THE SAPROLITE AT THE PRECAMBRIAN-CAMBRIAN CONTACT, IRVINE PARK, CHIPPEWA FALLS, WISCONSIN

M. L. CUMMINGS AND J. V. SCRIVNER
Department of Geology
University of Wisconsin-Eau Claire

Abstract

The contact between metamorphosed Precambrian rocks and Cambrian sandstones in west-central Wisconsin is a sharp angular unconformity. Weathering of trondhjemite gneiss during the late Precambrian and possibly early Cambrian developed a saprolite that is exposed at Irvine Park, Chippewa Falls, Wisconsin. The saprolite is mainly kaolinite, quartz and chlorite, its minerology suggests that weathering occurred in a tropical climate that developed in the Wisconsin area as the North American continent drifted southward across the paleoequator in the late Precambrian. Weathered materials from the saprolite became part of the detrital material deposited in the basal unit of the upper Cambrian Mt. Simon Formation.

INTRODUCTION

In the upper Midwest the contact between metamorphosed Precambrian basement rocks and upper Cambrian sandstone is a sharp angular unconformity. The erosional surface at the top of the Precambrian rocks is an irregular surface that truncates the typically steeply-dipping structural grain of the basement. The basal upper Cambrian sedimentary rocks are subhorizontal conglomeratic to fine-grained sandstones and in west-central Wisconsin are the Mt. Simon Formation. Often at the contact is a clay-rich zone for which the time of formation and origin are questioned. This contact is exposed at several localities in west-central Wisconsin including Irvine Park, in southern Chippewa County, Big Falls County Park in north-central Eau Claire County, the Neillsville area in Clark County and south of Ladysmith in Rusk County.

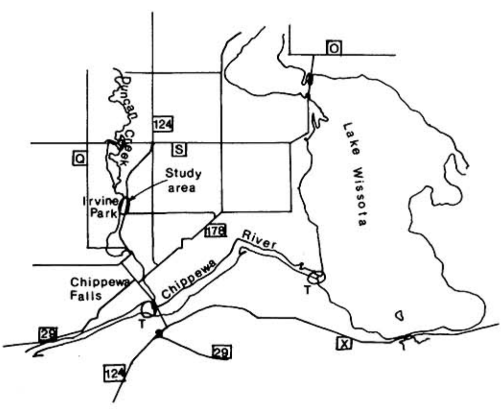

Fig. 1. Map of the Irvine Park study area. T indicates the location of outcrops of trondhjemitic rock at Wissota dam and the dam in Chippewa Falls.

The Precambrian-Cambrian contact and the basal Mt. Simon Formation were studied the Irvine Park (Fig. 1) where they are exposed in the east bank of Duncan Creek. A rock fall during the spring of 1979 provided an excellent unweathered outcrop which instigated this study. The elevations of Precambrian exposures in the immediate area suggest that the Precambrian outcrop at Irvine Park is a topographic high in the basement surface. A zone, at least 2 m and possibly 3.5 m thick, of gray-green, clay-rich material occurs immediately below the contact of the basal Mt. Simon Formation. Approximately 13 m of sandstone are exposed at the site; the lower 5 m and the Precambrian contact are exposed in an unweathered outcrop.

This study was undertaken to 1) determine the mineralogy of the Precambrian basement and the clay-rich zone, as well as the heavy mineral suite of the lower part of the Mt. Simon Formation; and 2) determine the mode and time of formation of the clay-rich zone.

Previous Work

The Precambrian rocks of west-central Wisconsin are strongly deformed amphibolite gneisses and schists, and quartzo-feldspathic gneisses that have been intruded by granitic to tonalitic intrusives. The time of plutonic emplacement relative to regional deformation and metamorphism during a complicated geologic history is reflected in the textures and structures of the intrusives (Myers, 1976, Cummings and Myers, 1978, Cummings, 1975). The amphibolites are considered Archean while the intrusives are of differing ages. Many were intruded during the Proterozoic I Penokean orogeny, *circa* 1850 m.y. (Van Schmus, 1976, 1980).

The lower Paleozoic Mt. Simon Formation was deposited during the Dresbachian stage (late Cambrian). The formation increases in thickness to the south from 100 feet thick in the Chippewa Falls, Wisconsin, area to approximately 800 feet thick in southern Wisconsin (Asthana, 1969). Outcrops of the Mt. Simon Formation occur for at least 50 miles north of Chippewa Falls (e.g. outcrops at Conrath and Ladysmith, Wisconsin). The northernmost outcrops apparently represent the original northern extent of the formation. However, Asthana (1969), on the basis of lithologic characteristics and mineralogical composition, suggested that the Mt. Simon Formation was correlative with the Jacobsville Formation of northern Michigan, part of the Bayfield Group of northern Wisconsin, and the Hinckley-Fond du Lac Formations of Minnesota. Drill core data from central Minnesota indicates that the Mt. Simon Formation is stratigraphically above the Hinckley-Fond du Lac Formation, which, with the Bayfield Group and Jacobsville Formation are believed to be upper Precambrian Formations (Tryhorn and Ojakangas, 1972). However, the absence of fossils in the postulated upper Precambrian sandstones and the lower unit of the Mt. Simon Formation leaves the age question unsettled.

The Mt. Simon Formation is divided into 3 units: the lower of conglomerate to pebbly sandstone, the middle of coarse to medium-grained sandstone and the upper of coarse to very fine-grained sandstone. Fossil fragments and trace fossils are present especially in the upper unit and indicate marine deposition. Trace fossils are the only evidence that the lower and middle Mt. Simon Formation are marine deposits.

The upper Cambrian section in the Midcontinent Region has traditionally been interpreted as sediment deposited during repeated marine encroachments onto the Wisconsin dome. Asthana (1969) interpreted the Mt. Simon Formation as the lowermost formation in a transgressive sequence. The overlying Eau Claire Formation, a fine-grained sandstone to shale, represents the near shore environment.

Byers (1978), citing a lack of recognizable "quiet water" offshore environments, lack of fossil diversity, and exposure indicators, argued that the basal sandstones of the Cambrian sequence were best interpreted as subtidal shelf or tidal-channel deposits. The Eau Claire and Mt. Simon sequence was considered pro-gradational. Driese (1979b), basing his arguements on sedimentary structures and paleontologic evidence, interpreted the Mt. Simon Formation 'as largely progradational, shoaling- and fining-upward tidal sequence." The same sedimentation pattern continued during deposition of the Eau Claire Formation.

The sandstones exposed at Irvine Park are part of the lower and middle units of the Mt. Simon Formation (Driese, 1979a).

Method of Study

Phe Precambrian trondhjemite and clay-rich zone were sampled to represent the gradation from fresh to altered rock. The trondhjemite was studied in thin section and chemically stained to indicate feldspar types. The intensely altered trondhjemite was disaggregated in water and sieved. The coarser fractions were studied under a binocular microscope, the clay fraction was x-rayed and the heavy mineral suite was separated from the fine sand fraction and studied under a petrographic microscope.

Two stratigraphic sections of the Mt. Simon Formation were measured from the basal contact and samples representing the main lithologies were fragmented and sieved. Histograms and cumulative percent curves were constructed from sieve analyses. A Franz-Isodynamic separator was used to separate the heavy minerals from the fine sand fraction. The suites were mounted and studied under a petrographic microscope.

Description of Units

The basement rock at Irvine Park is medium grained, weakly foliated, reddish-pink trondhjemite. The minerals of the trondhjemite are plagioclase, quartz, and biotite. Zircon and ilmenite are accessory. Similar trondhjemite rocks crop out at dams on the Chippewa River at Lake Wissota and Chip-

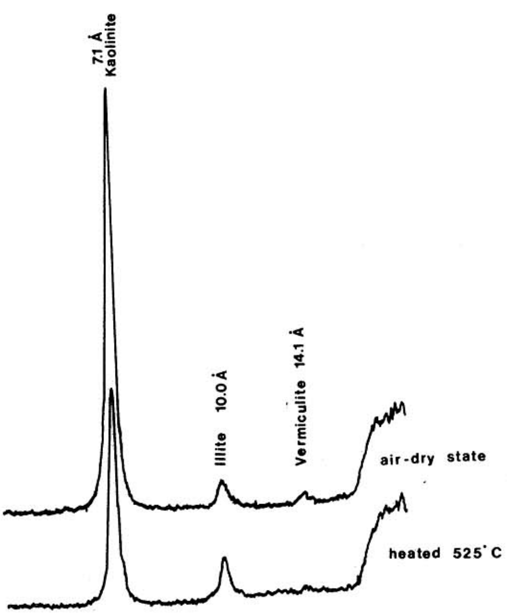

Fig. 2. X-ray diffraction pattern for clays from the Precambrian regolith at Irvine Park. Analyses were provided by S. W. Bailey, University of Wisconsin-Madison.

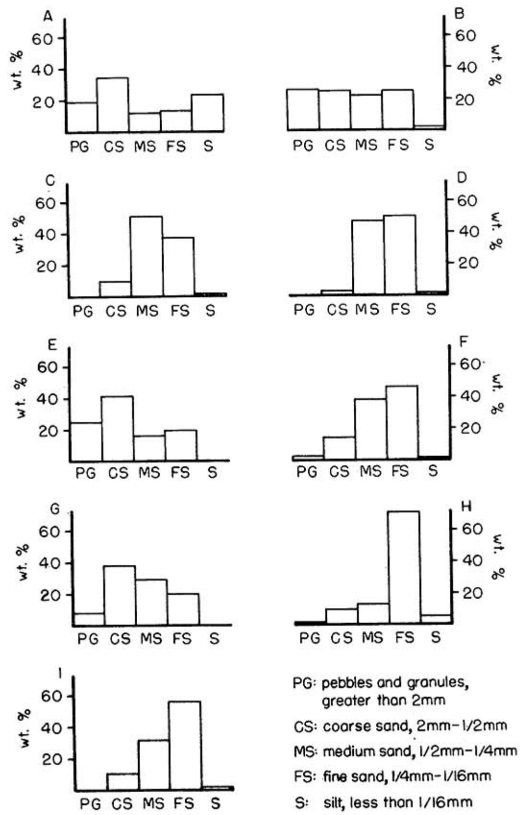

Fig. 3. Histograms of the Mt. Simon Formation and weathered trondhjemite at Irvine Park. A) Weathered trondhjemite, B) Subunit 1, sample 1, C) Subunit 1, sample 3, D) Subunit 2, sample 4, E) Subunit 3, sample 6, F) Subunit 3, sample 7, G) Subunit 4, sample 15, H) Subunit 4, sample 19, I) Subunit 5, sample 18.

pewa Falls (Fig. 1), but the relation among the outcrops is not certain.

The fresh trondhjemite becomes increasingly altered to clay minerals as the contact with the overlying sandstone is approached. At the contact the minerals of the altered rock are chiefly quartz, clay minerals and chlorite. Strongly altered plagioclase, ilmenite and zircon are accessory minerals. Biotite in the trondhjemite apparently is altered to chlorite and plagioclase mainly to clay minerals. Clay minerals separated from the zone were analyzed by x-ray diffraction: 80-90% of the clay is kaolinite while the remaining 10-20% is illite and vermiculite (Fig. 2). The altered trondhjemite is soft and upon drying can be disaggregated and sieved (Fig. 3). Examination of the various size fractions indicate that grains greater than 1.0 mm are composites of quartz and plagioclase. The composite grains are as small as 0.59 mm but are absent in finer size fractions. Although the alteration of the trondhjemite is extreme, metamorphic textures of gniess are preserved in the clay-rich zone to the contact; a paleosol has not been observed.

Locally the altered material has been exposed to recent weathering and is maroon-red rather than the usual gray-green. The color of the clay-rich zone results primarily from the chlorite. Upon weathering hematite becomes concentrated as red spots in the chlorite producing the maroon-red color of the zone.

The lower unit and lower 3 m of the middle unit of the Mt. Simon Formation are exposed at Irvine Park. The lower unit is divided into 4 subunits (Fig. 4). The subunits are generally similar to the sequences defined at the park by Driese (1979a). The reader is directed to the work of Driese who provides a thorough and extensive description of the lithologic units. This report presents information obtained from recent slumps that was not available to earlier authors.

The lowermost subunit contains interbedded and cross-bedded conglomerate, conglomeratic sandstone and fine to medium sandstone (Fig. 3, Table 1). The subunit unconformably overlies the irregular surface at the top of the clay-rich zone. Quartz clasts up to 7 cm long occur immediately above the basal contact. These clasts represent vein quartz that has weathered from the Precambrian basement. Sandstones at the contact, which are generally conglomeratic, are locally fine-grained and greenish clay occurs locally on cross-bed surfaces and discontinuous thin partings on the bedding planes. Cross-beds are poorly developed. The composition of the heavy mineral suites of two samples from the subunit was determined (Table 2). In sample 10, immediately above the contact, 20-30% of the heavy

TABLE 1. Mean diameters and sorting coefficients for the Mt. Simon Formation and regolith at Irvine Park, Chippewa Falls, Wisconsin. Units are listed in order of decreasing stratigraphic position.

Mt. Simon Formation	*Mean Diameter (mm)*	*Sorting Coefficient*	*Sample Number*
Subunit 5— Middle Unit	0.25	2.30	18
Subunit 4— Lower Unit	0.39	2.27	17
	0.55	3.93	16
	0.20	1.81	19
	0.64	4.54	15
Subunit 3	0.30	2.26	7
	0.24	2.18	20
	1.30	2.77	6
Subunit 2	0.27	1.32	5
	0.30	1.79	21
	0.28	1.27	4
Subunit 1	0.35	1.51	3
	0.73	3.58	1
	0.66	2.96	9
	0.83	3.21	10
Regolith			
Altered trondhjemite	0.85	21.25	8

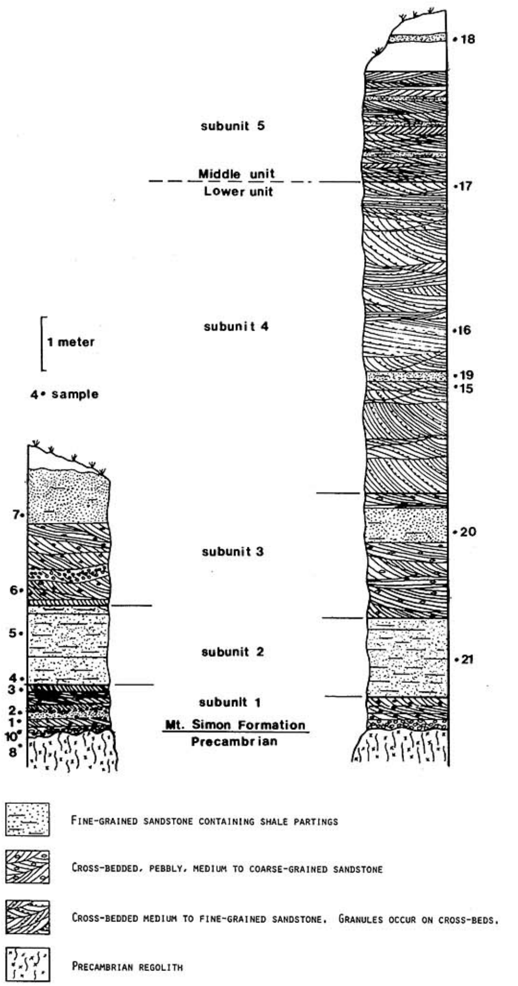

Fig. 4. Stratigraphic columns for the Mt. Simon Formation at Irvine Park, Chippewa Falls, Wisconsin. The left column (no. 1 in text) was prepared from an area of recent rock falls.

mineral suite is green chlorite, however, in sample 1, 0.5 m above the contact, chlorite is present in trace amounts. Altered grains of plagioclase are common to both samples.

The second subunit is well-sorted fine to medium sandstone (Fig. 3, Table 1) with parting lineation and low angle cross-lamination present. The top of the subunit in column 1 (Fig. 4) is marked by a mudstone bed up to 10 cm thick. The bed extends laterally only 5 m because at both ends it is erosionally truncated by a prominent cross-bedded bed 15 cm thick that defines the base of the third subunit. The top of the mudstone bed contains polygonal cracks believed to be dessication cracks, suggesting subaerial exposure of the bed before it was partially eroded. The top of the second subunit is also the top of an upward fining sequence from the bottom of subunit 1 at the basal contact of the formation (Table 1).

The base of the third subunit is marked by prominent through-set cross-bedding. Clasts of shale from the top of the underlying mudstone bed occur in the lowest beds of the third subunit in the area of column 1 (Fig. 4). The base of the subunit is much coarser and more poorly sorted (Table 1) than underlying subunit 2. The subunit contains medium to coarse-grained sand and granules which commonly occur on cross-bed surfaces. Interbedding of fine-grained and medium to coarse-grained sandstones is a common feature of subunits 3 and 4 (Table 1).

TABLE 2. Heavy minerals from the Precambrian regolith and the Mt. Simon Formation at Irvine Park, Chippewa Falls, Wisconsin. Minerals are listed in order of decreasing relative abundance.

Regolith	*Minerals are Mt. Simon Formation*		
Sample 8	Subunit 1	Subunit 1	Subunit 4
chlorite (green)	Sample 10	Sample 1	Sample 17
ilmenite	ilmenite	ilmenite	ilmenite
zircon	tourmaline	tourmaline	tourmaline
tourmaline	epidote	epidote	zircon
	chlorite (green)	zircon	garnet
	zircon	garnet	epidote
	garnet		chlorite (red-green)

The fourth subunit is characterized by large-scale tabular cross beds. Granules of quartz occur on cross-bed surfaces in medium to coarse-grained sandstone. In general this subunit has the greatest variability in sorting. Small amounts of reddish-green chlorite flakes occur in the heavy mineral suite of sample 17 (Table 2), approximately 9.5 m above the basal contact. Tourmaline, zircon and ilmenite are also present. The uppermost subunit defines a receding slope underlain by medium to fine-grained friable sandstone. The sandstone is locally finely cross-laminated. The fifth subunit of this study is the lowermost exposure of the middle unit of the Mt. Simon Formation.

INTERPRETATION

This study is concerned with the time of formation and origin of the clay-rich zone at the Precambrian-Cambrian contact. The angular unconformity between the Precambrian basement and the Mt. Simon Formation represents a time gap of several hundred million years in the geologic record of west-central Wisconsin. During this time the clay-rich layer at the contact developed either 1) by sedimentation, 2) by *in situ* chemical weathering of the basement during the late Precambrian or 3) by ground-water leaching after deposition of the Mt. Simon Formation.

We believe that the upward gradation from fresh trondhjemite to clay-rich material which preserves relic gneissic fabric precludes formation of the deposits by sedimentation during the late Precambrian.

Ground water seepage along the Precambrian-Cambrian contact is commonly observed in west-central Wisconsin. As water percolates down through the sandstone and migrates laterally, seeps develop along valleys that have been cut into the Precambrian basement. Such interaction between ground water and the basement rock could have leached and altered the Precambrian material after the Mt. Simon Formation was deposited. The fabric of the basement rock would be preserved under these conditions. Examples of saprolitization occurring beneath cover have been described by Carroll (1969). The saprolite develops if water percolates down through the overlying material and the covering material protects the developing saprolite from erosion.

Saprolites formed by Pre-Cretaceous weathering and characterized by excellent preservation of primary structures in Precambrian gneiss are recorded in the Minnesota River Valley (Goldich, 1938). Actually two extended periods of weathering are recorded in the Paleozoic-Mesozoic stratigraphy of Minnesota. The older occurs between the Precambrian basement and the Cambrian Mt. Simon Formation; the younger developed prior to deposition of the Cretaceous system. The clay-rich zone at Irvine Park is in the same relative stratigraphic position as the older saprolites in Minnesota, suggesting a similar origin.

If weathering in the late Precambrian formed the clay-rich zone, one would expect weathering products to occur in the Mt. Simon Formation. Two approaches to the problem were pursued: 1) comparison of the grain sizes of materials collected from the clay-rich zone and from the Mt. Simon Formation, 2) comparison of the heavy mineral suites of the materials.

The clay and silt sizes prominent in the clay-rich zone are not present or are present in small amounts in the sandstone (Fig. 3). Also the composite grains commonly observed in the sand-sized fractions from the clay-rich zone are not observed in the sandstone. However, the silt size fractions of both units contain altered plagioclase grains. The silt and clay size fractions from the clay zone were apparently winnowed from the sediment and the composite grains of plagioclase and quartz were destroyed during deposition of the sandstone. However, the altered plagioclase grains suggest a link between the two units.

The composition of the heavy mineral suites from the sandstone is more diverse than from the clay zone (Table 2). Garnet and epidote in the sandstone are possibly derived from locally occurring garnet amphibolites. Zircon, ilmenite and tourmaline are found in all suites. Zircons from the clay zone are zoned as are zircons from the basal sandstone, but the zircons occur in a coarser size-fraction (0.125 – 0.250 mm fraction) in the clay zone than in the sandstone (most occur in 0.062 – 0.125 mm, a few in 0.125 – 0.250 mm fractions). The difference in size does not allow a clear determination of local provenance for zircon in the sandstone but such a suggestion is not negated.

The best diagnostic mineral in the heavy mineral suites is chlorite. Chlorite is the primary heavy mineral in the clay zone (sample 8), occurring as thin, pale to medium green flakes of uniform color. Chlorite of the same physical appearance comprises 20-30% of the heavy mineral suite in sample 10 immediately above the contact. Chlorite flakes are rare 0.5 m above the contact and are present in small amounts in sample 17 approximately 9.5 m above the contact. The chlorites from sample 17 are more reddish-green than in sample 10, possibly indicating post-depositional oxidation. The chlorite flakes in the basal Mt. Simon Formation strongly suggest that the clay-rich zone provided weathered sediment to the Mt. Simon Formation and that the clay-rich zone is a saprolite that formed before the deposition of the Mt. Simon Formation.

The excellent unweathered exposures of the basal Mt. Simon Formation that were developed for a brief time at Irvine Park contain discontinuous clay partings and clay occurs interstitially to sand grains on cross-beds and bedding planes. These features are not visible on weathered outcrop surfaces. Such features occur mainly in the lower two subunits of the Mt. Simon Formation. The clays may have been derived from the clay zone, however available data does not confirm this interpretation.

If the clay zone developed by weathering during the late Precambrian, what were the conditions of weathering? The formation of clay minerals is a function of temperature, precipitation, topography, drainage and parent material (Loughnan, 1969). Kaolinite, illite and vermiculite are the clay minerals at the top of the weathering profile at Irvine Park. Kaolinite, the main clay mineral, can be formed by weathering of any aluminum silicate material by leaching of K^+, Na^+, Ca^{2+}, Mg^{2+}, and Fe^{2+} provided H^+ is added. The general conditions require precipitation greater than evaporation, permeable rock, percolating fresh water and oxidation of Fe^{2+} (Keller, 1970). The associated illite and vermiculite can be derived from weathering of micas and chlorite under the same conditions. The clay minerals from the regolith in the Minnesota River Valley indicate illite is the main clay deeper in the regolith and kaolinite is the main clay in the upper regolith (Morey, 1972). The sampling at Irvine Park was confined to the upper 0.2 m of the regolith so a similar pattern is not documented.

Paleomagnetic data indicate that western Wisconsin was equatorial during the late Precambrian. The paleoequator passed through Central Wisconsin in the Eocambrian (700 m.y. Dott and Batten, 1971) and by the late Cambrian Wisconsin was approximately 15° south latitude (Irving, 1964). Equatorial climates include humid tropical or tropical savanna; either would meet the requirements to produce kaolin-rich clay deposits such as those found in the saprolites of this period.

The weathering of the Precambrian rocks in west-central Wisconsin during the late Precambrian occurred under a humid tropical climate as the mid-continent region drifted southward from the equator. (Reconstructions based on the present configuration of the continents show the paleoequator north and south during the Precambrian so that the North American continent appears to have migrated from east to west during the Cambrian.) The tropical weathering conditions formed saprolites from Wisconsin into central and western Minnesota. The extent of the saprolites formed during the same weathering period in the mid-continent region is not known.

CONCLUSIONS

The exposures of the Precambrian-Cambrian contact and the lower unit of the Mt. Simon Formation at Irvine Park suggest the following conclusions.

1) The Precambrian trondhjemite was weathered to form a kaolinite-rich saprolite prior to deposition of the Mt. Simon Formation. Clastic materials from a saprolite were deposited in the basal Mt. Simon Formation.

2) Weathering to form a saprolite was controlled by a humid tropical climate that developed as the mid-continent region drifted southward during the late Precambrian.

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