PETROGRAPHIC STUDY OF THE PRECAMBRIAN

BASEMENT ROCKS OF OHIO

A Thesis

Presented in Partial Fulfillment of the Requirements for the Degree Master of Science

by

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The Ohio State University

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Approved by

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INTRODUCTION

PURPOSE AND PREVIOUS INVESTIGATIONS

This study was undertaken in order to systematically describe and catalogue the rock types of the Precambrian in some of the deep wells in Ohio. Since the last comprehensive study was made by McCormick in 1961 (table 2), many additional wells have been drilled and numerous studies have been made.

Summerson (1962) summarized the existing literature on the rock types, their distribution and geographic locations, and structural relations of the basement in and near Ohio.

The study was followed in 1965 by a paper by Rudman and others which had as its major purpose the description and interpretation of the configuration of the basement surface in the eastern United States based largely on well data. Some petrographic data were included in this paper.

A paper that is equally broad in scope (Lidisk et al, 1966) reported on a major attempt to date samples representative of the Precambrian of the mid-continental United States. The results of attempts to date some rocks from Ohio wells were published in the Ohio section of this paper. Of the 11 age determinations that were attempted, two were listed as "indeterminate" and dates were determined for the nine remaining wells, and brief comments on lithology were included.

Owens (1967) compiled a table of all Precambrian wells of Ohio, and included such vital statistics as location, depth to the Precambrian,
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total depth of the well, elevation at the well site, and types of logs available for study. This compilation includes the 94 deep wells drilled before 1967. Owens also constructed a contour map of the Precambrian surface of Ohio, for which he used well data as the control. Eleven additional wells have been drilled since that time; pertinent information about each of these is shown in Table 3.

Two papers have been published recently, each dealing with a single Precambrian well. The paper by Hofmann et al (1972), "Age determination of a Precambrian granite gneiss from Scioto County, Ohio" reports an age determination along with a brief petrographic description of the gneiss. The paper by Ross (1972) contains a rather detailed petrographic description of the Erie County core and an interpretation based on the petrology.

Of the 94 wells that penetrated the Precambrian by 1967, plus the 11 that have been drilled into the Precambrian since, 29 were included in the McCormick study (table 2) and are not included in this report. Of the remaining 76, 18 are included in Table 6 as "Undescribed Wells". These are mostly wells for which no samples were deposited with the Ohio Geological Survey or no Precambrian chips were recognized in the cuttings. Of the 58 that remain, 5 were cored either fully or partially. Figure 1 shows all wells that presently penetrate the Precambrian of Ohio (refer to tables 1, 2, and 4 for key to well names).

**INVESTIGATIVE PROCEDURES**

**Well Cores** - Of the five cores available for study, two are represented by pieces of rock less than 3.0 cm in thickness. Only one thin section was cut from each of these two samples because it was
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<th>Wall No.</th>
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* Published in Owens' report, but with no available information
representative of the entire specimen. The three remaining cores range from 22 to 10.3 feet in length; these were studied megascopically, lithologic changes were noted, and samples for thin sections were selected to represent all lithologies present.

These thin sections were studied under a petrographic microscope to determine the mineralogy. Percentages of minerals were determined by making a 1000-point count with a Chayes stage and Denominator counter (in which case the percentages are reported in tables), or by visual estimation. The chief method of determining the feldspar composition was that of measuring the β-index in immersion oils, and using the combined charts of Chayes and Tsuboi (as reproduced in Moorhouse, 1959) to convert this value to a feldspar composition. The Michel-Levy method was used only when it was not possible to make oil immersions of the plagioclase. Plagioclase compositions were determined only where plagioclase was an abundant component of the rock, i.e. for some gneiss and amphibolite, but not for granite.

Some of those minerals that were not readily identifiable either megascopically or in thin section were crushed to a powder and sieved through number 80 and 120 screens. The powder remaining on the 120 screen was separated by bromoform into heavy and light fractions, and mounted on glass slides for a run on a General Electric X-ray Diffractometer (XRD-6). Despite this separation into heavy and light fractions, the mineralogy of each fraction was quite varied. In some samples this diversity resulted in uninterpretable peaks on the x-ray chart; in others
the results were quite good and either confirmed or denied the suspected presence of a mineral.

Opaque minerals in these rocks were identified, when possible, under reflected light. This method does not, however, allow for the distinction between magnetite and ilmenite. For weathered samples, the secondary products hematite and leucoxene were used as indicators of the chemical makeup, although it is realized that this method is not infallible. Where these weathering products were not present, the opaque was termed "magnetite and/or ilmenite".

**Well Cuttings** - Well cuttings were studied with the aid of a binocular microscope under magnifications ranging from 15X to 90X. The size of the chips in these cuttings ranged from fine sand-sized to greater than 2.0 cm. The cuttings of each well were separated according to intervals in which the lithology varied little or within certain limits. The range in depth of each rock type was noted in the report. Representative chips of each rock type were then crushed and mounted in index oils for determination of the constituent mineral grains. Percentages of mineral species were estimated visually.

In some chips, minerals were present that could not be readily identified megascopically or by oil immersions because of fine grain size of the rock. If the chips that contained these minerals were large enough, a flat surface was ground on the chip by hand with the aid of #600 grinding powder and a glass plate, and the chips were mounted on the glass slide and made into a thin section. The chips
from some wells were much too small to be treated by this procedure. These were sparsely sprinkled into Lakeside 70, ground to ± 0.03 mm, and mounted under a cover slip with Canada balsam. Chips mounted by either of these two methods were then studied under the petrographic microscope.

X-ray diffraction patterns were taken, as before, for the chips from some wells to confirm the presence or absence of a certain mineral. This procedure was particularly effective for the fine-grained volcanics that were encountered in some wells.

NOTES ON MINERALOGY

An abundant constituent in the rock from the upper part of the Precambrian in many of the wells studied is a pink or salmon-colored mineral that in thin section is very light pink to buff, has an index of about 1.525, a negative and generally small 2V, birefringence of about 0.01, and appears to be a secondary mineral. This was tentatively identified as a zeolite when first seen in the thin sections. Shortly thereafter, it was learned from Professor Manuel Bass, of the University of Hawaii, that this mineral is probably potassium feldspar (personal communication). Through his studies, Bass determined that this potassium feldspar is a "low-temperature, diagenetic adularia which is almost always monoclinic to x-rays". Preliminary dating has yielded an age younger than 500 m.y. In close association with this secondary feldspar, Bass also found that mafic minerals alter to some combination of dolomite, hematite, montmorillonite, chlorite, and corrensite.
This potassium feldspar has certain optical and physical properties that aid in its identification in thin section. All interference figures display broad brushes instead of sharp isogyres, but these show that the optic angle is lower than any of the common feldspars, except sanidine (figure 26); it was found to range between 0° and 20°. These optical data are very compatible with data collected by Vasil'kova (1959) in which she recorded the occurrence of adularia in an ore deposit of sulfide-cassiterite. She made 21 measurements of the 2V of adularia in five thin sections and obtained the following results:

one-third of the grains had the optic axis angle of 0°-10°; in four instances, -2V varied from -60° to -80°; for the balance, it had an intermediate value of -36° to -60°. Similar fluctuations have been established within a single grain: in the central part, -2V = 0°; for the periphery, -2V = -56°.

The variation of 2V within a single grain that Vasil'kova has recorded may explain why it is difficult to obtain good interference figures, i.e. if the optics vary within a grain, no one area will likely yield a sharp interference figure. In addition to the above data, Vasil'kova measured the indices of refraction and determined that \( N_x = 1.517 \pm 2 \) and \( N_z = 1.522 \pm 2 \). This too is compatible with the data obtained for the adularia of the Ohio Precambrian, but here, no specific values could be determined for the feldspar in most wells due to an abundance of inclusions within the grains, which prevented the effective use of the Becke line test.
However, the \( \beta \)-index of the adularia of the U.S. Steel well was measured and yielded a value of 1.524±.
The occurrence of authigenic potassium feldspar (microcline, adularia) has been previously reported. Authigenic here refers to mineral growth in its place of occurrence. In his study of authigenic feldspars, Baskin (1956) made the following observations in regard to their occurrence in carbonate rocks: 1) Textural features, such as interruption of carbonate crystal outlines by feldspar or pseudomorphs of soda feldspar (albite) after carbonate rhombohedrons, indicate that the feldspar invaded and replaced the carbonate rock. 2) Dolomitization and recrystallization had occurred in all of the carbonate rocks studied in which authigenic feldspar occurred.

From these observations Baskin then concluded that most authigenic feldspars are replacement or epigenetic in origin, and in the case of sedimentary rocks, usually occurs during consolidation (diagenesis); during dolomitization and recrystallization of the sediments; or during cementation of arenaceous sediments. Baskin also concluded that meteoric waters and the earth's thermal gradient were important in the crystallization of authigenic feldspar.

It is possible, then, that the same processes that act to produce authigenic feldspar in sedimentary rocks, either diagenetically or epigenetically, are responsible for the epigenetic introduction of the potassium feldspar (adularia) in the igneous and metamorphic rocks in the basement of Ohio.
ACKNOWLEDGMENTS

The writer would like to thank Dr. George E. Moore, Jr. of The Ohio State University for his suggestion of the problem and for his perserverance during the course of this study.

Acknowledgment is made to the Ohio Geological Survey for supplying the samples, and especially to Dr. Arie Janssens for his help in obtaining these samples and for information on specific wells.

The writer is also indebted to Dr. David Elliot of The Ohio State University for his help in identifying some of the minerals, and to Mr. Robert Wilkinson for his aid in the taking of photomicrographs, the film for which was supplied by the Ohio Geological Survey.

Grateful acknowledgments are also made to Dr. Manuel N. Bass, of the University of Hawaii in Honolulu for his valuable help on the problem of the potassium feldspars in the Precambrian of Ohio, and to Mr. John D. Starn of Starn & Bowlus, Attorneys-at-Law in Fremont, Ohio for supplying information and a small sample from the Ohio Liquid Disposal Well in Sandusky County.
The Calhio Chemicals Well in Ferry Township of Lake County penetrated 10.5 feet of Precambrian between the depths of 6066 and 6076.5 feet, all of which was cored. Three feet of rock at 6066 to 6069 feet and 1.2 feet of rock at 6072 to 6073.2 feet are very fine dark green schist, whereas the three feet of rock at 6069 to 6072 feet, and 3.3 feet at 6073.2 to 6076.5 feet is a very fine-grained medium gray weakly foliated diorite. The diorite has a pinkish tint which becomes much more pronounced upward.

Chlorite-Sericite-Biotite

*Macroscopic description* - A chlorite-sericite-biotite schist is present in the core from 6066 to 6069 and 6072 to 6073.2 feet. This schist is a dark blackish green very fine-grained inequigranular rock containing porphyroblasts of biotite ranging in size from 0.1 to 0.5 mm, depending on the position in the core, and occurring both as widely disseminated grains and as aggregations of grains. Grains of secondary potassium feldspar as much as 1.5 cm in diameter occur in pods that are flattened in the plane of foliation. Foliation is good and results from the orientation of the biotite metacrysts and the chlorite and sericite in the groundmass. Slickenside surfaces occur, are usually well-developed, and are nearly covered with biotite of a younger age than the biotite metacrysts mentioned above. The flakes are oriented such that their basal cleavage parallels the slickenside surfaces, imparting to the surface a somewhat silky sheen. These slickenside surfaces have a sub-parallel orientation to foliation.
Microscopic description - Thin sections of the schist were cut from the following depths: 6066, 6068, 6072.8, and 6073.2 feet. Minerals in thin section include the chlorite and sericite of the groundmass, porphyroblasts of biotite and chlorite, adularia, hematite, and accessory pyrite, apatite, and zircon.

The chlorite and sericite in the groundmass are extremely fine-grained, and are distributed very unevenly. Some patches of the groundmass are mostly sericite, whereas others are mostly chlorite. The sericite in the groundmass has a preferred orientation as evidenced by the parallel extinction positions of the flakes. This no doubt contributes in a large degree to the foliation. The groundmass comprises as much as 90 percent of the rock at the 6066-foot level, but its abundance decreases downward until it comprises 70-75 percent of the rock at the 6073.2-foot level. Adularia is rare and occurs in scattered grains (as much as 0.1 mm in diameter). Figure 2 shows the texture of this schist.

Biotite is present but is so altered to hematite that its properties are largely obscured. Basal sections are almost opaque; thin edges are red-brown. Sections cut perpendicular to the basal cleavage of the biotite show unreplaced remnants in a few grains. The cleavage traces of these can, however, be seen to contain hematite, resulting in parallel opaque laminae. Alterations of biotite to chlorite are also present and are shown by alternating foliae of highly birefringent biotite and very low birefringent chlorite in the same grain. This alteration is rare,
Figure 2. - Photomicrograph of chlorite schist from the Calhio Chemicals Well. Porphyroblasts of hematized biotite (dark) are set in a fine-grained chlorite-sericite groundmass (gray). Foliation trend is NW-SE. (Crossed nicols, X 30)

Figure 3. - Photomicrograph of extensively altered diorite from the Calhio Chemicals Well. The very light gray grains are authigenic adularia; the medium-gray grains are dolomite; the black lath-shaped grains are chlorite, and the black equant grains are leucoxene. (Crossed nicols, X 75.6)
however. The size and abundance of biotite increases from the top of the core down to 6068 feet, where it comprises 30-35 percent of the rock and reaches 0.25 mm in diameter. Beyond this depth, it comprises no more than 5-10 percent.

Hematite is present in a very finely disseminated state. It usually forms a red stain which follows the foliation in the rock, but also pseudomorphically replaces the biotite. In these, the deep red-brown of hematite can be seen in reflected light.

Diorite

Examination of the thin sections showed that the degree of alteration of the diorite decreases rapidly with depth, and therefore the deepest, least altered rock will be described first. Four thin sections of the diorite were made; these are from depths of 6076.5, 6076, 6068, and 6070 feet.

Chloritized diorite

The diorite that was cored at a depth of 6076.5 feet is highly chloritized. The rock at this depth is dark gray, fine-grained, and has much biotite and chlorite in a matrix of plagioclase. Foliation is weak.

A thin section was cut from the diorite. Minerals in the thin section include plagioclase of composition (Ab63An37), adularia, biotite, vermiculite, leucoxene, hematite, calcite, tan chlorite and accessory apatite and zircon. Figures 4 and 5 show the interlocking texture of the relatively fresh diorite.
Figure 4. - Photomicrograph of less-altered diorite from the Calhio Chemicals Well. Constituent minerals include plagioclase, biotite, vermiculite (?), and small amounts of adularia. (Crossed nicols, X 30)

Figure 5. - Photomicrograph of less-altered diorite from Calhio Chemicals Well. The narrow veinlets that cross the large plagioclase grain near the center of the field are adularia. (Crossed nicols, X 75.6)
The plagioclase comprises 75-80 percent of the rock. It occurs as subhedral, somewhat elongated grains, most showing good polysynthetic twinning. A slight sericitization and adularization can be seen in most grains, especially along grain boundaries, fractures, or cleavage planes. Grain size ranges from 0.25-0.50 mm in diameter. Distinct primary potassium feldspar grains are very rare, but where present appear as small grains which are pink in plane-polarized light.

Biotite, which comprises 10 percent of the rock, occurs as fresh irregular grains that lie in the plane of the foliation. Most grains are 0.25-0.50 mm in size.

Chlorite is present in light tan to buff-colored subhedral to anhedral grains that are only weakly pleochroic from light tan (with a faint greenish tint) to light straw-yellow. These grains have a very low birefringence and some display an aggregate growth habit. The chlorite is frequently associated with grains of vermiculite (?) that have a much higher birefringence, and which are described in detail in a lower interval. These two minerals are either intergrown in calcite veins, where they occur in patches, or occur as separate irregular grains set in the plagioclase.

Accessories include apatite, zircon, and hematite.

Leucoxene and ilmenite occur as small scattered grains, many showing unaltered ilmenite cores with a leucoxene rim. All gradations are present from pure ilmenite grains to grains in which leucoxene
has entirely replaced the ilmenite, the latter being much more abundant. These minerals comprise less than 1 percent of the rock.

Calcite in veins occurs as prismatic crystals that show very prominent banding parallel to the vein walls. The veins cut the rock at various angles, with the veins commonly being no more than 1.0 mm in width.

The fine-grained diorite was likely intruded into the schists and the entire mass was subsequently altered. The dolomite, adularia, leucoxene, chlorite, and hematite are undoubtedly secondary and perhaps resulted from the circulation of ground- or seawater throughout the country rock. Alteration and replacement decreases downward indicating that these processes were initiated from above the basement and not below. This interpretation is very compatible with the origin that Bass proposes for the adularia (personal communication).

**Adularized diorite**

A pink brown fine-grained very weakly-foliated equigranular rock containing potassium feldspar, biotite, and chlorite was cored at a depth of 6076 feet.

A thin section was made and showed that the rock is composed of adularia, biotite, chlorite, and opaques that include magnetite, ilmenite, hematite, and limonite.

The adularia comprises 90 to 95 percent of the rock. The grains are mostly anhedral, irregularly-shaped, and range from 0.1 mm to
2.0 mm in size. Some sericite is closely associated. The chlorite occurs as fibrous or platy aggregates with anomalous blue interference colors, is light green and has weak pleochroism.

Biotite occurs as relatively fresh, highly birefringent grains, not altered to chlorite, ranging in size from .05 to 0.75 mm. The smaller grains are mostly anhedral whereas the larger ones tend toward subhedral. Some contain hematite that lies along cleavage planes, the cleavage traces being outlined by opaques. Biotite comprises 5-10 percent of the rock at this depth. Some hematite is altered to limonite.

Dolomitized diorite

The diorite that was cored from 6069 to 6072 feet is rich in dolomite. The rock is a pinkish brown very fine-grained equigranular diorite that shows interlocking grain boundaries and contains abundant dolomite, adularia, and chlorite. Numerous subparallel dolomite veins cut the specimen and are commonly 0.25-0.50 mm in width. Another set of planar features as wide as 6 mm, cut the rock at random angles; these resemble veins, but show no subsequent crystallization of veining minerals. No foliation is present; the rock is massive (figure 3).

A thin section was cut of the dolomitized diorite from a depth of 6070 feet. Minerals in the thin section include dolomite, adularia, biotite, muscovite, leucoxene, hematite, and accessories of apatite and zircon.

Dolomite is one of the two major components of the rock, comprising 30-40 percent. It occurs mostly as subhedral grains, or grain aggregates,
ranging in size from 0.1 mm to 0.25 mm, but a few grains are euhedral rhombs. Rarely, some grains display distinct growth planes that parallel the sides of the rhomb, these planes are accentuated by inclusions along them. The planar features mentioned above are present in the thin section and are due to the concentration of dolomite and leucoxene, the dolomite being finer-grained and more intergrown than usual.

Adularia is the second of the two major components. It occurs as subhedral, equant (up to 0.5 mm) or prismatic (to 0.75 mm in length) grains, and is moderately sericitized. Chlorite also occurs in some of these adularia grains. In plane polarized light, the mineral is pink and is responsible for the pink color of the hand specimen and the thin section. The adularia shows anomalously low 2\(\nu\) angles; it comprises 35 to 40 percent of the rock.

The chlorite occurs in anhedral grains (which are actually grain aggregates) ranging in size from 0.1 to 0.25 mm, and are either non-peochroic or only weakly so. This chlorite is commonly associated with hematite. Grains displaying a remnant high birefringence are present, but rare, and indicate that the chlorite is an alteration product of biotite. Total chlorite comprises approximately 15 percent.

In this lowest sample a mineral that shows anomalous birefringence colors occurs in an abundance that is as great as 5 percent. The mineral was studied in immersion oils, in thin section, and was x-rayed. All of the information indicates that this mineral is secondary, based
on its close association with calcite and dolomite veins and with biotite and chlorite. Table 4 represents a collection of the various data that were obtained. The data indicates that this minerals is vermiculite (?)..

**TABLE 4**

CHARACTERISTICS OF THE BLUE-GREEN UNKNOWN PRESENT IN THE 6076.5-FOOT SAMPLE

\[ \beta = 1.607 \]
\[ 2V (-) \text{ very small} \]
Fleochroic: colorless-light bluish green-dark bluish green
Extinction angle - less than 10°
X-ray chart indicates that the mineral is a sheet silicate
Identification based on x-ray chart plus all above data-
Hydrobiotite-vermiculite

Hematite is very fine-grained except for a few grains, and is widely disseminated throughout the rock, imparting a reddish hue to the slide. Leucoxene is only a minor constituent (less than 1 percent) except in the above-mentioned "vein", where it comprises as much as 4-5 percent of the bulk and occurs at the expense of chlorite. This indicates that an alteration, which concentrated the dolomite and altered the chlorite to leucoxene, has probably occurred along this plane.

Accessories include apatite and zircon.

The rocks in this wall grade from a slightly altered diorite lowest in the well to a chlorite schist highest in the well. The occurrence of the hydrobiotite-vermiculite, the calcite and dolomite veins, and the concentrations of leucoxene probably indicates a slight amount
of hydrothermal activity in the area. The andesine in the diorite has been replaced in varying degrees by adularia, depending on the depth in the well. This replacement ranges from complete at the 6076-foot level and above to less complete at 6076.5 feet. Above the diorite are schistose rocks that have a high chlorite-sericite content. Many slickenside surfaces are present in these higher rocks and indicate that the rock in this area has been highly sheared. Robert Vargo (unpublished senior thesis, Ohio State University 1972) calculated an age of $566 \pm 45$ m.y. This date is anomalously low and was reconciled by Vargo as being the result of active tectonism in the Grenville Province into Cambrian time, which reset the Rb/Sr clock.

However, the sample that was chosen for dating was from the dolomitized interval, which has been largely replaced by adularia and dolomite; the biotite has gone to chlorite and there are significant amounts of leucoxene. Very little, if any, of the unreplaced primary minerals are present and it would be expected that, with the exception of chlorite, these minerals should yield a younger date due to their secondary origin. In essence, then, the date that was obtained for this rock is more aptly a date of the adularia-dolomite replacement (assuming that these minerals originated at nearly the same time). The date may be slightly higher than would be a date on the adularia alone because of the presence of abundant chlorite that is probably older.
Herman Well

The Herman Well in Florence Township of Erie County was drilled 16 feet into a Precambrian quartz-feldspar gneiss, all of which was cored. Slabs were cut from different depths of the core and were deposited at the Ohio Geologic Survey. Twenty-seven slabs ranging in size from 4.0 to 15.0 cm long and 2.0 to 6.0 cm wide were then obtained from the Survey for study purposes. No information is available on how these slabs were cut from the core, and it is, therefore, not possible to determine whether the change in lithology from one slab to another was abrupt or gradational. For those depths from which more than one slab was cut, the relative positions of these slabs for that particular depth was not preserved, so it is not possible to place them in their original position. For this reason, the format used for the sample descriptions of this well differs from that used for other wells. These samples are described according to their depth in the core, the top of the core being described first and the bottom last. For those depths that have numerous slabs, a general description is given that encompasses all differences.

Ross (1972) did a petrographic study of a suite of samples from the Herman Well and reported saussuritization of the plagioclase. However, none was seen in those thin sections cut from the slabs for this study.

Rock Samples From 4449 Feet

Megascopic description - Two slabs of a banded inequigranular gneiss were available for study from this depth, one of these slabs is a medium-to dark gray rock composed of rounded to angular clastic sand-sized
grains of clear quartz and feldspar and some grains of pink feldspar, all in a dark gray aphanitic matrix that has a weak foliation (figure 6). This dark band lies between light grayish pink bands. The light bands differ from those dark bands described above in that they contain relatively more potassium feldspar and quartz and relatively less matrix.

Microscopic description - The thin sections from this depth show a gneiss composed of clastic quartz and microcline, most grains between 0.25 and 1.0 mm in diameter, with minor zircon, apatite, sphene, and opaques set in a very fine-grained medium- to light-brown micaceous matrix. These clasts occur mostly as isolated grains displaying resorbed angular boundaries. Much of the matrix appears to be fine-grained biotite; other lighter parts of the matrix are mainly quartz, feldspar (?), biotite, and zoisite (?). A weak foliation is produced by biotite and by the lighter and darker bands in the matrix. A few large lithic clasts of quartz and microcline with interlocking contacts are probably the result of primary crystallization and not of recrystallization during metamorphism. The light grayish pink bands contain detrital grains like those in the dark bands, but the matrix of the light bands differs from that of the dark bands in that it contains much feldspar and some muscovite. The feldspar has a low negative 2V and locally replaces the matrix. The biotite in the light bands is less abundant, coarser, and porphyroblastic in origin; in some grains it is altered along cleavage planes to chlorite and opaques (iron and titanium oxides ?). In some books, these grains of oxides grew large enough to deform the enclosing book of biotite (figure 7).
Figure 6. - Photomicrograph of the gneiss from the Herman Well. Rounded to sub-rounded clasts of quartz and microcline are set in a fine-grained groundmass of sericite and biotite. (Uncrossed nicols, X 75.6)

Figure 7. - Photomicrograph of a biotite grain from the Herman Well. The grain has been deformed by a grain of magnetite/ilmenite (black grain in lower part of the biotite) that grew inside of the biotite grain. (Crossed nicols, X 75.6)
Accessory amounts of zircon, apatite, magnetite, hematite, and leucoxene are present.

Rock Samples From 4450 and 4451 Feet

Megascopic description - Eight slabs were cut from a depth of 4450 feet, and two from 4451 feet. The rock from this interval shows great variation in lithology, though all are varieties of quartz-feldspar-biotite gneiss with well-developed foliation and compositional banding. These gneisses range from fine- to medium-grained, and from light gray-pink through light-gray to medium-gray. Some are composed of interlocking grains of quartz, feldspar, and biotite whereas others are composed of quartz, feldspar, and biotite grains scattered through an abundant aphanitic matrix. Most of the slabs show only one lithology, but some show more than one; in the latter case the change in lithology is very sharp. In general, these gneisses are slightly coarser than those from 4449 feet; they have more sharply defined compositional banding and better foliation.

Microscopic description - The thin sections of the slabs from this depth show that the gradational bands of shallower depths have given way to very sharp compositional banding. In the darker bands, anhedral porphyroblasts of biotite as much as 3.5 mm long are set in a fine-grained groundmass like that in the gneiss from 4449 feet. Magnetite has developed along the cleavage planes of some of the biotite either as lenses, long thin stringers, or equant grains. When present as lenses, many of the flakes of biotite are deformed in the same manner as those shown on figure 7.
This same pattern is also commonly shown by lenses of calcite (figure 9). Some of the biotite is pleochroic in shades of brown and other biotite in shades of green, even in the same compositional layer. A minor amount of the biotite has been altered to light-green chlorite. These bands also contain differing but minor amounts of detrital grains of quartz, microcline, and accessory minerals.

The groundmass of the lighter bands looks much the same as that at 4449 feet, with clasts of quartz and microcline, and smaller porphyroblasts of biotite. The quartz and microcline show highly corroded grain boundaries, and some show thin reaction rims. Magnetite is present as fresh anhedral equant grains, or as skeletal grains as much as 0.85 mm in diameter that are oxidized at least in part to hematite; the skeletal grains are particularly abundant in the slabs from 4451 feet. Some areas contain highly altered plagioclase with very abundant sericite, hematite, and chlorite. Many of these grains show the low ZV that was described above. Polysynthetic twinning ranges from very distinct in the less altered grains to very faint in the altered grains.

Some lens-shaped areas, as much as 1.5 cm x 0.5 cm, are isolated in the groundmass and are composed of quartz, microcline, and biotite that may display an interlocking fabric. These areas likely represent small pods of pegmatitic material that formed along foliation in response to metamorphism.

Accessory apatite, zircon, and tourmaline are present.
Figure 8. - Photomicrograph of the gneiss of the Herman Well, showing the contact between a biotite-rich band below and a biotite-poor band above. (Crossed nicols, X 75.6)

Figure 9. - Photomicrograph of the gneiss of the Herman Well, showing a biotite grain that has been deformed by the growth of secondary carbonate. (Uncrossed nicols, X 75.6)
Rock Samples From 4452 Feet

**Megascopic description** - Three slabs were cut from the rock from this depth. The rock is a gneiss that has a gray-pink to orange-pink very fine-grained granular matrix and light smoky gray quartz grains or aggregates that are as much as 2.0 cm wide and greater than 2.5 cm long (the full width of the slab). Foliation of the gneiss is absent in one slab and weak in the other two. In the nonfoliated slab, the rock resembles a coarse-grained granite with large anhedral equant grains of quartz isolated in an orange-pink groundmass that resembles altered coarse-grained potassium feldspar. This sample could be from a lens of coarse-grained pegmatite in the metasedimentary gneiss.

**Microscopic description** - The thin sections of these rocks show a very fine-grained matrix of pinkish potassium feldspar, sericite, and colorless quartz in which are lenses of coarse-grained quartz and/or microcline, in varying proportions, that show interlocking grain boundaries. Parts of both the groundmass and the quartz-microcline in the lenses have been replaced by pinkish adularia, in grains mostly 0.5 to 1.0 mm in diameter. Some of these grains of adularia are criss-crossed by irregular streaks of fine-grained matrix and the separate patches of adularia have unit extinction (figure 10). Likewise, single large microcline grains that were incompletely replaced by adularia show isolated remnants, all of which have unit extinction. These relations are interpreted to mean that the groundmass of the metasediment and clastic grains of the metasediment were replaced by fine-grained adularia which later recrystallized into the larger adularia. The thin section of the slab that looks
Figure 10. - Photomicrograph of a gneiss from the Herman Well showing adularia (light gray in the center of the photomicrograph) that has recrystallized from the fine-grained adularia-rich matrix in which it occurs. Unit extinction is exhibited by these grains. (Crossed nicols, X 30)

Figure 11. - Photomicrograph of gneiss from the Herman Well showing a large elongate quartz grain (at extinction) that has undulatory extinction. (Crossed nicols, X 30)
like a coarse pegmatite shows relations about as described above. The orange-pink groundmass is mostly fine-grained adularia and quartz with some remnants of feldspar, and with larger grains of adularia resulting from recrystallization of the groundmass. The quartz has undulatory extinction and tends toward being biaxial. Some of the groundmass was crushed and mounted in oils; it proved to have an average index of about 1.525, to have a small optic angle, and to be negative. This is adularia.

Replacement minerals include adularia, sericite, hematite, chlorite, kaolinite (?), and calcite. Opaques, mostly magnetite, comprise less than 1 percent of the rock. Many of these magnetite grains are skeletal in outline.

Rock Samples From 4453 and 4454 Feet

**Megasopic description** - The samples from these depths are so similar that all are described together. Two slabs were cut from the depth of 4453 feet, and three from a depth of 4454 feet. At these depths, the salmon-pink and dark gray gneiss has a fine-grained well-foliated groundmass containing lenses of pegmatitic quartz and microcline like those described above. The foliation is imparted by the lens boundaries being parallel to the preferred orientation of the books of biotite and the elongate directions of the small quartz grains. Compositional banding also aids the foliation. Some bands are composed largely of hematized biotite in which light minerals are only minor constituents, whereas other bands are very deficient in biotite and contain greater amounts of quartz and feldspar set in the fine-grained matrix.
Microscopic description - As seen in thin sections, the gneiss from these depths is very similar to that from the 4451-foot sample, except for the extreme replacement of biotite by hematite. The hematite is widely disseminated throughout the books of biotite, but appears to be somewhat concentrated along cleavage planes, and is associated with chlorite, magnetite, and leucoxene. The abundant hematite causes the biotite to appear rusty red in reflected light.

An additional change from the 4451-foot sample is the occurrence of medium-grained intergrown grains of quartz, microcline, plagioclase, magnetite and hematite, and muscovite that make up approximately one-fourth of one of the thin sections from a depth of 4454 feet. Of these minerals, only quartz has an unusual habit. Many of the grains of quartz are greatly elongated in the plane of the foliation and may represent porphyroblasts or may simply be greatly elongate pods like those described from some intervals above (figure 11). Some of these grains have a length : width ratio of 8 : 1 and are as long as 8.0 mm. A few of the quartz grains in one of the thin sections from 4454 feet are well rounded grains that appear to be clastic grains like those in the rock from the depth of 4449 feet.

Rock Sample From 4455 Feet

Megascopic description - Only one slab was cut from the core at this depth. Approximately two-thirds of this slab is composed of dark bands like those described above. The slab is compositionally banded with the contacts between bands being very sharp; a pinkish black biotite-rich
band more than 6.0 cm wide is in contact with a salmon-pink biotite-poor band that is less than 2.5 cm wide. The gneiss has an inequigranular texture with a very fine-grained groundmass that comprises as much as 50 percent of the rock; it has pods of quartz and potassium feldspar as much as 1.0 cm in width that cross the entire slab and are set in the fine-grained matrix. In addition to these pods, other pods are composed of single large grains of quartz, or single large grains of microcline that are mostly almond-shaped.

**Microscopic description** - Thin sections of the gneiss at the 4455-foot interval show a foliated banded gneiss composed of porphyroblasts of biotite, plus microcline and quartz as secondary pegmatitic material, all set in a fine-grained matrix rich in adularia.

The rock is very similar to the darker bands of the higher slabs, except for the greater concentration of biotite. As much as 60 percent of the rock in the dark band at this depth is biotite that has an average size of approximately 0.25 mm.

Pods of quartz and microcline like those in most of the higher intervals of the gneiss are also present at this depth, but are considerably more elongated. These pods now appear as long narrow lenticular bodies that may completely cross the thin section, and be no more than 0.5 mm in thickness, which means that the length:width ratio of these bodies is extremely high. These pods are composed of a number of elongated quartz grains that have grown end-to-end. Also occurring separately in these pods are intergrown grains of angular microcline
averaging approximately 0.5 mm in diameter. Microcline and quartz are intergrown in a few pods (Figure 12).

Accessory magnetite and/or ilmenite, hematite, leucoxene, apatite, zircon, chlorite, and sericite are present. In addition to the occurrence of opaques as fine-grained replacement material in the biotite, anhedral grains of these minerals are scattered through the groundmass. Magnetite and/or ilmenite range from highly replaced by hematite to very fresh and unoxidized.

Rock Sample From 4458 Feet

**Megascopic description** - One slab was cut from a depth of 4458 feet. At this depth, the gneiss is a greenish black and pink inequigranular rock composed of a fine-grained grayish pink groundmass rich in potassium feldspar that contains bands of large grains of clear to milky quartz and pink potassium feldspar alternating with bands of fine-grained quartz, feldspar, biotite, and chlorite. Foliation is good and is enhanced by the orientation of the biotite and chlorite, plus the orientation of the platy bodies described above as pods.

**Microscopic description** - The alternating bands described above are very apparent in this section. In addition to those minerals listed above as occurring in the finer-grained bands, plagioclase is present, and although highly altered, some faint polysynthetic twinning can be seen. This plagioclase has been largely replaced by adularia. Alteration products of hematite, chlorite, and sericite are enclosed in the grains. Chlorite occurs as very small flakes in the plagioclase, and in the groundmass in
Figure 12. - Photomicrograph of gneiss from the Herman Wall showing large elongate pegmatitic pod of quartz and microcline in a fine-grained groundmass of adularia. (Crossed nicols, X 30)

Figure 13. - Photomicrograph of gneiss from the Herman Wall showing extensively-replaced plagioclase grain that still shows faint twinning. Alteration products in the plagioclase grain include adularia, sericite, and hematite. (Crossed nicols, X 30)
Figure 14. - Photomicrograph showing closeup of the same plagioclase grain as in figure 13. Small light gray flecks that are oriented NW-SE are sericite. (Crossed nicols, X 75.6)

Figure 15. - Photomicrograph of gneiss from Herman Well. Secondary sheaf-like quartz occurs in veins that cut the foliation of the gneiss. (Crossed nicols, X 30)
grains as much as 0.5 mm in diameter, is mostly parallel to the foliation, and commonly is closely associated with biotite. The biotite flakes show good parallel orientation and are largely replaced by magnetite, hematite, and leucoxene. The replacement is so extensive that most of these grains of biotite appear opaque in plane light. High birefringence can be seen in small remnant areas of a few grains. Many anhedral grains of magnetite and/or ilmenite that contain almond-shaped grains of calcite are also associated with the biotite. The magnetite/ilmenite is highly altered to hematite. Calcite also occurs as euhedral rhombs scattered throughout the rock.

Large irregular slightly elongate porphyroblasts of quartz and microcline are also present in alternate bands. Some of these grains are as much as 11.5 mm in length and along with altered plagioclase grains exhibit interlocking grain contacts in these bands.

Accessory apatite and zircon are present.

Rock Sample From 4462 Feet

Megasopic description - This rock is a salmon- to reddish pink medium-grained equigranular gneiss speckled with black biotite and is composed of potassium and plagioclase feldspar, quartz, biotite, and chlorite. The weak foliation, as opposed to strong foliation of samples higher in the well, is mainly due to the absence of compositional banding, the small amount of biotite and chlorite, and the lack of effective grain size differences. The observed foliation is imparted by orientation of the biotite.
Microscopic description - The rock at this depth shows a stage of alteration and a texture heretofore unseen in the well. All of the grains are interlocking and have a seriate fabric. Most of the grains are between 1.0 and 2.0 mm in diameter; extreme grain sizes are 0.1 and 5.0 mm with all intermediate sizes being present.

The rock is composed of plagioclase, quartz, microcline, biotite, penninite, muscovite, hematite, leucoxene, magnetite, ilmenite, pyrite, and accessory apatite and zircon. Quartz, which has mild undulose extinction, and microcline, which shows good grid-twinning, appear relatively fresh, whereas the plagioclase is somewhat altered. Polysynthetic twinning in the plagioclase, although not common, is present. Alteration products include hematite, chlorite, and sericite, as described above, and adularia, which partly to completely replaces plagioclase. Adularia in the plagioclase is recognized by gray areas of very low birefringence. The adularia replacements destroy the twinning of the plagioclase, change the optic angle from that of "normal" plagioclase to one as small as 5 to 10°, and lower the index of refraction to an index below plagioclase. All gradations between completely replaced plagioclase to totally un replaced plagioclase grains are present in the rock. Figures 13 and 14 show a plagioclase grain that is partly replaced by adularia, sericite, and hematite, but faint polysynthetic twins can still be seen, indicating that the replacement is not complete.

Intergrown biotite-muscovite-chlorite (penninite)-leucoxene comprise approximately 3 percent of the rock. These grains probably represent initially intergrown grains of muscovite and Ti-rich biotite. The biotite
has since been altered to penninite. The alteration was accompanied by the exsolution and subsequent oxidation of the titanium to produce leucocoxene. Anhedral grains of magnetite and/or ilmenite with only a small amount of hematite stain are equally abundant.

Rock Sample From 4463 Feet

_Megascopic description_ - Only one slab was available from a depth of 4463 feet. The rock at this depth is a medium- to dark greenish gray inequigranular rock composed of a fine-grained groundmass of chlorite, biotite, hematite, quartz, potassium feldspar, magnetite and/or ilmenite, and pyrite, in which there are a few medium-grained salmon- to reddish pink bands of quartz and potassium feldspar as much as 3.0 mm thick and 25 mm long. A moderate to good foliation results from the parallel alignment of the long dimension of most grains, as well as by the parallelism of the compositional bands.

Veins of secondary calcite and dolomite, mostly less than 1.0 mm wide, cut the rock in a direction almost perpendicular to foliation.

_Microscopic description_ - The majority of the gneiss is fine- to medium-grained and is composed of microcline, quartz, plagioclase, biotite, chlorite, adularia, sericite, hematite, and magnetite/ilmenite.

A very few grains of plagioclase show polysynthetic twinning, but most grains have been so completely altered to an intergrowth of chlorite and adularia that the twinning can no longer be seen. These replaced grains of plagioclase are 60 to 70 percent chlorite and 30 to 40 percent adularia. The chlorite-adularia intergrowths are characterized by the
small angular equant grains of chlorite in an adularia matrix, or long thin grains of chlorite having a preferred orientation within any one area, perhaps due to control by the crystal structure of the original plagioclase grain. Adularia has also replaced some of the microcline; some clear grains of low index feldspar that gives an optic angle of about 40° has remnant grid-twinning of microcline in unreplaced parts of the grain. The other alteration products of plagioclase are hematite and sericite.

Biotite is present in grains as large as 1.40 mm and is extensively replaced along cleavage planes by hematite. Most of the biotite flakes have an orientation that is parallel to the foliation of the rock; some, however, have an orientation that is almost perpendicular to foliation and are subparallel to the above-mentioned calcite and dolomite veins.

Opaques are a major accessory and occur in grains that show no oxidation to hematite. These grains do, however, show alteration to leucoxene and because of this relationship, are likely ilmenite instead of magnetite. Other accessory minerals include apatite and zircon.

The veins in this rock are mainly calcite, dolomite, and quartz in anhedral irregular grains that are slightly elongate parallel to the vein boundaries. Pyrite occurs both within and in close proximity to the veins. These veins probably originated from hydrothermal emanations at some time after metamorphism.
Rock Sample From 4465 Feet

One slab was available for study from this depth, which represents the lowest sample in the well. No significant differences exist either mega- or microscopically from the 4463-foot sample. However, the number and degree of development of the secondary veins, as well as the abundance of quartz has increased downward. Quartz comprises approximately 66 percent of some of the veins, has a fibrous sheaf-like form, and is biaxial (figure 15).

The rock of the Herman Well likely represents a quartz-feldspar gneiss that is the result of relatively high grade metamorphism of sediments. Three stages of alteration are thought to be present: 1) The chlorite-sericite that is present in the plagioclase may have a hydrothermal origin or may simply be the products of "weathering". 2) The production of the angular corroded grain boundaries was likely the result of a metamorphic event, which may be Grenville in age. 3) The final alteration was that produced during the adularization of the rock—i.e. the replacement of most all of the plagioclase, plus some other minerals, by adularia. It cannot be ruled out that chlorite-sericite-hematite assemblage found in the plagioclase arose during this event, instead of hydrothermally or by "weathering". Indeed, Bass favors this interpretation based upon his work (personal communication).
U.S. STEEL WELL

The U.S. Steel Well in Green Township of Scioto County penetrated a reported 37 feet of Precambrian (Ohio Geological Survey, well card). However, depths recorded on the core indicate a total penetration of only 22 feet. Twenty-two thin sections were cut from samples of this core from the following depths: 5595, 5596.5, 5598.5, 5599.5, 5601 (3 thin sections), 5602.5, 5604.5, 5605.5 (2 thin sections), 5606 (2 thin sections), 5608.5 (4 thin sections), 5611 (2 thin sections), 5613, and 5614 feet (2 thin sections). Selected chips and thin sections were stained for potassium feldspar by the Bailey and Stevens (1960) method. Lithologic changes in the rock from this well occur at depths of about 5601 and about 5605.5 feet.

**Megascopic description** - A medium- to coarse-grained pinkish gray and dark gray gneiss that varies in lithology with depth was penetrated in this well.

Between the depths of 5595-5601 feet, the rock is mostly salmon- to reddish pink with large green patches, is coarse-grained, equigranular, and composed of potassium feldspar, plagioclase, chlorite, biotite, and magnetite. Well-developed foliation is produced by parallel orientation of biotite and chlorite, and by lens-shaped grains of quartz and feldspar. Fractures filled with secondary calcite, dolomite, and large patches of anhydrite are abundant and are as much as 2.0 mm thick.

The rock in the interval 5601-5605.5 feet is a medium- to dark gray coarse-grained gneiss in which the feldspar is greenish gray and is mostly plagioclase as shown by polysynthetic twinning. Hornblende is
present in abundance, and the biotite : chlorite ratio is greater than in the next higher interval. The biotite shows yellowish limonite between cleavage planes, which indicates some weathering of the rock. The foliation is enhanced by a compositional banding that appears in this interval. These bands are on the order of tens of centimeters thick. The dark bands are composed mainly of biotite, chlorite, and hornblendes; the light bands are reddish gray and are composed mainly of plagioclase, potassium feldspar, and quartz.

Below a depth on 5605.5 feet, the core is characterized by compositional bands as much as 10 cm thick. Because of the thickness of the compositional bands from this part of the core, the core at any given depth may show only one band. Veins of secondary minerals like those described from the 5601-5605.5 interval are also present in these lower samples. The thickness and attitude of these veins are variable.

**Microscopic description** - For purposes of microscopic description, the core was divided into the three intervals used above.

**Rock Samples From 5595-5601 Feet**

The gneiss in this interval is a medium- to coarse-grained equigranular rock composed of plagioclase, adularia, biotite, chlorite, hematite, magnetite, pyrite, leucoxene, apatite, zircon, calcite, and dolomite. Foliation is good and is produced mainly by the sub-parallel arrangement of the books of biotite. The rock in this interval is nearly devoid of quartz.
Figure 16. - Photomicrograph of biotite-hornblende gneiss from the U.S. Steel Well. The grain in the SE corner is a completely chloritized grain of hornblende. The grain in the west-center is an extensively sdularized plagioclase grain that still shows faint twinning. (Crossed nicols, X 30)

Figure 17. - Photomicrograph of secondary dolomite vein that cuts the biotite-hornblende gneiss of the U.S. Steel Well. (Crossed nicols, X 30)
Figure 18. - Photomicrograph of gneiss from the U.S. Steel Well, showing plagioclase grain that has been extensively replaced by adularia on alternate twins. The narrow light gray twins that cross the grain are unaltered plagioclase. (Crossed nicols, X 75.6)

Figure 19. - Photomicrograph of gneiss from U.S. Steel Well showing small remnants of hornblende (dark gray) surrounded by chlorite (light gray). Remnant cleavage appears as faint gray lines in the chlorite. The black grain in the NE corner is magnetite/ilmenite. (Uncrossed nicols, X 30)
The plagioclase occurs in anhedral irregular grains most of which range between 2.5-5.0 mm in diameter and comprises no more than 5 percent. It has been extensively replaced by adularia and much less extensively by very fine-grained chlorite, sericite, and hematite. The alteration of plagioclase to chlorite tends to follow cleavage of the feldspar.

Adularia has completely replaced some grains of plagioclase. It comprises as much as 80 percent of the rock. Other grains of plagioclase are only partly replaced. The unreplaced plagioclase in places occurs as patchy to blocky remnants whose distribution is controlled at least in part by cleavage; or the unreplaced plagioclase may be in certain plagioclase twin lamellae or perthitic stringers. In certain cases alternate twin lamellae are replaced (figure 18). The separated patchy to blocky remnants of plagioclase show optical continuity and have an extinction position different from that of the adularia that has replaced the plagioclase. The adularia has a pinkish hue in plane light, a small negative optic angle, and an index of refraction of about 1.53.

The biotite, which makes up approximately 10 percent of the rock, is relatively fresh and unaltered. Some grains show alteration to magnetite and hematite along cleavage planes, but this alteration is mostly confined to thin zones along the cleavage planes and only rarely does the entire grain show replacement. In general, this replacement seems to have advanced further in areas where carbonate is also present. This perhaps indicates that the agents which resulted in the deposition of calcite and dolomite also resulted in the alteration of the biotite.
Most of the biotite grains are subidioblastic and some are as much as 5.0 mm in length. The average length, however, is between 2.5–3.0 mm. The biotite is strongly pleochroism from dark greenish brown to light yellowish brown.

Chlorite completely replaces hornblende and occurs as a fine-grained aggregate inside the remnant hornblende outlines (figure 16). The chlorite is pale green to light tan in plane light and pleochroism is very weak to absent. In many grains, the chlorite is associated with calcite, dolomite, and very minor amounts of muscovite. The grains of carbonate are mostly anhedral, but a few show a rhombic outline, especially if they occur as veining material. Hematite is also associated with these veined areas. It typically fills cleavage planes of minerals or fractures that are in close proximity to the veins. This hematite probably resulted from the migration of Fe\(^{++}\), derived from the biotite or hornblende during the circulation of the fluids that deposited the secondary minerals, and its subsequent oxidation and deposition in available fractures. In addition, numerous very small grains of leucoxene are sprinkled throughout the chlorite.

Apatite, magnetite, and pyrite are present in accessory amounts but as relatively large grains. Grains of apatite are as much as 1.1 mm, whereas those of magnetite and pyrite approach 3.0 mm in diameter. A few grains of zircon are present but these are mostly less than 0.5 mm. The total accessories comprise less than 3 percent.

The rock in this interval likely represents a metamorphic rock that
approximated the composition of a biotite-hornblende gneiss before replacement by the adularia.

Rock Samples From 5601-5605.5 Feet

The rock from this interval is somewhat different mineralogically from that above, but it shows essentially the same texture and fabric, i.e. mostly coarse-grained, equigranular, and well-foliated. Constituent minerals include plagioclase, adularia, biotite, hornblende, chlorite, calcite, dolomite, hematite, and limonite.

Many of the plagioclase grains show distinct polysynthetic twinning, whereas in the next higher interval only a few grains showed distinct twinning, a few showed faint twinning, and most showed no twinning. Adularia, as a replacement mineral, is less abundant and is present mostly along twin planes of the plagioclase, though some grains of plagioclase are almost wholly replaced.

The hornblende is present only as remnants in the 5601-foot sample. These remnants occur as small disconnected patchy areas that show optical continuity. The remnants are completely surrounded by larger areas of fine-grained chlorite identical to that described above. However, the degree of chloritization of the hornblende generally decreases downward and at the 5605.5-foot-level is manifested mostly by thin veins of chlorite and/or calcite cutting otherwise fresh hornblende. A few grains of hornblende have been partly to completely replaced by fine grained anhedral closely-arranged calcite, quartz, and chlorite. The chlorite tends to wrap around the calcite grains. This relationship seems
to imply that although relatively fresh hornblende is present in certain
areas of the rock, severe alteration is still prominent in local areas
at these depths.

The only other mineral here to fore undescribed is limonite, which
occurs as fillings of cleavage cracks and other fractures, mainly in the
biotite. It also fills cleavage cracks in the feldspars, and forms a
thin rind around some of the large magnetite grains.

The rock in this interval represents a less altered equivalent of
the rock above.

Rock Samples From 5605.5-5614 Feet

This interval is characterized by very strikingly perthitic ortho-
clace, by relatively little adularia, and by relatively abundant quartz.
Foliation is excellent and is enhanced by the parallel orientation of
biotite and elongate grains of magnetite, compositional bands, and bands
resulting from differences in grain size.

In the 5605.5-foot sample, a medium- to coarse-grained band composed
mainly of plagioclase, biotite, hornblende, and chlorite lies between
bands that are fine- to medium-grained and are composed of perthitic
feldspars, biotite, carbonate, quartz, chlorite, and magnetite. Most
grains in the lighter-colored coarser-grained bands below 5605.5 feet
are subequant and randomly oriented. The plagioclase is near the albite
end member; most grains do not show polysynthetic twinning and it is
relatively obscure even in those that do. Minor replacement of the
plagioclase by chlorite, sericite, and lesser amounts of carbonates has
occurred along grain boundaries and twin planes. Most of the biotite is relatively fresh and unaltered except for a limonite stain along the cleavage planes, but some has been altered to chlorite and vermiculite (?). The biotite is strongly pleochroic from dark red-brown to light yellow or brownish yellow. Small prisms of quartz have grown perpendicularly to cleavage planes of biotite and has resulted in a bifurcating habit for the biotite (figures 20 and 21). This relationship is shown mostly in areas where alteration has been extensive. Hornblende is present in grains that are almost completely replaced by fibrous chlorite and as fresh grains that show no alteration. In the highly replaced areas the hornblende has completely gone to chlorite and carbonate. Fine-grained chlorite and sericite as well as cross-cutting veins of the minerals are present in the plagioclase.

In the darker bands, the feldspars are highly perthitic (figure 23). Orthoclase, plagioclase, biotite, and hornblende are the main constituents of these bands. The orthoclase contains exsolved plagioclase that is extremely variable in amount and shape of the grain. Quartz, in addition to the occurrence in the biotite, also occurs as large elongate grains that give the appearance of bands that are also closely associated with alteration and replacement products such as chlorite, hematite, and carbonates.

As depth of the core increases, the differences in grain size of different bands disappear and the foliation is dependent upon the compositional bands and the parallelism of the books of biotite. Quartz becomes more abundant with depth and forms mostly large irregular to
Figure 20. - Photomicrograph of gneiss from the U.S. Steel Wall showing biotite grains with small prisms of quartz growing in between, and perpendicular to, cleavage planes. (Crossed nicols, X 30)

Figure 21. - Photomicrograph of biotite grain from U.S. Steel Wall that shows the same relationship as that in figure 20. (Crossed nicols, X 75.6)
Figure 22. - Photomicrograph of untwinned plagioclase grain, from the gneiss of the U.S. Steel Well, that shows stringlets of adularia (dark gray) crossing the grain. (Crossed nicols, X 75.6)

Figure 23. - Photomicrograph of strongly perthitic orthoclase from the less-extensively replaced part of the gneiss near the bottom of the U.S. Steel Well. (Crossed nicols, X 75.6)
Figure 24. - Photomicrograph showing perthite from lower portions of the gneiss of the U.S. Steel Well. (Crossed nicols, X 30)

Figure 25. - Photomicrograph of plagioclase grain from gneiss of the lower portion of U.S. Steel Well. The sharpness of the twins indicates less replacement by adularia than is present higher in the well. (Crossed nicols, X 75.6)
slightly elongate grains that interlock with the plagioclase and perthite. The compositional bands that become more sharply defined at these lower depths are distinguished by the presence of biotite and fresh hornblende in bands as thin as 1.5 cm set in very broad bands that are largely free of these dark minerals and are rich in quartz. Where small "clumps" of biotite and hornblende occur in these broad bands, the hornblende has been replaced by intergrown fine-grained anhedral grains of quartz, chlorite, carbonate, and minor hematite. The vermiculite (?) shows birefringence as much as 0.024, is strongly pleochroic from a deep blue-green to a lighter olive green, has a low negative optical angle, and shows what is typically called "bird's eye extinction".

The rock in this core probably resulted from medium-grade metamorphism of sedimentary rocks, which would account for the thick compositional bands; it possibly represents the metamorphism of an acidic igneous rock that contained dark schleiren. The upward increase in the amount of adularia in the Precambrian rock of this well is clearly displayed. In the top part of the Precambrian almost all the plagioclase has been replaced by adularia; the amount of replacement gradually changes in the second interval, where there is relatively more plagioclase/less adularia; a few grains of plagioclase show distinct polysynthetic twinning. The lower parts of the core show replacement only along twin planes and grain boundaries, with most grains of plagioclase showing very sharp, distinct twinning.
EMPIRE REEVES WELL

The Empire Reeves Well in Madison Township of Richland County was drilled into the top of the Precambrian. One small section of Precambrian core was obtained, the exact depth of which is not known. Since drilling ceased near the top of the Precambrian, at a depth of 5085 feet, (Ohio Geological Survey, well card), it is likely that the sample came from this depth.

Megascopic description - This core is from an orange-pink inequigranular massive "granite" composed of a fine-grained salmon-colored feldspar matrix enclosing large grains of quartz, plus a trace of biotite. The quartz grains are light smoky gray, very angular, and range in size from 0.1 mm to 13.0 mm. All are highly fractured and give the appearance of having been "pulled apart". The rock contains a small number of irregularly-shaped cavities, most of which are associated with books of biotite. Biotite occurs in books, ranges up to 5.0 mm in size, and is the most abundant mica present; small amounts of muscovite do occur.

Microscopic description - A thin section of the "granite" shows quartz, microcline, biotite, muscovite, chlorite, sericite, adularia as fine-grained aggregates replacing microcline and quartz, and accessories of apatite, zircon, and limonite.

The quartz, which makes up 15-20 percent of the rock, occurs as very large angular fragments and has been extensively replaced by adularia along fractures. Strain of the quartz is indicated by its undulatory extinction (figure 27).
Figure 26. - Photomicrograph of typical interference figure obtained on a grain of adularia from the U.S. Steel well. The interference figure shows a very low 2V (less than 5°) and is of the SE quadrant. (CROSSED NICOLS, X 787.5)

Figure 27. - Photomicrograph of "granite" from Empire-Reeves well showing large angular grains of quartz in a fine-grained groundmass of adularia. The quartz has strongly undulose extinction and has been replaced along fractures by adularia. (CROSSED NICOLS, X 30)
Some microcline grains show tartan twinning. Most are very irregular, angular to subangular, and occur isolated by the fine-grained potassium feldspar groundmass. The microcline grains range in size from 0.5-2.5 mm, and comprise less than 1 percent of the rock. Most of the large grains have corroded boundaries.

Adularia is present as fine-grained aggregates and as individual euclidean to subhedral grains. The most frequent occurrence of the euclidean grains, which are approximately 0.025 mm in size, is as a lining of very small cavities. Most of the fine-grained fraction of this rock is adularia and represents a nearly complete adularization of the feldspar of the original coarse-grained granite. Although recognized as adularia by the low birefringence and extremely low index, no interference figures could be obtained because of the extremely fine-grain size. Figure 28 shows the fine-grained groundmass of adularia.

The biotite occurs as relatively large irregular books, and comprises less than 1 percent of the "granite". Small anhedral equant grains of leucoxene interspersed in the biotite resulted from the alteration of the biotite. Leucoxene is also dispersed through the matrix, and by its abundance suggests a source in addition to, or in place of, the biotite.

Only minor amounts of muscovite and sericite occur, and are both associated with accessory chlorite.

The rock sample from the Empire Reeves Well is undoubtedly highly altered. The abundant quartz plus the very scarce grains of microcline and biotite represent unreplaced remnants of the original rock. Although
it is not possible to be positive about the original mineralogy, these remnants seem to indicate that the composition was that of an acidic igneous rock and would probably fall within the granite range.
Figure 28. - Photomicrograph of the fine-grained groundmass of the "granite" from the Empire-Reeves Well showing small blocky euhedral crystals of adularia that project into small cavities. The cavities appear as light gray areas due to the weak birefringence of the mounting medium (epoxy). (Crossed nicols, X 75.6)

Figure 29. - Photomicrograph of gneissic monzonite from Ohio Liquid Disposal Well showing weak foliation produced by the quartz grains (very light gray grains in NE quadrant). Plagioclase is abundant. (Crossed nicols, X 30)
THE OHIO LIQUID DISPOSAL WELL

The Ohio Liquid Disposal Well was drilled in Riley Township of Sandusky County. Approximately 1 foot of Precambrian, which was penetrated at a depth of 2933 feet, was cored. Mr. John D. Starn (See Acknowledgements) provided a small piece of core for study and also provided the statistics on the well.

**Megasopic description** - The Precambrian rock in this well is a dark reddish brown fine- to medium-grained equigranular rock composed of potassium feldspar, plagioclase, quartz, and biotite. A well-defined foliation is produced by the sub-parallel orientation of the biotite flakes. The quartz and feldspar grains are slightly flattened in a plane parallel to the cleavage flakes of biotite, which adds to foliation.

**Microscopic description** - A thin section of this rock reveals an allotriomorphic equigranular texture shown by quartz, microcline, plagioclase, and biotite, with accessory magnetite and/or ilmenite, leucoxene, hematite, zircon, and apatite (figure 29).

Approximately 35 percent of the rock is microcline, most grains of which show excellent tarten twinning. The microcline is anhedral and as large as 2.5 mm, but averages approximately 1.0 mm in diameter. Most of the grains have a length : width ratio of about 3 : 1, but the ratio ranges from 1 : 1 to 5 : 1. The microcline is relatively fresh, showing only a small amount of alteration along twin planes. A few grains of the microcline show perthitic texture; in these plagioclase forms very small thin stringers.
Oligoclase comprises approximately 30 percent of the rock and occurs as irregularly-shaped slightly elongate anhedral grains averaging approximately 1.0 mm in diameter. Most of the oligoclase shows excellent polysynthetic twinning and minor alteration to sericite. Quartz makes up approximately 30 percent of the rock and occurs as slightly elongate grains that show undulatory extinction. Biotite comprises less than 5 percent of the rock and occurs in grains mostly between 0.5 mm and 1.0 mm long and about 0.25 mm wide.

Accessories of magnetite or ilmenite, leucoxene, apatite, and zircon together comprise less than 1 percent of the gneiss.

Hematite occurs as a stain that is most prominent along grain boundaries and twin planes in both the oligoclase and the microcline. Sericite is closely associated with the hematite but occurs only in small amounts.

The foliation of the rock may have been produced by metamorphism, but is more likely a result of syntectonic intrusion of magma, based on the appearance of grain contacts, which are not overly sutured, the paucity of compositional banding, and the lack of granulation along grain boundaries.

The rock is most probably a gneissic quartz monzonite.
### TABLE 5

PERCENTAGES OF MINERALS IN THE GNEISSIC QUARTZ MONZONITE OF THE OHIO LIQUID DISPOSAL WELL

<table>
<thead>
<tr>
<th>Mineral</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quartz</td>
<td>31.9%</td>
</tr>
<tr>
<td>Microcline</td>
<td>34.1%</td>
</tr>
<tr>
<td>Plagioclase</td>
<td>27.4%</td>
</tr>
<tr>
<td>Biotite</td>
<td>4.8%</td>
</tr>
<tr>
<td>Accessories</td>
<td>0.5%</td>
</tr>
<tr>
<td>Perthite</td>
<td>1.3%</td>
</tr>
</tbody>
</table>
RHOA WELL

The Rhoa Well in Trumbull Township of Ashtabula County was drilled a reported 10 feet into the Precambrian (Owens, 1967). Samples, which were collected at 10-foot intervals, were obtained for the interval 6720–6750 feet. The contact between Cambrian and Precambrian was marked by the appearance of granite in the sample from the interval 6740–6750 feet.

The granite is a salmon-colored medium-grained equigranular rock composed predominantly of potassium feldspar, quartz, and plagioclase, with minor amounts of biotite and chlorite. A hypidiomorphic-interlocking fabric prevails.

The potassium feldspar grains are mostly anhedral, irregular, and are as large as 3.5 mm in diameter. Under a petrographic microscope, the potassium feldspar displays good tartan twinning, indicating microcline. The plagioclase, unless fractured, occurs as very clear glassy irregular anhedral to subhedral grains, ranging in size from 1.0 to 2.5 mm, that interlock with pink potassium feldspar grains. Quartz is also clear and glassy, and occurs in anhedral grains.

Biotite is present as irregularly-shaped books mostly less than 0.1 mm thick, but a few are as thick as 0.5 mm. Diameters of these books range from 0.1 mm to 1.0 mm. The books show no common orientation and are commonly embedded in the microcline. Biotite comprises approximately 1 percent of the rock.
Chlorite may comprise as much as 20 percent of certain individual rock chips. Microscopically, it is dark green and shows a very granular texture. It seems to be closely associated with quartz, although not exclusively so.

**BRAYMAN WELL**

The Brayman Well in Pierpont Township of Ashtabula County penetrated only one foot of Precambrian (Owens, 1967). Samples were collected at 10-foot intervals, except for the last interval, which represents 16 feet (6900-6916 feet). However, if the content of the samples is used as the only criterion for picking the top of the Precambrian, a penetration of as much as 16 feet cannot be ruled out.

The Precambrian cuttings are composed of two types of lithic fragments. One type is salmon-pink, medium-grained, and is composed of potassium feldspar, quartz, magnetite, and chlorite. These chips are much fewer in number than the second type of lithic fragments, and comprise no more than 5 percent of the total Precambrian chips. The feldspar is probably adularia as evidenced by the low 2V of the mineral.

Most of the chips of the well are amphibolite composed of clear glassy plagioclase \((Ab_85An_{15})\), or rarely translucent red due to hematite stain, biotite, quartz, and hornblende as slightly prismatic cleavage fragments as much as 1.5 mm long. The ferromagnesians constitute 10 to 15 percent of the lithic fragments. Biotite comprises at least one
half of the ferromagnesians and occurs in fresh black subhedral flakes as much as 1.5 mm in thickness and 1.0 mm in diameter. A good foliation is indicated by the subparallel orientation of these flakes as well as by the subalignment of the hornblende grains.

The adularia-rich chips probably represent the upper altered and replaced portion of the amphibolite, which is likely fresh at depth.

**KrysiK-Wakefield Well**

The KrysiK-Wakefield Well in Florence Township of Erie County penetrated a reported 8 feet of Precambrian quartz monzonite (Owens, 1967). This well was sampled at 10-foot intervals except the lowest sample, which represents the bottom 3 feet of the hole. The rock is grayish pink, medium-grained, equigranular, and is composed of potassium feldspar, plagioclase, quartz, chlorite, biotite, and traces of hematite, pyrrhotite, and magnetite.

The potassium feldspar is mostly salmon-pink, anhedral, and soft, indicating it has been altered. Under high magnification of the petrographic microscope, the grains of potassium feldspar show inclusions of sericite, and a few show microcline tartan twinning. The plagioclase is clear to frosty white, subhedral, and some grains display excellent polysynthetic twins. The plagioclase is interlocked with grains of quartz and microcline, and it commonly encloses biotite grains. Quartz is clear, glassy, and occurs as anhedral grains. Chlorite occurs in the
chips as segregations of fine-grained aggregates. Occasional distinct single grains have hematite pseudomorphs after biotite associated with them. Biotite is present both as fresh subhedral books in the plagioclase and as anhedral grains that have been replaced by hematite; the latter form usually occurs in the chlorite. Many of the grains associated with the potassium feldspar appear "bleached" and have been altered to muscovite or chlorite. Traces of hematite are found as a stain, as pseudomorphs after biotite, and as specular hematite. The latter form is the most rare. Other minerals occurring in trace amounts are pyrrhotite and magnetite.

WOOD WELL

The Wood Well in Franklin Township of Jackson County was drilled a reported 102 feet into the Precambrian (Owens, 1967). Samples, which were collected at 5-foot intervals, were obtained for study for the interval 6200-6320 feet.

The highest Precambrian chips occur in the 6210-6215-foot interval and are lithic fragments of a dark green fine-grained chlorite-rich rock similar to those that are commonly associated with altered plutonic rocks in other wells. The chips are composed of fine-grained chlorite and books of biotite as much as 3.0 mm in diameter that are partially or wholly replaced by hematite. Small chips of potassium feldspar with minor plagioclase become more abundant in the following interval,
indicating that all of the chips from this interval are probably from
the weathered zone of the basement rocks. The character of these two
types of chips remains essentially unchanged to a depth of 6230 feet.

The sample from the depth 6230-6235 feet is composed almost
entirely of clear glassy plagioclase (Ab45An55), hornblende, chlorite,
biotite, and magnetite. The chips are largely monomineralic; this,
according to McCormick (1961, p. 49), indicates that the parent rock
was relatively coarse-grained. Hornblende comprises approximately 10
percent of the sample at this depth and occurs as fresh greenish black
grains that show excellent cleavage. Biotite comprises 2 to 3 percent
of the sample and occurs as small books that appear fresh. The
chlorite, 2 to 3 percent of the sample, occurs in books as large as
2.0 mm in diameter and apparently represents complete chloritization
of some of the biotite. Accessories include pyrite and subhedral
octahedra of magnetite. The parent rock of these chips is perhaps a
labradorite-rich gneiss or anorthosite.

The following sample (6235-6240 feet) contains very abundant
hornblende, biotite, and chlorite. The chlorite is abundant in this
one sample only, and hornblende and biotite become the dominant dark
minerals in the interval 6240-6295 feet. In this latter section, the
hornblende : biotite ratio is approximately 4 : 1, quartz is present,
but has an abundance less than 5 percent, and plagioclase comprises
approximately 20 percent of the chips. Pink garnets occur as an
accessory. These chips most likely are from an amphibolite.
A medium- to coarse-grained plagioclase gneiss or anorthosite reappears in the samples between 6290-6295 feet and is nearly identical to the 6230-6235-foot sample. Chips with this character are present to the bottom of the well.

SLAVENS WELL

The Slavens Well in Hamilton Township of Jackson County penetrated a reported 106 feet of Precambrian (Owens, 1967). Samples, which were collected at 10-foot intervals, were obtained for the range 5560-5681 feet.

Chips from a rock rich in plagioclase (Ab$_{52}$An$_{48}$) and biotite appear in the cuttings from the 5570-5580-foot interval. These chips are mainly composed of colorless to reddish andesine plus minor amounts of quartz, chlorite, and biotite. Potassium feldspar comprises approximately 20 percent of the total feldspar in this interval, but within two samples, plagioclase and biotite become dominant and the potassium feldspar and chlorite have disappeared. The reddish hue of the andesine also gradually disappears downward until it becomes nearly transparent. In addition, good cleavage is exhibited by andesine, but polysynthetic twinning is very scarce.

Very small subhedral grains of hornblende appear below 5675 feet and replace the biotite in importance in the bottom sample (5681 feet).

This rock is probably metamorphic for it exhibits foliation of the biotite and hornblende, and platiness of the plagioclase, and is termed an andesine-biotite gneiss.
The Bailey Well in Jefferson Township of Adams County is very similar to the Covert Well, also in Adams County. In both wells, the samples are of poor quality because of their small size and monomineralic character. The sampling interval varied from 2 to 10 feet; samples were obtained for the section from 3730-3760 feet, and 3774-3790 feet. (The samples for 3760-3774 are missing.) The Bailey Well penetrated a reported 50 feet of Precambrian (Owens, 1967). However, in the present study, cuttings from definite Precambrian rock were not observed above the interval 3774-3776 feet, making the total Precambrian penetration at least 14 feet and possibly no more than 30 feet, if all of the missing samples were Precambrian.

A dark reddish pink medium-grained equigranular quartz monzonite appears in the 3774-3776 interval and is present to the bottom of the well. The most distinctive feature of the rock is a dark hematitic stain that is present in both plagioclase (Ab95An5) and potassium feldspar. This stain results in the extremely dark appearance of the grains when mounted in oil and viewed under the petrographic microscope. Also present in the chips, in addition to the feldspars, are quartz, chlorite, biotite, hornblende, and magnetite, with the abundance of hornblende greatly increasing downward.
COVERT WELL

The Covert Well in Jefferson Township is one of two wells presently penetrating the Precambrian in Adams County. Total penetration was reported by Owans (1967) to be 57 feet. Samples were collected at 10-foot intervals, and those for the interval 3760-3830 feet were obtained for study.

Most of the chips in this well are small and monomineralic, and it is therefore not possible to determine if any structure is present in the rock. The following minerals are listed in their order of decreasing abundance in the sample: potassium feldspar, quartz, plagioclase, magnetite, and biotite. The rock represented could be granite, based solely on minerals present.

In addition to the granite fragments, a small number of lithic fragments are composed of grayish white plagioclase, quartz, and biotite and show an interlocking fabric. The scarcity plus the diverse mineralogy and texture of these chips suggest that they probably originated from a pegmatite within the granite body.

HOCKMAN WELL

The Hockman Well in Starr Township of Hocking County penetrated a reported 26 feet of Precambrian granite (Owens, 1967). Samples were taken from the cuttings at 5-foot intervals, and these were separated by the driller into coarse and fine fractions by sieving. Granite chips are almost absent from the coarse fractions, which contains chips
of Cambrian sedimentary rock with diameters averaging approximately 1.0 cm, and are greatly concentrated in the fine fraction. This is perhaps due to the brittleness of the granite relative to that of the sedimentary rocks and its greater susceptibility to granulation by a "hard rock" drill bit. This process could perhaps explain the absence of igneous chips from some of the wells where only coarse cuttings were sampled.

The granite is reddish pink, fine- to medium-grained, and contains potassium feldspar, plagioclase, and quartz with accessories of hematite, pyrite, magnetite, and chlorite. Most of the magnetite occurs in octahedra; however, both anhedral and subhedral grains are present.

ULLMAN WELL

The deepest well in Ohio to date, the Ullman Well, is in Elk Township of Noble County. Its total depth is 11,442 feet and it reportedly penetrated 27 feet of Precambrian (Owens, 1967). Samples were collected at 5-foot intervals; the cuttings from the interval 11,405-11,442 feet were obtained for study.

Precambrian chips appear highest in the well in the interval 11,415-11,420 feet; most of these chips are of orange- to red-pink potassium feldspar, plagioclase (Ab_{65}An_{35}), and quartz, with abundant pseudomorphs of hematite after biotite and minor amounts of chlorite and magnetite. In the next lower sample, at 11,420-11,425 feet, these chips are negligible as a component of the Precambrian cuttings and they do not recur deeper in the well.
Also present in the 11,415-11,420-foot interval are some chips of a reddish black medium-grained equigranular amphibolite composed primarily of clear to reddish subhedral andesine, subhedral fragments of black hornblende, and biotite that is either fresh or slightly chloritized. Trace amounts of pink garnet and platy quartz are also present. The hornblende to biotite ratio is small at this depth, but increases with depth in the well until the hornblende is the dominant ferromagnesian. The amphibolite is present continuously from the top Precambrian sample to the bottom of the well. The light pinkish color of the plagioclase near the top of the Precambrian gradually disappears downward until it is almost absent near the well bottom, which suggests that the pink color near the top is a result of near surface weathering. The lighter potassium feldspar-chlorite-rich chips probably resulted from the near surface weathering of the amphibolite.

LEE WELL

The Lee Well in Jefferson Township of Coshocton County was reportedly drilled 23 feet into the Precambrian (Ohio Geological Survey, well card), here represented by a pink medium-grained equigranular quartz monzonite that has a hypidiomorphic-interlocking fabric. This rock is composed of plagioclase, microcline, and quartz, and is characterized by a very small amount of dark minerals. Accessories include garnet, pyrite, magnetite, and chlorite. Oligoclase comprises as much as 85 percent of the rock.
The Drake Well in Wayne Township of Wayne County penetrated a reported 197 feet of Precambrian (Owens, 1967). Samples were collected at 10-foot intervals and those obtained for study are from the interval 6700-6897 feet. The highest Precambrian samples are largely of monomineralic chips of highly sericitized plagioclase (Ab66An14) and occur in the 6710-6720-foot sample; these are white, or reddish pink owing to minute inclusions of hematite, are medium-grained, and equigranular. Also associated are accessory amounts of chlorite and pyrite. Other intervals in which these monomineralic chips are present in abundance are 6720-6730, 6770-6790, and 6830-6880 feet. The cuttings from the Precambrian in this well are very poor because they contain large and abundant fragments of Paleozoic sedimentary rocks. As postulated in the discussion of the Hocking Well, it is possible that the Precambrian igneous fraction passed off with the fines during collection. Therefore, its absence from certain samples may not necessarily indicate the absence of igneous rocks in the basement at a corresponding depth.

Lithic fragments of black to gray medium-grained equigranular amphibolite composed of clear glassy plagioclase, hornblende, and minor biotite is present from 6730 feet to the bottom of the well. Its character is constant throughout the well, except for those intervals noted above in which large monomineralic chips of slightly to highly sericitized and hematized oligoclase is present.
STEINER WELL

The Steiner Well in Chippewa Township of Wayne County penetrated 19 feet of Precambrian, according to Owens (1967). The sampling interval was not constant and ranged from 6 to 19 feet. The intervals 6890-6900 and 6904-6919 feet were obtained for study (6900-6904 feet is missing). A Precambrian feldspar-quartz-biotite gneiss appeared in the 6904-6910-foot sample, and is a light gray-white medium-grained equigranular rock composed predominately of plagioclase (Ab100-Ab90), quartz, and biotite, with small amounts of potassium feldspar. Chlorite, pyrite, and garnet are present as accessories.

The albite occurs as clear glassy subhedral grains that surround small sub-parallel flakes of fresh biotite. The quartz occurs as large glassy platy fragments, many of which contain biotite with a parallel orientation. Potassium feldspar is relatively scarce; where present it is light brown-pink and generally associated with biotite and quartz.

The strained quartz plus the platiness of the quartz and plagioclase as well as the parallel orientation of some of the biotite flakes indicate that the rock is probably metamorphic, and the garnet indicates a rather high grade.

SCOTT WELL

The Scott Well in Washington Township of Richland County penetrated a reported 20 feet of Precambrian (Owens, 1967). Samples, which were collected at 5-foot intervals, were obtained for study for the interval
5480-5503 feet. No Precambrian chips were found above the 5490-5495-foot interval. Therefore, if the top of the Precambrian is in this interval, the well penetrated no more than 13 feet of these rocks.

The highest feldspar grains are in the 5490-5495-foot interval, and because there is little or no coarse-grained arkose overlying the Precambrian in this well, this interval is considered to contain the top of the Precambrian. The Precambrian chips appear to be of a salmon-pink medium-grained equigranular granite composed of salmon-pink potassium feldspar, slightly pinkish to clear plagioclase, quartz, and biotite showing small segregations of hematite between its cleavage planes, plus lesser amounts of hornblende, chlorite, and accessory pyrite. Some of the chips are as much as 4.0 mm in diameter. The biotite, which is mostly black and fresh, appears to impart a weak foliation to the rock because of the sub-parallel orientation of the books of biotite.

HUDDLESTON WELL

The Huddleston Well in Hilliar Township of Knox County was drilled 27 feet into the Precambrian, as reported by Owens (1967). Samples, which were taken at 10-foot intervals, were obtained for the interval 4760-4807 feet.

Megascopic description - The cuttings from the Huddleston Well are of such a large size that it was possible to make thin sections of three dominant types of chips.

The most abundant chips are of a pale pink medium- to coarse-grained
equigranular rock composed mostly of potassium feldspar, quartz, and biotite, with minor plagioclase, accessory magnetite, chlorite, and garnet, and traces of chalcopyrite. The microcline and quartz are present in lithic fragments composed of grains as much as 10 mm in diameter. This rock is moderately foliated as a result of the parallel arrangement of the biotite flakes.

The second most abundant type of chip is greenish black, medium-grained, mesocratic, and is composed of plagioclase feldspar (Ab35An15), hornblende, biotite, and chlorite with traces of hematite. The hornblende and biotite grains commonly occur as parallel intergrowths, both of these in turn being randomly intergrown with the plagioclase, giving the rock a massive appearance. A greenish hue is imparted to the rock by the greenish black hornblende.

The above-described chips appear relatively fresh. However, chips of chloritized amphibolite are also present in the cuttings. Some of these chips are apple green with small grains of salmon-pink feldspar, whereas others are a dark blackish green. Textures and fabrics of these chips are similar to those of the fresh amphibolite.

**Microscopic description** - A thin section was made from a large lithic fragment of the most abundant type as described above, from the 4880-4890-foot interval. The chip is of a medium-grained allotriomorphic equigranular leucocratic rock that is composed of microcline, quartz, plagioclase, biotite, garnet, apatite, zircon, magnetite, ilmenite, and hematite.

Microcline, which comprises 55-60 percent of the rock, is unaltered, shows good tartan twinning, and occurs in grains most of which range in
size from 0.5 to 1.5 mm.

Quartz occurs in very irregular grains that range from subequant to platy (or prismatic—the difference cannot be detected in thin section). The ratio of the length to the width in some of these grains is as much as 10 to 3. Approximately 20 percent of the rock is composed of quartz. Plagioclase, which comprises 10-15 percent of the rock, is present as grains that are very irregular in outline, and shows much sericitization. Only a few grains show polysynthetic twinning, and in most of these it is obscure. Sericitization may be used to distinguish plagioclase from microcline. Biotite occurs in small grains comprising less than 5 percent of the rock and adds to foliation. Apatite comprises less than 1 percent of the rock and is mostly in small equant anhedral grains. Other accessories include garnet, zircon, single grains of intergrown magnetite and hematite, and single grains of ilmenite and leucoxene. Hematite also occurs as a stain around grain boundaries and along twin planes in some of the feldspars.

These chips are very similar to the rock from the Ohio Liquid Disposal Well of Sandusky County, from which a core of a gneissic quartz monzonite was obtained.

A thin section of a hornblende-rich chip, from a depth of 4800-4810 feet, shows a medium-grained alliotriomorphic inequigranular mesocratic rock. It is composed of hornblende, quartz, plagioclase, microcline, biotite, opaques (magnetite and/or ilmenite), and apatite (figure 31).

The hornblende occurs as anhedral grains that average 1.0 to 1.5 mm in length but are as large as 2.5 mm and comprises about 45 percent of
Figure 30. - Photomicrograph of granite gneiss from Huffman Well showing a large grain of hornblende (dark gray in lower two-thirds of photograph) that has been replaced by chlorite along fractures. (Crossed nicols, X 200)

Figure 31. - Photomicrograph of granite gneiss from the Huffman Well showing a chip with a massive texture that is composed of quartz (very light gray), hornblende (medium gray to black), and plagioclase (bottom center). (Crossed nicols, X 30)
the chip. The hornblende has been partly replaced by chlorite and talc along many cleavage planes. The width of the alteration along these planes is seldom greater than 0.05 mm. A few grains of hornblende have been partly replaced by carbonate; this carbonate occurs in elongated lenses that parallel the cleavage traces.

Most of the biotite occurs as small anhedral grains, some of which show long thin stringers of magnetite and hematite along cleavage traces. A minor amount of the biotite occurs as intergrowths with hornblende. In these grains the cleavage traces of the biotite are parallel to those of hornblende. Biotite comprises less than 2 percent of the chip.

Plagioclase (Ab88An12), which comprises about 30 percent of the chip, shows only faint polysynthetic twins in a few grains, and no twinning in most. The microcline makes up approximately 10 percent of the chip and only very rarely shows tartan twinning. A few small grains show a vermicular intergrowth of plagioclase and quartz.

Very irregular small (0.25-0.5 mm) anhedral grains of quartz with undulatory extinction constitute approximately 10 percent of the chip. This small grain size, plus the very irregular grain boundaries suggests that the quartz crystallized last and merely filled in small interstices.

Accessories of apatite, hematite, and magnetite and/or ilmenite are present but comprise less than 3 percent of the chips.

Several thin sections of a "chloritized amphibolite from 4880-4890 feet" show a texture and fabric very comparable to the texture and fabric of the unaltered amphibolite. This altered rock is composed of chlorite, plagioclase, potassium feldspar, quartz, talc, biotite, carbonate,
apatite, magnetite and/or ilmenite, leucoxene, and hematite.

Talc and chlorite have partially or completely replaced the hornblende, and appear as fine-grained intergrowths in thin section. The talc occurs as irregularly-shaped patches of randomly intergrown minute flakes or as elongate flakes that show a subparallel orientation. The orientation of the original hornblende grain is thought to have controlled the direction of growth of these latter grains, i.e. these talc grains likely originated along cleavage planes of the hornblende. Chlorite is pleochroic from yellowish green to light blue-green (figure 30).

The plagioclase has been replaced, to varying degrees, by adularia. Some grains are almost completely replaced; these are recognized, when viewed between crossed nicols, as dark gray to black patches in the plagioclase grains, or when viewed in plane polarized light as slightly pinkish areas of low relief. In other grains, the adularia occurs as thin parallel plates that outline the twin planes; these plates are also visible in plane polarized light.

In a few places, calcite (or dolomite) replaces plagioclase. It occurs as massive irregular patches that only rarely show traces of rhombohedral cleavage.

Some minerals appear not to be altered, or altered to a much lesser degree than those described above. Among these are quartz, biotite, apatite, magnetite, and/or ilmenite.

At least four possibilities exist that explain the close association of three distinct lithologic types in the cuttings: 1) An igneous rock (e.g. a granite) contains inclusions of the rock through which it passed
(amphibolite) during emplacement. These were subsequently altered (hydrothermally or deuterically) to produce local chloritized areas within the granite body. 2) The drill hole crossed the contact between an igneous rock and a more basic country rock that has been deuterically or hydrothermally altered. 3) The light and dark chips represent a coarse-grained igneous rock that has abundant hornblende-rich segregations. 4) The country rock is actually a relatively high grade metamorphic rock (i.e. a granite gneiss) that is coarse-grained and compositionally banded, such that the quartz and feldspar occur in some distinct bands, and the ferromagnesians occur in other bands.

The latter interpretation is favored because of: (a) the presence in dark chips of quartz and feldspar that are very similar to that of the granitic chips, i.e. the polysynthetic twinning of the feldspar is mostly faint and obscure, which generally indicates a metamorphic origin, (b) the abundant occurrence of the large grains of apatite in both kinds of chips, and (c) the presence in the U.S. Steel Well of a foliated very broadly-banded gneissic rock that could be similar to the rock in this well. This would account for the variation in mineralogical composition and degree of foliation from chip to chip.

LARIMORE WELL

The Larimore Well in Milford Township of Knox County penetrated a reported 21 feet of Precambrian (Owens, 1967). However, lithic fragments of granite are present at least 15 feet above the depth where it was reported. The samples were taken at 5-foot intervals and show a
total Precambrian penetration in excess of 30 feet. The samples for the interval 5325-5370 feet were obtained for study. Because of the presence of an overlying arkose, the determination of an exact top is difficult.

The chips in the Larimore Well can be divided into two types, each having its own set of physical characters. Those chips in the interval 5325-5360 feet are pale yellowish pink medium-grained syenite that contains abundant hematized and chloritized biotite. The rock is predominately potassium feldspar and sericite. Evidence of alteration of the rock is present not only in the altered biotite, but also in the pale, bleached appearance of the feldspar and in its relative softness.

The interval 5360-5370 feet shows an abrupt change in the character of the syenite. In this portion of the well, the potassium feldspar is a deeper reddish pink, and plagioclase appears, some of which exhibits polysynthetic twinning. Although the biotite is altered, the degree of alteration is not as great. Chlorite occurs as dark green aphanitic aggregates that may pseudomorphically replace hornblende. The textures of the two rocks are nearly identical, indicating that the upper chips are a more highly weathered "cap" of the lower material, which may represent an altered amphibolite. This cannot be proven, however, because the penetration of the well was too shallow.

ROBERTS WELL

The Roberts Well in Hartford Township of Licking County was drilled approximately 3.75 miles from the Huffman Well of Knox County. The two wells have very similar lithologies. In the Roberts Well, a granite was
penetrated in the 4910-4915-foot interval. However, because the Precambrian
is here overlain by a Cambrian arkose, exact determination of the top of
the granite is difficult. Owens (1967) reported 42 feet of Precambrian
in this well; samples were collected at 5-foot intervals.

The granite is salmon-pink, medium-grained, and is composed of
potassium and plagioclase feldspar, quartz, and only traces of chlorite,
biotite, and magnetite. The quartz and feldspars occur as intergrowths.
The biotite is largely altered to green chlorite and occurs as anhedral
books; chlorite also occurs as very fine-grained aggregates. Magnetite
is present in trace amounts, a few grains of which are small octahedra.
The granite is perhaps most distinctive in its very small amount of dark
minerals.

CROWLEY WELL

The Crowley Well in Mary Ann Township of Licking County penetrated
a reported 13 feet of Precambrian gneissic granite (Owens, 1967). Samples
were taken at 5-foot intervals and were obtained for the range 5970-5990
feet. The highest feldspar grains occur in the 5975-5980-foot sample.
The gneiss is light orange-pink, medium-grained, and is composed of clear
glassy plagioclase, pink potassium feldspar, very clear vitreous quartz,
and accessory chlorite, biotite, magnetite, and hornblende. Much of the
biotite has been chloritized, with some of the biotite remnants replaced
by hematite. Magnetite occurs in euhedral to subhedral grains usually
less than 0.5 mm in diameter.

The platiness of many of the individual chips, especially those
composed predominately of quartz, indicated a foliation—therefore the
descriptive term "gneissic" is used.

**SCHINELZER WELL**

The Schinelzer Well in Lima Township of Licking County penetrated
a reported 17 feet of Precambrian (Owens, 1967). Samples were collected
at 10-foot intervals and were obtained for study between 4770 and 4802
feet.

A few grains of chloritized hornblende and of plagioclase, plus
fragments of fine-grained chlorite are present in the 4780-4790-foot
sample. The scarcity of these suggests that the top of the Precambrian
surface is in the lower part of this interval.

In the next lower interval, 4790-4800 feet, intergrown hornblende
and plagioclase (Ab69An31) become abundant, and comprise the majority
of the Precambrian chips down to the bottom of the well. Most of the
hornblende has undergone slight chloritization and comprises approximately
25 percent of the rock, whereas most of the plagioclase has been replaced
by potassium feldspar and sericitized. An amphibolite is likely the
parent rock of these chips.

A much smaller percentage of chips are of a potassium feldspar-rich
rock that shows variable foliation from very good to very poor. In these,
quartz, minor plagioclase, and chlorite are the components, and probably
represent chips that are from the weathered zone near the top of the
Precambrian.
Chlorite associated with hematized biotite occurs in green fine-grained lithic fragments that are relatively abundant throughout the Precambrian of the well. These are very similar to the lithic fragments of chlorite in the Precambrian of many of the other wells. In these wells, the lithic fragments were interpreted as localized areas of alteration within the parent rock, perhaps due to deuteritic or hydrothermal activity. The same interpretation is made here.

CROMAN WELL

The Croman Well was drilled in Jackson Township of Pickaway County and penetrated a reported 46 feet of Precambrian (Owens, 1967). Samples were collected at 5-foot intervals, and were obtained for study for the interval 3675-3730 feet.

An orange-pink medium-grained equigranular banded granitic gneiss is present at 3685 feet. Many of the chips have the bleached appearance that is thought to mark a weathered zone in other wells. These "weathered fragments" persist for only about 5 feet before redder fresher-appearing chips appear in the cuttings at about 3690 feet in depth. The weathered gneiss is made up of medium-grained potassium feldspar and blue-gray quartz. Some chips show thin streaky bands of quartz alternating with the feldspar. The banded nature is not as apparent in the weathered zone as it is at greater depths; it is thought that weathering around grain boundaries served to obliterate the banded nature of this gneiss.

Chips of the fresher variety of the granite gneiss are abundant at the 3690-foot level. This rock is darker red and has bands that have
sharper boundaries than the weathered rock. The bands are mostly thin layers of blue-gray quartz or fine-grained opaque set in a matrix of potassium feldspar or more rarely, actually alternate with equally thin bands of the potassium feldspar. The bands range in thickness from 0.1 mm, in most fragments, to 0.5 mm, in which case the bands are not uniform in thickness but thicken and thin laterally.

Scattered chips of a pegmatite are present throughout the well. These are recognized by the much coarser grain size of the quartz and microcline, which may be as large as 5 mm. In this pegmatite, bands may be present or absent.

MILLER WELL

The Miller Well was drilled in Pickaway Township of Pickaway County and penetrated a reported 31 feet of Precambrian (Owens, 1967). The sample-collection interval varied from 4 to 19 feet; samples were obtained for study from the interval 4103-4170 feet. A weathered granite that is pale pink to salmon-pink appeared in the samples at the 4137-4150-foot level; it is composed of potassium feldspar, quartz, biotite, plagioclase, and chlorite.

The potassium feldspar is present as both weathered and relatively fresh grains, although most grains are weathered. The weathered feldspar has unidentifiable fine-grained material around the interlocking grain boundaries, and has a "dusty" appearance when mounted in oils. Some grains are also highly sericitized. Only a few unaltered grains are present; most of these are colorless to slightly reddish (due to hematite
inclusions) and show no grid-twinning.

Quartz is present as small (0.1-0.5 mm) grains in chips that are mostly feldspar and as larger grains (to 3.0 mm) with numerous small included flakes of biotite. Biotite is present as small flakes that are highly chloritized, and in immersion oils it is dark green with black opaque inclusions (Fe-Ti oxides?). Chlorite is interleaved with biotite in some chips, and in others it occurs as fine-grained aggregates in lithic fragments that are a light "malachite-green" in color.

Although not recorded in the samples, a fresher granite is probably present at depth as in other wells. Total Precambrian penetration was only 31 feet; therefore the well could have bottomed in the weathered zone.

CLARK WELL

The Clark Well in Concord Township of Ross County penetrated 18 feet of Precambrian granite gneiss (Owens, 1967). Driller's samples, collected at 5-foot intervals, were examined for the interval 3840-3862 feet. The gneiss, which first appears in the 3845-3850-foot interval, is brownish salmon-pink, medium-grained, and contains plagioclase and potassium feldspar, quartz, green chloritized-biotite, hornblende, magnetite, and hematite. In this interval, the dark minerals comprise as much as 25 percent of many of the chips, the most abundant of which is chlorite. Chlorite occurs mostly as apple-green to dark-green fine-grained aggregates that enclose remnants of biotite grains; some of the biotite grains are pseudomorphically replaced by hematite. Small patches of aphanitic earthy hematite also occur in the chlorite. The biotite
occurs in subhedral to anhedral flakes, most less than 1.0 mm in diameter, and most of it is oriented so as to produce a good foliation. The majority of the potassium and plagioclase feldspars are intergrown. The chips of feldspar and quartz are platy, indicating that the parent rock is foliated.

No noticeable change occurs in the cuttings above the depth of 3862 feet. Below this depth the microcline becomes redder, more abundant (comprising as much as 50 percent of the rock), and less altered.

COURTNEY WELL

One of the most recently completed Precambrian wells in the state of Ohio is the Courtney Well in Fairfield Township of Highland County. This well, whose completion date was January, 1972, reportedly penetrated 5 feet of Precambrian (Ohio Geological Survey, well card). The sampling interval used by the driller ranged from 3 to 10 feet. For the purpose of study, samples representing 3547 to 3610 feet in depth were obtained.

Most of the chips from this well are monomineralic; a few are lithic fragments. The highest sample that contains feldspar (3573-3578 feet) could possibly be from an arkose. However, the presence of feldspar, quartz, and biotite that display interlocking grain boundaries indicates an igneous origin for those particular lithic fragments as no lithic fragments were directly observed in the arkose. The minerals present in their order of decreasing abundance include salmon-pink grains of microcline, transparent to translucent white plagioclase (Ab90An10), potassium feldspar, biotite that is fresh to slightly hematized, quartz, chlorite, hematite, magnetite, and limonite. The occurrence and abundance
of these minerals is fairly constant for the interval 3573-3602 feet. The remaining 8 feet of well cuttings are mostly clear plagioclase that shows fairly good cleavage and polysynthetic twinning, biotite of a variety fresher than that above, and minor quartz and hornblende. Limonite exists only as a stain in this lowest interval. The potassium feldspar that is so abundant throughout most of the well is probably adularia, because of its high sericite-hematite-chlorite content and low ZV; this indicates replacement of the upper portion of the original rock of either plagioclase or microcline. Some microcline occurs in the lower part of the well where the rock is less altered.

It is difficult to name this rock, simply because the lack of good lithic fragments prevents the determination of texture and structure of the rock. If the lower 8 feet approach the appearance and mineralogy of the parent rock before alteration, the rock could be a monzonite, assuming that it is a plutonic igneous rock.

HUME WELL

The Hume Well in Fairfield Township of Madison County penetrated a reported 17 feet of Precambrian (Owens, 1967). The samples that were studied were from the interval 3600-3631 feet.

A reddish pink medium- to coarse-grained equigranular granite is present in the 3610-3620-foot sample. It is composed of microcline, quartz, hornblende, and biotite, with lesser amounts of chlorite and hematite, plus accessory apatite.
The microcline is present mostly as reddish pink grains, but may rarely occur as grains that are colorless and translucent. Hematite stains much of microcline and is responsible for the reddish color. Grid twinning, as seen in grain mounts in index oils, is present but not common.

The quartz occurs as transparent anhedral grains that interlock with the microcline. Biotite is present as books or flakes mostly less than 0.5 mm in diameter. Chloritization of the biotite is common; some of the intergrown chlorite-biotite flakes display small aggregates of hematite on cleavage planes. Hornblende occurs as small subhedral grains, and is the major dark mineral near the bottom of the well. Apatite is detectable only microscopically and is present as small subhedral crystals in the quartz or microcline.

A few chips of a yellow-pink granite are present. This granite has been weathered--sericitization of the microcline is very common, and the biotite has been almost completely replaced by hematite. The platy cleavage of the biotite is rarely in evidence. These patches appear as the earthy variety of hematite, but when scraped with a needle, yield small remnant platy cleavage flakes.

ELCAMERE FARMS WELL

The Ecamere Farms Well in Harmony Township of Clark County reportedly penetrated 35 feet of Precambrian (Owens, 1967). Samples were collected from the following interval: 3510-3520, 3550-3560, and 3560-3580 feet. (Those samples from 3520-3550 feet are missing.)
The highest Precambrian chips are in the 3550-3560-foot sample and are of a dark greenish to reddish brown medium- to coarse-grained equigranular diorite that is composed of secondary (?) potassium feldspar, plagioclase, and chlorite, with lesser amounts of quartz, magnetite, hematite, and pyrite.

The plagioclase feldspar is very highly sericitized and appears as reddish pink grains, as large as 8.0 mm but average about 4.0 mm, that display good cleavage and polysynthetic twins. Because of the high degree of sericitization, the exact composition could not be determined, but it appeared to be somewhat less than An50. The chlorite occurs as large aphanitic masses and as pseudomorphs after biotite. These pseudomorphs are tabular and resemble the books of biotite in this rock. The plagioclase is mostly intergrown with the pseudomorphs or with the aphanitic masses of chlorite. Only a few grains of quartz are present; these are as large as 2.0 mm.

The Precambrian rock in this well appears to be diorite, which has been highly replaced near the Precambrian surface by potassium feldspar, and which yields chips very similar in color and composition to that of the upper portion of the U & Steel Well in Scioto County. The Eioamere Farms Well is approximately 5 miles south of the R & E. Brown Well, also in Clark County, in which a gabbro is present.
R. & E. BROWN WELL

The R. & E. Brown Well in Pleasant Township of Clark County penetrated between 14 and 24 feet of Precambrian gabbro. Samples were collected at 10-foot intervals and were obtained for the section between the depths of 3610 and 3644 feet. Two grain mounts were made (see introduction) of samples from the depths of 3620-3630 feet and 3640-3644 feet.

The gabbro is a dark greenish black fine-grained rock that is composed mostly of plagioclase (Ab$_{47}$-Ab$_{50}$) and augite (figure 32). Accessory biotite, chlorite, magnetite, quartz, apatite, and hematite are also present.

The plagioclase (labradorite) is translucent, greenish gray, and occurs in long laths that show good polysynthetic twins. The width of most of the laths is between 0.1 and 0.5 mm; the length is as much as 3.0 mm. The plagioclase grains are randomly intergrown with each other and with the augite and magnetite. The augite from the upper 20 feet of the Precambrian portion of the well shows extensive chloritization, but it becomes fresher as depth increases. The augite is present in grains as much as 0.9 mm in diameter, comprises 40 to 50 percent of many of the chips, and is a pinkish brown in plane-polarized light. Some augite grains have a rim of magnetite formed as a result of the oxidation of the ferrous ion. Hematite is present as a stain on the chlorite and augite, or more rarely as small aggregates between the cleavage planes of the few biotite flakes that are present. Apatite is present as very small subhedral to euhedral grains that are detectable only when chips are viewed in oil.
Figure 32. - Photomicrograph of gabbro from the R. & E. Brown Well showing interlocking laths of labradorite (light gray) and anhedral equant opaques (NW quadrant). The large dark area on the east in a hole in the slide. (Crossed nicols, X 75.6)

Figure 33. - Photomicrograph of granitic gneiss from Myers Well showing alteration of plagioclase and microcline. The dark gray areas in the feldspars are sericite and adularia. (Crossed nicols, X 30)
Because the amount of chloritization of the augite decreases downward, this well likely shows surface weathering of the gabbroic body.

**MARBLE CLIFF WELL**

The samples from the Marble Cliff Well of Franklin Township of Franklin County are extremely poor—they are highly contaminated with an overlying Cambrian arkose, and are also small and mostly monomineralic. As a result, it is impossible to accurately determine the depth of the top of the Precambrian in this well. Definite lithic fragments of a gneissic granite are present below 3615 feet, whereas monomineralic chips of potassium feldspar, quartz, biotite, magnetite, and chlorite are present in abundance between 3605 and 3615 feet. It is likely that the top of the Precambrian lies somewhere in the 3605–3610-foot interval. This would yield a total Precambrian penetration of at least 12 feet. (Owens, 1967, reported 3 feet of penetration.)

Near the bottom of the well, at 3622 feet, lithic fragments are present in addition to the monomineralic fragments. These are composed mostly of plagioclase, quartz, and biotite with small amounts of hornblende, plus accessory chlorite, magnetite, and pyrite.

The predominance of the potassium feldspar near the top of the Precambrian portion of the well is consistent with the altered zone present in most other wells. The fresher chips near the bottom apparently came from a gneissic granite.
The Zenith Well in Union Township of Union County was drilled 7 feet into the Precambrian (Owens, 1967). Samples were taken at 5-foot intervals, and for study, were obtained for those sections of the well between 3330-3335 and 3345-3355 feet (3335-3345 feet is missing). Samples from this well are highly contaminated with overlying Paleozoic sedimentary rocks, especially arkose. This makes the exact determination of the top of the Precambrian difficult.

Small lithic fragments composed of salmon-pink microcline and quartz are present in the 3345-3350-foot interval. They probably are from a granite that is most distinctive for its extremely low content of ferromagnesians.

A few flakes of biotite are present in the 3350-3355-foot sample; these have been bleached and appear "silvery" and opaque. This sample also contains a dark gray to pinkish gray fine-grained rock showing a schistose fabric. It is composed of quartz, sericite, feldspar, biotite, hematite, and chlorite. Biotite and sericite both contribute to the foliation. The biotite has undergone much hematization and some chloritization and appears opaque in transmitted light. The feldspar is a plagioclase but the composition cannot be determined because of extreme sericitization. The grain size of these chips precludes further mineralogical identification of constituents. These chips most likely represent a schist, which might be an inclusion in the granite or it might be the country rock into which the granite was intruded.
LINDSEY WELL

The Lindsey Well was drilled in Genoa Township of Delaware County and penetrated a reported 18 feet of Precambrian (Owens, 1967). Samples were obtained at both 5- and 10-foot intervals and were obtained for the interval 4030-4070 feet for study.

The Precambrian at 4050-4060 feet is represented by a whitish to salmon-pink medium-grained gneissic granite. Most of the chips are small and monomineralic. Structure in the rock is not easily discerned for this reason. In general, the platiness of the quartz and the feldspars indicate that the rock is gneissic. The rock is composed of colorless microcline, quartz, minor plagioclase, biotite, hornblende, and accessory chlorite, magnetite, apatite, and pyrite. The ferromagnesian fraction is much reduced above 4060 feet and below 4065 feet. The rock in the 4060-4065-foot sample is about 20 percent dark mineral, whereas that above and below is less than 3 percent ferromagnesian, which may indicate that broad compositional bands as are present in the gneiss of the U.S. Steel Well.

In the lowest sample, the chips are much larger than those above. Some of these chips are monomineralic and as much as 6.0 mm in diameter, indicating that the rock is coarse-grained. This may indicate a banding due to grain size, or may simply mean that these samples were less granulated than those higher in the well.
GREGORY WELL

The Gregory Well in Porter Township of Delaware County was drilled 15 feet into a Precambrian granite. Samples were collected at 10-foot intervals, and the section from 4670 to 4700 feet was obtained for study.

The highest Precambrian chips appear in the 4680-4690-foot sample and are mostly small and monomineralic. These chips are from a salmon-pink medium-grained leucocratic rock composed of potassium feldspar, plagioclase, biotite, hornblende, and chlorite. Because of the size of the chips, it is impossible to determine whether any foliation is present.

The following interval, 4690-4700 feet, shows a sharp reduction in the amount of potassium feldspar and hematite stains, and an increase in the amount of plagioclase (Ab\text{77}An\text{23}), biotite, and minor hornblende.

Because the amount of plagioclase that is present in this interval is significantly greater than the amount present higher in the well, and because the minerals present lowest in the well appear less altered, it is likely that these chips are from a plagioclase gneiss or anorthosite that has undergone alteration near the surface.

H. & H. SMITH WELL

The H. & H. Smith Well in Brown Township of Delaware County penetrated a reported 45 feet of Precambrian (Owens, 1967). Samples were obtained for the range 3980-4035 feet with a 5-foot sample interval. Nearly all of the cuttings are of small monomineralic chips, which do not reflect the structure or grain size of the parent rock.
The upper part of the Precambrian portion of the well is characterized by hematized biotite flakes as much as 2.0 mm across and by fine-grained chlorite. Sericitized potassium feldspar and quartz are present as monomineralic fragments in the interval 3980-3985, abundant in the interval 3990-3995, and scarce in samples below the depth of 3995 feet.

Hornblende first appears in the 3995-4000-foot sample, increases in abundance downward and comprises as much as 50 percent of the samples at and below the depth of 4000 feet. Abundant lithic fragments are present only in the lowermost sample (4035 feet). In these fragments, fresh subhedral or rare euhedral hornblende grains occur with fresh colorless plagioclase (andesine, Ab65An35) and quartz. These fragments are approximately 50 percent hornblende.

It appears that the upper 15 feet of the Precambrian rock in this well is a weathered cap of the amphibolite that occurs at a depth of 4000 feet. It is likely that the potassium feldspar of the altered zone is secondary adularia like that in the U.S. Steel Well of Scioto County.

SPRAIN WELL

The Sprain Well was drilled in Oxford Township of Delaware County and penetrated a reported 41 feet of Precambrian. Samples, which were collected at 5-foot intervals, were obtained for study for the range 3990-4026 feet. Although the top was reported as 3994 feet, (Owens, 1967), no Precambrian material was seen by the author above the 4000-4005-foot interval. At this depth excellent large lithic fragments of a reddish pink fine-grained leucocratic equigranular granite that shows
weak foliation are present as the major constituent of the cuttings. The rock is composed of the following minerals in their order of decreasing abundance: microcline, plagioclase, quartz, biotite, chlorite, and magnetite.

The character of the granite changes with depth. The books of biotite become slightly parallel, imparting better foliation to the rock; hornblende appears at a depth of 4010 feet, but comprises less than 2 percent of the rock; magnetite, a few grains of which are euhedral, becomes much more abundant and increases in grain size to 2.0 mm. Traces of pyrite are also present.

MCBEE WELL

The McBee Well in Bennington Township of Morrow County was drilled 15 feet into a Precambrian granite (Owens, 1967). Samples were obtained for the section between 4425 and 4450 feet; each sample represents 10 feet.

The granite is a salmon-pink medium-grained leucocratic equigranular rock composed of potassium feldspar, quartz, plagioclase, minor biotite and magnetite.

The potassium feldspar is microcline that gives the rock its salmon-pink color, and is recognized by grid twinning under the microscope. It displays excellent cleavage and is intergrown with plagioclase. In immersion oils, the microcline appears "cloudy" or "dusty" indicating slight alteration, probably to kaolinite.
The plagioclase occurs as subhedral slightly cloudy to frosty-white grains that display good cleavage and albite twinning. Some quartz is intergrown with the plagioclase and occurs as clear glassy anhedral grains that display excellent conchoidal fracture. Biotite commonly is present as subhedral books; most are randomly embedded in the microcline. These books are as much as 0.5 mm thick and 2.0 mm in diameter. The biotite is fairly fresh and unaltered.

**SHAVER-NEFF WELL**

The Shaver-Neff Well, drilled in Peru Township of Morrow County, penetrated a reported 20 feet of Precambrian (Owens, 1967). Samples were collected at 10-foot intervals and were obtained for the depths 4175 to 4215 feet.

Granite is present in the 4190-4200-foot interval and is mostly fine- to medium-grained, orange-pink and reddish pink, equigranular, and composed of potassium feldspar, quartz, and plagioclase with traces of biotite, chlorite, and magnetite. The reddish pink lithic fragments seem to be relatively fresh and the orange-pink fragments appear highly altered. The orange-pink fragments are composed mostly of potassium feldspar, quartz, and plagioclase, and display a fine-grained weathering product, probably a clay, around the grain boundaries.

The reddish pink granite chips have a texture similar to the altered chips, and lack only the weathered grain boundaries. Potassium feldspar and quartz are the major constituents, with lesser amounts of plagioclase
and only traces of biotite, mostly chloritized, and magnetite that occurs as small anhedral grains or rarely as subhedral octahedra.

The altered chips probably represent weathered granite that was subjected to surface or near surface conditions over a period of time, whereas the reddish pink fraction likely approximates the unweathered granite.

MYERS WELL

The Myers Well in Canaan Township of Morrow County penetrated a reported 98 feet of Precambrian (Owens, 1967). Samples were collected at 5-foot intervals and those obtained for study were from the interval 3990-4090 feet.

These samples are in very good condition, i.e. large lithic fragments are abundant, with very little contamination from Paleozoic sedimentary formations. The highest Precambrian cuttings occur in the 4000-4005-foot interval and are of a salmon-pink coarse-grained leucoocratic equigranular granitic gneiss. This rock undergoes local changes but the granitic character is evident to the bottom of the well. In the highest samples, the granitic gneiss is composed of interlocking grains of salmon-pink microcline that are relatively fresh and show good cleavage, quartz in equant glassy grains, and plagioclase as salmon-pink or colorless grains showing good cleavage, excellent polysynthetic twinning, and slight sericitization. Also present in these upper samples is a small amount of biotite, which occurs as fresh books up to
2.0 mm in diameter. Chips with relatively few heavy minerals represent the upper 10 feet of the well; in the 4010-4015-foot sample and all subsequent samples, both hornblende and biotite are abundant.

In general, the presence of some chips that are mostly light minerals and others that are mostly ferromagnesian (these latter ones usually associated with abundant plagioclase) indicates that the rock is probably compositionally banded.

**Microscopic description** - Thin sections were made from some of the larger chips from the following intervals: 1) 4010-4015; 2) 4020-4025; 3) 4035-4040; 4) 4040-4045; and 5) 4070-4075 feet.

The interval 4010-4015 feet is characterized by intergrown equant plagioclase (Ab92-Ab100) and quartz, lesser amounts of microcline, biotite, and hornblende, and accessory apatite, zircon, sericite, leucoxene, calcite, chlorite, and hematite. Most of the albite grains show good polysynthetic twinning and a moderate amount of sericitization (figure 33). Some chips also appear fresh (figure 34). Both perthitic and vermicular fabrics are also shown, but are not abundant. Quartz occurs in anhedral grains that show undulatory extinction.

Biotite is present in very irregular grains that show deep embayment by adjacent quartz and feldspars. Thin stringers of hematite lie along cleavage planes of the biotite. Some of the flakes are crinkled, which indicates stress in the rock after crystallization of the biotite. Hornblende occurs in anhedral grains and shows chloritization along the cleavage. In some areas, the chlorite has replaced areas adjacent to,
but away from, the cleavage planes, giving relatively large patches of chlorite.

The interval 4020-4025 feet is represented by chips that contain much more quartz and microcline and much less plagioclase than the interval 4010-4015 feet. Sericitization, although in evidence, is not as prominent as higher. The grain size of constituents has decreased from 3.0-4.0 mm in the highest interval to an average of approximately 1.0 mm. Also, mineral grains are not equant as above, but are flattened in a common plane. The length to width ratio is as much as 3 to 1. The grain boundaries are increasingly sutured and the rock has taken on a gneissic character. Hornblende occurs in grains smaller in size than above. In addition, the grains appear much fresher, i.e. they are not chloritized, and rarely occur as intergrowths with biotite. The biotite, as above, shows deep embayment.

Further detailed descriptions of the thin sections from the remaining intervals listed above are not warranted because of their similarity to those described above. In general, the amount of foliation increases downward, whereas the alteration decreases.

All evidence seems to indicate that the country rock from which these chips came is a granitic gneiss that has well-developed foliation and compositional banding; the presence of sericite and chlorite in the upper parts of the Precambrian portion of the well indicates that the rock was probably subjected to weathering at surface or near surface conditions at some time in the past.
Figure 34. - Photomicrograph of granitic gneiss from Myers Well showing intergrown plagioclase (with excellent twinning), biotite (lath-shaped), hornblende (dark gray grain in west-center), and quartz (very dark gray and very light gray in center). (Crossed nicols X 30)

Figure 35. - Photomicrograph of andesite from Kennerk Well showing magnetite-rimmed altered phenocrysts in a fine-grained groundmass of plagioclase. The phenocrysts were probably originally pyroxene that has been replaced by fine-grained chlorite and talc. (Crossed nicols, X 30)
IREY WELL

The Irey Well in Canaan Township of Morrow County penetrated a reported 6 feet of Precambrian rock (Owens, 1967). The well is approximately 2 miles west-northwest of the Myers Well, which is also in Morrow County. Only three samples were collected from the Precambrian rocks of the Irey Well: one from 3850-3860, one from 3860-3870, and one from 3876 feet, (3870-3876 feet is missing). The highest sample containing chips of Precambrian rocks is the 3876-foot sample.

The rocks of the Irey and Myers Wells are very similar; those in the Irey Well show some weathering, however. The granite gneiss in this well shows some sericitization of the feldspars and some chloritization of the biotite.

WINDEIGLER WELL

The Windbigler Well in Troy Township of Morrow County penetrated a reported 18 feet of Precambrian (Owens, 1967). Samples were taken at 5-foot intervals and were obtained for study for the interval 4865-4890 feet.

The 4670-4675-foot sample contains a very light gray medium-grained diorite composed of translucent whitish gray oligoclase (Ab85An15) in polysynthetically-twinned grains as much as 4.0 mm in diameter, hornblende, biotite mostly in grains less than 0.5 mm, and accessories of magnetite, chlorite, and pyrite. Some of the chips appear to have a foliation.
The character of the rock changes little as depth in the well increases, except for one sample. In the sample from the interval 4880-4885 feet, large fragments of pink oligoclase are associated with some quartz and microcline but with little or no heavy minerals. The pink color is due to minute inclusions of hematite that can be seen when the oligoclase is viewed in immersion oils. The pink oligoclase is coarser than the grains of the diorite, with some grains as much as 1.0 cm in diameter; these chips probably represent a pegmatite. The pink chips are abundant in only one sample, which probably indicates that the pegmatite is relatively thin.

MITCHELL WELL

The Mitchell Well in Claridon Township of Marion County penetrated a reported 7 feet of Precambrian (Owens, 1967). The well site is approximately 2.5 miles due west of the Irey Well. As might be expected, the rock types of the two wells are similar. Samples were collected at 10-foot intervals, and for study purposes were obtained for the interval 3640-3675 feet.

Granite appears in the 3650-3660-foot interval and occurs as a reddish to salmon-pink medium-grained equigranular rock composed of strongly microperthitic microcline, plagioclase (Ab63An37), quartz, biotite and hornblende that have undergone some chloritization, and accessories of magnetite, pyrite, garnet, and hematite as a dark stain on some of the feldspar.
Some chips contain much plagioclase that shows excellent polsytetetic twinning, and hornblende that occurs as irregular to slightly prismatic grains with the long dimension rarely exceeding 1.0 mm, plus minor biotite; clear glassy anhedral grains of the plagioclase are intergrown with the hornblende. A moderate lineation is produced by the subparallel alignment of the prisms of hornblende.

The close association of these two types of chips may result from the segregation of ferromagnesians into "clumps" in a hornblende-rich granite, or from inclusion of the country rock (amphibolite) through which the granite passed during emplacement. Because of the similarity in texture and fabric of the different chips, the former interpretation is favored.

LEONHARDT WELL

The Leonhardt Well in Chatfield Township of Crawford County penetrated 4 feet of Precambrian (Owens, 1967). Samples were taken at 10-foot intervals and those obtained for study were from 3750 to 3772 feet.

Samples from this well are poor. Contamination from Paleozoic sedimentary rocks is great and the chips are small and mostly monomineralic. Only a few small lithic fragments are present.

Examination of some of the chips in immersion oils confirmed the presence of oligoclase (Ab₈₅An₁₅) and microcline, with lesser amounts of quartz, and accessories of biotite, chlorite, hematite, and magnetite. The oligoclase to microcline ratio is about 3 to 1. Both of the feldspars show some sericitization and hematite staining. They are very similar
in hue, mostly colorless and glassy to slightly pinkish, and only in oil can the species be detected. Because of the size of the fragments, structure and grain size of the parent rock is not revealed. The rock from which these cuttings came is likely a monzonite.

EYESTONE WELL

The Eyestone Well in Eden Township of Wyandot County penetrated a reported 20 feet of Precambrian (Owens, 1967). The samples that were obtained for study are from the interval 3220 to 3260 feet; each sample represents 10 feet.

A very light pink to yellowish pink medium-grained equigranular monzonite with about 10 percent ferromagnesian minerals is present in the 3250-3260-foot sample and contains approximately equal amounts of plagioclase (Ab$_8$An$_{15}$) and microcline. Quartz is present in amounts less than 5 percent. The ferromagnesian minerals are hornblende and lesser amounts of biotite. Some of the biotite is chloritized. Accessories include magnetite, apatite, sphene, pyrite, and limonite.

The oligoclase and the microcline are similar in appearance and occur as colorless translucent grains that exhibit poor to fair cleavage, or as slightly reddish pink grains. Polysynthetic twinning is shown clearly by some of the plagioclase. Grid twinning of microcline is evident when viewed under the microscope. Grains crushed and mounted in oil indicate an approximate ratio of oligoclase to microcline of 1 to 1.
Hornblende occurs as irregular to slightly prismatic grains that show some chloritization. A few fresh cleavage fragments occur in the 3240–3250-foot sample and, along with some feldspar grains, indicate that the top of the Precambrian falls in this interval. Biotite likewise shows chloritization.

Magnetite is a relatively abundant accessory and occurs mostly as poorly-formed octahedra. Pyrite is a very minor constituent and is mostly associated with chlorite. Limonite occurs as a stain on many of the grains.

The bottom sample (3260 feet) shows a sharp reduction in the abundance of heavy minerals, a moderate increase in amount of quartz, and an increase in grain size. Heavy minerals make up perhaps 2 percent of these cuttings. Many of the single-grain feldspar chips are 4.0 mm across.

**BOWEN WELL**

The Bowen Well in Mifflin Township of Wyandot County penetrated a reported 52 feet of Precambrian (Owens, 1967) for which samples were collected at 5-foot intervals between the depths of 2845 and 2900 feet.

An overlying Cambrian arkose, small size of the chips, and much contamination from overlying Paleozoics make determination of the top of the Precambrian difficult in the Bowen Well. The highest Precambrian chips occur in the 2855–2860-foot sample and are composed of altered potassium feldspar (whose variety is undeterminable due to lack of twinning or good cleavage), plagioclase (Ab$_{63}$An$_{37}$), hornblende, hematized
biotite, magnetite, chlorite, pyrite, and small subhedral pink garnets less than 0.5 mm in diameter. Many of these garnets show weak birefringence. The amount of quartz present in the Precambrian is questionable. An overlying quartz sandstone has thoroughly contaminated the well. Therefore, only those quartz grains present in lithic fragments are known for sure to be Precambrian, and this amount appears to be relatively small.

No significant change in the mineralogy of the cuttings occurs as depth increases, and no structure is discernible because of the small size of the chips.

The mineralogical composition of rock in this well is similar to that in wells which lie in closest proximity, i.e. the Eyestone and Leonhardt. Therefore, the parent rock in the area of the Bowen Well is likely related to the parent rock in the area of these wells—i.e. a quartz monzonite. The composition indicates that the parent rock of these chips is likely close to a quartz monzonite in mineralogy.

FREY WELL

The Frey Well in Salem Township of Wyandot County was drilled 13 feet into the Precambrian (Owens, 1967). Samples were collected at intervals ranging from 10 to 13 feet, and were obtained for study for the interval 2833 to 2870 feet.

Two types of Precambrian chips are present in the 2845-2857-foot sample. One is reddish brown, fine-grained, equigranular, and is composed of greatly altered potassium feldspar, chlorite, quartz, and biotite.
The feldspar is soft, contains much sericite, and has the characteristic "bleached appearance" of the upper weathered part of the Precambrian in many wells of Ohio. Biotite has been largely altered to hematite, and the rock is highly chloritized.

The second type of chip is rich in plagioclase (Ab77An23), hornblende, and biotite, and shows weak foliation. In these, oligoclase is transparent to translucent, lacks polysynthetic twinning, occurs in roughly equant grains, and comprises 80-85 percent of the rock. Biotite, hornblende, and minor quartz are set in the oligoclase matrix and may impart weak foliation.

These cuttings may represent an amphibolite that has been altered by subaerial or subaqueous weathering.

D. & D. JONES WELL

The D. & D. Jones Well in Jackson Township is the only well to date that has penetrated the Precambrian in Hardin County. Owens (1967) reported a penetration of 16 feet of the Precambrian. Samples were obtained for study purposes for the interval 2800-2835 feet; each sample was collected at a 5-foot interval. Samples are very poor due to much contamination by overlying arkose, quartz sandstone, and shale. Most of the Precambrian chips are very small, making structure of the parent rock impossible to discern.

The rocks in the D. & D. Jones Well are very similar to chips of the weathered rock in the Frey Well that is located approximately 8 miles to the northeast, i.e. a very light pink fine-grained potassium
feldspar-rich rock in which the biotite is locally chloritized. The chloritization is shown by fine-grained dark green chips, some of which contain flakes of hematite. Magnetite and subhedral crystals of garnet are present in these chips as accessories.

The similarity to the weathered cap overlying the amphibolite in the Frey Well probably indicates that the well bottomed in the weathered zone. Because of the similarity in the weathered zone of different wells, regardless of the original mineralogy, it is not possible to identify the basement rock in this well.

DRUMMELSMITH WELL

The Drummelsmith Well in Jackson Township of Hancock County was reported to have been drilled only 5 feet into the Precambrian (Owens, 1967). Samples were collected at 10-foot intervals and were obtained for purposes of study from 2790 to 2807 feet.

The Precambrian in the Drummelsmith Well consists mainly of highly altered pale pink chips and salmon-colored chips. A few of the pale pink chips are present in the 2790-2800-foot interval, but they become very abundant in the 2800-2807-foot sample. These chips are composed of potassium feldspar that has been altered to sericite, quartz, biotite, chlorite, and accessory magnetite. Some grains of biotite are highly discolored. This discoloration of biotite plus that of the feldspars indicates bleaching of the granite.

The salmon-colored chips are considerably less abundant and are composed of reddish to salmon-pink potassium feldspar and anhedral grains
of quartz, and are distinctive in that they contain very little or no biotite. The salmon-colored chips may represent a less weathered part or may represent unweathered remnants in the weathered zone. The latter is probably the correct interpretation since some of the chips may be redder near the center but become increasingly pale outward.

The alteration is such that a name cannot be placed on the rock with confidence. Therefore, the general term granite will be used.

KERBEL WELL

The Kerbel Well in Woodville Township of Sandusky County penetrated a reported 47 feet of Precambrian (Owens, 1967). Samples were taken at 5-foot intervals and were obtained for the section of the well between 2730 and 2785 feet.

Almost all of the samples of this well are made up of very small monomineralic chips. Fine-grained chlorite that contains hematized biotite flakes appear in the well between 2735 and 2755 feet. In the 2755-foot sample, and in all of those below, biotite and plagioclase (Ab35-Ab40) are the two main constituents. Hornblende also appears at this depth, as a minor constituent, but its abundance increases greatly downward until it comprises as much as 10 percent of the total rock in the bottom sample.

Because of the very small size of the largely monomineralic chips (mostly less than 1.0 mm), it is very difficult to identify the rock from which these chips came. It is likely, however, if McCormick (1961) is correct in his identification of a granite and amphibolite in the Bruns
Well (which is approximately 4 miles southwest of the Kerbel Well),
that the rocks in this well are also granite and amphibolite.

CARTER WELL

The top of the Precambrian in the Carter Well in Center Township of
Wood County was reported by Owens (1967) to be at 2810 feet. Samples
were obtained for the interval from 2790 to 2810 feet; those samples from
2810-2827 feet are missing.

Lithic fragments of a highly chloritized granite do occur in all
samples studied; these are similar to cuttings from the Knauss Well,
which is located approximately 4 miles south-southwest of the Carter
Well. An overlying Cambrian arkose introduces some uncertainty into the
picking of the top of the Precambrian. Because none of the chloritized
granite chips were observed in the relatively large lithic fragments of
arkose, and because a few chips of fresh granite were present, it was
concluded that the top of the Precambrian does actually lie somewhere in
the 2790-2800-foot interval. Total penetration of the Precambrian is
therefore between 27 and 37 feet.

KNAUSS WELL

The Knauss Well in Center Township of Wood County penetrated a
reported 44 feet of Precambrian (Owens, 1967). Samples were collected
at 5-foot intervals and were obtained for study for the section between
2705-2765 feet.
A weathered granite appears highest in the well in the 2710-2715-foot sample and is pale pink, medium-grained, and equigranular. It is made up of potassium feldspar, minor plagioclase, quartz, chlorite, biotite, garnet, magnetite, and hematite, and shows the effects of alteration, i.e. chloritization and hematization of the biotite, sericitization of the feldspars, and bleached appearance of the lithic fragments. The character of the cuttings and the relative abundance of the minerals in them remain essentially unchanged throughout the 50 to 55 feet of the Precambrian portion of the well except in the 2750-2755-foot sample, which is composed of coarser-grained chips that are predominately of two varieties of microcline. A colorless glassy to gray variety is relatively fresh and displays good cleavage. Excellent grid twinning may be seen in this rarer variety. Microcline is also present as highly sericitized reddish pink grains with cleavage not so well developed. Also present are quartz, muscovite, magnetite, pink garnet, pyrite, and hematite. Quartz is in grains as much as 8.0 mm in diameter, muscovite in books as much as 5.0 mm in diameter, and the feldspars in grains as much as 6.0 mm. The restricted occurrence of the coarser-grained rock, and the mineral composition, suggests that the drill bit passed through a pegmatite dike approximately 5 feet in thickness that crosscuts the granitic body.
R. SMITH WELL

The R. Smith Well in Plain Township of Wood County is approximately 2 miles west of the Carter Well, also in Wood County. Owens (1967) reported 13 feet of Precambrian rock in this well. Samples obtained for study were from the interval 2750-2785 feet.

The top of the Precambrian is in the 2770-2775-foot interval and is represented by an abrupt change from chips of arkose to chips of orthoclase (as determined by the extinction angle on cleavage faces) and chips of garnet-biotite-hornblende schist. The orthoclase is light bluish gray, fresh, and shows excellent cleavage. It occurs in chips as much as 5.0 mm in size that are largely monomineralic, but it may be associated with other minerals. These include quartz, biotite, hornblende, garnet, chlorite, magnetite, and minor amounts of pyrite and plagioclase. Those grains not composed of orthoclase are made up of quartz, very abundant pink garnet, hornblende, biotite, and magnetite. The grain size of these minerals is much smaller than the orthoclase grains; most are less than 0.5 mm but all are less than 1.0 mm. This distinct difference in grain size imparts an inequigranular texture to the rock.

The abundance of the orthoclase greatly decreases downward in the well, and garnet, hornblende, and magnetite become the abundant minerals.

The relations described above indicate that a magma of syenitic composition was intruded into schists, or that inclusions of a schistose country rock through which the magma passed during emplacement were incorporated into the magma.
ASMUS WELL

The Asmus Well in Middleton Township of Wood County reportedly penetrated 25 feet of Precambrian (Owens, 1967). Samples were collected at both 5- and 10-foot intervals, and for study purposes were obtained for that section of the well between 2790 and 2825 feet.

Most of the chips from the Asmus Well are small and monomineralic. Minerals present in order of decreasing abundance include highly sericitized potassium feldspar; quartz (although the exact amount cannot be determined because of contamination by a relatively clean overlying Paleozoic quartz sandstone); biotite that has undergone chloritization and hematization; chlorite that is present as dark green books to 2.0 mm in size, as fine-grained aggregates comprising lithic fragments, or as a replacement of biotite; and accessory garnet and magnetite. The chlorite content greatly increases with depth in the well.

These monomineralic chips are similar to the mineral grains in the lithic fragments of the Carter Well, also in Wood County; the Carter Well is approximately 2 miles east of the Asmus Well.

The parent rock is probably granitic in character; it is not possible to determine from these cuttings whether the rock possesses any structure.

KETRING WELL

The Ketring Well in Harding Township of Lucas County, drilled in August, 1972, is the most recently-drilled well in Ohio to penetrated the Precambrian. Total penetration is reported as 292 feet (Ohio Geological Survey, well card). Samples were obtained for the interval 3593-3915
feet; those from 3903 to 3915 are missing. The range in feet of each sample varies, but is mostly less than 10 feet.

The top of the Precambrian is at 3623 feet as shown by the well card. Chips of a biotite-quartz-feldspar gneiss are present highest in the well in the 3613-3620-foot interval. Therefore, the total penetration may be 3 to 10 feet greater than that reported on the well card. Some of the chips in the 3613-3620-foot interval are dark blackish brown and some are greenish black and white "speckled". The rock is fine- to medium-grained, inequigranular, leucocratic, gneissic, and is composed of potassium feldspar, quartz, biotite, plagioclase, calcite, hematite, chlorite, garnet, zircon, muscovite, and apatite. The quartz and feldspar are intergrown and occur in bands between abundant foliated flakes of biotite that have been rather thoroughly hematized. The extremely good orientation of the biotite is in large part responsible for the excellent foliation and gneissic fabric of the rock. The compositional bands also aid the foliation. Intergrown quartz and pink potassium feldspar occur in biotite-free bands as much as 4.0 mm thick. In these bands the grain size of the quartz and feldspar averages approximately 2.0 to 3.0 mm, whereas in the biotite-rich bands the grain size of these minerals is less than 0.3 mm. As a result of grain size, most of the quartz and feldspar from the biotite-free bands occur as large monomineralic chips, whereas the biotite-rich bands occur in large lithic foliated rock chips made up of fine-grained quartz, feldspar, and biotite.

Below the depth of 3666 feet, pyrite and chalcopyrite occur as mostly subhedral monomineralic chips, but rarely as very small thin veins
penetrating the gneiss; graphite is present as foliated platy masses, and may comprise a significant part of those chips in which it occurs.

The character of the gneiss as described above persists to the 3748-3752-foot interval. At this depth the cuttings are much lighter in color, due to the increase in the amount of quartz and plagioclase, and the decrease in the amount of biotite. These lighter chips persist less than 25 feet; in the interval 3765-3773 feet there is a change to a graphite-bearing dark gray-black to greenish black very fine-grained rock with a prominent schistose fabric. Although some of the graphite is in flakes oriented such as to produce a weak foliation, much of it is finer grained, more massive, and intergrown with other minerals. Some of the feldspar is stained "malachite-green" at this depth as well as higher in the well.

In the 3843-3850-foot sample, another change in lithology occurs. A rock rich in quartz and oligoclase (Ab80-Ab90) becomes prominent and is similar in fabric and texture to the gneiss above the depth of 3748 feet. However, the reduction in the abundance of biotite, and the appearance of fine-grained foliated muscovite distinguishes these chips from those above. The oligoclase is highly sericitized as it is above, and because of this, has a translucent milky white color. Much accessory pyrite and chalcopyrite, plus traces of arsenopyrite, occur.

The presence of abundant graphite in chips from most samples in the well probably indicate carbonaceous sediments as the parent material of the gneiss. The presence of distinct compositional banding of quartz, feldspar, and biotite, and gneissosity of the chips, and the presence of
accessory garnet indicates that the rock is of relatively high grade. The presence of abundant sulfides perhaps is a manifestation of later hydrothermal activity in the area.

STOREHOLDER WELL

The Storeholder Well in Swan Creek Township of Fulton County penetrated a reported 146 feet of Precambrian (Ohio Geological Survey, well card). Samples were obtained for study purposes for the intervals 3540-3600 and 3670-3700 feet. The interval 3600-3670 feet is missing.

Because of the size of these chips (less than 1.0 mm), the minerals could not be determined megascopically. A representative sample of the grains present in each interval was mounted on a slide in Lakeside 70, as described in the introduction, and studied under the petrographic microscope.

Small chips of highly sericitized reddish salmon-pink potassium feldspar that is probably replacement in origin occur highest in the well in the 3560-3570-foot sample. These chips comprise as much as 85 percent of the total sample. A very few chips also contain chlorite and quartz, which are mostly present as monomineralic grains. The remaining 15 percent is lithium fragments of a dark greenish black fine-grained rock. The abundance of the dark chips greatly increases downward to a maximum in the 3590-3600-foot interval. In this interval, the entire sample is made up of the dark lithic fragments, which are almost exclusively sodium-rich plagioclase and biotite. The plagioclase forms the matrix in which very small (mostly less than 0.001 mm) anhedral flakes or books of biotite
occur. These grains of biotite are pleochroic from dark green to light green and have a subparallel orientation.

Somewhere in the missing interval the dark plagioclase-biotite rock grades into, or is in contact with, rock of a third rock type present in the well. The chips of this third type are small, monomineralic, and of white microcline that shows good tartan twinning under the microscope, quartz, and minor amounts of biotite. The microcline shows excellent cleavage on most of the grains, which indicates that the rock is at least medium-grained. The biotite occurs as fresh black monomineralic flakes. A few flakes of chlorite are also present, but both of these minerals together make up less than 3 percent of the sample. Accessory apatite and zircon are present. The quartz : microcline ratio is approximately 1 : 2.

The third rock type described above is probably a granite that intruded sediments that were calcium-rich, as represented by those dark greenish black chips. A contact metamorphic aureole was then created which was rich in plagioclase and biotite, in which the biotite formed very small microscopic grains in a matrix of plagioclase. The resulting rock is represented by those dark greenish black chips that were described above and can be termed a hornfels. The potassium feldspar from the zone near the top of the well likely has an origin similar to that of the diagenetic adularia that is present in most other wells. However, due to the fine grain size of these chips of feldspar, no optical properties can be determined; thus, the presence of adularia cannot be proven as it was in numerous other wells.
KENNERK WELL

The Kennerk Well in St. Joseph Township of Williams County is especially significant for the following reasons: 1) It is the northwestern-most Precambrian well drilled in Ohio to date. 2) A total of 211 feet (Owens, 1967) of Precambrian was penetrated. 3) The well is isolated from other Precambrian wells—the nearest such well is the Storeholder Well of Fulton County, which is more than 40 miles to the east.

Samples from this well were collected at 5-foot intervals, and were obtained for study for that section of the well between the depths of 3900-4137 feet.

The highest Precambrian chips in the well occur in the 3905-3910-foot interval and are of a reddish brown to dark chocolate brown aphanitic highly altered volcanic rock. Because of the small size of the chips and their very small grain size, several representative chips from selected depths were mounted in Lakeside 70 and ground to approximately .03 mm (See introduction for procedure). Minerals present as determined from thin sections are plagioclase, chlorite, chalcedony, hematite, magnetite and/or ilmenite, and apatite. Vesicles as much as about 1.0 mm in diameter are present but not abundant, and are commonly filled with chalcedony. This portion of the well has been very highly oxidized as evidenced by the dark-red hematite stain that is present over all the chips.

A change in color occurs in the 3950-3956-foot interval and persists for approximately 50 feet. The color at these depths has changed in
hue to a greenish and reddish brown as a result of a great increase in the amount of chlorite. Some of this chlorite has replaced former phenocrysts that show a very sharp distinct crystal outline as much as 1.65 mm in length, that is now thinly rimmed by magnetite (figure 35). Magnetite also occurs in small remnant patches scattered throughout these phenocrysts. Hematite is present on both sides of this rim, i.e. both in the center of the altered crystal and as a stain of the groundmass as above. The crystal form indicates that the original phenocryst was probably a pyroxene.

A thin section was made of chips from the 4000-4004-foot interval. The chips from this interval are slightly darker than those from 3950-3956 feet; they contain some pink dolomite as vesicle fillings, and abundant subhedral grains of chlorite that appear to have replaced ferromagnesian minerals of the groundmass.

The rock at 4041-4045 feet is composed of plagioclase with a β-index slightly above balsam; a smaller amount of feldspar with a β-index of about 1.525 and a very low optic angle, might be adularia; pale green chlorite; very fine grained talc in the groundmass and as replacements of phenocrysts that probably were pyroxene; opaque minerals scattered through the groundmass and also as rims around the replaced pyroxene (?) phenocrysts, which are as much as 2.1 mm in length; calcite as vesicle fillings; and minor accessories. A pistachio-green mineral makes its highest appearance in the relatively large chips of this interval. The mineral is epidote and occurs in aggregates of small grains in segregated
Figure 36. - Photomicrograph of andesite from Kennerk Wall showing an amygdule (SW quadrant) in which epidote (circular medium gray area in center) is surrounded by fine-grained chalcedony (light gray area around the epidote). (Crossed nicols, X 30)

Figure 37. - Photomicrograph of andesite from Kennerk Wall showing texture of the fine-grained groundmass. (Crossed nicols, X 76.5)
patches in the rock; in plane polarized light it is yellowish green and nonpleochroic, and it has a cloudy appearance.

As depth in the well increases, the abundance of epidote also increases. In the 4075–4079-foot interval, the thin section shows epidote occurring inside the magnetite-rimmed phenocrysts as a replacement product. In addition, epidote occurs in some vesicles along with a granular intergrowth of small grains of chalcedony. The epidote may serve as the outer lining, inside of which is the chalcedony, or the chalcedony may serve as the lining with epidote in the center (figure 36). Chlorite and small euhedral octahedra of magnetite are also common in these vesicles.

This rock is probably a volcanic-flow rock, as shown by its texture and fabric (figure 37) and the composition is probably andesitic. The secondary chalcedony and epidote were likely deposited from solutions that were circulating through the vesicles of the rock, and resulted in amygdaloidal fillings. The presence of potassium feldspar as the most abundant feldspar of some chips may indicate either replacement by adularia as is so widespread elsewhere, or may be primary in origin; if the latter, the rock is more latitic in composition than is presently believed.
Figure 38. - Photomicrograph of andesite from Wikoff Well showing vesicles that have been filled with very fine-grained chalcedony set in a fine-grained groundmass of plagioclase and hematite. The light area crossing the slide is a crack in which the mounting medium (epoxy) has birefringence. (Crossed nicols, X 30)

Figure 39. - Photomicrograph of andesite from Wikoff Well showing sub-alignment of the laths of plagioclase (trachytic texture), which indicates flow. (Crossed nicols, X 75.6)
WIKOFF WELL

The Wikoff Well in Stonelick Township of Clermont County is important for control purposes in that it is the southwesternmost Precambrian well drilled in Ohio to date. A reported 125 feet (Owens, 1967) of Precambrian was drilled, with samples being collected at 5-foot intervals. Samples were obtained for study between the depths of 3305 and 3435 feet.

Because of the extremely small grain size of the cuttings from this well, it was necessary to make thin sections of some of the chips (See introduction for procedure).

Chips from the Precambrian rocks of this well are dark reddish to greenish brown, very fine-grained, and are of a vesicular to amygdaloidal extrusive igneous rock showing relatively good flow structure in thin section. Minerals comprising the groundmass include plagioclase, magnetite, hematite, and limonite. (See figure 39 for flow structure.)

Plagioclase occurs in laths that range from approximately 0.05 to 0.20 mm in length and from 0.025 to 0.05 mm in width, and manifests flow structure by the subparallel alignment of its long axes. The composition cannot be accurately determined because of the small grain size but lies somewhere between Ab85 and Ab65.

Very abundant anhedral magnetite occurs interstitially between the plagioclase laths. Hematite is ubiquitous throughout the cuttings and represents an extensive oxidation product of the magnetite. The hematite imparts its very distinctive red color to the cuttings through
Figure 40. - Photomicrograph of andesite from Wikoff Well showing an amygdule of dolomite (medium-gray area on east edge) enclosing a center of low birefringent adularia (very dark gray in center to light gray nearer the edge). (Crossed nicols, X 76.5)

Figure 41. - Photomicrograph of an amygdule (which covers the entire photograph) of banded chalcedony in andesite of the Wikoff Well. (Crossed nicols, X 200)
Figure 42. - Photomicrograph of silicified rock (?) from Hoelscher Well showing small rounded grains of quartz in which are set larger clasts of quartz that show an overgrowth of secondary quartz. The very small light areas that appear as "dust-like" inclusions in the quartz are fine-grained muscovite. (Crossed nicols, X 30)

Figure 43. - Photomicrograph of silicified rock (?) from Hoelscher Well showing a large clast of quartz (at extinction) with an overgrowth that contains abundant fine-grained muscovite. (Crossed nicols, X 30).
out the well and probably indicates that the hematite was formed when
the flow was extruded and the magnetite was exposed to the oxygen in
the air. Some of the hematite shows further alteration (hydration)
to limonite.

Vesicles are contained in the rock, most of which are mineralized.
Calcite, chalcedony, and adularia are common fillings. The vesicles
range from spherical to irregular. Those that are spherical may have
a diameter as much as 1.45 mm, whereas those that are irregular are as
much as 2.65 mm in their long dimension. Chalcedony characteristically
fills the vesicles that tend toward spherical, whereas calcite and
adularia are more common in the irregular ones (figures 38, 40, and 41).

An attempt was made by Lidiak, et al (1966) to date this volcanic
flow rock (probably an andesite), but the date was listed as "indeter-
minate" (table 7).

HOELSCHER WELL

The Hoelscher Well in St. Mary's Township of Auglaize County,
which is the only Precambrian well in west-central Ohio, penetrated
a reported 125 feet of Precambrian (Ohio Geological Survey, well card).
Samples were collected at 10-foot intervals and obtained for that portion
of the well between 2930-3067 feet, (with the exception of the sample
from 3030-3040 feet, which is missing).

The highest Precambrian chips occur in the 2950-2960-foot interval,
and are of a salmon-pink to light-pink rock composed of round to sub-
round pink grains about 0.1 mm in diameter with a small amount of soft
white interstitial material, all of which forms a matrix for clear light smoky-gray well-rounded quartz sand grains. The quartz sand comprises no more than 10 percent of the rock. The 0.1 mm pink grains are friable but will scratch glass. This kind of rock continues to the bottom of the well, but the color varies locally throughout the well to a gray-pink.

The round to sub-round pink grains, as seen in thin section, have an index of about 1.54, birefringence of about 0.01, and are uniaxial positive; these appear to be quartz. They contain small flakes of muscovite and a horde of dust-size inclusions of hematite (?) that probably produce the pink color seen megascopically. An interstitial cement appears to be microcrystalline quartz and much very fine-grained muscovite. The rounded sand grains of quartz range between 1.0 mm and 3.0 mm in diameter and many show resorption. An overgrowth is present around the boundaries of most of these grains. This overgrowth is mostly less than 0.1 mm thick and appears very similar to the smaller round quartz grains, i.e. it contains much fine-grained muscovite in contrast to the clear clast itself, and has grown in optical continuity with the quartz of the clast (figures 42 and 43).

Aggregates of light apple-green muscovite are also present in the rock. These aggregates may be as large as some of the larger quartz clasts, but are not as abundant. White grains of dolomite that show cleavage are abundant in the lowest sample.

Because of the fine grain-size of this rock, two x-ray diffraction runs were made—one on a crushed lithic fragment and one on the apple
green aggregates that had been concentrated by hand (see introduction for procedure). The x-ray pattern that resulted from the crushed lithic fragment indicated the largest component of the rock was quartz, whereas the pattern that resulted from the green aggregates, plus immersion oils, indicated muscovite.

The origin of this rock is very puzzling. The fact that the quartz overgrowths on the large clasts are composed of material identical, or very similar, to the material that comprises the small subrounded grains of quartz indicates: 1) that the two probably had a similar origin, and 2) that this origin is secondary. The roundness of the larger grains of quartz indicates that these grains are probably detrital. This data seems to indicate that the rock is the result of silicification of some original sedimentary material that was entirely replaced except for the large quartz clasts. This process may have resulted from either hydrothermal activity or metamorphism. However, since no metamorphic rocks have been found by the writer in this part of the state, hydrothermal processes are favored.
UNDESCRIBED WELLS

No data could be acquired on the wells listed in Table 6. Samples were not available at the Ohio Geological Survey for some wells, and no chips of Precambrian crystalline rocks were distinguished in the cuttings from other wells. This may have resulted from poor sampling techniques such as sieving the sample and retaining only the coarse fraction, thereby letting the Precambrian chips pass off with the fines; from poor recovery of the cuttings, such as would result from much caving in the well; or this may be the result of actually not penetrating the Precambrian.

<table>
<thead>
<tr>
<th>Well Name</th>
<th>County</th>
<th>Township</th>
<th>Reason</th>
<th>Figure</th>
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<td>Spencer</td>
<td>NS</td>
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<td>2 Murray</td>
<td>Columbiana</td>
<td>Hanover</td>
<td>NPS</td>
<td>60</td>
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<td>3 Spitler-Brown</td>
<td>Crawford</td>
<td>Lykens</td>
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<td>4 F. Jones</td>
<td>Delaware</td>
<td>Radnor</td>
<td>NPS</td>
<td>62</td>
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<tr>
<td>5 W. G. Brown</td>
<td>Jackson</td>
<td>Franklin</td>
<td>NS</td>
<td>63</td>
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<tr>
<td>6 Cunningham</td>
<td>Knox</td>
<td>Pike</td>
<td>NPS</td>
<td>64</td>
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<td>7 Payne</td>
<td>Lawrence</td>
<td>Symmes</td>
<td>NS</td>
<td>65</td>
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<td>8 Gruber</td>
<td>Marion</td>
<td>Claridon</td>
<td>NS</td>
<td>66</td>
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<td>9 Bush</td>
<td>Morrow</td>
<td>Cardington</td>
<td>NPS</td>
<td>67</td>
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<td>10 Henry</td>
<td>Morrow</td>
<td>Westfield</td>
<td>NPS</td>
<td>68</td>
</tr>
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<td>11 Recker</td>
<td>Sandusky</td>
<td>Ballville</td>
<td>NS</td>
<td>69</td>
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<td>12 Aleshire-Marathon</td>
<td>Sandusky</td>
<td>Madison</td>
<td>NS</td>
<td>70</td>
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<td>13 Lane</td>
<td>Union</td>
<td>Washington</td>
<td>NS</td>
<td>71</td>
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<tr>
<td>14 Peek</td>
<td>Wood</td>
<td>Liberty</td>
<td>NS</td>
<td>72</td>
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<td>15 Frazier</td>
<td>Hancock</td>
<td>Union</td>
<td>NPS</td>
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<td>Highland</td>
<td>Fairfield</td>
<td>NPS</td>
<td>74</td>
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<td>17 Yewey</td>
<td>Mercer</td>
<td>Center</td>
<td>NPS</td>
<td>75</td>
</tr>
<tr>
<td>18 Stigamire</td>
<td>Seneca</td>
<td>Adams</td>
<td>Not Available for Study</td>
<td>76</td>
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</table>

NS = No Sample at the Ohio Geological Survey
NPS = No Precambrian material recognized in the sample
AGE DETERMINATIONS OF PRECAMBRIAN ROCKS IN OHIO

Several dates have been determined for rocks of the basement of Ohio. Table 7 gives these calculated ages plus other pertinent information, and was reproduced, in large part, from Lidiak and others (1966).

TABLE 7

<table>
<thead>
<tr>
<th>Well Name</th>
<th>County</th>
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<th>Investigator</th>
<th>Date</th>
<th>K-Ar</th>
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<td>Lidiak</td>
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<td>960 (B)</td>
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<td>935 (B)</td>
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<td>Huron</td>
<td>Peru</td>
<td>Lidiak</td>
<td>870 (B)</td>
<td>935 (B)</td>
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<td>Perry</td>
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<td>McArthur</td>
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<tr>
<td>* 7 Myers</td>
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<td>Canaan</td>
<td>Lidiak</td>
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<td>940 (B)</td>
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<td>Union</td>
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<td>890 (B)</td>
<td>980 (B)</td>
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<td>Fayette</td>
<td>Concord</td>
<td>Lidiak</td>
<td>880 (B)</td>
<td>990 (B)</td>
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<td>* 11 Wikoff</td>
<td>Clermont</td>
<td>Stonelick</td>
<td>Lidiak</td>
<td>Indeterminate</td>
<td>(R)</td>
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<td>* 12 U.S. Steel</td>
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<td>Green</td>
<td>Hofmann</td>
<td>898 (B)</td>
<td>1242 (F)</td>
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<td>* 13 Calhio Chemicals</td>
<td>Lake</td>
<td>Perry</td>
<td>Vargo</td>
<td>566 (R)</td>
<td></td>
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</tbody>
</table>

* Wells included in this study
** Wells included in McCormick (1961)

References:
Hofmann, et al (1972)
Vargo (1972)

B = Biotite
M = Muscovite
R = Whole rock
F = Feldspar
CONCLUSION

The north-south line across western Ohio that separates volcanic rocks to the west from plutonic igneous and metamorphic rocks to the east, and that has been reported by Bass (1960), McCormick (1961), and Hofmann et al (1972) is substantiated by the present study. These igneous rocks are mostly felsic in composition, such as granites and monzonites, whereas the metamorphics are mostly gneisses and amphibolites that represent medium- to high-grade metamorphism. The volcanics to the west of the line are mostly of intermediate composition, and many represent surface flows. This break has been postulated by those mentioned above as the southern extension of the western boundary of the Grenville Province. However, no evidence was discovered during the course of this study that bears on whether any of these rocks are Grenville. It is suggested here that lithology, when used alone, is not sufficient evidence on which to define a geologic province.

Those volcanics to the west that were included in this study showed no effects of regional metamorphism, indicating that these volcanics are, indeed, of a different age than the Grenville metamorphic rocks. They did, however, show replacement by adularia near the top of the Precambrian. The lack of metamorphism of these volcanics indicates that they are either: 1) older than the rocks to the east but were not affected by the Grenville thermal event, presumably because they lay outside the metamorphic belt, or 2) actually younger than this thermal event and merely were extruded through these older metamorphics.
The widespread occurrence of secondary adularia, near the top of
the Precambrian, that decreases in abundance with depth in most wells
suggests that the process or processes responsible for this replacement
originated from above, and not below, which rules out deuteric or hydro-
thermal alterations. These latter processes are usually regarded as
somewhat localized in areal extent, whereas this adularia replacement
occurs at least over most of the state. The optical and physical
properties that are exhibited by the adularia are not those of either
microcline or orthoclase, and the fact that the mineral must be low-
temperature because of its origin from above, also rules out either of
the above species. These properties, plus those determined by Bass,
indicate that the species of feldspar is indeed adularia. The source
of the potassium for the adularia may have been the Cambro-Ordovician
sea that inundated the Precambrian basement rocks of what is now Ohio,
which probably allowed for the downward percolation of some of the sea-
water into these rocks, resulting in the widespread replacement of the
plagioclase and other minerals.

It is possible, then, that this adularia, if it is significantly
younger than the rocks in which it occurs, influences age dates that
are determined for these rocks; this would, perhaps, be particularly
significant for whole rock or feldspar analyses. The age dates thus
calculated might be younger than the true date, as was illustrated by
the age that was calculated for a section of the core from the Calhio
Chemicals Well of Lake County, (Vargo, 1972).
SELECTED REFERENCES


Hofmann, C. M., Gunter Faure, and Arie Janssens, 1972, Age determination of a granite gneiss from the Precambrian basement of Scioto County, Ohio; Ohio Journal of Science, v. 72, no. 1, p. 49-53.


Ross, Martin E., 1972, Precambrian quartz-feldspathic gneiss from the Herman 1A Well; Erie County, Ohio; Ohio Journal of Science, v. 72, no. 2, p. 105-109.


Vargo, Robert T., 1972, Sr-Rb Age Determination of a Precambrian rock from Lake County, Ohio; Ohio State University Senior Thesis (unpublished).


FIGURE 1. - Locations of wells penetrating the Precambrian of Ohio. For key to well numbers, refer to Tables 1, 2, and 6. If more than one rock type is present in the well, the symbol for the major lithology is plotted on the map. Other less abundant lithologies are indicated by the appropriate letter symbols. Wells numbered 1 - 58 are described in this report; wells numbered 59 - 76 are undescribed wells; and those numbered 77 - 105 are described in McCormick (1961).

<table>
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<tr>
<th>Symbols for Minor lithologies</th>
<th>Rock Types</th>
<th>Symbols for Major lithologies</th>
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<td></td>
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<tr>
<td>L</td>
<td>Limestone</td>
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</table>

"NO SYMBOL" *

*For wells numbered 1 - 58 and 78 - 105, the absence of any "major lithology" symbol indicates the presence of "acidic plutonic igneous and metamorphics"."