.& Kind	from	to	Dia.	Wgt.& Kind	from	to
8"	0	21'	6"	21'	373'	6"	new black steel P.E. welded jts. x .280' A 53 B Sumitomo	0	21'				

Drilling method: rotary method
Samples from 0 to 373' Rec'd: 4/29/77

Studied by: R. M. Peters

Grout	from	to
cement	0	21'

Issued:

Formations:

Remarks: Well tested for 196 hours at 118 GPM with 208.5 feet of drawdown.
Water enters from broken zone from 344' to 349'.

LOG OF WELL:

	Depths	Graphic Section	Rock Type	Color	Grain Size Mode	Grain Size Range	Miscellaneous Characteristics
2'FILL	0-2		NO SAMPLE. Driller reports fill.				
7'Sfc.	2-9		Soil	V dk brown	—	—	Much sand. Trace gravel. Little organic matter.
6'Dft.	9-15		Sand	Mxd yl bn	C	Vfn/VC	Much gravel, silt.
PRECAMBRIAN	15-20		Granite	Pink & bk	Fn	Fn	—
	20-25		"	Red & bk	"	"	Trace weathering.
	25-30		"	"	"	"	Trace weathering.
	30-35		"	"	"	"	Trace weathering.
	35-40		"	"	"	"	Same.
	40-45		"	"	"	"	"
	45-50		"	"	"	"	"
	50-55		"	Pink & bk	"	"	—
	55-60		"	"	"	"	Trace weathering.
	60-65		"	"	"	"	—
	65-68		"	"	"	"	—
	68-78		"	Lt gy & bk	"	"	—
	78-80		"	"	"	"	—
	80-85		"	Red & bk	"	"	Trace weathering.
	85-90		"	"	"	"	—
	90-95		"	"	"	"	—
	95-100		"	"	"	"	—
	100-105		"	"	"	"	—
	105-110		"	"	"	"	—
	110-115		"	"	"	"	—
	115-120		NO SAMPLE. Driller reports same as adjacent intervals.				
	120-125		Granite	Red & bk	Fn	Fn	—
	125-130		"	"	"	"	—
	130-135		"	"	"	"	—
	135-140		"	"	"	"	Trace weathering.
	140-145		"	"	"	"	Same.
	145-150		"	"	"	"	Trace epidote?
	150-155		"	"	"	"	—
	155-160		"	"	"	"	Trace epidote?, pyrite.

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UNIVERSITY OF WISCONSIN GEOLOGICAL & NATURAL HISTORY SURVEY
1815 University Avenue, Madison, Wisconsin 53706

Log No.
Sample Nos.

Well name: Sentry Insurance Co., Inc. Test Hole & Final Well

	Depths	Graphic Section	Rock Type	Color	Grain Size Mode	Grain Size Range	Miscellaneous Characteristics
	160-165		Granite	Red & bk	Fn	Fn	—
P	165-170		"	"	"	"	—
	170-175		"	"	"	"	—
R	175-180		"	Rd, lt gy&bk	"	"	—
	180-185		"	"	"	"	—
E	185-190		"	Pk, lt gy&bk	"	"	—
	190-195		"	Lt gy, bk&pk	"	"	—
C	195-200		"	"	"	"	—
	200-205		"	"	"	"	—
A	205-210		"	"	"	"	—
	210-215		"	"	"	"	—
M	215-220		"	"	"	"	—
	220-225		"	Lt gy & bk	"	"	—
B	225-230		"	Lt gy, bk&pk	"	"	—
	230-235		"	"	"	"	—
R	235-240		"	"	"	"	—
	240-245		"	Rd, bk&lt gy	"	"	Trace epidote?
I	245-250		"	Red & bk	"	"	—
	250-255		"	"	"	"	—
A	255-260		"	"	"	"	Trace epidote veinlets.
	260-265		"	"	"	"	Trace epidote.
N	265-270		"	Rd, bk&lt gy	"	"	—
	270-275		"	Red & bk	"	"	—
	275-280		"	"	"	"	—
	280-285		"	"	"	"	—
	285-290		"	"	"	"	Trace epidote veinlets.
	290-295		"	"	"	"	—
	295-300		"	"	"	"	—
	300-305		"	"	"	"	—
	305-310		"	"	"	"	—
	310-315		"	"	"	"	Trace epidote?
	315-320		"	"	"	"	Trace epidote? veinlets.
	320-325		"	"	"	"	Trace epidote?
	325-330		"	"	"	"	—
	330-335		"	"	"	"	—
	335-340		"	"	"	"	Trace epidote.
	340-344		"	"	"	"	Trace epidote?
	344-349		"	"	"	"	Trace weathered granite.
	349-354		"	Pink & bk	"	"	Same.
	354-359		"	"	"	"	"
	359-364		"	"	"	"	Trace caved weathered material, weathered granite.
	364-269		"	"	"	"	Trace weathered granite.
358	369-373		"	"	"	"	Same.
			END	OF LOG			

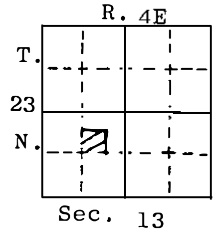
Page 2 of 2

UNIVERSITY OF WISCONSIN GEOLOGICAL & NATURAL HISTORY SURVEY
1815 University Avenue, Madison, Wisconsin 53706

Log No. 70-Wd-467
Sample Nos. Selective Retention

County: Wood

Well name	Vesper Village Well #2 Hansen Township	Completed...	June 17, 1969
Owner....	Village of Vesper	Field check.	
Address..	Vesper, Wisconsin	Altitude....	
		Use.........	Municipal
Driller..	Haupt Well & Pump Co.	Static w.l..	4'
Engineer.	Becher-Hoppe Engineers, Inc. Schofield, Wisconsin	Spec. cap...	1.6



Quad. Wisconsin Rapids 15' (P)

Drill Hole						Casing & Liner Pipe or Curbing							
Dia.	from	to	Dia.	from	to	Dia.	Wgt.& Kind	from	to	Dia.	Wgt.& Kind	from	to
12" 8"	0 30'	30' 138'				12"	Steel Casing (outer)	0	13'	8"	New black steel P.E. welded jts. .375" ASTM A-53, Grade B	+44"	30'

Grout: Kind	from	to
Neat Cement	0	29.5'
Sand Seal	29.5'	30'

Samples from 13' to 143.5' Rec'd: 6/25/69 Studied by: Mary Roshardt Issued: Jan.1970

Formations: Precambrian.

Remarks: Well tested for 24 hours at 100 gpm with 62 feet of drawdown.
Well rotary drilled.

LOG OF WELL:

	Depths	Graphic Section	Rock Type	Color	Grain Size Mode	Grain Size Range	Miscellaneous Characteristics
	0-13		Not to scale. NO SAMPLE - Driller reports clay/trace sand and weathered rock.				
PRECAMBRIAN	13-18 S		Granite	Red or	C	--	Dark orange feldspars. Slightly weathered.
	18-23		"	"	"	--	Same
	23-28		"	Pnk or gry	"	--	Dark orange feldspars.Fresh.
	28-30		"	"	"	--	Same
	30-35 S		"	"	"	--	"
	35-40 S		"	Red brown	"	--	Slightly altered.
	40-45		"	"	"	--	Same
	45-50 S		"	"	"	--	Much alteration.
	50-55		"	"	"	--	Same
	55-60		"	"	"	--	Little alteration.
	60-65 S		"	"	"	--	Same
	65-70 S		"	Pink or	"	--	Much orange feldspar.
	70-75		"	"	"	--	Same
	75-80		"	"	"	--	"
	80-85		"	"	"	--	"
	85-90		"	"	"	--	"
	90-95		"	"	"	--	"
	95-100 S		"	"	"	--	Slightly altered.
	100-105		"	"	"	--	Same
	105-110		"	"	"	--	"
	110-115		"	"	"	--	"
	115-120		"	"	"	--	"
	120-125		"	"	"	--	"
	125-130		"	"	"	--	"
	130-135		"	"	"	--	"
130'	135-138 S		"	"	"	--	"
6"	138-143.5S		"	"	"	--	"

END OF LOG

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UNIVERSITY OF WISCONSIN GEOLOGICAL & NATURAL HISTORY SURVEY — Log No. F80-Wd-449
1815 University Avenue, Madison, Wisconsin 53706

Well name	Pittsville City Test Hole & Well #4 Wood Township	County:	Wood
Owner....	City of Pittsville	Completed...	9/11/76
Address..	City Hall Pittsville, WI 54466	Field check.	
Driller..	Haupt Well & Pump Co., Inc.	Altitude....	
Engineer.	General Engineering Co. Portage, Wisconsin	Use.........	Municipal
		Static w.l..	16'
		Spec. cap...	1.5 GPM/ft

T. 23 N. R. 3E. Sec. 27

Quad.

Drill Hole

Dia.	from	to	Dia.	from	to
14"	0	41'	10"	41'	312'
6"	312'	353'			

Casing & Liner Pipe or Curbing

Dia.	Wgt.& Kind	from	to	Dia.	Wgt.& Kind	from	to
10"	new prime pipe P.E. welded jts. .365"	0	41'	14"	new steel casing	0	30'

Drilling method: rotary method
Samples from 42' to 353' Rec'd: 12/8/75

Grout	from	to
cement	0	41'

Studied by: R.M. Peters

Issued:

Formations:

Remarks: Well tested for 12 hours at 200 GPM with 134 feet of drawdown.

LOG OF WELL:

Depths	Graphic Section	Rock Type	Color	Grain Size Mode	Grain Size Range	Miscellaneous Characteristics
0-38		NO SAMPLE. Driller reports sand.				
38-42		NO SAMPLE. Driller reports same as following intervals.				
42-45		Amph	Black	Fn	Fn	Trace epidote, pyrite, weathering.
45-50		"	V dk gray	"	"	Trace hematite, pyrite. Much weathering.
50-55		"	Green bk	"	"	Very weathered, saprolitic.
55-60		Saprolite	Dk red bn	—	—	Hard.
60-65		Amph	Green bk	Fn	Fn	Very weathered, saprolitic.
65-70		"	"	"	"	Many veinlets. Trace weathering, pyrite.
70-75		Quartz	White & bk	—	—	Massive. Little weathered saprolitic amphibolite.
75-80		Amph	Gn bk & wh	Fn	Fn	Very weathered, saprolitic. Much white quartz.
80-85		Amph	Bk wh & rd	Fn	Fn	Mny veinlets. Mch grntic intrus mat. Ltl cvd? wh qtz. Tr wea.
85-90		Amph	Bk wh&pnk	"	"	V wea, sapric. Tr calc, cvd? wh qtz. Ltl grntic intrus pyr.
90-95		Amph	Black	"	"	Mny veinlets. Well fol. Ltl wea. Tr pyr,epid, grntic mat.
95-100		"	Bk & yl gn	"	"	Mny veinlets. Well fol. Tr pyr, wea. Mch epidote. intrus mat.
100-105		"	Bk wh&yl gn	"	"	Mny veinlets. Well fol. Mch wh qtz. Tr pyr, wea, epidote, calc.
105-110		"	Black	"	"	Few veins. Tr weathering, epidote, grntic intrusive material.
110-115		"	"	"	"	Tr veins, wea, grntic intrus mat, pyr, cvd? wh qtz, calcite.
115-120		"	"	"	"	Few veinlets. Tr weathering, pyrite, calcite, cvd? wh quartz.
120-125		"	Bk & yl gn	"	"	Ltl epidote, grntic intrus mat. Tr veinlets, pyrite, wea.
125-130		"	"	"	"	Much epidote, grntic intrus mat. Tr calc, pyr, wea, veinlets.
130-135		"	Mxd gn bk	"	"	Very weathered, saprolitic. Trace veinlets.
135-140		"	Green black	"	"	Mch sapric mat(cvd?). Ltl wea, grntic intrus mat. Tr pyr, veins
140-145		"	Black green	"	"	V sapric. Mch wea, foliation. Little pyrite. Trace hematite.
145-150		Felsic Volc	"	"	"	Tr calc, wea, pyr. Mch cvd? wea pyric amph, cvd? sapric mat.
150-155		"	Green Black	"	"	Trace pyrite, calcite. Little weathered material.
155-160		"	"	"	"	Trace pyrite, veinlets. Little weathered material, calcite.

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Sample Nos.

Well name: Pittsville City Test Hole & Well #4

Depths	Graphic Section	Rock Type	Color	Grain Size		Miscellaneous Characteristics
				Mode	Range	
160-165		Felsic Volc	Green Black	Fn	Fn	Little weathered material. Trace calcite.
165-170		"	"	"	"	Trace pyrite. weathered material, calcite.
170-175		"	"	"	"	Little weathered material. Trace pyrite, calcite.
175-180		"	"	"	"	Trace weathered material(caved?), calcite.
180-185		"	"	"	"	Trace calcite. pyrite.
185-190		"	"	"	"	Same.
190-195		"	"	"	"	--
195-200		"	"	"	"	Trace calcite, pyrite.
200-205		"	Bk gn & gy	"	"	Little calcite. Trace pyrite.
205-210		"	V dk gy & [illegible]	"	"	Much pink feldspar. Trace calcite.
210-215		"	V dk gray	"	"	Trace pink feldspar, calcite.
215-220		"	"	"	"	Little pink feldspar. Trace calcite.
220-225		"	"	"	"	Same plus trace hematite.
225-230		"	V dk gy&rd	"	"	Much pink feldspar. Little calcite.
230-235		"	V dk gray	"	"	Little pink feldspar. Trace calcite.
235-240		"	"	"	"	Same.
240-245		"	Dk gn gy	"	"	Trace calcite, pyrite.
245-250		"	"	"	"	Same.
250-255		"	Green black	"	"	"
255-260		"	Dk gn gy	"	"	Trace calcite.
260-265		"	"	"	"	Trace massive white quartz.
265-270		"	"	"	"	Trace pyrite.
270-275		"	"	"	"	Trace calcite, pink feldspar, epidote veinlets.
275-280		"	"	"	"	Trace calcite.
280-285		"	"	"	"	Trace calcite. epidote veinlets. pyrite.
285-290		"	"	"	"	Trace calcite, massive white quartz.
290-295		"	"	"	"	Trace calcite, pyrite, epidote.
295-300		"	"	"	"	Trace calcite.
300-305		"	"	"	"	Same.
305-310		"	Dk gn&gy wh	"	"	Much massive white quartz. Little calcite.
310-315		"	"	"	"	Much massive white quartz, calcite. Trace pyrite.
315-320		"	Dk gn gy	"	"	Trace calcite.
320-325		"	"	"	"	Same.
325-330		"	Dk gn gy& gn bk	"	"	Trace calcite, massive white quartz.
330-335		"	Dk gn gy	"	"	Trace pyrite.
335-340		"	"	"	"	Same.
340-345		"	"	"	"	--
345-350		"	"	"	"	Trace calcite.
350-353		"	"	"	"	Trace calcite, pyrite.