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THE LITHOLOGY OF SELECTED FOSSILIFEROUS TERTIARY SEDIMENTS

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INTRODUCTION

In the past few years the development of various techniques for the investigation of sedimentary rocks has made it possible to examine detrital deposits in more detail than formerly. Up to now very little work has been done on the lithology of the fossiliferous continental Tertiary sediments. It seems desirable at present to undertake such studies, since a knowledge of the character of the sediments adds to the information on the habitat of the fossil fauna and may also prove useful in the correlation of the continental Tertiary deposits.

The fourteen specimens described in the following pages were collected from eight well-known fossil localities (Fig. 1). They have been examined either in thin section or by gravity separation, the method employed depending on the degree of lithification of the rocks. Mechanical analyses were made of the specimens treated by the latter process. The procedure followed in the gravity method is that of Milner (1929, pp. 37–43). It involves a separation of the light and heavy minerals of the rock specimen. These minerals are then mounted in balsam and studied under the microscope. The light minerals are those having a specific gravity less than 2.72. The technique of the mechanical analyses is essentially that of Crook (1913, p. 5) and involves a determination of the percentage weight of mud, silt, sand, and "coarse" constituents. The percentage weight of calcite and other acid-soluble material is included in the results of the mechanical analyses.

In the section headed Conclusions, the results of the investigation are summarized and attempts are made to interpret the conditions of deposition of the various specimens examined.

The author wishes to acknowledge the generosity of the Department of Vertebrate Palæontology of The American Museum of Natural History in furnishing much of the material described in this paper. He is indebted to Curator Chester A. Reeds of the Department of Geology of that institution for editing and seeing the paper through publication.

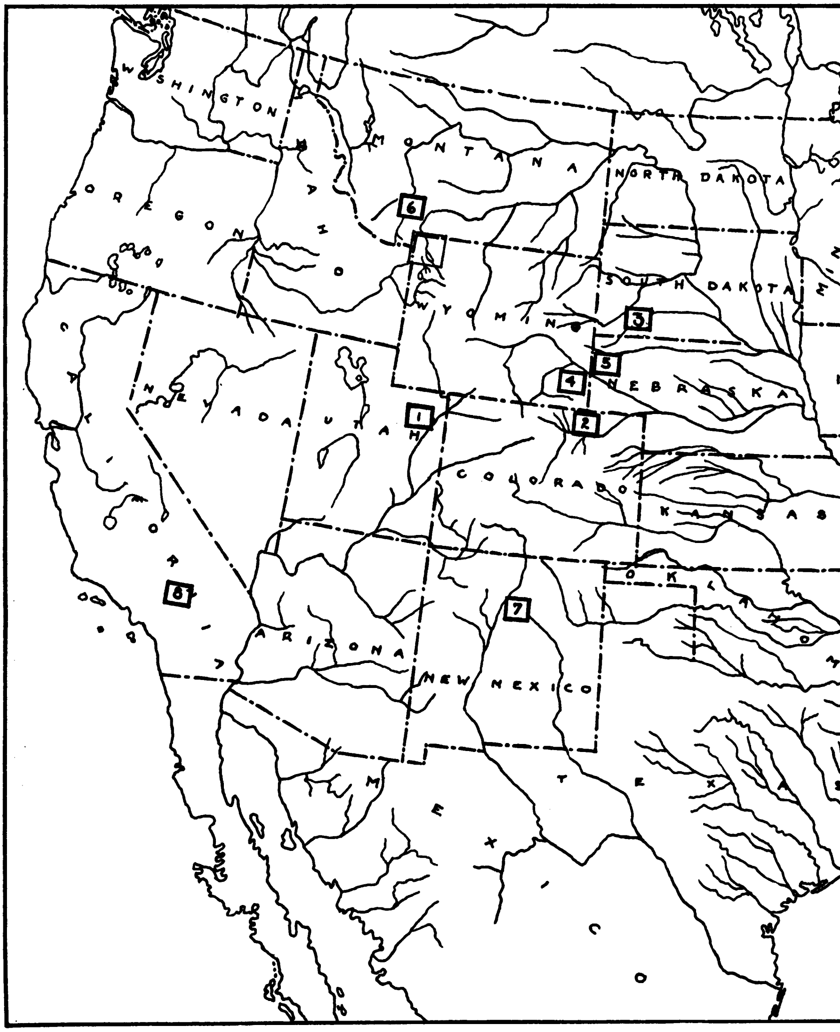

Fig. 1

LOCALITY MAP

	Specimen Number
1—Uinta Basin, Utah	1, 2, 3
2—Weld County, Colorado	4
3—Big Badlands, South Dakota	5, 6
4—Torrington, Wyoming	7
5—Agate, Nebraska	8
6—Madison Valley, Montana	9
7—Santa Fé Marls, New Mexico	10, 11, 12
8—Barstow, California	13, 14

Professors L. E. Spock and H. E. Wood of New York University offered much helpful criticism and advice in the preparation of the manuscript.

DESCRIPTION OF SPECIMENS

Specimen No. 1

Locality

A specimen from Horizon C of the Uinta formation near Ouray, Utah (Fig. 1). Donated by The American Museum of Natural History.

Hand Specimen

A brownish-gray, fine-grained, compact sandstone with a rough feel. Color uniform, texture homogeneous.

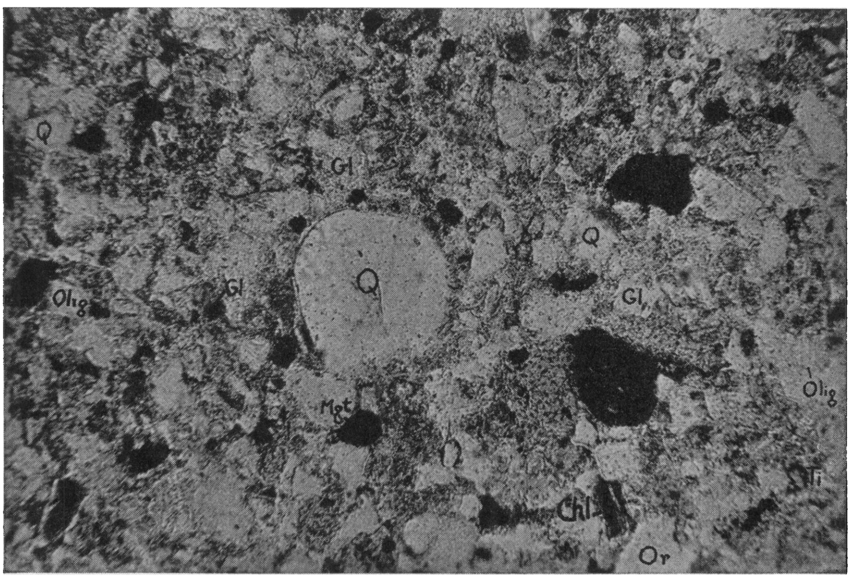

Fig. 2. Specimen 1. Ouray, Utah. The illustration shows sharply angular pyroclastic fragments embedded in a matrix of clay and calcite. The large, well-rounded quartz grain is of fluviatile origin. Chlorite (Chl), Glass (Gl), Magnetite (Mgt), Oligoclase (Olig), Orthoclase (Or), Quartz (Q), Titanite (Ti). Plane-polarized light, × 40.

Thin Section (Fig. 2)

The thin section shows clastic fragments embedded in a matrix of clay and calcite. Nearly all the fragments are angular, although some of the larger quartz grains are well rounded. The average size of the constituent fragments is 0.1 mm. A few quartz grains reach 0.3 mm., and biotite shreds up to 0.4 mm. are present.

Mineral constituents

Quartz—Abundant. Inclusions common, some liquid. A few grains show strain shadows. The larger grains are rounded.

Feldspar—Abundant. Oligoclase common, orthoclase rare. In various stages of decomposition.

Biotite—Common. Acicular shreds.

Hornblende—Common. Prismatic fragments.

Magnetite—Common. Small fragments.

Garnet and Titanite—Very rare. Small fragments.

Chlorite, Kaolin and Sericite—Abundant as secondary products.

Iron oxide—Nearly all the fragments are coated with ferric oxides.

Carbonaceous material (?)—Common.

Glass—Abundant. Altered. Some fragments shard-like in shape.

Special features

There are present in the section a series of light brown areas with hazy to sharply defined boundaries which occur up to 8.0 mm. in size. Johannsen (1914, p. 212) noted in one of his hand specimens from the Uinta formation the presence of "large dark brown inclusions," but found no evidence of these in his thin section. The areas are local concentrations of lime carbonate. Where the concentration is weak, the individual grains of the rock show through; where strong, the grains are not visible and have probably been entirely replaced by the lime carbonate. These areas are interpreted as incipient lime nodules.

PETROLOGY

The abundance of glass indicates a tuff. The mineralogy suggests derivation from crystalline rocks of intermediate composition.

CLASSIFICATION

A dacite tuff.

SPECIMEN No. 2

LOCALITY

Horizon C of the Uinta formation. Exact locality in the Uinta Basin unknown. (Fig. 1). Donated by The American Museum of Natural History.

HAND SPECIMEN

A coarse, arkosic sandstone of gray color, speckled with variously colored mineral grains. The specimen is well indurated. No apparent structure.

THIN SECTION

The grains vary from angular to rounded. The sorting is good. The cement is calcite and comprises probably 50 per cent. of the rock. The average size of the fragments is 0.5 mm., with some grains ranging up to 2.0 mm.

Mineral constituents

Quartz—Abundant. Inclusions common, often in linear arrangement. Strain shadows common.

Feldspar—Orthoclase and microcline abundant, albite common, oligoclase rather rare. Fresh and decomposed. A few of the orthoclase grains are twinned.

Muscovite—Rather rare. Occurs in irregular, short fragments.
Biotite—Rather rare. In shreds up to 0.35 mm.
Titanite and Garnet—Rather rare and smaller than average size.
Magnetite—Rather rare. Irregular grains.
Epidote—Rare. Small irregular grains.
Apatite—Rare. Small fragments.
Chlorite, Kaolin and Sericite—Common as alteration products.
Glass (?)—Rare. Spherulite fragments—Rare.

Lithic fragments.
Quartzite—Common.
Red-bed arkose—Rare.

PETROLOGY

The rock is a fluviatile sediment. The mineralogy suggests that several different kinds of rock furnished the materials of which the sediment is composed. It is probable that the most important contributor was a salic igneous rock. It is possible, however, that the material was derived from an earlier sediment of arkosic character. Some of the fragments appear to have come from a quartzite.

CLASSIFICATION

An arkosic sandstone.

SPECIMEN NO. 3

LOCALITY

A specimen from Horizon C of the Uinta formation. Collected by Dr. H. E. Wood near Myton, Utah (Fig. 1).

HAND SPECIMEN

An earthy-gray, fine-grained sandstone. Weathers on the surface to a pale buff color. Indurated only in part so that the rock is somewhat friable. Contains small fragments of fossil bones. Disseminated specks of dark minerals.

THIN SECTION

Angular to subrounded clastic fragments in a matrix of clay and calcite. Grains of rather uniform size with an average diameter of 0.2 mm. A few fragments occur up to 0.8 mm. in size.

Mineral constituents
Quartz—Abundant. Inclusions and strain shadows common. Some fragments contain liquid inclusions.
Feldspar—Abundant. Oligoclase abundant; orthoclase, microcline, and albite fairly common. In various stages of decomposition.
Muscovite—Common. Flakes.
Biotite—Common. Iron-rich.
Garnet—Common. Small, irregular grains.
Magnetite—Common. Small, irregular grains.
Hornblende—Rather rare. Short, prismatic fragments.
Titanite—Rather rare. Small, irregular grains.
Tourmaline—Rather rare. Brown.
Chlorite, Sericite, and Kaolin—Common as secondary products.
Iron oxide—Common as coatings.

Glass—Abundant. Angular to subrounded fragments in various stages of alteration.

PETROLOGY

The relative abundance of angular glass fragments indicates that the rock is a tuff. The variety and character of the feldspar suggest derivation from igneous rocks of intermediate composition.

CLASSIFICATION

A dacite tuff.

SPECIMEN NO. 4

LOCALITY

A specimen from the lower Oligocene of Weld County, Colorado (Fig. 1). Collected by Dr. Florence D. Wood from the lower Trigonias quarry of the Colorado Museum.

Fig. 3

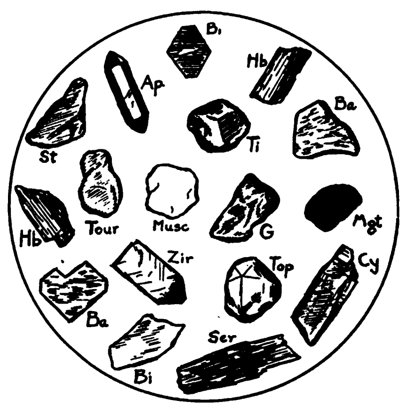

Fig. 4

Fig. 3. Specimen 4. Weld County, Colorado. Light crop. Note the crispness of the glass shards and the presence of contained cavities and capillary tubes. The angularity of the shards and the presence of a brittle zeolite fragment eliminate the possibility of working by water. Glass (Gl), Plagioclase (Pl), Quartz (Q), Zeolite (Zeol). Average size of fragments, 0.1 mm.

Fig. 4. Specimen 4. Weld County, Colorado. Heavy crop. The presence of crystal faces and sharply defined cleavage fragments is evidence of direct deposition from air. Apatite (Ap), Barite (Ba), Biotite (Bi), Cyanite (Cy), Garnet (G), Hornblende (Hb), Magnetite (Mgt), Muscovite (Musc), Serpentine (Ser), Staurolite (St), Titanite (Ti), Topaz (Top), Tourmaline (Tour), Zircon (Zir). Average size of fragments, 0.1 mm.

HAND SPECIMEN

A light-gray to white, fine-grained, friable rock without apparent internal structure. Under the hand lens, shows a few tiny specks of dark minerals.

MECHANICAL ANALYSIS (INCLUDING DETERMINATION OF CALCITE AND OTHER ACID-SOLUBLE MATERIAL)

Calcite, etc.	5.5 per cent.
Mud	13.0 per cent.
Silt	36.0 per cent.
Sand	43.0 per cent.
Coarse	Remainder

GRAVITY SEPARATION

Light crop (Fig. 3)

Glass—Very abundant. Shards coated with clay probably derived from the decomposition of the feldspar.

Quartz—Abundant. Inclusions fairly common.

Feldspar—Common. Various stages of alteration. Only oligoclase identified.

Zeolite—Rare. A cone-shaped fragment about 1.25 mm. in length. Resembles Pectolite.

Heavy Crop (Fig. 4)

Biotite—Very abundant. Sometimes red. Perfect hexagonal plates common.

Magnetite—Abundant. Crystal faces common.

Barite—Abundant. Cleavage fragments.

Hornblende—Abundant. Prismatic fragments.

Garnet—Common. Colorless to pink. Irregular fragments.

Titanite—Common. Crystal faces common. Irregular fragments.

Muscovite—Rather common. Basal flakes.

Zircon—Rather common. Elongated fragments and fractions of crystals.

Apatite—Rather rare. Euhedra and semirounded grains.

Topaz—Rather rare. Irregular grains and a fraction of a crystal.

Cyanite—Rare. Elongated cleavage fragment.

Tourmaline—Rare. Brown. Semirounded fragment.

Staurolite—Rare. Irregular fragment.

Serpentine—Rare. Fibrous fragment.

PETROLOGY

The abundance of glass shards indicates a tuff. The fragments are angular to subrounded. The mineralogy is that of a dacite.

CLASSIFICATION

A dacite tuff.

SPECIMEN NO. 5

LOCALITY

A specimen from the Turtle-Oreodon zone, or lower Nodular layer, of the Brule formation of Oligocene age. Collected by Dr. H. E. Wood about 2 miles south of Scenic in the Big Badlands, South Dakota (Fig. 1).

HAND SPECIMEN

An extremely fine-grained, light-colored, clay rock without apparent structure.

THIN SECTION

Under plane-polarized light the rock is seen to consist of distinct fragments, so that the original clastic character of the rock is apparent. However, the individual "grains" have been almost entirely replaced by carbonate material. With the nicols crossed the individuality of the separate fragments is lost and the rock appears to be a homogeneous mixture of calcite and clay. The average size of the primary grains is about 0.05 mm., although some exceed 1.0 mm. in diameter. Many of them show rounded outlines. A few extremely small grains of quartz, feldspar, biotite, and glass are scattered through the groundmass. Sericite and chlorite are common as secondary products, and the presence of iron oxide lends a reddish-brown color to the section. The original sediment was apparently a fine-grained siltstone, but the replacement by calcite is almost complete.

CLASSIFICATION

A sedimentary clay rock containing minor amounts of volcanic glass.

SPECIMEN No. 6

LOCALITY

A specimen from the upper Nodular layer (75 to 100 feet higher than the preceding) of the Brule formation, Oligocene. Collected by Mr. E. J. Schlaikjer from the White River beds of South Dakota (Fig. 1).

HAND SPECIMEN

A grayish-white, dense, structureless clay rock. Under the hand lens shows a few small, isolated mineral grains.

THIN SECTION

This rock is essentially the same in its general appearance as the preceding specimen, and has apparently passed through the same history. It differs from the preceding only in the absence of the reddish-brown iron-oxide tint, and in the presence of disseminated specks of an unknown black substance which may be carbonaceous. In addition, a few small needles of hornblende are present. That no glass was directly observed is not necessarily evidence of its absence. The presence of a few fragments of glass might easily be obscured by the clay and calcite.

CLASSIFICATION

A sedimentary clay rock.

SPECIMEN No. 7

LOCALITY

A specimen of Oligocene age collected by Mr. E. J. Schlaikjer at the Harvard fossil quarry, four and one half miles southwest of Torrington, Wyoming (Fig. 1).

HAND SPECIMEN

A grayish-white, indurated, clay rock showing a few minute dark grains. No apparent structure.

THIN SECTION (FIG. 5)

Sharply angular grains embedded in an extremely dense matrix of clay and calcite. The fragments, both glass and mineral, have an average size of about 0.03 mm. Quartz and hornblende grains occur up to 0.4 mm.

Mineral Constituents

Quartz—Abundant. Some of the fragments show strain shadows. Inclusions not very common.

Feldspar—Abundant. Oligoclase abundant; albite common. Fragments in various stages of decomposition. Inclusions common.
Hornblende—Common. Prismatic fragments.
Biotite—Rather common. Shreds.
Titanite—Rare. Small irregular grains.
Chlorite, Sericite and Kaolin—Common as secondary products.
Glass—Extremely abundant. Highly angular fragments. The shards are very small, having an average size of 0.03 mm. Some, however, occur up to 0.25 mm.

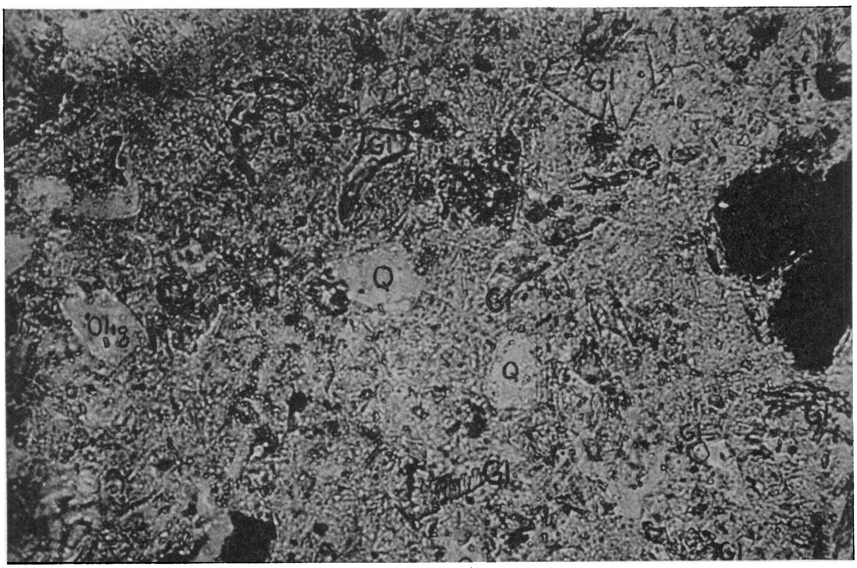

Fig. 5. Specimen 7. Torrington, Wyoming. The illustration shows abundant glass and pyroclastic mineral fragments in a matrix of clay and calcite. The angularity of the shards indicates direct deposition from air and no subsequent working by water. Glass (Gl), Oligoclase (Olig), Quartz (Q), Titanite (Ti). The dark blotches at the right are iron oxide stains. Average size of fragments, 0.03 mm. Plane polarized light, ×230.

PETROLOGY

The abundance of shards indicates a tuff. The mineral suite is suggestive of an igneous rock of intermediate composition.

CLASSIFICATION

A dacite tuff.

SPECIMEN NO. 8

LOCALITY

A specimen from the lower Harrison formation (lower Miocene) at the Agate Fossil Quarry, Sioux County, Nebraska (Fig. 1).

Hand Specimen

A light-gray to white, friable sandstone. Abundant dark minerals are visible under the hand lens. No apparent structure.

Mechanical Analysis (Including Determination of Calcite and Other Acid-soluble Material).

Calcite, etc.	40 per cent.
Mud	1 per cent.
Silt	2 per cent.
Sand	57 per cent.
Coarse	Negligible

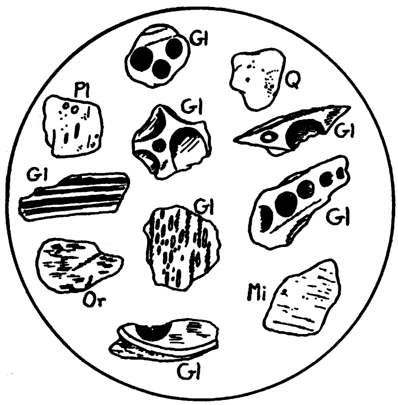

Fig. 6

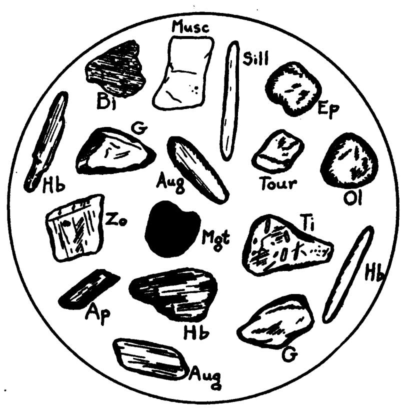

Fig. 7

Fig. 6. Specimen 8. Agate, Nebraska. Light crop. Note the abundance of glass shards showing cavities and capillary tubes and in one instance a parallel arrangement of liquid inclusions. Glass (G1), Microcline (Mi), Orthoclase (Or), Plagioclase (P1), Quartz (Q). Average size of fragments, 0.1 mm.

Fig. 7. Specimen 8. Agate, Nebraska. Heavy crop. The presence of chemically unstable olivine, augite, and apatite, rather distant from the nearest source of supply, is evidence for direct deposition from air. Apatite (Ap), Augite (Aug), Biotite (Bi), Epidote (Ep), Garnet (G), Hornblende (Hb), Magnetite (Mgt), Muscovite (Musc), Olivine (O1), Sillimanite (Sill), Titanite (Ti), Tourmaline (Tour), Zoisite (Zo). Average size of fragments, 0.1 mm.

Gravity Separation

Light Crop (Fig. 6)

Glass (salic)—Extremely abundant. Highly angular to slightly rounded. Some of the shards show spherulitic cavities and capillary tubes; others contain liquid inclusions of comparatively large size.

Quartz—Abundant. Liquid inclusions common.

Feldspar—Abundant. Orthoclase, microcline, albite and oligoclase in equal amounts. Fresh to only slightly altered. Inclusions rather common in the plagioclases.

Heavy Crop (Fig. 7)

Hornblende—Very abundant. Long, slender fragments with rounded extremities.
Garnet—Very abundant. Pink and colorless.
Biotite—Common. Basal flakes.
Magnetite—Common. Fairly well-rounded grains.
Augite—Rather common. Prismatic fragments.
Muscovite—Rather rare. Basal flakes.
Sillimanite—Rather rare. Long prismatic fragments with rounded extremities.
Tourmaline—Rare. Deep blue (indicolite) and brown.
Epidote—Rare. Rounded grains.
Titanite—Rare. Subrounded grains. Abundant and large inclusions.
Olivine—Rare. Rounded.
Apatite—Rare. Portion of euhedron.
Zoisite—Rare. Cleavage fragment.

PETROLOGY

The mechanical analysis shows 57 per cent. of the rock to be composed of fragments of sand grade while 40 per cent. is calcite matrix. The texture is therefore that of a sandstone. Hornblende and sillimanite fragments occur two to three times the size of the other fragments. The mineral grains are imperfectly to perfectly rounded. The mineral suite suggests derivation from salic rocks in part metamorphic, as indicated by the elongated fragments of sillimanite and hornblende The specimen is obviously a tuff from the abundance of glass shards.

CLASSIFICATION

A dacite tuff.

SPECIMEN No. 9

LOCALITY

A specimen from the Neogene deposits of Madison Valley, Montana. Either upper Miocene or lower Pliocene in age (Fig. 1). Donated by The American Museum of Natural History.

HAND SPECIMEN

A gray, rather firmly indurated sandstone with intercalated seams of fine gravel. Dark minerals appear somewhat abundant.

THIN SECTION (FIG. 8)

The section shows sharply angular fragments embedded in a coarsely crystalline calcite matrix. The calcite comprises probably 50 per cent. of the rock. The average size of the constituent fragments is about 0.25 mm., with some biotite shreds up to 0.55 mm. Glass is extremely abundant.

Mineral constituents

Quartz—Abundant. Inclusions and strain shadows common. The inclusions often show a linear arrangement.
Feldspar—Very abundant. Oligoclase abundant; orthoclase, albite common; microcline rare. Fresh to decomposed.
Hornblende—Rather common. Elongated fragments.
Biotite—Rather common. Shreds.
Muscovite—Rather rare. Shreds.

Garnet, Titanite and Magnetite—Rare. Small, irregular grains.
Kaolin and Sericite—Common as alteration products of the feldspars.
Glass (femic)—Shards very abundant. The average size of the glass fragments is 0.25 mm.; the maximum size, 0.5 mm.

Lithic fragments
Fine sandstone—Rare.

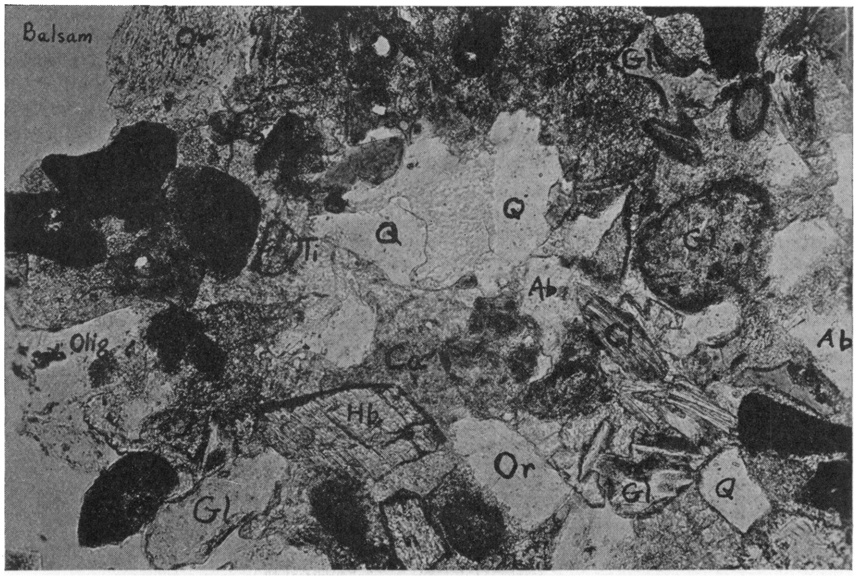

Fig. 8. Specimen 9. Madison Valley, Montana. The illustration shows highly angular pyroclastic constituents in a coarsely crystalline calcite matrix. Note the abundance and the angularity of the glass shards. Albite (Ab), Glass (Gl), Hornblende (Hb), Oligoclase (Olig), Orthoclase (Or), Quartz (Q), Titanite, (Ti). Average size of fragments, 0.25 mm. Plane polarized light, × 108.

PETROLOGY

The abundance of shards indicates a tuff. The mineral suite suggests an igneous rock of intermediate composition. The refractive index and the brown color of the glass are indicative of a femic composition.

CLASSIFICATION

A dacite tuff.

SPECIMEN No. 10

LOCALITY

A specimen of Neogene age from the Santa Fé Marls; upper Miocene or lower Pliocene. Collected by Mr. Childs Frick of The American Museum of Natural History, near Espanola, New Mexico (Fig. 1).

HAND SPECIMEN

A brownish-gray, medium to fine-grained, rather compact sandstone, showing grains of quartz, feldspar, and abundant dark minerals.

THIN SECTION

Angular to subrounded grains embedded in a coarsely crystalline matrix which comprises 40 to 50 per cent. of the rock. The average grain size is 0.2 mm., with some grains up to 0.5 mm.

Mineral Constituents

Quartz—Abundant. Strain shadows fairly common. Both solid and liquid inclusions observed. Inclusions often in linear arrangement.

Feldspar—Abundant. Orthoclase and albite abundant; microcline common. Fresh to almost entirely decomposed.

Hornblende—Common. Prismatic fragments.

Magnetite—Common. Small grains.

Titanite—Rather rare. Small grains.

Biotite—Rather rare. Shreds.

Muscovite—Rare. Shreds.

Apatite—Rare. Small grains.

Corundum—Very rare. Angular fragment.

Chlorite, Sericite, and Kaolin—Common as secondary products.

Glass (?)—Rare. Some of the grains present are believed to be altered glass.

Lithic fragments

Arkosic siltstone and vein (?) quartz—Rather common.

PETROLOGY

The mineralogy of the rock, particularly the character of the feldspar, suggests derivation from salic igneous rocks. In addition, the presence of arkosic siltstone fragments, and fragments of glass (?) point toward partial derivation of material from sedimentary and volcanic rocks.

CLASSIFICATION

A fine-grained arkosic sandstone.

SPECIMEN No. 11

LOCALITY

A specimen of Neogene age from the Santa Fé Marls. Upper Miocene or lower Pliocene. Collected by Mr. Childs Frick, near Espanola, New Mexico, in the same general locality as the preceding specimen. (Fig. 1).

HAND SPECIMEN

A light tan, fine-grained sandstone which weathers on the surface to a brown color. No apparent structure.

THIN SECTION (FIG. 9)

The average size of the constituent fragments is 0.15 mm. The larger fragments occur up to 0.6 mm. The material is poorly sorted. The fragments are angular to subrounded. The matrix is coarsely crystalline calcite and comprises probably 50 to 60 per cent. of the rock.

Mineral constituents

Quartz—Abundant. Inclusions and strain shadows common. Some of the inclusions are acicular, others are liquid. They are often in linear arrangement.

Feldspar—Abundant. Orthoclase and albite abundant; microcline common. Many of the grains are completely decomposed.
Hornblende—Common. Prismatic fragments.
Magnetite—Common. Small irregular grains.
Biotite—Rather rare. Shreds.
Titanite—Rather rare. Small irregular grains.
Muscovite—Rare. Shreds.
Olivine (?)—Rare. Irregular grains.
Tourmaline—Rare. Brown and blue.
Kaolin and Sericite—Abundant as alteration products of the feldspars.
Glass (?)—Rare. Fragments of brownish material which may be altered glass.

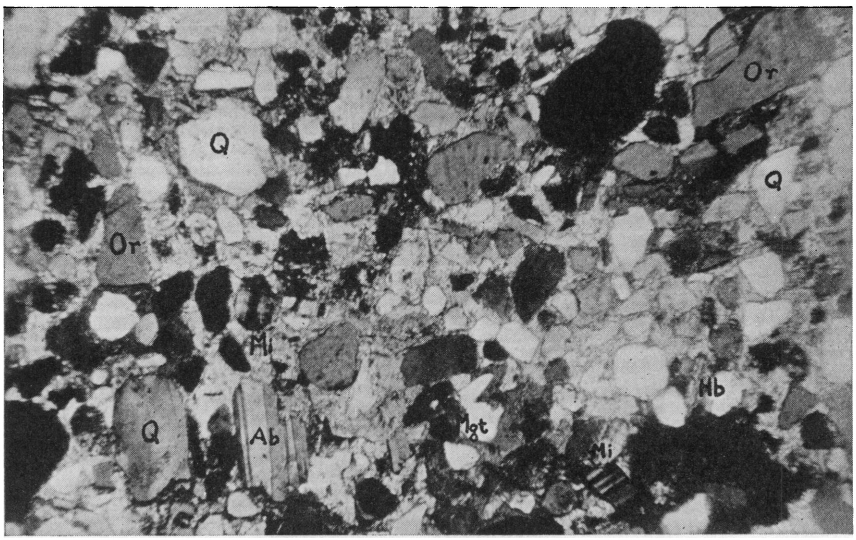

Fig. 9. Specimen 11. Espanola, New Mexico. Note the sharp angularity and the poor sorting of the mineral fragments. The cement is coarsely crystalline calcite. Albite (Ab), Hornblende (Hb), Magnetite (Mgt), Microcline (Mi), Orthoclase (Or), Quartz (Q). Crossed nicols, × 40.

Lithic fragments

Vein (?) quartz—Fragments of extremely fine-grained quartz which may represent vein material.

PETROLOGY

Differs from the preceding specimen only in the slightly greater variation in grain size, and in the presence of tourmaline. The mineral suite suggests derivation from salic igneous rocks.

CLASSIFICATION

A fine-grained arkosic sandstone.

Specimen No. 12

Locality

A specimen of Neogene age from the Santa Fé Marls. Upper Miocene or lower Pliocene. From the same general locality as specimens 10 and 11 (Fig. 1).

Hand Specimen

A grayish-white, fine-grained, friable sandstone showing a few dark minerals. Weathers on the surface to a dull, pale-buff color. No apparent structure.

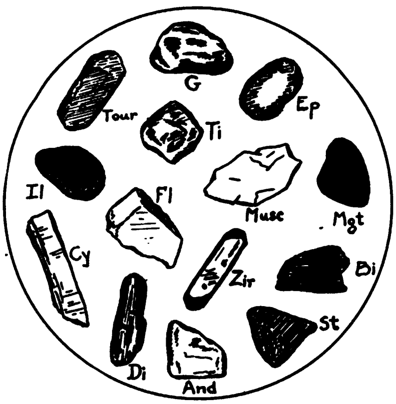

Fig. 10

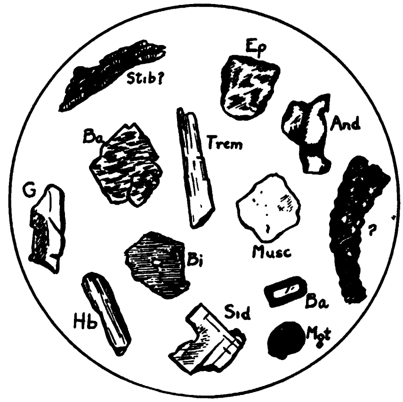

Fig. 11

Fig. 10. Specimen 12. Espanola, New Mexico. Heavy crop. The rounded character of some of the fragments is attributed to wind. Note the partial alteration of ilmenite to leucoxene. Andalusite (And), Biotite (Bi), Cyanite (Cy), Diopside (Di), Epidote (Ep), Fluorite (Fl), Garnet (G), Ilmenite (Il), Magnetite (Mgt), Muscovite (Musc), Staurolite (St), Titanite (Ti), Tourmaline (Tour), Zircon (Zir). Average size of fragments, 0.1 mm.

Fig. 11. Specimen 13. Barstow, California. Heavy crop. The fragments are angular although rather distant from the nearest source of material. Their size, however, is below the limit of water-rounding. Andalusite (And), Barite (Ba), Biotite (Bi), Epidote (Ep), Garnet (G), Hornblende (Hb), Magnetite (Mgt), Muscocovite (Musc), Siderite (Sid), Stibnite (Stib), Tremolite (Trem). Average size of fragments, 0.08 mm.

Mechanical Analysis (Including Determination of Calcite and Other Acid-soluble Material)

Calcite, etc.	1 per cent.
Mud	8 per cent.
Silt	13 per cent.
Sand	78 per cent.
Coarse	Negligible

GRAVITY SEPARATION

Light Crop

Quartz—Abundant. Inclusions abundant, some liquid; a linear arrangement common.

Feldspar—Abundant. Orthoclase and microcline common; albite rather rare; oligoclase rare. Fresh and decomposed.

Vein (?) quartz—Rare. Dense, fine-grained quartz.

Heavy Crop (Fig. 10).

Muscovite—Abundant. Basal flakes.

Garnet—Abundant. Reddish-pink. Angular to rounded.

Epidote—Abundant. Well-rounded grains.

Magnetite—Abundant. Rounded grains.

Tourmaline—Reddish-brown, common; blue (indicolite), very rare.

Zircon—Common. Euhedra and fractions of euhedra.

Ilmenite—Rather common. Rounded grains. Partially altered to leucoxene.

Diopside—Rather common. Prismatic fragments.

Titanite—Rather rare. Slightly rounded grains.

Biotite—Rather rare. Some flakes almost red in color.

Fluorite—Rare. Octahedral cleavage fragments.

Andalusite—Very rare. Slightly rounded fragment.

Cyanite—Very rare. Bladed fragments.

Staurolite—Very rare. Slightly rounded fragment.

PETROLOGY

The mechanical analysis shows 78 per cent. of the rock to be composed of particles of sand grade. The grains are angular to perfectly rounded. The mineral suite suggests derivation from salic igneous rocks in large part, and from highly aluminous metamorphic rocks to a lesser degree.

CLASSIFICATION

A fine-grained arkosic sandstone.

SPECIMEN No. 13

LOCALITY

A specimen from the upper Miocene or lower Pliocene (Neogene) beds near Barstow, California (Fig. 1). Collected by Mr. Childs Frick of The American Museum of Natural History.

HAND SPECIMEN

A greenish-gray, friable clay rock locally discolored by iron oxide. Many slickensided surfaces occur as a result of tiny slip-faults within the rock.

MECHANICAL ANALYSIS (INCLUDING DETERMINATION OF CALCITE AND OTHER ACID-SOLUBLE MATERIAL).

Calcite, etc.	27 per cent.
Mud	26 per cent.
Silt	26 per cent.
Sand (?)	21 per cent.

The percentage of sand is very likely too high. The sand constituents appear to be fragments of highly indurated portions of the rock.

GRAVITY SEPARATION

Light Crop

Quartz—Abundant. Inclusions rather common.

Feldspar—The feldspars are so intensely altered that their exact identity is unknown. Two fragments of Oligoclase were identified.

Glass (?)—There are present fragments of an unknown isotropic substance which may be glass. Rather rare.

Heavy Crop (Fig. 11).

Hornblende—Common. Prismatic fragments.

Magnetite—Common. Subrounded grains.

Garnet—Common. Irregular fragments.

Biotite—Common. Basal fragments.

Barite—Common. Cleavage fragments and a fraction of a crystal.

Muscovite—Rather rare. Basal fragments of larger than average size.

Siderite—Rather rare. Cleavage fragments.

Epidote—Rather rare. Subrounded fragments.

Stibnite (?)—A lamellar, silver-gray mineral which closely resembles stibnite. Rather rare.

Tremolite—Rare. Prismatic fragments.

Andalusite—Rare. Irregular fragment.

PETROLOGY

Seventy-nine per cent. of the rock is composed of fragments less than 0.1 mm. in diameter. The fragments are angular. The uncertainty of the species of feldspar present makes it impossible to say whether salic or femic rocks furnished the mineral constituents.

CLASSIFICATION

A sedimentary clay rock.

SPECIMEN NO. 14

LOCALITY

A specimen from the upper Miocene or lower Pliocene (Neogene) beds near Barstow, California, collected from the same general locality as the preceding specimen. (Fig. 1).

HAND SPECIMEN

A greenish-gray, indurated, friable clay rock containing abundant bone fragments. Iron oxide stains are common. The specimen shows a platy, sheath-like structure due to tiny slip-faults. The slip-planes serve as water channels. Their surfaces are heavily coated by iron oxide.

MECHANICAL ANALYSIS (INCLUDING DETERMINATION OF CALCITE AND OTHER ACID-SOLUBLE MATERIAL)

Calcite, etc.	51 per cent.
Mud	17 per cent.
Silt	15 per cent.
Sand	17 per cent.

The percentage of sand is probably too high. The constituents appear to be highly indurated fragments of the rock.

GRAVITY SEPARATION

Light Crop

The character of the grains of the light crop is obscured by iron oxide and alteration products. The only mineral definitely determined is quartz. The quartz contains inclusions which are often in linear arrangement. No glass was observed.

Heavy Crop (Fig. 12).

The very abundant heavy residue is composed almost exclusively of clear, transparent, well-defined crystals of barite, some of which are doubly terminated. The crystals are elongated parallel to the "a" axis. The common forms are the pinacoid (001), the prism (110), the prism or macrodome (102), the prism or brachydome (011), and the rhombic bipyramid (111). The crystals appear to line the tiny fault surfaces within the sediment and were probably formed in place through precipitation from barium-rich solutions. The barium itself may have been derived from other sediments in which it acted as the cementing medium; from massive deposits of barite; or from metalliferous veins. The remainder of the heavy crop consists of hornblende and magnetite. The hornblende occurs as prismatic fragments; the magnetite as small, subrounded grains.

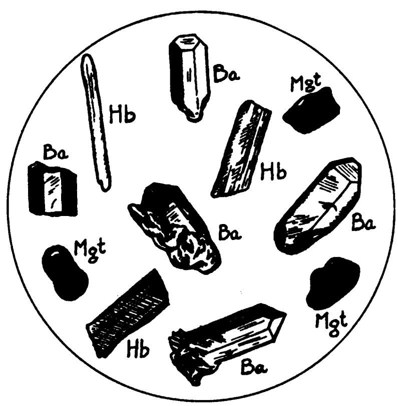

Fig. 12. Specimen 14. Barstow, California. Heavy crop. Note the clearly defined, authigenous barite crystals. Barite (Ba), Hornblende (Hb), Magnetite (Mgt). Average size of constituents, 0.1 mm.

PETROLOGY

The mechanical analysis shows 83 per cent. of the sediment to be composed of grains less than 0.1 mm. in size. The obscure character of the minerals of the light crop makes impossible a determination of the character of the source rocks.

CLASSIFICATION

A sedimentary clay rock.

CONCLUSIONS

EOCENE. UINTA BASIN, UTAH

Johannsen (1914, pp. 212–214) has described both hydroclastic and pyroclastic rocks from horizons A and B of the Uinta formation. The one specimen from horizon C which he described is a pyroclastic. Of the three specimens from horizon C analyzed in the present investigation, two are dacite tuffs, the third a fluviatile sediment. Consequently it seems that during Uinta time volcanic activity was intermittent in character. The pyroclastic constituents of the tuffs decrease in size from Myton to Ouray, that is, from west to east. It is probable, therefore, that the volcanic source was to the west.

The two specimens of tuff examined show no signs of working by water; the fragments are sharply angular. However, both contain occasional water-worn fragments which may have been introduced by adjacent rivers in times of flood. Those of the Ouray specimen are rather well-rounded (Fig. 2). The decreasing size and the increasing roundness of the fluviatile fragments from Myton to Ouray suggest that the direction of flow of the drainage between the two localities has remained unchanged. This is in keeping with the belief (Osborn, 1909, p. 21; 1929, p. 51)) that the drainage and general geographic setting of the mountain-basins have remained essentially unchanged since the middle Eocene.

LOWER OLIGOCENE. WELD COUNTY, COLORADO

The specimen from the lower Trigonias quarry at Weld County, Colorado, is a dacite tuff. The constituents of the rock, both mineral and glass, vary from sharply angular to slightly rounded. The clearly defined shards, the presence of crystal faces on many minerals, and sharply defined cleavage fragments, all rather distant from the nearest known source of supply, indicate volcanic derivation and direct deposition from the air, with little or no modification by running water. On the basis of the mineralogy, the source material would approximate a granodiorite in composition. Although this fossil quarry has been considered (Gregory and Cook, 1928, p. 3) the site of an ancient "mucky water-hole" because of the "absence of grit" and the "clearly-defined floor and abrupt margins" of the deposit, the analysis of the specimen examined in this investigation shows over 80 per cent. grit, indicating sandier conditions than previously supposed. The appearance of the material is misleading. The decomposition of the feldspar has resulted in abundant clay products which coat the other constituents.

NODULAR LAYERS, OLIGOCENE. SOUTH DAKOTA

Both the lower and upper nodular layers are sedimentary clay rocks. The cement is calcite and has almost completely replaced the constituent fragments. The cryptocrystalline cement suggests precipitation from quiet water (Emmons, 1928, p. 740) such as one would find in this area, according to the description of Sinclair (1921) and Wanless (1922, p. 202) who pictured the region as one of low relief partly covered by shallow ponds. The small amount of volcanic glass in the middle and lower Oligocene of South Dakota is in contrast with the abundance of ash in the lower Oligocene of Weld County, Colorado, to the southwest.

OLIGOCENE. TORRINGTON, WYOMING

The specimen from the Torrington fossil quarry is a dacite tuff. The pyroclastic constituents are of small size, averaging only 0.03 mm. The Torrington horizon is probably of middle Oligocene age.[1] The abundance of ash at Torrington in contrast to its paucity in the middle Oligocene of South Dakota appears to place the volcanic center in the Rockies somewhere to the west or southwest. This may explain the still coarser pyroclastic material farther south in the lower Oligocene of Weld County, Colorado. The same inference as to the location of the volcanic center which supplied Nebraska with its ash deposits has been drawn by Barbour.

MIOCENE. AGATE, NEBRASKA

The specimen from the Agate fossil quarry is a pure ash. No fluviatile material is recognized. The feldspar is unaltered. This suggests deposition in a dry climate. The precipitation of the cement, furthermore, must have been rapid enough to protect the feldspar from decomposition. Peterson (1906, pp. 493–4) mentions lamination in the quarry level. This, considered with the evidence for rapid precipitation of the cementing medium, appears to indicate that the Agate quarry was the site of a shallow pond. Evaporation, in a dry climate, would cause the calcium carbonate in solution to precipitate fairly rapidly.

The fragments are perfectly sorted and in general angular, although some of the heavy minerals are well-rounded. The sorting, the angularity, and the pyroclastic origin of the material point to deposition from the air. The occasional rounding may be due to slight working by wind before deposition. The presence of augite and olivine, both un-

[1]Mr. E. J. Schlaikjer—verbal communication.

stable minerals, so far from the nearest source of supply, is evidence against a fluviatile origin of the Agate deposit.

UPPER MIOCENE OR LOWER PLIOCENE, MADISON VALLEY, MONTANA

The specimen examined is a tuff composed of highly angular fragments. It is cemented by coarsely crystalline calcite. Emmons (1928, p. 740) found by experiment that calcium carbonate precipitates from quiet water as a fine powder, and from circulating water as a coarsely crystalline product. If this is a criterion, the cement in this specimen was precipitated from freely circulating groundwater. The decomposition of much of the feldspar may also indicate contact with acidulated groundwater. The pyroclastic constituents show no signs of water-working, yet the hand specimen shows intercalated seams of gravel. The gravel seams may represent the overflow products of an adjacent river. The pebbles occur up to 8.0 mm. in size. This suggests that the river current was fairly vigorous.

The large pyroclastic constituents point to a relatively close volcanic center. This is not surprising, since the area is so close to the Yellowstone Park region, believed by Rowe (1903, p. 6) to be a possible source of the material. The large size of the pebbles in the gravel seams is likewise indicative of the proximity of the source of these materials.

SANTA FÉ MARLS. ESPANOLA, NEW MEXICO

Three specimens of the Santa Fé Marls have been examined in the present investigation. The most friable one was investigated by the gravity separation method, the others by thin section. The two firm specimens contain angular to subrounded, poorly sorted fragments in a coarsely crystalline calcite matrix which comprises 40 to 60 per cent. of the rock. The feldspar occurs fresh and partially decomposed.

Johnson (1903) disproved the lacustrine theory of the origin of the Santa Fé Marls, by a careful study of the sediments, and concluded that these deposits are wholly the result of laterally confluent alluvial fans spreading out from the neighboring mountain ranges. The lithologic evidence is in agreement. The angular character of the fragments suggests proximity to the source of material. The poor sorting and the irregular bedding observed in one specimen, are both indicative of the fluctuating conditions governing such deposits. The friable specimen, on the other hand, contains sufficiently well-rounded and well-sorted fragments to be considered of eolian origin. The evidence for eolian deposition, and the occurrence of fresh feldspar in all three specimens examined, indicate deposition in a dry climate.

Upper Miocene or Lower Pliocene, Barstow, California

Two specimens from the Pliocene deposits near Barstow, California, have been examined. The fine texture of the fragments, and the decomposition of the feldspar, point to long transportation by water. The fragments have remained angular because below 0.1 mm. in size, generally considered the lowest limit of water rounding. No glass was identified.

This study, in addition to furnishing information concerning the individual specimens examined, serves to emphasize the large, although not exclusive, part played by volcanic activity in building up the western continental Tertiary deposits, and in preserving their extraordinary record of mammalian evolution.

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