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THE DESCRIPTION AND INTERPRETATION OF A TERTIARY
SILICEOUS ROCK IN WESTERN NORTH DAKOTA

by

Craig R. Schmit

A Senior Thesis

Submitted to the

Faculty of the Department of Geology

of the

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in partial fulfillment of the requirements

for the degree of

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Please note:

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This Thesis submitted by Craig R. Schmit in partial fulfillment of the requirements for the Degree of B.S. in Geology from the University of North Dakota is hereby approved by the Faculty Advisor under whom the work has been done.

Frank Kerner
(Advisor)

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ABSTRACT

IN SOUTHEASTERN NORTH DAKOTA, NORTHWESTERN SOUTH DAKOTA AND SOUTHEASTERN MONTANA, A PREVIOUSLY POORLY STUDIED TERTIARY SILICEOUS ROCK OCCURS IN PLACE, AS RESIDUAL BOULDERS AND AS A GRAVEL CONSTITUENT. THIS ROCK IS FOUND ASSOCIATED WITH OUTCROPS OF ALL FORMATIONS FROM THE CRETACEOUS HELL CREEK FORMATION TO THE EOCENE GOLDEN VALLEY FORMATION, THOUGH IT CAN ONLY BE DEFINITELY ATTRIBUTED TO THE LATTER. IT VARIES FROM AN ARENACEOUS CHERT TO A SANDY CHERT-CEMENTED SILTSTONE, THE DEFINING FACTOR BEING THE CHERT TO DETRITAL GRAIN RATIO. MACROSCOPICALLY, IT IS TYPICALLY DENSE, HARD AND DARK GRAY IN ADDITION TO CONTAINING NUMEROUS PLANT FOSSILS. EXCEPTIONAL OCCURRENCES ARE CONCRETION-LIKE. THE DETRITAL GRAINS ARE GENERALLY MODERATELY WELL SORTED, SUBANGULAR AND SILT-SIZE. SOME EXHIBIT SECONDARY OVERGROWTHS. CHERT AND PLANT MATTER, REPLACED AND UNREPLACED, COMPOSE THE REST OF THE ROCK.

THE SILICEOUS ROCK SEEMS TO HAVE BEEN FORMED IN A MARSH OR POND ENVIRONMENT CHARACTERIZED BY AN EXTENSIVE SHALLOW BASIN WITH LOCAL DEPRESSIONS. SEDIMENTS DEPOSITED IN THESE DEPRESSIONS WERE SILICIFIED BY THE PRECIPITATION OF GROUND WATER-TRANSPORTED SILICA. PRECIPITATION OF THIS SILICA, IN THE FORM OF CHERT AND SECONDARY OVERGROWTHS, WAS FACILITATED BY AN ACIDIC ENVIRONMENT AT THE SITE OF PRECIPITATION, A RESULT OF THE INTRODUCTION OF CO_2 AND/OR HUMIC ACIDS DUE TO THE DECOMPOSITION OF ORGANIC MATTER.

LIMITED EVIDENCE SUGGESTS A MULTIPLE-HORIZON SOURCE FOR THE SILICEOUS ROCK.

THE DESCRIPTION AND INTERPRETATION OF A TERTIARY
SILICEOUS ROCK IN WESTERN NORTH DAKOTA

INTRODUCTION

GENERAL STATEMENT

IN SOUTHWESTERN NORTH DAKOTA, NORTHWESTERN SOUTH DAKOTA AND SOUTHEASTERN MONTANA, A TERTIARY SILICEOUS ROCK, WHICH VARIES FROM AN ARENACEOUS CHERT TO A CHERT-CEMENTED SILTSTONE, OCCURS IN PLACE, AS RESIDUAL BOULDERS AND AS A GRAVEL CONSTITUENT. LOCALLY KNOWN AS "PSEUDOQUARTZITE" DUE TO ITS QUARTZITE-LIKE APPEARANCE, IT HAS PREVIOUSLY BEEN THE SUBJECT OF ONLY LIMITED STUDY, MOST OF WHICH HAS CONSISTED OF THE FORMATION OF HYPOTHESES BASED ON FIELD OBSERVATIONS MADE IN THE CONTEXT OF OTHER RESEARCH. AS A RESULT, NEITHER ITS STRATIGRAPHIC POSITION NOR ITS DIAGENETIC HISTORY HAS BEEN ESTABLISHED WITH ANY DEGREE OF CERTAINTY. IT IS THE PURPOSE OF THIS PAPER TO PRESENT A SUMMARY OF THE PETROGRAPHY OF THIS SILICEOUS ROCK, BASED PRIMARILY ON THE RESULTS OF FIELD AND LABORATORY WORK PERFORMED BY THE AUTHOR DURING 1969 AND 1970.

PREVIOUS LITERATURE

N.H. WINCHELL (1874, IN HARES, 1928, P.34) WAS THE FIRST TO RECORD THE OCCURRENCE OF THIS SILICEOUS ROCK, REFERRING TO IT AS BOTH A GRAY QUARTZITE AND A SILICEOUS LIMESTONE. HIS OBSERVATIONS, WHICH WERE MADE BETWEEN BISMARCK, NORTH DAKOTA, AND THE BLACK HILLS OF SOUTH DAKOTA, WERE OF RESIDUAL BOULDERS OF THE MATERIAL WITH THE EXCEPTION OF AN ALLEGED "IN PLACE" DEPOSIT AT LUDLOW CAVE IN THE NORTH CAVE HILLS, SOUTH DAKOTA. IN 1885, WILLIS (P.11) NOTED ITS OCCURRENCE IN SOUTH-CENTRAL NORTH DAKOTA AS "ERRATIC BLOCKS" WITH A HIGH SILICIFIED WOOD CONTENT. HE FELT THAT THIS LATTER CHARACTERISTIC MADE IT EQUIVALENT TO THE "DAKOTA QUARTZITES" OF THE BLACK HILLS. BEFORE THE TURN OF THE CENTURY, TODD REFERRED TO THE SILICEOUS ROCK TWICE IN PAPERS ON THE

AREA. HIS FIRST REFERENCE (1892, P.36 AND P.54) WAS TO "A VERY COMPACT GREENISH QUARTZITE" WHICH CONTAINED AN ABUNDANCE OF PLANT IMPRINTS, PARTICULARLY VERTICAL STEM CASTS. THIS "QUARTZITE" OCCURRED IN THE BEAVER CREEK REGION OF SOUTH-CENTRAL NORTH DAKOTA AS "VERY SMALL BOULDERS" RARELY GREATER THAN SIX INCHES IN DIAMETER. TODD INITIALLY ASSIGNED IT TO THE CRETACEOUS FOX HILLS FORMATION, BUT SUBSEQUENTLY REASSIGNED IT TO THE "LOWER LOUP FORK FORMATION" (THE MIOCENE ARIKAREE FORMATION). HIS SECOND REFERENCE (1898, P.60-61) WAS TO A "QUARTZITE" WHICH OCCURRED IN GREAT ABUNDANCE IN NORTHWESTERN SOUTH DAKOTA, PARTICULARLY IN THE CAVE HILLS IN HARDING COUNTY, WHERE HE REPORTED IT IN PLACE AT TWO LOCATIONS IN OLIGOCENE WHITE RIVER FORMATION OUTCROPS. HE CALLED THIS "QUARTZITE," WHICH PRESUMABLY WAS THE SAME AS THAT REPORTED BY WINCHELL IN 1874 (IN HARES, 1928, P.34), "BUHRSTONE" AFTER A SIMILAR ROCK TYPE IN THE PARIS BASIN, AND MADE SPECIAL NOTE OF THE INCLUDED, VERTICALLY-ORIENTED ROOT CAVITIES, WHICH RANGED FROM $\frac{1}{4}$ TO $\frac{1}{2}$ INCHES IN DIAMETER. IN VIEW OF THIS LATTER OBSERVATION, TODD HYPOTHESIZED "IN PLACE" DIAGENESIS OF THE "QUARTZITE" BOULDERS IN A MARSHY ENVIRONMENT. LLOYD (1914, P.251) OBSERVED "QUARTZITE" BOULDERS IN THE CANNONBALL RIVER AREA OF NORTH DAKOTA AND ASSIGNED THEM TO THE PALEOCENE FT. UNION "FORMATION" (GROUP). TWO YEARS LATER, WINCHESTER AND OTHERS (1916, P.30-31) NOTED THE OCCURRENCE OF "QUARTZITE" IN THE SAME FORM ON THE OUTCROPPING LOWER AND MIDDLE BEDS OF THE CRETACEOUS LANCE FORMATION, BUT THEY SAID ONLY THAT ITS SOURCE WAS IN BEDS YOUNGER THAN THOSE ON WHICH IT OCCURRED. BAUER (1922, P.115), ON OBSERVING RESIDUAL BOULDERS ASSOCIATED WITH AN 18 INCH THICK, "IN PLACE" RIDGE OF THE SILICEOUS ROCK IN WEST-CENTRAL NORTH DAKOTA, T148N R92W AND T148N R93W, SUGGESTED THAT ITS ORIGIN WAS LINKED TO THE REPLACEMENT OF CARBON BY SILICA IN A SOIL OR MUCK DEPOSIT. IN 1928, HARES (P.34-36) MADE THE MOST COMPLETE PRESENTATION CONCERNING THE SILICEOUS ROCK, CITING ALL PREVIOUS REFERENCES TO IT IN ADDITION TO PRESENTING HIS OWN OBSERVATIONS. HIS MOST SIGNIFICANT ORIGINAL CONTRIBUTION WAS HIS ASSIGNMENT OF THE "QUARTZITE" TO A POSITION 60 TO 200 FEET

ABOVE THE BASE OF THE TONGUE RIVER "MEMBER" (FORMATION) OF THE PALEOCENE FT. UNION "FORMATION" (GROUP).

RECENT WORK CONCERNING THE SILICEOUS ROCK HAS BEEN NEITHER MORE EXTENSIVE NOR MORE FRUITFUL. TISDALE (1941, P.13-14), WHILE MAPPING THE HEART BUTTE QUADRANGLE IN NORTH DAKOTA, OBSERVED TWO TYPES OF SILICIFIED ROCKS ASSOCIATED WITH OUTCROPS OF THE PALEOCENE FT. UNION "FORMATION" (GROUP). ONE WAS A SILICIFIED, LIGHT-COLORED SHALE CONTAINING NUMEROUS ROOT CAVITIES WHILE THE OTHER WAS A DENSE, GRAY, SILICIFIED SANDSTONE. HE ATTRIBUTED THEIR ORIGIN TO THE EVAPORATION OF DISCHARGING, SILICA-RICH GROUND WATER CONTAINING SODIUM CARBONATE. IN ADDITION, HE FELT THAT THEIR OCCURRENCE AT VARIOUS ELEVATIONS AND NUMEROUS LOCATIONS INDICATED A MULTIPLE-HORIZON SOURCE. LAIRD AND MITCHELL (1942, P.22) NOTED THE OCCURRENCE OF RESIDUAL "QUARTZITIC BOULDERS" IN SOUTHERN MORTON COUNTY, NORTH DAKOTA, AND ASSIGNED THEM TO THE PALEOCENE TONGUE RIVER FORMATION. CLAYTON (1952, P.52-53) ASSIGNED A "SANDY CHERT," WHICH HE OBSERVED ASSOCIATED WITH THE DRIFT IN THE WESTERN HALF OF LOGAN AND MCINTOSH COUNTIES, NORTH DAKOTA, TO THE SAME SOURCE. MOST RECENTLY, HICKEY (1966, P.48-55) DESCRIBED A LIGHT-COLORED SILICIFIED SILTSTONE CONTAINING ABUNDANT, VERTICALLY-ORIENTED ROOT CAVITIES, WHICH OUTCROPS IN WEST-CENTRAL NORTH DAKOTA. HE ASSIGNED THIS SILTSTONE, WHICH MAY VERY POSSIBLY BE THE SAME AS THE SILICIFIED ROCKS OBSERVED BY TISDALE (1941, P.13-14), TO THE TAYLOR BED OF THE HEBRON MEMBER OF THE EOCENE GOLDEN VALLEY FORMATION. IN ADDITION, HE TOO HYPOTHESIZED "IN PLACE" DIAGENESIS OF THE ROCK IN A MARSHY ENVIRONMENT, JUST AS TODD HAD DONE MANY YEARS BEFORE, (1898, P.60-61).

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GEOLOGY

GEOLOGIC SETTING

IN THE STUDY AREA, WHICH WAS LIMITED TO NORTH DAKOTA, THE SILICEOUS ROCK IS ASSOCIATED WITH OUTCROPS OF ALL FORMATIONS FROM THE CRETACEOUS HELL CREEK FORMATION TO THE EOCENE GOLDEN VALLEY FORMATION PRIMARILY AS RESIDUAL BOULDERS OR WELL-WEATHERED SLABS BUT ALSO AS A CONSTITUENT OF POSSIBLE PLIOCENE GRAVELS AND SEDIMENT GRAVELS OF UNKNOWN AGE. IN ADDITION, THE SILICEOUS ROCK WAS OBSERVED DEFINITELY IN PLACE AT TWO SITES, AND ALTHOUGH THIS MODE OF OCCURRENCE WAS UNCOMMON, IT IS THE MOST IMPORTANT TO BE CONSIDERED IN THIS STUDY.

THE FIRST OF THESE TWO "IN PLACE" OCCURRENCES IS AT PRETTY ROCK BUTTE IN GRANT COUNTY, T13IN R98W, WHERE THE SILICEOUS ROCK IS EXPOSED ON THE BUTTE'S SOUTH AND EAST SLOPES UNDERLYING UP TO 20 FEET OF CLAY, WHICH VARIES IN COLOR FROM DARK GRAY TO PLUM TO GOLDEN YELLOW. THIS CLAY, WHICH FORMS THE TOP OF THE BUTTE, IS IN TURN COVERED BY VERY DENSE, GRAY, WIND-POLISHED BOULDERS OF THE SILICEOUS ROCK. UNDERLYING THE "IN PLACE" SILICEOUS ROCK IS A FIVE FOOT THICK WHITE CLAY BED WITH WHICH IT IS GRADATIONAL (FIGURE 1). THIS CLAY, AS WELL AS THE OVERLYING SILICEOUS ROCK, CONTAINS SUBANGULAR TO ANGULAR, SILT TO SAND-SIZE QUARTZ GRAINS AS WELL AS PLANT FOSSILS, THE LATTER CONSISTING OF VARIABLY SILICIFIED PLANT FRAGMENTS AND WOOD, AND WOOD, ROOT AND STEM CAVITIES. THE GRADATION FROM THE CLAY INTO THE SILICEOUS ROCK IS CHARACTERIZED BY AN INCREASE IN SILICIFICATION, DENSITY AND THE NUMBER AND SIZE OF THE PLANT FOSSILS. UNDERLYING THE WHITE CLAY BED IS A FIVE FOOT THICK BED OF LAVENDER TO GRAY CLAY WHICH IN TURN IS UNDERLAIN BY ABOUT 100 FEET OF SANDS, SILTS AND CLAYS RESEMBLING



FIG. 1A. -- WHITE CLAY - SILICEOUS ROCK (LEDGE) - VARIEGATED CLAY - SILICEOUS ROCK (BOULDERS) SECTION AT PRETTY ROCK BUTTE, GRANT COUNTY, T13IN R98W.



FIG. 2A. -- SECTION OF HEBRON MEMBER OF EOCENE GOLDEN VALLEY FORMATION. TAYLOR BED (LIGHT BROWN) CAPS THE SECTION. STARK COUNTY.



FIG. 1B. -- CLOSE-UP OF WHITE CLAY (BOTTOM) - SILICEOUS ROCK (TOP) GRADATIONAL CONTACT AT PRETTY ROCK BUTTE. NOTE SILICIFIED PLANT FRAGMENT (LIGHT BROWN) IN THE SILICEOUS ROCK.



FIG. 2B. -- CLOSE UP OF WHITE CLAY (BOTTOM) - SILICEOUS ROCK (TOP) GRADATIONAL CONTACT IN HEBRON MEMBER OF THE EOCENE GOLDEN VALLEY FORMATION. STARK COUNTY.

STRATA OF THE SENTINEL BUTTE FORMATION OF THE PALEOCENE FORT UNION GROUP (L. CLAYTON, PERSONAL COMMUNICATION, 1970), WHICH OUTCROPS EXTENSIVELY NEAR THIS LOCATION. CONTRARY TO THE IMPLICATION OF LLOYD (1914, P.277), THOUGH, THAT PRETTY ROCK BUTTE IS COMPOSED SOLELY OF FT. UNION STRATA, THE UPPER SECTION, THAT IS THE DARK CLAY-WHITE CLAY-SILICEOUS ROCK-VARIEGATED CLAY SECTION, MORE CLOSELY RESEMBLES THE HEBRON MEMBER OF THE EOCENE GOLDEN VALLEY FORMATION, WHICH IMMEDIATELY OVERLIES THE SENTINEL BUTTE FORMATION WHERE IT DOES OUTCROP IN NORTH DAKOTA. A LACK OF DETAILED STRATIGRAPHIC WORK PREVENTS THE FORMATION OF ANY DEFINITE CONCLUSIONS REGARDING THE AGE OF THESE STRATA BUT THE PROBLEM ASSUMES ADDED SIGNIFICANCE WHEN THE SECOND "IN PLACE" OCCURRENCE OF THE SILICEOUS ROCK IS CONSIDERED, THAT BEING THE TAYLOR BED OF THE HEBRON MEMBER OF THE EOCENE GOLDEN VALLEY FORMATION. THE TAYLOR BED, WHICH OUTCROPS IN MCKENZIE, STARK, HETTINGER, BILLINGS AND EASTERN DUNN COUNTIES (HICKEY, 1966, P. 51), IS CHARACTERIZED BY A SILICEOUS ROCK, HICKEY'S "SILICIFIED SILTSTONE" (1966, P. 48), THAT IS BASICALLY SIMILAR TO THAT OBSERVED AT PRETTY ROCK BUTTE AND ELSEWHERE. FURTHERMORE, IT OVERLIES A WHITE KAOLINITE BED WITH WHICH IT IS GRADATIONAL, EXHIBITING A RELATIONSHIP SIMILAR TO THAT OBSERVED AT PRETTY ROCK BUTTE (FIGURE 2). THUS, THOUGH IT CANNOT YET BE VALIDATED, THE POSSIBILITY OF A RELATIONSHIP BETWEEN THESE TWO "IN PLACE" OCCURRENCES DEFINITELY EXISTS. IN ADDITION, THE EOCENE GOLDEN VALLEY FORMATION MUST BE CONSIDERED A SOURCE OF THE SILICEOUS ROCK BEING STUDIED.

A MUCH MORE COMMON YET PERHAPS JUST AS IMPORTANT MODE OF OCCURRENCE OF THE SILICEOUS ROCK IS AS EXTENSIVE WELL-WEATHERED SLABS OR "CAPROCK," THE LATTER NAME DUE TO THE FACT THAT THE SILICEOUS ROCK IN THIS FORM TYPICALLY "CAPS" BUTTES AND HILLS IN THE STUDY AREA. ITS SIGNIFICANCE LIES IN THE FACT THAT THESE MAY BE POSSIBLE "IN PLACE" OCCURRENCES WITH THE OVERBURDEN ERODED AWAY. AT THESE LOCATIONS, WHICH ARE MOST COMMON IN ADAMS, BOWMAN AND GRANT COUNTIES,



Cow Butte, Adams

Section from High



FIG. 3. -- SILICEOUS ROCK COVERING THE TOP OF COW BUTTE,
ADAMS COUNTY, T128N R98W. FRACTURES PRESUMABLY EXPRESS
"FOSSIL" PATTERNED GROUND.

THE SILICEOUS ROCK OCCURS AS LARGE, WIND-POLISHED SLABS UP TO $1\frac{1}{2}$ FEET THICK AND COVERING AREAS UP TO $\frac{1}{4}$ MILES SQUARE. THESE SLABS, THOUGH ESSENTIALLY CONTINUOUS, ARE LOCALLY BROKEN UP INTO SMALLER BLOCKS. AN EXCELLENT EXAMPLE OF THIS TYPE OF OCCURRENCE EXISTS IN ADAMS COUNTY, T128N R98W, WHERE THE SILICEOUS ROCK CAPS COW BUTTE (FIGURE 3) IN A SLAB THAT IS CONTINUOUS TO THE EXTENT THAT "FOSSIL" PATTERNED GROUND, PROBABLY RELATED TO PLEISTOCENE COLD PERIODS, IS EXPRESSED IN IT (P.K. BAILEY AND L. CLAYTON, PERSONAL COMMUNICATION, 1970). ALSO, AT NEARLY EVERY SITE AT WHICH IT OCCURS IN THIS FORM, IT OVERLIES A WHITE CLAY BED SIMILAR TO THAT OBSERVED AT PRETTY ROCK BUTTE, THIS OBSERVATION, DESPITE THE FACT THAT THIS TYPE OF OCCURRENCE HAS BEEN ATTRIBUTED TO A NUMBER OF STRATIGRAPHIC UNITS, EG. T138N R102W - TONGUE RIVER FORMATION; T131N R104W - LUDLOW FORMATION; T131N R93W - CANNONBALL FORMATION (L. CLAYTON, PERSONAL COMMUNICATION, 1970).

THE OCCURRENCES OF THE SILICEOUS ROCK AS A GRAVEL CONSTITUENT ARE QUITE RARE. AT A SITE IN NORTHERN MCKENZIE COUNTY, T147N R101W, IT OCCURS AS WELL-ROUNDED COBBLES IN LOCAL PATCHES OF FLAXVILLE (PLIOCENE)-LIKE GRAVELS (HOWARD, 1956, P.1205). AT SITES IN SLOPE COUNTY, T133N R106W, AND T134N R106W, IT AGAIN OCCURS AS WELL-ROUNDED COBBLES BUT IN PEDIMENT GRAVELS OF UNKNOWN AGE (L. CLAYTON, PERSONAL COMMUNICATION, 1970). THESE GRAVELS PARTIALLY COVER THE BUTTES IN THE AREA (FIGURE 4) AS WELL AS COMPRISE A SUBSTANTIAL PORTION OF THE ARROYO-FILL IN THE CANNONBALL CREEK AREA.

THE MOST COMMON MODE OF OCCURRENCE OF THE SILICEOUS ROCK IS AS RESIDUAL BOULDERS. THESE BOULDERS, WHICH ARE GENERALLY WELL-WEATHERED, DENSE AND GRAY, COVER THE TERRAIN IN MANY LOCALITIES IN THE STUDY AREA IN VARYING DEGREES OF ABUNDANCE (FIGURE 5).

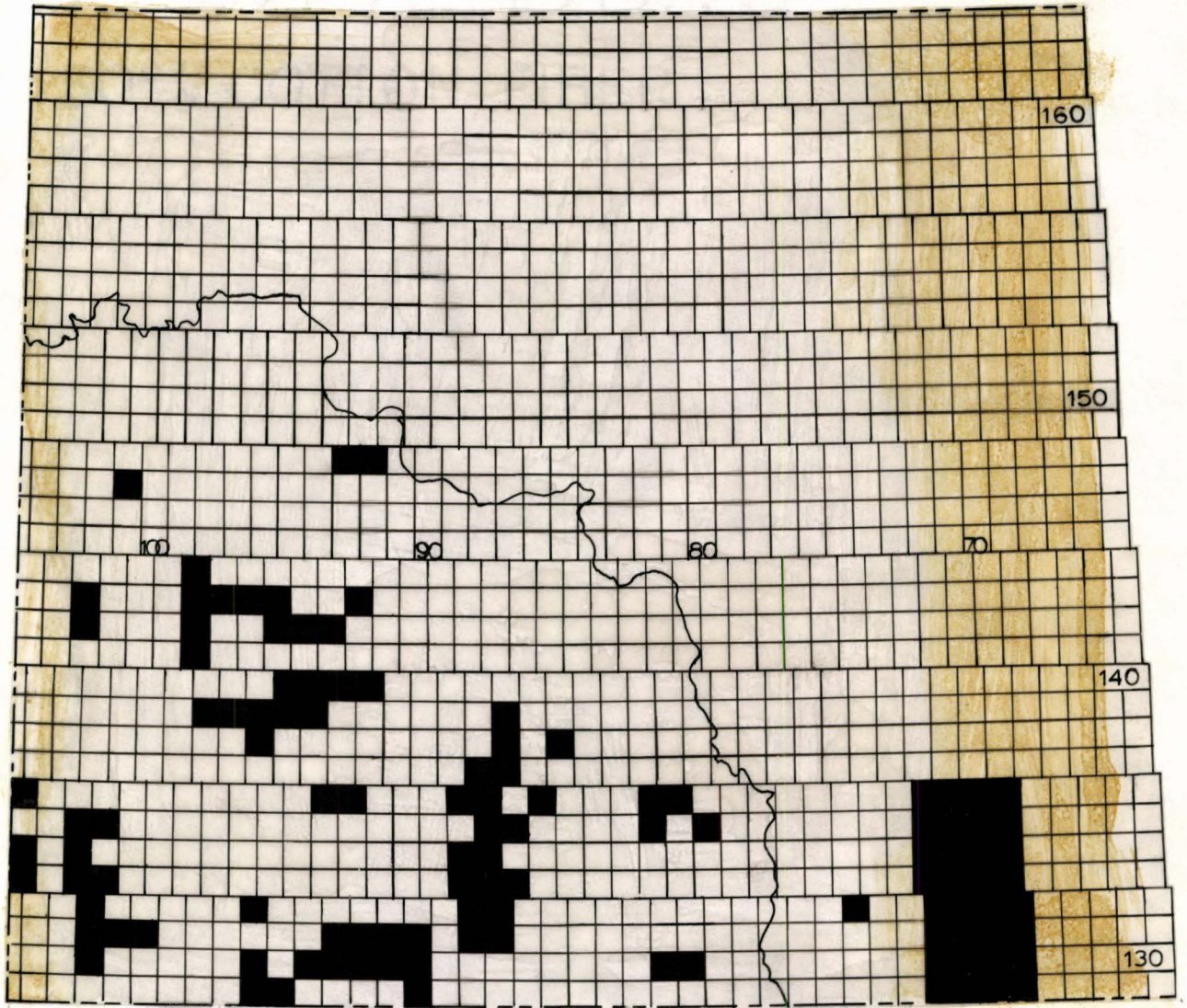
A MAP NOTING ALL OF THE DOCUMENTED OCCURRENCES OF THE SILICEOUS ROCK UNDER STUDY BY TOWNSHIP AND RANGE IS SHOWN IN FIGURE 6. AN IMPORTANT OBSERVATION IS THAT THE SILICEOUS ROCK OCCURS ALMOST EXCLUSIVELY IN UNGLACIATED AREAS, THAT IS IN AREAS BOUNDED ON THE NORTH AND EAST BY THE MISSOURI RIVER. THIS IS SIGNIFICANT IN THAT IT EXCLUDES THE POSSIBILITY OF THE SILICEOUS ROCK BEING GLACIALLY TRANS-



FIG. 4. -- PEDIMENT GRAVELS WITH HIGH SILICEOUS ROCK CONTENT COVERING TERRAIN IN SLOPE COUNTY, T133N R106W.



FIG. 5. -- BOULDERS OF SILICEOUS ROCK COVERING TERRAIN IN GOLDEN VALLEY COUNTY, T143N R103W.



■ SILICEOUS ROCK OBSERVED

FIG. 6. -- MAP OF WESTERN NORTH DAKOTA SHOWING ALL DOCUMENTED OCCURRENCES OF THE SILICEOUS ROCK.

PORTED INTO THE AREA OR FORMING FROM, OR IN, GLACIALLY-DERIVED SEDIMENTS. ALSO IT SHOULD BE NOTED THAT THE SILICEOUS ROCK DOES NOT OCCUR CONTINUOUSLY THROUGHOUT THE EXTENT OF ITS RANGE, AN OBSERVATION THAT MAY BE IMPORTANT IN RECONSTRUCTING ITS DEPOSITIONAL AND DIAGENETIC HISTORY.

PETROGRAPHY

FIELD CHARACTER

UPON VISUAL EXAMINATION, HAND SPECIMENS COLLECTED THROUGHOUT THE STUDY AREA WERE FOUND TO VARY FROM A SILICA-CEMENTED SILTSTONE TO AN ARENACEOUS SILICEOUS ROCK, PRESUMABLY CHERT. IN ADDITION, MANY CONTAINED A SMALL SAND-SIZE DETRITAL GRAIN FRACTION, WHILE SEVERAL HAD A MINOR AMOUNT OF CALCITE CEMENT, IN ADDITION TO THE SILICA. CLOSER EXAMINATION OF THESE SAMPLES WITH A BINOCULAR MICROSCOPE REVEALED THAT BOTH THE SILT-SIZE AND SAND-SIZE DETRITAL FRACTIONS ARE COMPOSED ALMOST ENTIRELY OF QUARTZ GRAINS WHICH ARE SUBROUNDED TO ANGULAR, THOUGH MOST ARE SUBANGULAR. IN ADDITION, THE SAND-SIZE GRAINS, WHICH INVARIABLY AMOUNT TO A MINORITY OF THE GRAINS PRESENT, RANGE FROM VERY FINE TO FINE ON WENTWORTH'S SCALE. THE CEMENT, WITH THE EXCEPTION OF THE FEW PREVIOUSLY NOTED SAMPLES, IS SILICA. IN GENERAL THE ROCK IS QUITE DENSE, WITH THE DENSITY VARYING DIRECTLY WITH THE DEGREE OF SILICIFICATION. IN ADDITION, THE HIGH SILICA CONTENT OF THE ROCK GIVES IT A GENERALLY UNIFORM HARDNESS. AS A RESULT, WHEN IT BREAKS, IT DOES SO ACROSS ITS CONSTITUENT GRAINS INTO IRREGULAR BLOCKS.

THE SILICEOUS ROCK IS TYPICALLY GRAY TO GRAY-BROWN. A NOTEWORTHY EXCEPTION IS THAT OF THE TAYLOR BED, WHICH VARIES FROM LIGHT BROWN TO YELLOW-BROWN TO LIGHT GRAY, THE LATTER GRADING LOCALLY TO THE MORE TYPICAL DARK GRAY. ON THE WEATHERED SURFACE IT IS GENERALLY SOME SHADE OF BROWN, POSSIBLY DENOTING HIGHER CONCENTRATIONS OF IRON-OXIDES. INCLUDED PLANT MATTER WHICH HAS BEEN SILICIFIED IS LIGHT BROWN WHILE VERY DARK GRAY TO BLACK STREAKS AND PATCHES ARE COMMON AND

ARE THOUGHT TO REPRESENT CONCENTRATIONS OF UNREPLACED ORGANIC MATTER.

AT MANY LOCALITIES WHERE THE SILICEOUS ROCK OCCURS IN FORMS OTHER THAN RESIDUAL BOULDERS, IT EXHIBITS A LIGHT BROWN TO GRAY-BROWN LAYER OF LESS DENSE, SOFTER MATERIAL UP TO SEVERAL INCHES THICK AROUND ITS OUTSIDE (FIGURE 7). THIS MATERIAL IS GRADATIONAL WITH THE MORE TYPICAL, GRAY, DENSE ROCK WHICH IT SURROUNDS AND THUS COULD EITHER BE A WEATHERED RIND OF THE MORE TYPICAL MATERIAL OR MATERIAL WHICH HAS NOT YET UNDERGONE SILICIFICATION. THE FORMER ALTERNATIVE IS FAVORED FOR SEVERAL REASONS. FIRST OF ALL, IN THIS SECTION THE MORE TYPICAL SILICEOUS ~~*** ROCK~~ AND THE SOFTER MATERIAL CANNOT BE DISTINGUISHED FROM ONE ANOTHER EXCEPT FOR A GENERALLY HIGHER CONCENTRATION OF IRON-OXIDES, A COMMON WEATHERING PRODUCT, IN THE LATTER. IN ADDITION, THE LAYER OF SOFT MATERIAL WAS OBSERVED TO COMPLETELY ENVELOPE THE MORE TYPICAL SILICEOUS ROCK IN SEVERAL SAMPLES, A VIRTUAL IMPOSSIBILITY IF THE FORMER WAS TO REPRESENT UNSILICIFIED MATERIAL OF THE SAME COMPOSITION AS THE LATTER. A POSSIBLE REASON FOR THE WEATHERING OF SUCH A HIGHLY SILICEOUS ROCK COULD BE THAT LOCALLY, THE UNREPLACED ORGANIC MATTER CONTENT IS HIGHER THAN NORMAL THUS MAKING THE ROCK MORE SUBJECT TO WEATHERING AND SUBSEQUENTLY RESULTING IN A PRODUCT SUCH AS WAS OBSERVED.

IN ADAMS COUNTY, T130N R98W, SOME OF THE SILICEOUS ROCK WAS FOUND WEATHERED TO RED-BROWN, FRIABLE, RELATIVELY LIGHT MASSES, BUT THIS WAS EXCEPTIONAL. THE SILICEOUS ROCK FOUND IN GRAVEL DEPOSITS WAS GENERALLY WELL-WEATHERED AND USUALLY EXHIBITED A THIN BROWN PATINA. ELSEWHERE, SMOOTH, WIND-POLISHED SURFACES WERE THE RULE. OFTEN THESE SURFACES WERE PITTED AND GROOVED, PRESUMABLY BY WIND-DRIVEN SAND. AN EXCELLENT EXAMPLE OF THIS OCCURS IN ADAMS COUNTY, T130N R98W, WHERE WIND-DRIVEN SAND HAS WORN A DISCONTINUOUS SET OF NW-SE TRENDING GROOVES INTO THE EXTENSIVE SLABS OF SILICEOUS ROCK OCCURRING THERE (FIGURE 8) AND THEREIN EXPRESSING THE PREVAILING WIND DIRECTION DURING THE QUATERNARY PERIOD.

IN CONTRAST TO ITS GENERALLY SLAB-LIKE FORM, THE SILICEOUS ROCK, THOUGH



FIG. 7. -- SILICEOUS ROCK EXHIBITING LIGHT BROWN, WEATHERED RIND, ADAMS COUNTY, T130N R98W. NOTE ROOT CAVITY IN SAMPLE ON THE LEFT.

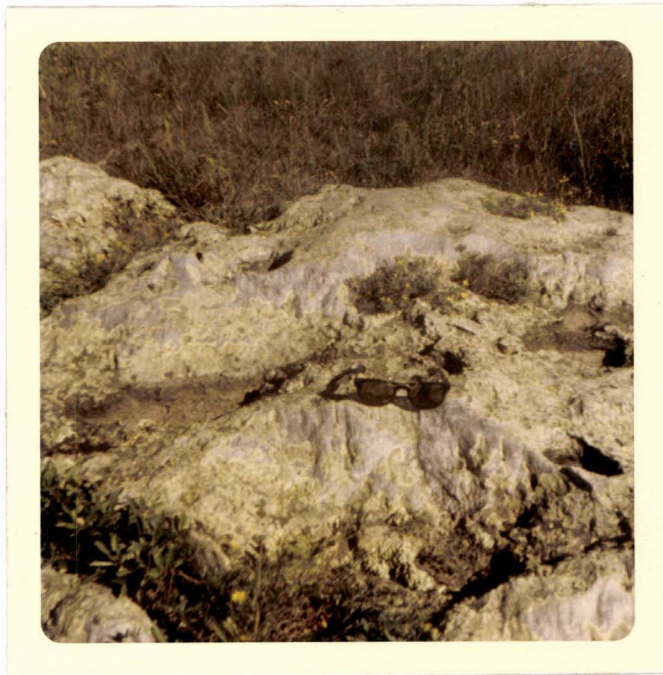


FIG. 8. -- SILICEOUS ROCK EXHIBITING ROUGHLY PARALLEL PITS AND GROOVES PROBABLY CAUSED BY WIND - DRIVEN SAND. PREFERRED WIND DIRECTION EXPRESSED IS FROM THE NORTHWEST (BOTTOM) TO THE SOUTHEAST (TOP). ADAMS COUNTY, T130N R98W.

TYPICALLY GRAY AND DENSE, EXHIBITS CHARACTERISTICS AT SEVERAL LOCALITIES, WHICH ARE USUALLY RELATED TO CONCRETIONS AND THUS SUGGEST A CONCRETIONARY ORIGIN, POSSIBLY BY THE DEPOSITION OF COLLOIDAL SILICA. THESE INCLUDE ALTERNATING LIGHT AND DARK BANDS, POSSIBLY RELATED TO CONCENTRATIONS OF UNREPLACED ORGANIC MATTER (FIGURE 9), REGULAR, ROUNDED AND EVEN NODULAR FORM (FIGURE 10), AND MAMMALLARY STRUCTURE ON BOTH SIDES OF SPECIMENS (FIGURE 11). IT SHOULD BE NOTED THAT THIS MAMMALLARY STRUCTURE WAS ALSO OBSERVED ELSEWHERE IN THE STUDY AREA BUT ONLY ON ONE SIDE OF WHAT WERE CONSIDERED TYPICAL SLABS OF THE SILICEOUS ROCK, THAT BEING THE TOP. WHETHER THESE EXCEPTIONAL SPECIMENS HAVE BEEN FORMED LIKE OTHER CONCRETIONS EXHIBITING SIMILAR PROPERTIES AND WHETHER THE DEPOSITION OF COLLOIDAL SILICA WAS LOCALLY PART OF THE DIAGENETIC HISTORY OF THE SILICEOUS ROCK ARE BOTH QUESTIONS WHICH CANNOT BE ANSWERED WITHOUT MORE DETAILED WORK. YET THE POSSIBILITY THAT BOTH SUPPOSITIONS ARE CORRECT IS SUGGESTED BY THE OBSERVATIONS AND THUS MUST DEFINITELY BE CONSIDERED IN ANY DISCUSSION CONCERNING THE ORIGIN OF THE SILICEOUS ROCK.

PERHAPS THE MOST NOTEWORTHY CHARACTERISTIC OF THE SILICEOUS ROCK IS THE PLANT FOSSILS WHICH IT CONTAINS (FIGURE 12). THESE INCLUDE VARIABLY SILICIFIED PLANT MATERIAL AND WOOD, AND WOOD, ROOT AND STEM CAVITIES, OR MORE CORRECTLY CASTS. THE INCLUDED PLANT MATTER OCCURS MAINLY AS DISSEMINATED PARTICLES WHICH ARE OFTEN CONCENTRATED IN STREAKS OR PATCHES, THOUGH LARGER FRAGMENTS ARE NOT UNCOMMON. THE WOOD OCCURS TYPICALLY AS BRANCHES OR BROKEN PIECES, THE LATTER OFTEN MORE THAN A FOOT IN LENGTH. WHEN EITHER WOOD OR OTHER PLANT MATTER OR BOTH ARE PRESENT IN THE SILICEOUS ROCK, THEY ARE READILY DISTINGUISHABLE FROM THE HOST ROCK BOTH BY THE PLANT STRUCTURES THAT THEY RETAIN IF THEY AREN'T DISSEMINATED AND BY THEIR COLOR. IF COMPLETE SILICIFICATION HAS OCCURRED, THE INCLUDED MATTER IS TYPICALLY LIGHT BROWN, OR LIGHTER THAN THE SILICEOUS ROCK. ON THE OTHER HAND, IF NEGLIGIBLE SILICIFICATION HAS OCCURRED, THE INCLUDED MATTER IS VERY



FIG. 9. -- SILICEOUS ROCK EXHIBITING ALTERNATING LIGHT AND DARK BANDS. GOLDEN VALLEY COUNTY, T143N R103W.

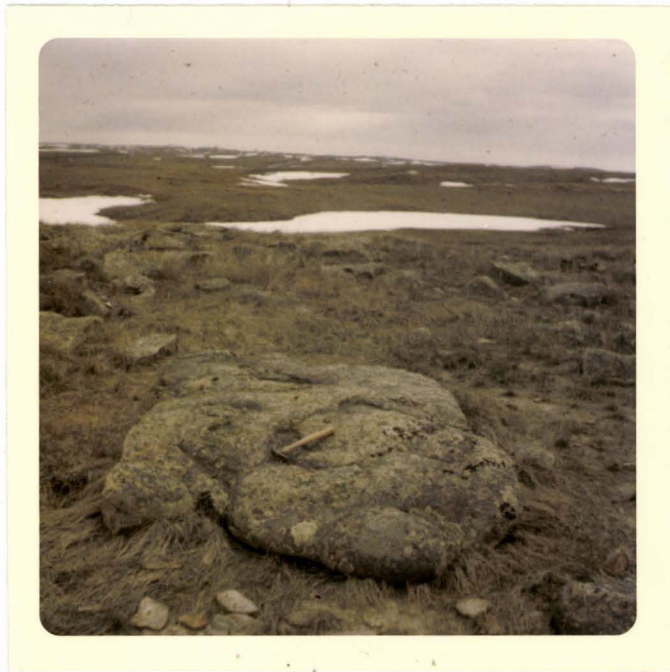


FIG. 10. -- SILICEOUS ROCK EXHIBITING ROUNDED, NODULAR FORM. BILLINGS COUNTY, T132N R90W.

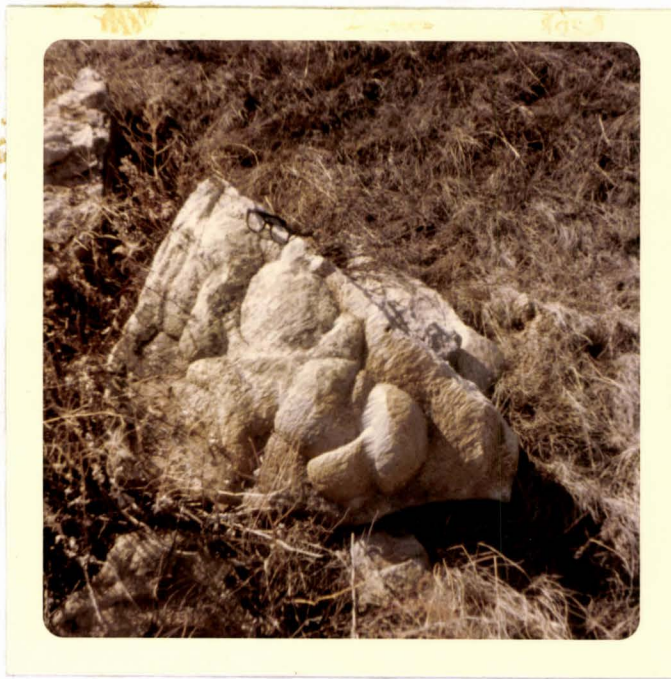


FIG. 11. -- SILICEOUS ROCK EXHIBITING MAMMALLARY STRUCTURE. ^{SP?}
LOCATION UNKNOWN.



FIG. 12. -- SILICEOUS ROCK WITH INCLUDED SILICIFIED PLANT
REMAINS (LIGHT BROWN). ADAMS COUNTY, T130N R98W.

DARK GRAY TO BLACK. STREAKS AND PATCHES OF BOTH COLORS ARE EXHIBITED BY THE INCLUDED MATTER AT ANY INTERMEDIATE STAGE OF SILICIFICATION.

A COMMON PHENOMENON IS FOR PIECES OF WOOD AND MORE COMMONLY LARGER PLANT FRAGMENTS INCLUDING ROOTS AND STEMS TO DECOMPOSE OR WEATHER OUT OF THE SILICEOUS ROCK, PRESUMABLY BEFORE THEY ARE COMPLETELY SILICIFIED. THIS RESULTS IN NUMEROUS CAVITIES IN THE SILICEOUS ROCK, WHICH ARE ACTUALLY CASTS OF THE ABSENT MATERIAL. THESE CAVITIES ARE OFTEN LINED WITH IRON-OXIDES, AND FREQUENTLY EXHIBIT IMPRESSIONS OF KNOTS, BORINGS, BARK AND OTHER PLANT FEATURES. THOSE OF ROOTS AND STEMS RANGE UP TO THREE INCHES IN DIAMETER WHILE THOSE OF WOOD ATTAIN MUCH GREATER DIMENSIONS. WHERE THE SILICEOUS ROCK IS FOUND IN PLACE, OR PRESUMABLY SO, THE ROOT AND STEM CAVITIES ARE ORIENTED VERTICALLY, OR NEARLY SO, WHILE THE INCLUDED WOOD AND/OR WOOD CASTS ARE RANDOMLY ORIENTED. THIS IMPLIES "IN PLACE" DIAGENESIS OF THE SILICEOUS ROCK IN A PLANT-PRODUCING ENVIRONMENT, PRESUMABLY AQUATIC, NEAR WHICH SUBSTANTIAL STANDS OF TREES GREW. A MARSH OR POND ENVIRONMENT IS SUGGESTED.

THIN SECTION

IN THIN SECTION, THE SILICEOUS ROCK WAS GENERALLY OBSERVED TO VARY FROM AN ARENACEOUS CHERT (FIGURE 13) TO A SANDY, CHERT-CEMENTED SILTSTONE (FIGURE 14), THE DEFINING FACTOR BEING THE SECONDARY CHERT TO DETRITAL GRAIN RATIO. THIS VARIATION WAS NOT ONLY NOTICEABLE FROM SITE TO SITE AND BETWEEN SAMPLES FROM THE SAME SITE BUT EVEN IN INDIVIDUAL THIN SECTIONS. SEVERAL THIN SECTIONS FROM THE SENTINEL BUTTE AREA, T142N R103W AND T143N R103W, WERE FOUND TO BE OF A VERY WELL-CEMENTED, CLEAN, QUARTZOSE SANDSTONE WITH THE CEMENT BEING SILICA WITH SECONDARY CALCITE. THIS SANDSTONE, THOUGH VERY POSSIBLY SUBJECTED TO THE SAME DIAGENETIC PROCESSES, WAS QUITE DIFFERENT FROM THE SILICEOUS ROCK OBSERVED ELSEWHERE AND SHALL BE TREATED AS AN EXCEPTION.

THE GRAINS OF THE DETRITAL FRACTION, WHETHER MORE OR LESS ABUNDANT THAN THE CHERT, RANGE IN SIZE FROM CLAY TO FINE SAND ACCORDING TO WENTWORTH'S SCALE (FIGURE 15). IN REGARD TO GRAIN-SIZE DISTRIBUTION, THE SILT-SIZE GRAINS ARE

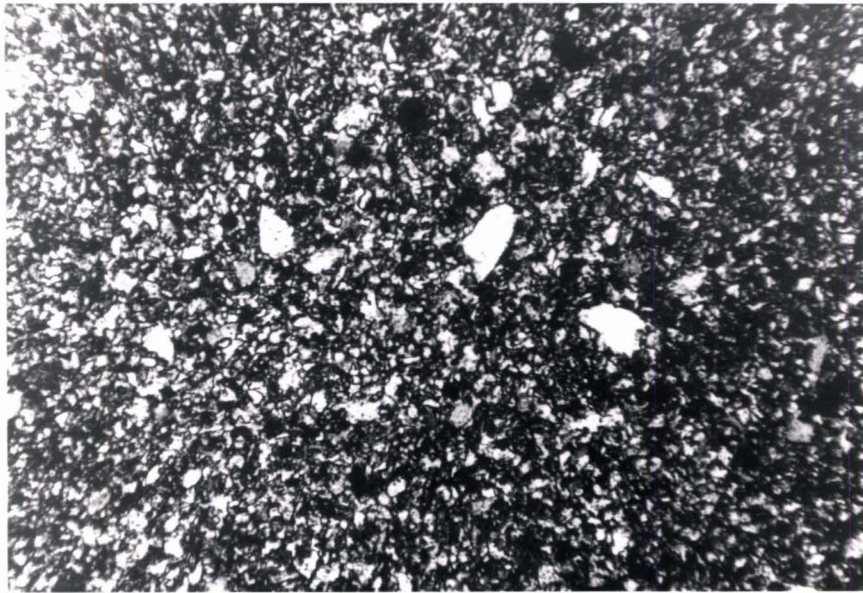


FIG. 13 -- PHOTOMICROGRAPH OF A TYPICAL ARENACEOUS CHERT.
NOTE THE DETRITAL QUARTZ GRAINS NEAR THE CENTER. CROSSED
NIC/OLS, X 35.

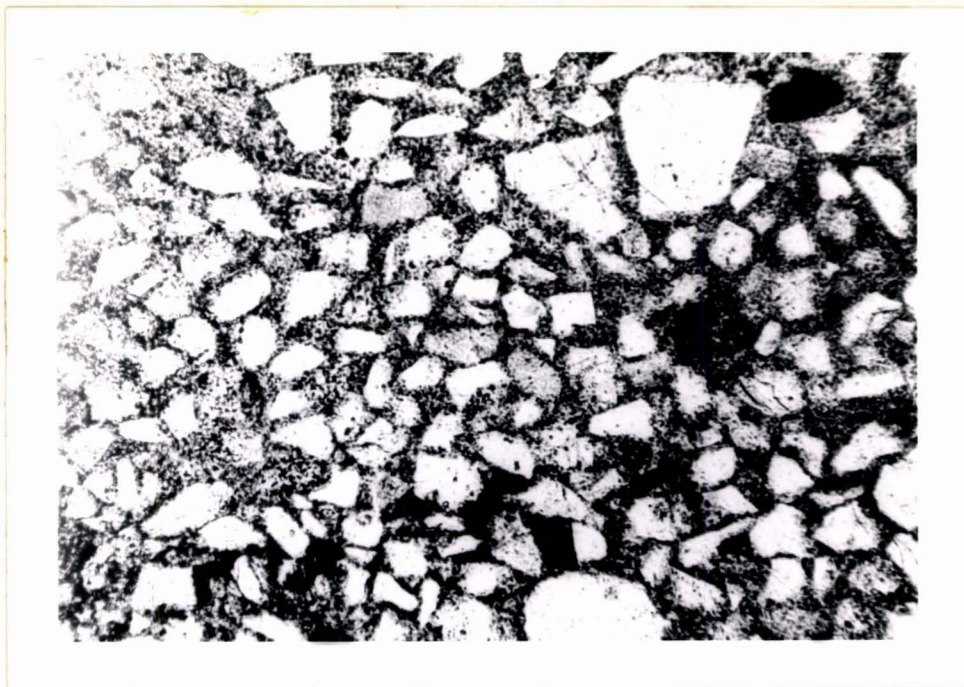


FIG. 14 A. -- PHOTOMICROGRAPH OF A TYPICAL SANDY, CHERT-CEMENTED SILTSTONE. NOTE THE FRINGE-LIKE MARGINS ON MANY OF THE DETRITAL GRAINS. DARK MATERIAL IN THE MATRIX IS DISSEMINATED, UNREPLACED ORGANIC MATTER. X 35.

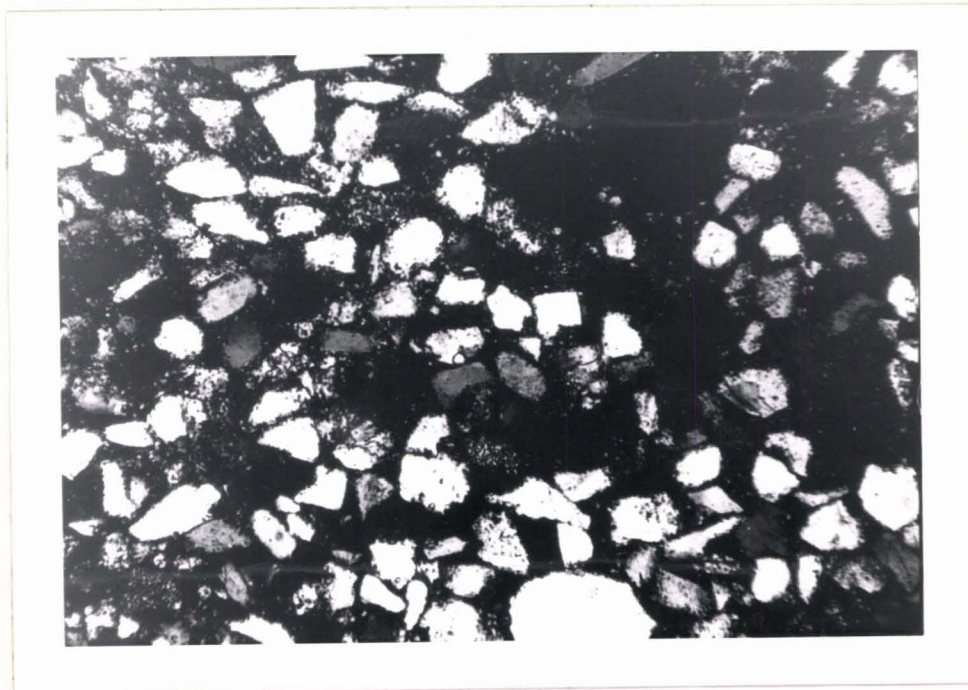


FIG. 14 B. -- SAME AS FIG. 14 A. BUT WITH CROSSED NICOLS.

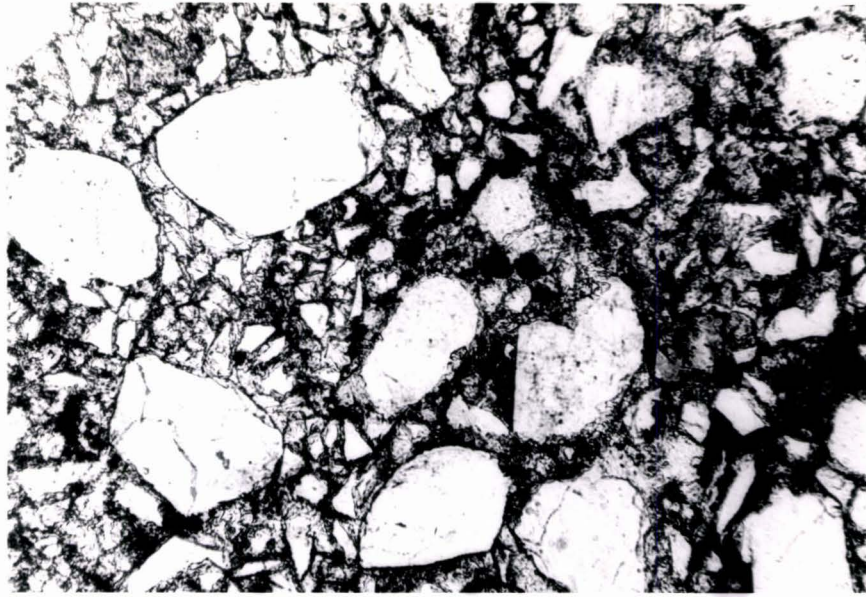


FIG. 15 A. -- PHOTOMICROGRAPH OF A SANDY, CHERT-CEMENTED SILTSTONE WITH DETRITAL GRAINS RANGING FROM SILT TO FINE-SAND SIZE. X 35.

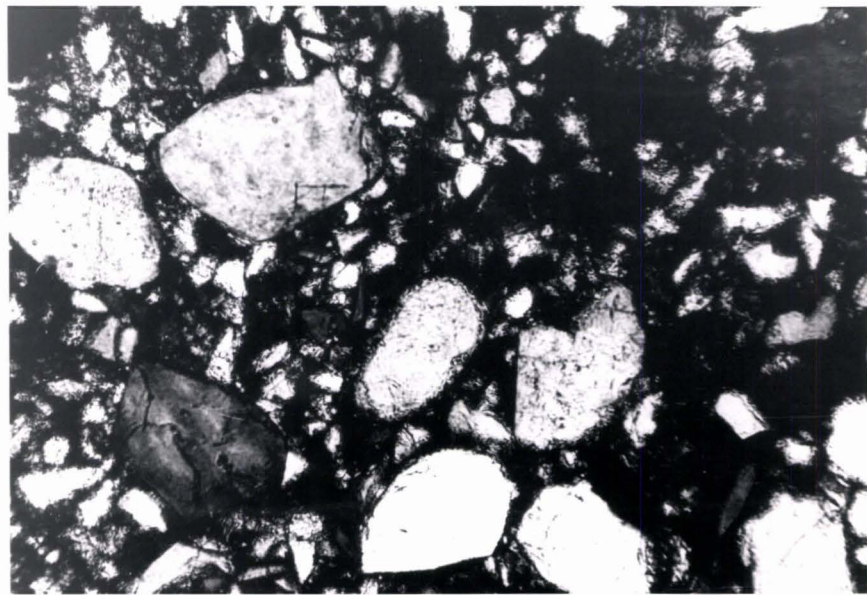


FIG. 15 B. -- SAME AS FIG. 15 A. BUT WITH CROSSED NICKOLS.

WITHOUT EXCEPTION THE MOST ABUNDANT WHILE THE FINE-SIZE SAND GRAINS ARE LEAST ABUNDANT WHERE PRESENT AT ALL. THE RELATIVE ABUNDANCE OF THE CLAY-SIZE FRACTION WAS DIFFICULT TO ESTIMATE. THE DETRITAL GRAINS ARE COMPOSED MAINLY OF QUARTZ THOUGH SCATTERED GRAINS OF CHERT AND ASSORTED HEAVY MINERALS, EG. SPHENE, EPIDOTE, HORNBLLENDE, MUSCOVITE AND GARNET, WERE OBSERVED. ALSO, AT LEAST PART OF THE CLAY-SIZE GRAINS ARE PRESUMABLY COMPOSED OF ONE OR MORE OF THE CLAY MINERALS. ALL OF THESE GRAINS ARE SUBROUNDED TO ANGULAR WITH THE DEGREE OF ROUNDNESS INCREASING WITH GRAIN SIZE. THEY ARE ALSO GENERALLY MODERATELY WELL SORTED AND RANDOMLY ORIENTED, EXHIBITING NO DISCERNIBLE SEDIMENTARY STRUCTURES OR TEXTURES OTHER THAN IRREGULAR LOCAL CONCENTRATIONS OF DETRITAL GRAINS. COMMON TO THE SILT-SIZE GRAIN FRACTION ARE GRAINS SHAPED LIKE SPLINTERS OR ELONGATE CHIPS. THE "SECONDARY" SILICA, WHETHER MAKING UP A MINOR OR MAJOR PORTION OF THE ROCK, IS MOST COMMONLY IN THE FORM OF MICROCRYSTALLINE QUARTZ OR CHERT. THIS CHERT, THOUGH LOCALLY CLEAR, MORE GENERALLY CONTAINS SMALL DISSEMINATED PARTICLES OF ORGANIC MATTER, POSSIBLE SCATTERED GRAINS OF CLAY, AND LIQUID AND GAS INCLUSIONS. IN ADDITION, THERE IS A DEFINITE RELATIONSHIP BETWEEN THE AMOUNT OF ORGANIC MATTER AND THE AMOUNT OF CHERT PRESENT IN ANY GIVEN THIN SECTION EXAMINED. THE BLACK TO BROWN TO RED-BROWN ORGANIC MATTER, WHICH IS A COMMON CONSTITUENT OF THE SILICEOUS ROCK STUDIED AND OCCURS AS BOTH DISSEMINATED PARTICLES AND VARIABLY REPLACED PLANT FRAGMENTS (FIGURE 16), GIVES THE ROCK A DIRTY APPEARANCE, ESPECIALLY WHERE HEAVILY CONCENTRATED. IN THESE AREAS OF HEAVY ORGANIC MATTER CONCENTRATION, WHICH ARE OFTEN THE SAME AREAS OF LOCAL DETRITAL GRAIN CONCENTRATION, THE AMOUNT OF CHERT VARIES FROM NEGLIGIBLE TO SCATTERED PATCHES (FIGURE 17). AS THE AMOUNT OF ORGANIC MATTER, WHICH IN THESE CASES IS GENERALLY IN THE FORM OF DISSEMINATED PARTICLES, DECREASES, THE AMOUNT OF CHERT INCREASES, RESULTING FINALLY IN THE PREVIOUSLY MENTIONED AREAS OF CLEAR, OR ALMOST CLEAR, CHERT. THE RELATIONSHIP

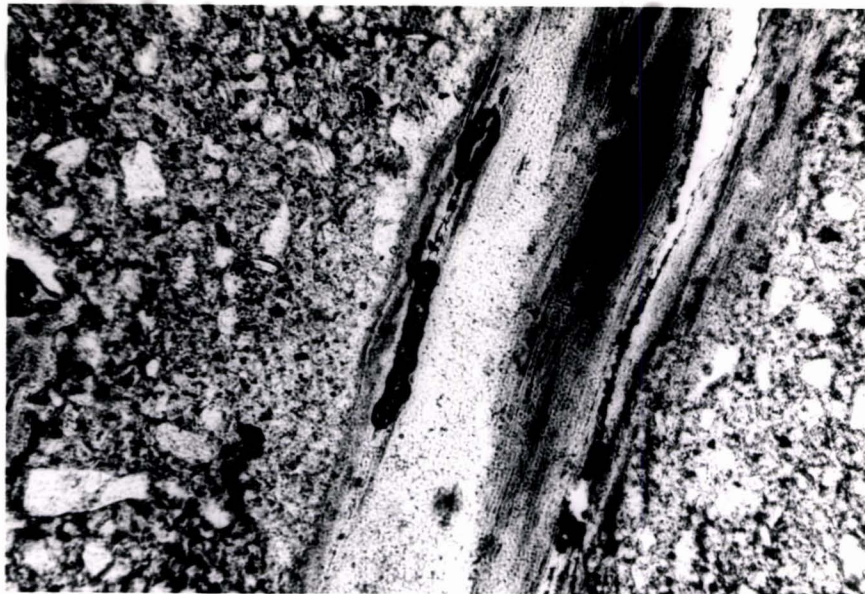


FIG. 16 A. -- PHOTOMICROGRAPH OF AN ARENACEOUS CHERT CONTAINING A PLANT FRAGMENT THAT IS PARTIALLY REPLACED BY CHERT. NOTE THAT THE DARK AREAS ARE UNREPLACED ORGANIC MATTER AND THE LIGHTER AREAS ARE CHERT. X 35.

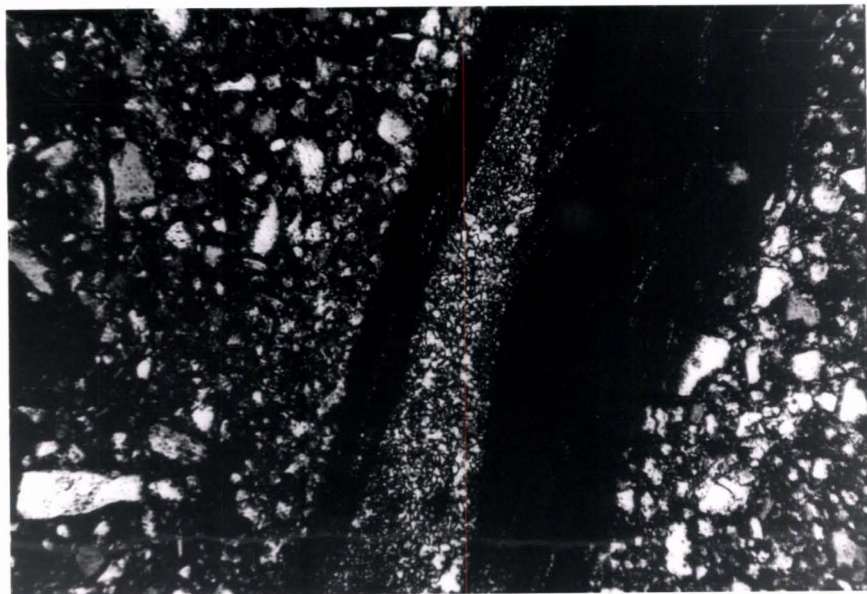


FIG. 16 B. -- SAME AS FIG. 16 A. BUT WITH CROSSED NICOLS.

PLATE NO. 16
AMONG OTHERS

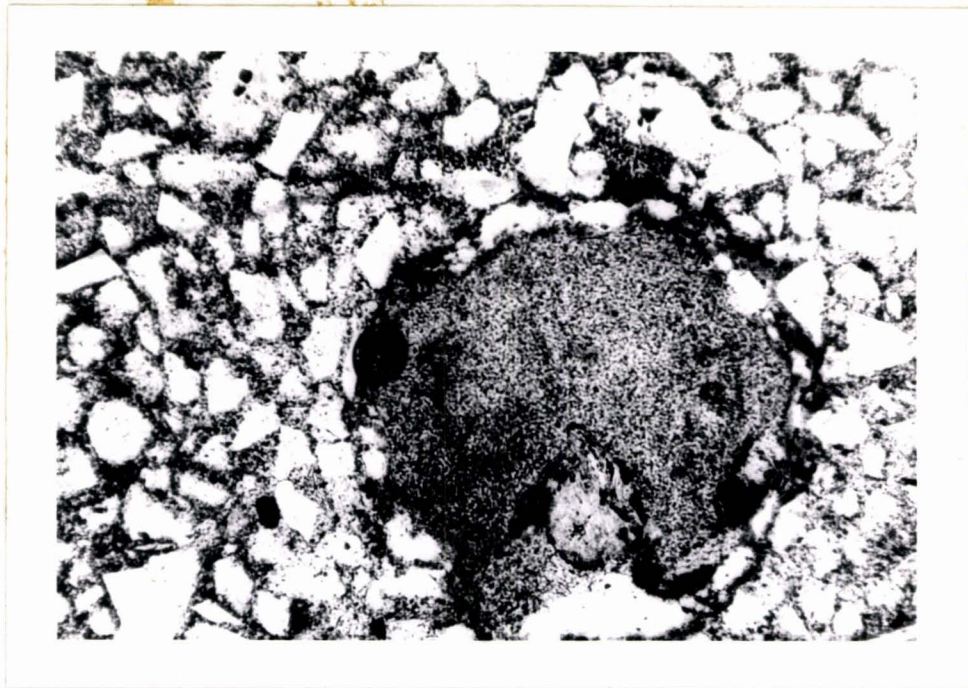


FIG. 17 A. -- PHOTOMICROGRAPH OF A CHERT-CEMENTED SILSTONE IN WHICH THE AMOUNT OF CHERT IS QUITE SMALL IN COMPARISON TO THE AMOUNT OF UNREPLACED ORGANIC MATTER (DARK), WHICH OCCURS AS DISSEMINATED PARTICLES. NOTE THAT THE ROUND FEATURE IS A ROOT CAVITY CONTAINING PARTIALLY CHERT-REPLACED ORGANIC MATTER. X 35.

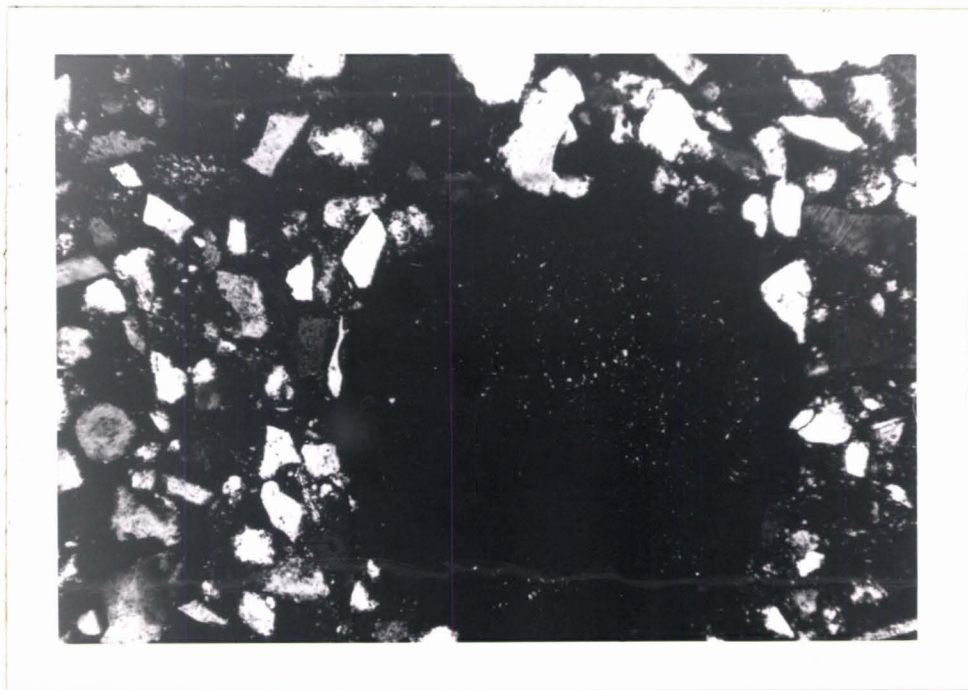


FIG. 17 B. -- SAME AS FIG. 17 A. BUT WITH CROSSED NICOLS.

BETWEEN THE CHERT AND THE LARGER PLANT FRAGMENTS IS ALSO AN INVERSE ONE IN WHICH THE CHERT REPLACES THE ORGANIC MATTER IN THE PLANT FRAGMENTS (FIGURES 18 AND 19). THE PROCESS INITIALLY BEGINS ANYWHERE IN THE PLANT FRAGMENT WITH THE DEPOSITION OF EXTREMELY FINE-GRAINED CHERT. REPLACEMENT AND RECRYSTALLIZATION THEN PROGRESS UNTIL THE ORGANIC MATTER IS ENTIRELY REPLACED BY CHERT THAT TYPICALLY GRADES FROM VERY FINELY CRYSTALLINE ON THE MARGINS OF THE REPLACED FRAGMENT TO COARSELY CRYSTALLINE IN THE MIDDLE.

ANOTHER FORM OF "SECONDARY" SILICA IS AS OVERGROWTHS OR PARTIAL OVERGROWTHS ON DETRITAL QUARTZ GRAINS (FIGURE 20). WHERE THEY OCCUR, THEY ARE TYPICALLY OPTICALLY CONTINUOUS WITH THE GRAINS THEY ENVELOPE AND ARE NOT READILY DISTINGUISHABLE EXCEPT WHERE SEPARATED FROM THE DETRITAL GRAINS BY THIN LAYERS OF DISSEMINATED ORGANIC MATTER, CLAY PARTICLES, OR LIQUID OR GAS INCLUSIONS, ALL OF WHICH ARE PRESENT ELSEWHERE IN THE ROCK. MORE TYPICALLY THOUGH, THE DETRITAL GRAINS EXHIBIT A FRINGE-LIKE CHARACTER AROUND THEIR MARGINS (FIGURE 21). IN THESE CASES, IT IS POSSIBLE THAT CONCENTRATIONS OF CLAY AND/OR ORGANIC MATTER ABOUT OR NEAR THE GRAINS HAVE PROHIBITED THE COMPLETE DEPOSITION OF SILICA OVERGROWTHS (HEALD, 1956, P.19). ON THE OTHER HAND, THESE FRINGE-LIKE BORDERS MAY BE DUE TO SOME REACTION BETWEEN THE DETRITAL GRAINS AND THE SURROUNDING MATRIX SOMETIME DURING ITS DIAGENETIC HISTORY. THIS LATTER EXPLANATION IMPLIES THE OCCURRENCE OF AT LEAST PARTIAL SOLUTION OF THE GRAINS WHICH WOULD HAVE NECESSITATED AN EXTREMELY ALKALINE ENVIRONMENT. ON THE CONTRARY, THE HIGH SECONDARY SILICA CONTENT OF THE ROCK INDICATES AN ACIDIC ENVIRONMENT, THAT IS ONE FAVORABLE FOR THE DEPOSITION OF SILICA. THUS THE RETARDATION OF SILICA OVERGROWTH DEPOSITION BY ORGANIC AND/OR CLAY RIMS SEEMS THE PROBABLE EXPLANATION.

IN THE THIN SECTIONS STUDIED, CARBONATES WERE TOTALLY LACKING WITH ONE EXCEPTION. THIS WAS THE GROUP OF SAMPLES FROM THE PREVIOUSLY MENTIONED SENTINEL BUTTE SITE, T142N R103W AND T143N R103W, WHICH CONTAINED SOME CALCITE,

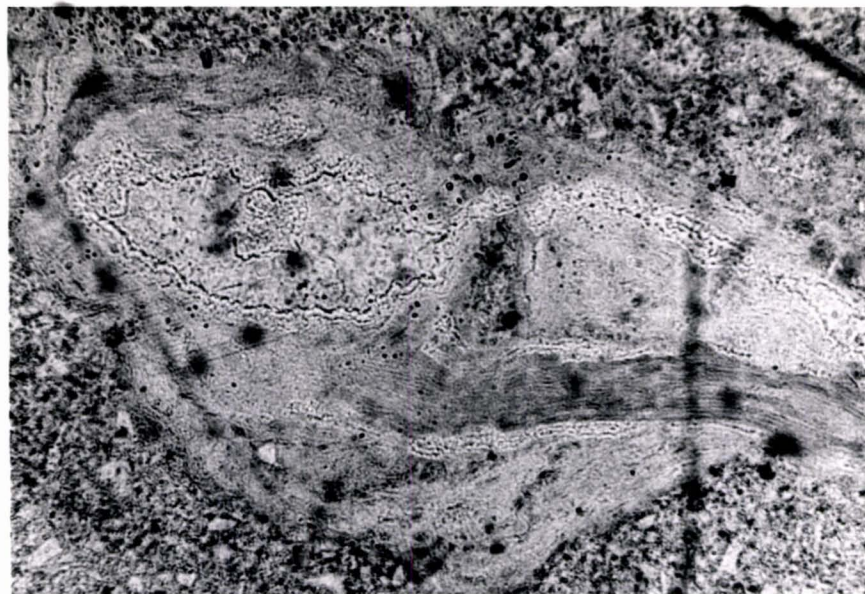


FIG. 18 A. -- PHOTOMICROGRAPH OF AN ARENACEOUS CHERT CONTAINING A PLANT FRAGMENT THAT HAS BEEN ALMOST ENTIRELY REPLACED BY CHERT. X 35.

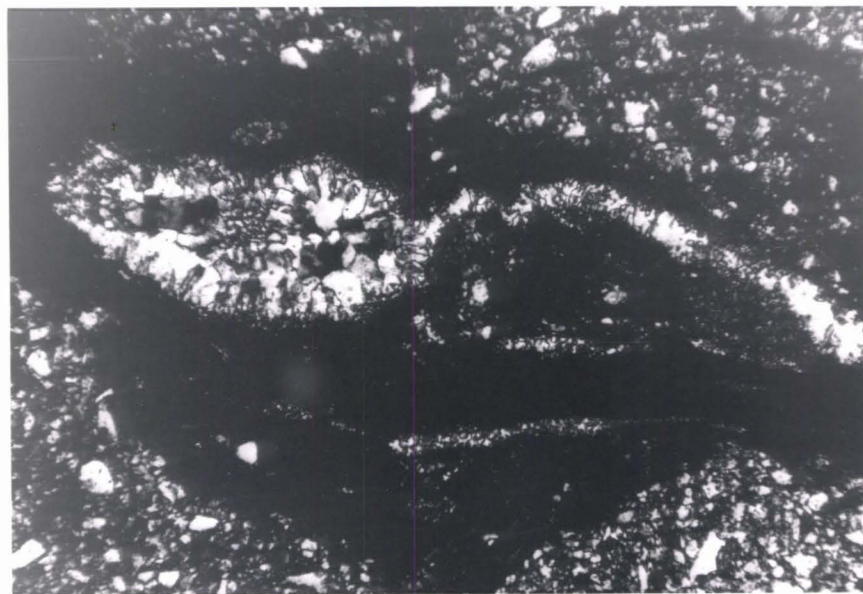


FIG. 18 B. -- SAME AS FIG. 18 A. BUT WITH CROSSED NICOLS. NOTE THE GRADATION FROM FINELY CRYSTALLINE CHERT ON THE MARGINS OF THE PLANT FRAGMENT TO COARSELY CRYSTALLINE CHERT AT THE CENTER.

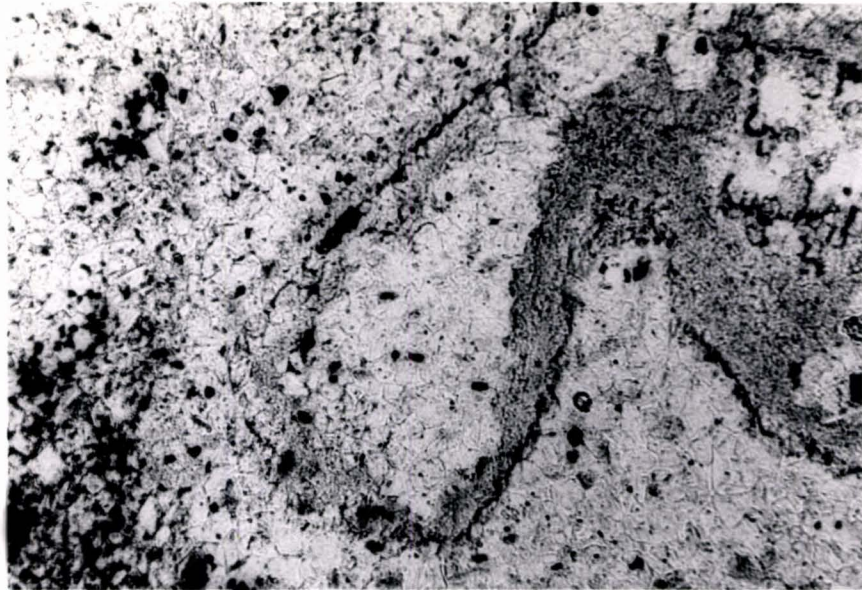


FIG. 19 A. -- PHOTOMICROGRAPH OF AN ARENACEOUS CHERT CONTAINING A PLANT FRAGMENT THAT HAS BEEN ALMOST ENTIRELY REPLACED BY CHERT. X 35.



FIG. 19 B. -- SAME AS FIG. 19 A. BUT WITH CROSSED NICOLS. NOTE THE GRADATION FROM FINELY CRYSTALLINE CHERT ON THE MARGINS OF THE PLANT FRAGMENT TO COARSELY CRYSTALLINE CHERT AT THE CENTER.

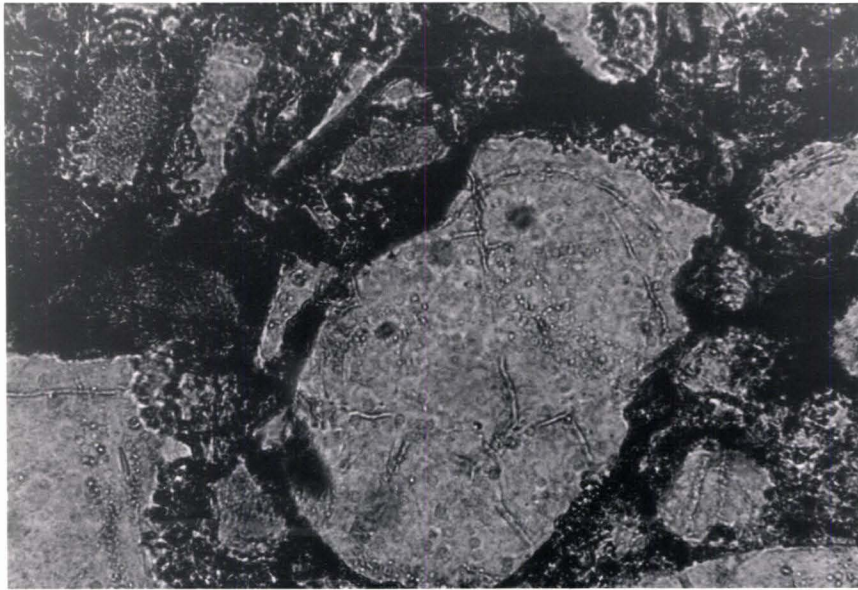


FIG. 20. -- PHOTOMICROGRAPH OF A SANDY, CHERT-CEMENTED SILTSTONE WITH A DETRITAL GRAIN (CENTER) EXHIBITING A PARTIAL SECONDARY QUARTZ OVERGROWTH. CROSSED NICOLS, X 100.

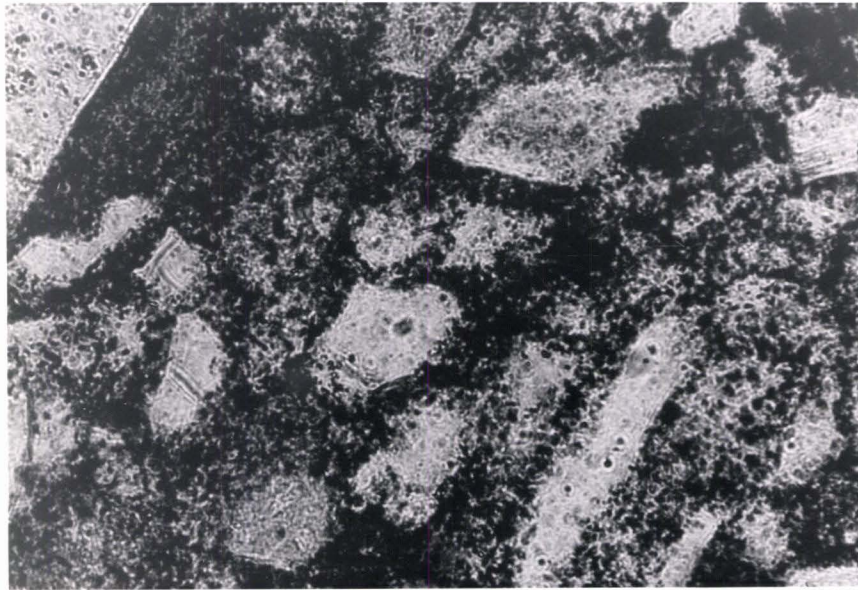


FIG. 21 -- PHOTOMICROGRAPH OF A SANDY, CHERT-CEMENTED SILTSTONE WITH THE DETRITAL GRAINS EXHIBITING FRINGE-LIKE MARGINS. CROSSED NICOLS, X 100.

PRESUMABLY AS A PARTIAL REPLACEMENT PRODUCT OF THE CHERT CEMENT AND SECONDARY QUARTZ OVERGROWTHS.

DISCUSSION

SPECULATION ON THE ORIGIN OF THE SILICEOUS ROCK IS AS INTERESTING AS THE CHARACTERISTICS WHICH IT EXHIBITS, AND INCLUDES SUCH TOPICS AS THE DEPOSITION OF THE DETRITAL GRAINS, THE SOURCE OF THE SILICA, THE TRANSPORTATION OF THE SILICA TO THE SITE OF DEPOSITION AND THE ACTUAL DEPOSITION OF THE SILICA. PERHAPS THE INITIAL CONSIDERATION SHOULD BE THE PROBLEM OF THE DEPOSITION OF THE DETRITAL GRAIN FRACTION OF THE SILICEOUS ROCK SINCE IT WAS PRESUMABLY THE INITIAL EVENT IN ITS DIAGENETIC HISTORY.

THE DETRITAL GRAINS THEMSELVES SUGGEST A NUMBER OF THINGS CONCERNING BOTH THEIR SOURCE AND THEIR ENVIRONMENT OF DEPOSITION. THEIR GENERAL SUBANGULARITY INDICATES THAT THEY WERE REWORKED LITTLE, IF AT ALL, DURING THEIR TRANSPORT TO AND DEPOSITION AT THE SITE OF DEPOSITION. THIS IN TURN SUGGESTS BOTH THAT THE SEDIMENT SOURCE AREA WAS RELATIVELY NEAR THE SITE OF DEPOSITION AND THAT A LOW ENERGY ENVIRONMENT EXISTED AT THAT SITE. THE RELATIVELY FINE GRAIN SIZE ALSO SUGGESTS A LOW ENERGY ENVIRONMENT OF DEPOSITION IN ADDITION TO POSSIBLY REFLECTING A LIMITED SEDIMENT SUPPLY. THIS LATTER IMPLICATION IS ALSO SUGGESTED BY THE VARIABILITY OF THE SIZE OF THE DETRITAL GRAIN FRACTION THROUGHOUT THE STUDY AREA. THE MODERATELY GOOD SORTING OF THE DETRITAL GRAIN FRACTION, NOT BEING CHARACTERISTIC OF A LOW ENERGY ENVIRONMENT, PROBABLY RESULTED FROM THE NATURE OF THE SEDIMENT SOURCE AND/OR PROCESSES ASSOCIATED WITH THE SEDIMENT TRANSPORTING MEDIUM.

FURTHER DISCUSSION OF THE SOURCE AND TRANSPORTATION OF THE SEDIMENTS IN QUESTION NOT ONLY WOULD BE PURELY SPECULATIVE BUT WOULD ADD LITTLE TO THIS DISCUSSION, THE MAIN CONCERN OF WHICH IS THE ENVIRONMENT OF SEDIMENT DEPOSITION, AND THUS WILL NOT BE PURSUED. ON THE OTHER HAND, OTHER CHARACTERISTICS OF THE

SILICEOUS ROCK PROVIDE ADDITIONAL INFORMATION CONCERNING THIS ENVIRONMENT OF DEPOSITION AND THUS MUST BE CONSIDERED. FOREMOST AMONG THESE IS THE ABUNDANCE OF PLANT FOSSILS IN THE SILICEOUS ROCK. THESE FOSSILS, WHICH CONTAIN NOT ONLY PLANT FRAGMENTS BUT MORE SIGNIFICANTLY, VERTICALLY-ORIENTED ROOTS AND STEMS AND/OR THEIR CAVITIES, PROVIDE FURTHER EVIDENCE FOR A LOW ENERGY ENVIRONMENT OF DEPOSITION SINCE THEY WOULD NOT BE PRESERVED AT ALL IN A HIGH ENERGY ENVIRONMENT. FURTHERMORE, THEIR ABUNDANCE INDICATES THAT THE ENVIRONMENT OF SEDIMENT DEPOSITION ALSO PROMOTED PROLIFIC PLANT PRODUCTION. SUCH AN ENVIRONMENT WOULD MOST LIKELY HAVE BEEN AQUATIC, AND IF SO, NECESSARILY SHALLOW.

CONSIDERING THE FOREGOING INFERENCES COLLECTIVELY, A MARSH OR POND ENVIRONMENT WOULD SEEM MOST REASONABLE AS THE ENVIRONMENT OF SEDIMENT DEPOSITION. SUCH AN ENVIRONMENT WOULD NOT ONLY ACCOUNT FOR THE ABOVE CHARACTERISTICS AND INFERENCES, BUT ALSO FOR THE INCLUSION OF RANDOMLY ORIENTED WOOD AND WOOD CASTS, SINCE STANDS OF TREES, A NECESSARY SOURCE OF THE WOOD DETRITUS, OFTEN OCCUR ASSOCIATED WITH THIS TYPE OF ENVIRONMENT. THE DETRITUS, IN THE FORM OF BRANCHES AND THE LIKE, WOULD HAVE BEEN INTRODUCED INTO THESE LOW AREAS BY STORM WINDS, ETC, AND WOULD SUBSEQUENTLY HAVE SETTLED TO THE BOTTOM WITH NO PREFERRED ORIENTATION.

THE RELATIVE CONSISTENCY OF THE SILICEOUS ROCK THROUGHOUT THE STUDY AREA SUGGESTS THAT IT WAS ALL FORMED IN THE SAME TYPE OF ENVIRONMENT. YET, IT IS ONLY LOCALLY ABUNDANT IN THE STUDY AREA WITH NO EXISTING EVIDENCE THAT IT WAS EVER CONTINUOUS OVER THE ENTIRE EXTENT OF ITS RANGE. THIS WOULD SEEM TO INDICATE THE EXISTENCE OF MANY PONDS OR MARSHES AT THE TIME OF SEDIMENT DEPOSITION. THOUGH THIS IS A DEFINITE POSSIBILITY, PERHAPS A BETTER EXPLANATION WOULD BE THAT A MARSH-LIKE ENVIRONMENT COVERED THE ENTIRE AREA IN THE FORM OF A SHALLOW BASIN, WHICH IN TURN CONTAINED MANY LOCAL DEPRESSIONS (HICKEY, 1966, P.173). PRESUMABLY THEN, IT WAS IN THESE LOCAL DEPRESSIONS THAT VARIABLE AMOUNTS OF FINE-GRAINED SEDIMENTS WERE DEPOSITED AND SUBSEQUENTLY MIXED WITH THE ABUNDANT ORGANIC MATTER PRODUCED THERE.

BOTH TODD (1898, P.60-61) AND HICKEY (1966, P.48-55), NOTING THE VERTICALLY-

ORIENTED ROOTS, STEMS, AND ROOT AND STEM CAVITIES, HYPOTHESIZED "IN PLACE" DIAGENESIS OF THE SILICEOUS ROCK. IN OTHER WORDS, THEY FELT THAT THE SEDIMENT WAS LITHIFIED -- IN THIS CASE SILICIFIED -- IN ITS ENVIRONMENT OF DEPOSITION, AND THUS NECESSARILY VERY EARLY IN ITS DIAGENETIC HISTORY. CONSIDERATION OF THIS POSSIBILITY SEEMS TO SUBSTANTIATE THEIR HYPOTHESIS.

IT IS SEEMINGLY QUITE SIGNIFICANT THAT AT LEAST A PORTION OF THE SILICEOUS ROCK HAS BEEN ATTRIBUTED TO THE EOCENE GOLDEN VALLEY FORMATION. THIS SIGNIFICANCE LIES IN THE FACT THAT THROUGHOUT THE STUDY AREA, THE GOLDEN VALLEY FORMATION OVERLIES THE PALEOCENE FT. UNION GROUP, WHICH TYPICALLY CONTAINS SEVERAL BENTONITE BEDS. IT IS GENERALLY ACCEPTED THAT BENTONITE IS FORMED BY THE DECOMPOSITION OF VOLCANIC ASH, A PROCESS WHICH RELEASES LARGE AMOUNTS OF SILICA. ASSUMING THAT THE FORMATION OF BENTONITES WAS STILL OCCURRING IN FT. UNION STRATA AT LEAST THROUGH MIDDLE EOCENE TIME, A SOURCE OF SILICA WAS READILY AVAILABLE, REQUIRING ONLY A TRANSPORTING AGENT TO GET IT TO THE SEDIMENTS THAT WERE EVENTUALLY SILICIFIED. IN THIS REGARD, IT IS A GENERALLY ACCEPTED FACT THAT MARSHES AND PONDS ARE GROUND WATER DISCHARGE AREAS. THUS, ASSUMING THAT THE INTERPRETATION OF THE ENVIRONMENT OF SEDIMENT DEPOSITION IS CORRECT, THE ENTIRE AREA WAS OF NECESSITY A GROUND WATER DISCHARGE AREA UNDERLAIN BY A VAST FLOW SYSTEM. FURTHERMORE, GROUND WATER FLOWING THROUGH SUCH A SYSTEM OF NECESSITY TRAVERSED THE UNDERLYING FT. UNION STRATA BEFORE DISCHARGING THROUGH THE BOTTOM SEDIMENTS OF THE NUMEROUS DEPRESSIONS IN THE AREA. THIS BEING THE CASE, THE GROUND WATER, NATURALLY QUITE UNDERSATURATED WITH SILICA, VERY PROBABLY TOOK UP SOME OF THE PREVIOUSLY MENTIONED EXCESS SILICA. THAT AT LEAST PART OF THIS SILICA WAS COLLOIDAL IS SUGGESTED BY THE PREVIOUSLY MENTIONED LOCAL CONCRETION-LIKE CHARACTERISTICS OF SOME OF THE SAMPLES. IN ACCORDANCE WITH THE WORK OF SHARMA (1965, P. 740), THE REST MAY PRESUMED TO HAVE BEEN IN TRUE SOLUTION. WHATEVER THE FORM OF THE SILICA THOUGH, THE FACT REMAINS THAT DURING MIDDLE EOCENE TIME AT LEAST, THERE WAS A SOURCE OF SILICA AVAILABLE AS WELL AS A MODE OF TRANSPORTATION FOR THAT SILICA TO BE TRANSPORTED TO AN ENVIRONMENT WHERE IT COULD BE DEPOSITED.

PROVIDING THAT THE PRECEDING INFERENCES ARE CORRECT, THE REMAINING CONSIDERATIONS CONCERN THE CONDITIONS NECESSARY TO HAVE INDUCED THE DEPOSITION OF THIS GROUNDWATER-TRANSPORTED SILICA IN THE BOTTOM SEDIMENTS OF THE DEPRESSIONS IN THE AREA. IN THIS REGARD, IT IS GENERALLY ACCEPTED THAT SILICA IN THE FORM OF QUARTZ IS PRECIPITATED, FROM SOLUTION AT LEAST, IN ENVIRONMENTS EXHIBITING A PH LOWER THAN 9.5, OR MORE GENERALLY, IN AN ACID ENVIRONMENT (BLATT, ORAL COMMUNICATION, 1966). IT IS ALSO GENERALLY ACCEPTED THAT AN INTRODUCTION OF CO₂ INTO A SYSTEM BY THE BACTERIAL DECOMPOSITION OF ORGANIC MATTER IN AN OXIDIZING ENVIRONMENT WILL LOWER THE PH OF THAT ENVIRONMENT (EMERY AND RITTENBERG, 1952, P.770). PROVIDING THAT THE WATER IN THE DEPRESSIONS WAS SHALLOW ENOUGH, AN OXIDIZING ENVIRONMENT WAS MAINTAINED ON THEIR BOTTOMS, WHICH WERE COMPOSED OF BOTH THE INTRODUCED SEDIMENTS AND ABUNDANT ORGANIC MATERIAL. SUCH AN ENVIRONMENT WOULD HAVE FAVORED THE DECOMPOSITION OF THE ORGANIC MATTER RESULTING IN THE PRODUCTION OF LARGE AMOUNTS OF CO₂ AND/OR HUMIC ACIDS. THESE IN TURN WOULD HAVE LOWERED THE PH, PRESUMABLY BELOW THE 6-8 RANGE CHARACTERISTIC OF NATURALLY-OCCURRING WATER (SHARMA, 1966, P.737), THUS PRODUCING AN ACIDIC ENVIRONMENT. SUBSEQUENTLY, THE SILICA-RICH DISCHARGING GROUND WATER WOULD HAVE TRAVERSED THIS ENVIRONMENT AND IN THE PROCESS SILICA WOULD HAVE BEEN DEPOSITED MAINLY AS MICROCRYSTALLINE QUARTZ, OR CHERT, BUT ALSO AS SECONDARY QUARTZ OVERGROWTHS. THE FACT THAT THE DECAY OF ORGANIC MATTER WOULD HAVE MAINTAINED A SATISFACTORY ENVIRONMENT FOR THE DEPOSITION OF SILICA ONLY IN THE UPPER PART OF THESE SEDIMENT ACCOUNTS FOR THE RELATIVE THINNESS OF THE SLABS AND "IN PLACE" DEPOSITS OF THE SILICEOUS ROCK.

TO BE SURE, THE PRECEDING IS A VERY SIMPLIFIED VERSION OF WHAT MAY HAVE HAPPENED CONSIDERING THE COMPLEXITY OF SILICA GEOCHEMISTRY, YET IS ENTIRELY FEASIBLE THAT THIS WAS THE BASIC SET OF DIAGENETIC EVENTS WHICH LED TO THE DEPOSITION OF THE SILICA, WHICH IN TURN RESULTED IN THE SILICEOUS ROCK AS WE NOW OBSERVE IT. FURTHERMORE, IT ACCOUNTS FOR THE VERY CHARACTERISTIC INVERSE RELATIONSHIP BETWEEN THE AMOUNT OF CHERT AND ORGANIC MATTER PRESENT IN THE SILICEOUS ROCK. IN OTHER WORDS,

THE MORE ORGANIC MATTER THAT DECOMPOSED, THE MORE CHERT THERE WAS DEPOSITED, OR AS THE ORGANIC MATTER WAS DECOMPOSED THE CHERT REPLACED IT. ONLY MORE DETAILED WORK BY ONE WELL VERSED IN GEOCHEMISTRY WOULD PROVIDE A MORE COMPLETE, AND PERHAPS REALISTIC, VERSION OF THIS PHASE OF THE DIAGENETIC HISTORY OF THE SILICEOUS ROCK.

ONE LAST MATTER FOR DISCUSSION CONCERNS THE STRATIGRAPHIC SOURCE OF THE SILICEOUS ROCK. AS HAS BEEN PREVIOUSLY NOTED, AT LEAST PART OF IT CAN BE ATTRIBUTED TO THE HEBRON MEMBER OF THE EOCENE GOLDEN VALLEY FORMATION. BEYOND THIS, THE LACK OF BOTH "IN PLACE" OUTCROPS AND THE DETAILED STRATIGRAPHIC WORK NECESSARY TO ARRIVE AT SUCH ANSWERS PREVENTS ANY FURTHER DEFINITE STATEMENTS IN THIS REGARD. IT MIGHT BE NOTED THOUGH THAT THE OCCURRENCE OF THE SILICEOUS ROCK AT TWO DIFFERENT LEVELS AT PRETTY ROCK BUTTE AT LEAST SUGGESTS A MULTIPLE - HORIZON SOURCE AS TISDALE (1941, P.13-14) HYPOTHESIZED.

CONCLUSIONS

1. A POSSIBLE ORIGIN OF THE SILICEOUS ROCK STUDIED INCLUDES THE FOLLOWING ELEMENTS:
 - A. THE SEDIMENTS IN THE SILICEOUS ROCK WERE DEPOSITED IN A MARSH OR POND ENVIRONMENT CHARACTERIZED BY AN EXTENSIVE SHALLOW BASIN WITH LOCAL DEPRESSIONS.
 - B. THE SEDIMENTS WERE SILICIFIED EARLY IN THEIR DIAGENETIC HISTORY AT THEIR SITES OF DEPOSITION, THE BOTTOMS OF THE PREVIOUSLY MENTIONED DEPRESSIONS.
 - C. SILICA WAS DERIVED FROM THE FORMATION OF BENTONITES AND TRANSPORTED TO THE SITE OF DEPOSITION BY GROUND WATER.
 - D. IN THE GROUND WATER, THE SILICA WAS BOTH IN COLLOIDAL SUSPENSION AND IN TRUE SOLUTION.
 - E. THE SILICA WAS DEPOSITED IN THE SEDIMENTS IN AN ACIDIC ENVIRONMENT RESULTING FROM THE INTRODUCTION OF CO₂ AND/OR HUMIC ACIDS DUE TO THE DECOMPOSITION OF ORGANIC MATTER.
2. THE LIMITED EVIDENCE AVAILABLE SUGGESTS A MULTIPLE-HORIZON SOURCE FOR THE SILICEOUS ROCK.

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