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# Jurassic Redbeds of the Connecticut Valley: (1) Brownstones of the Portland Formation; and (2) Playa-Playa Lake-Oligomictic Lake Model for Parts of the East Berlin, Shuttle Meadow, and Portland Formations

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# Mesozoic Geology

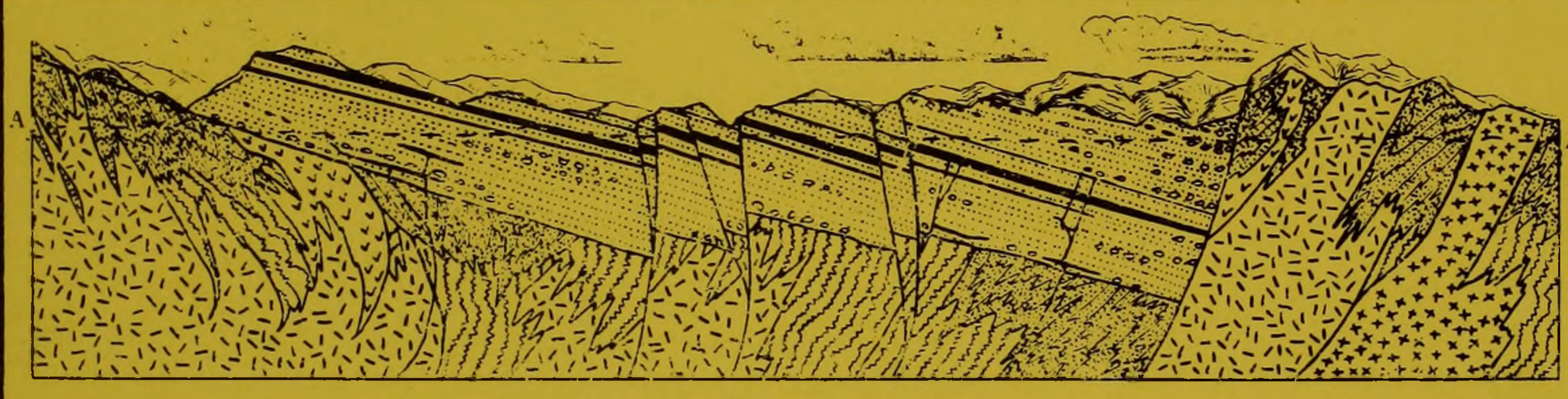


Figure 6. BLOCK MOUNTAINS OF THE EARLY JURASSIC

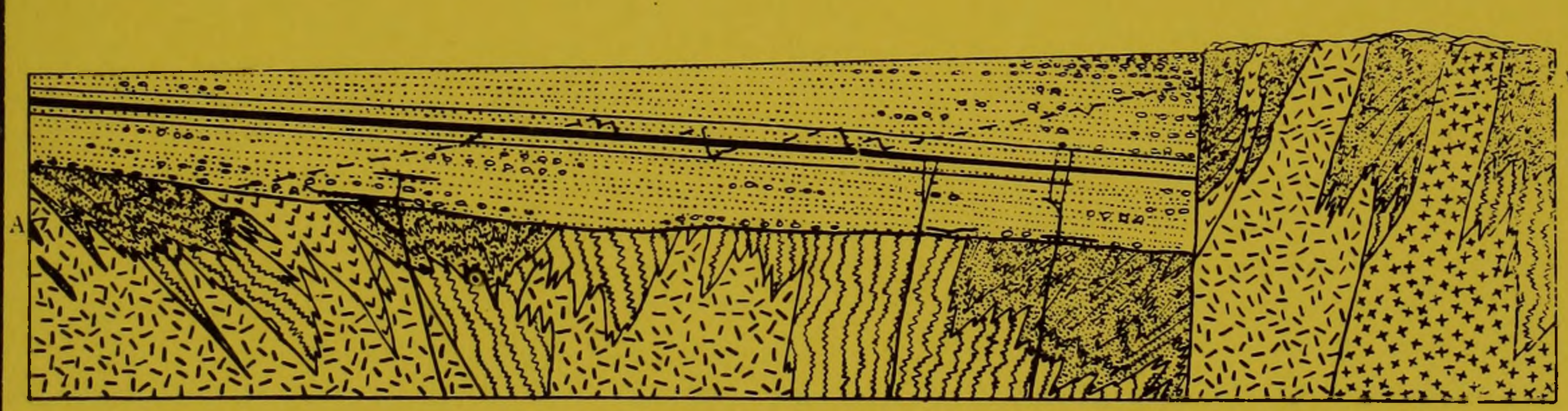


Figure 7. CLOSE OF THE TRIASSIC SEDIMENTATION

# JURASSIC REDBEDS OF THE CONNECTICUT VALLEY: (1) BROWNSTONES OF THE PORTLAND FORMATION; AND (2) PLAYA-PLAYA LAKE-OLIGOMICTIC LAKE MODEL FOR PARTS OF THE EAST BERLIN, SHUTTLE MEADOW, AND PORTLAND FORMATIONS

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## INTRODUCTION

The following description of the Buckland Brownstone Quarry in Manchester (stop 8) extends the earlier Guide to the Mesozoic Redbeds of Central Connecticut (Hubert et al., 1978). After the description of the Buckland brownstone quarry, we discuss the model for the playa-playa lake-oligomictic lake system, including an interpretation of the playa redbeds in the East Berlin Formation at stop 6. An expanded version of the objectives of our trip, the regional setting, and an abstract of the paleographic history are given in pages 1-8 of the 1978 guidebook.

This publication is Guidebook No. 4 of the Connecticut Geological and Natural History Survey. For information on ordering the guidebook and other publications of the Survey, consult the List of Publications available from the Department of Environmental Protection, State Office Building, Hartford, Connecticut 06115.

During our NEIGC trip, we present an overview of the history of the sedimentary and volcanic fill of the rift valley in Late Triassic and Early Jurassic time. We shall focus on interpretation of depositional environments, using primary sedimentary structures and stratigraphic sequences. The paleoenvironments emphasized are: alluvial-fan conglomerate (stop 1); paleosol caliche profiles (stop 2); braided-river sandstone and floodplain mudstone (stops 2, 5, 8), symmetrical cycles of gray mudstone-black shale-gray mudstone that accumulated in carbonate-producing alkaline lakes (stop 7); redbeds of playa-lake origin (stop 6); and playa red mudstones (stops 6, 7).

## STOP 8. BUCKLAND BROWNSTONE QUARRY IN THE PORTLAND FORMATION, MANCHESTER

*Little I ask; my wants are few;*
*I only wish a hut of stone*
*(A very plain brown stone will do),*
*That I may call my own;*
*And close at hand is such an one,*
*In yonder street that fronts the sun.*

*Contentment* *Oliver Wendell Holmes*

### Location

The brownstone quarry is in the small community of Buckland in the northwest corner of Manchester, Connecticut (Figs. 1, 2). Including small exposures, the quarry encompasses 45 m of section, approximately 1620 to 1665 m up in the 2,000 or so meters of the Portland Formation (Fig. 3; Sidney Quarrier, personal communication).

To reach the quarry, leave I-94 at Exit 93 and proceed northwest on Windsor Street. Turn right (east) on Burnham Street and then left (north) on Buckland Road. The quarry is hidden by trees and brush on the east side of Buckland Road, opposite the Hartman Tobacco Farm. These roads are shown on the Manchester 7.5 minute topographic quadrangle, which, however, does not show the site by a quarry symbol. Coltin (1965) shows the quarry on his bedrock geologic map of the Manchester quadrangle.

The Buckland quarry is privately owned and information about access should be obtained by contacting the State Geological and Natural History Survey of Connecticut, Department of Environmental Protection, State Office Building, Hartford, Connecticut 06115. Do not climb the rock faces.

### Objective of Stop 8

At this stop we see a quarry where brownstones was mined for many years with peak activity in the late 19th century. The quarry yielded a stone of high quality with thick beds of plane-bedded sandstone made hard by albite cement and of a lovely shade of red produced by hematite pigment. In the building trade it was called "redstone".

In its early days, Buckland was known as Jambstone Plain because of the numberous slabs of brownstone taken from the Buckland quarry for use as

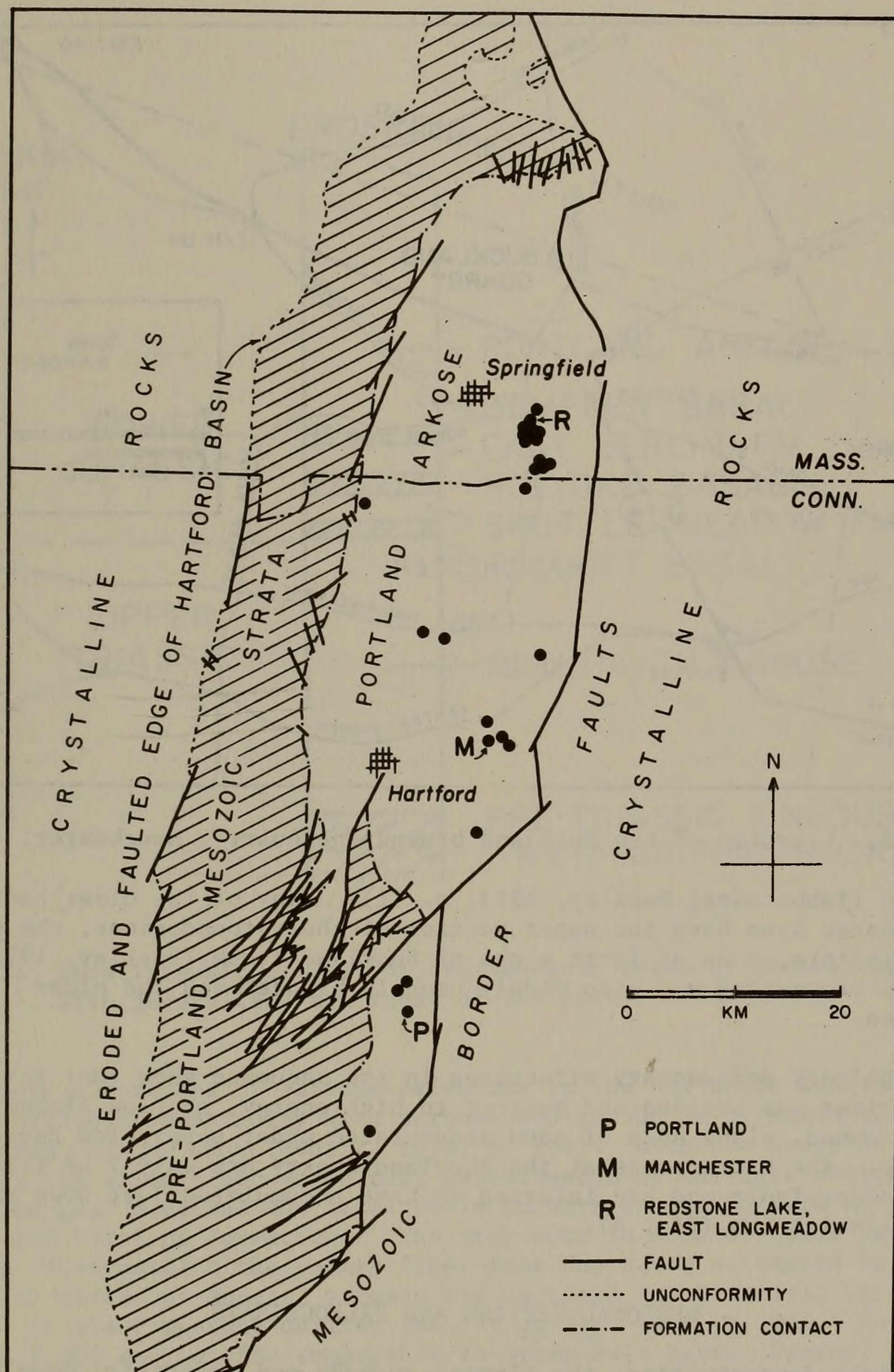


Fig. 1. Location of brownstone quarries in the Portland Formation in the Connecticut Valley, compiled largely from Smith (1982). The Buckland quarry (stop 8) is labelled M at Manchester.

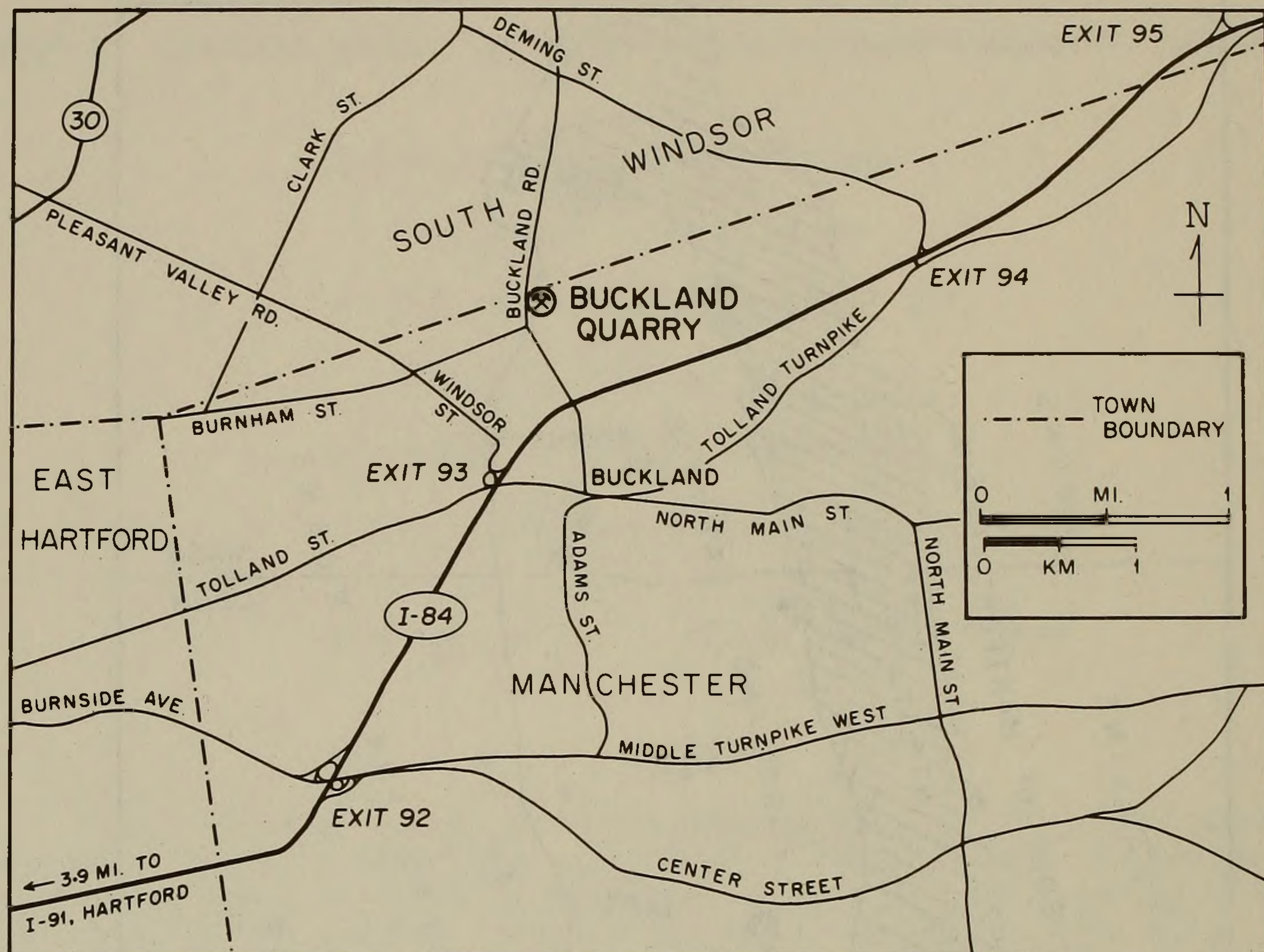


Fig. 2. Location of the Buckland brownstone quarry, Manchester.

doorstones (jambstones; Buckley, 1973, p. 11). Many of the older houses in the Manchester area have the upper section of their foundations, the part seen by visitors, made of large slabs of Buckland stone (Buckley, 1973, p. 11). This brownstone was also widely used in bridges and the older gravestones.

The primary sedimentary structures in the sequence show that the Early Jurassic river was braided and subject to high energy, shallow floods. As the flows waned, plane beds of sand accumulated under upper flow regime conditions. The brownstones at the Buckland quarry are only 7 km from the eastern border fault and are inferred to have accumulated just down slope from an alluvial fan (Fig. 4).

## REGIONAL SETTING AND PALEOCLIMATE

In Early Jurassic time, the fluvial redbeds and lacustrine gray mudstones of the Portland Formation accumulated in a subtropical rift valley at about 15°N paleolatitude (Van Houten, 1977, p. 93). Rivers flowed from highlands east of a fault-bounded escarpment, across alluvial fans and onto the valley floor, which at times was the site of perennial lakes (Fig. 4).

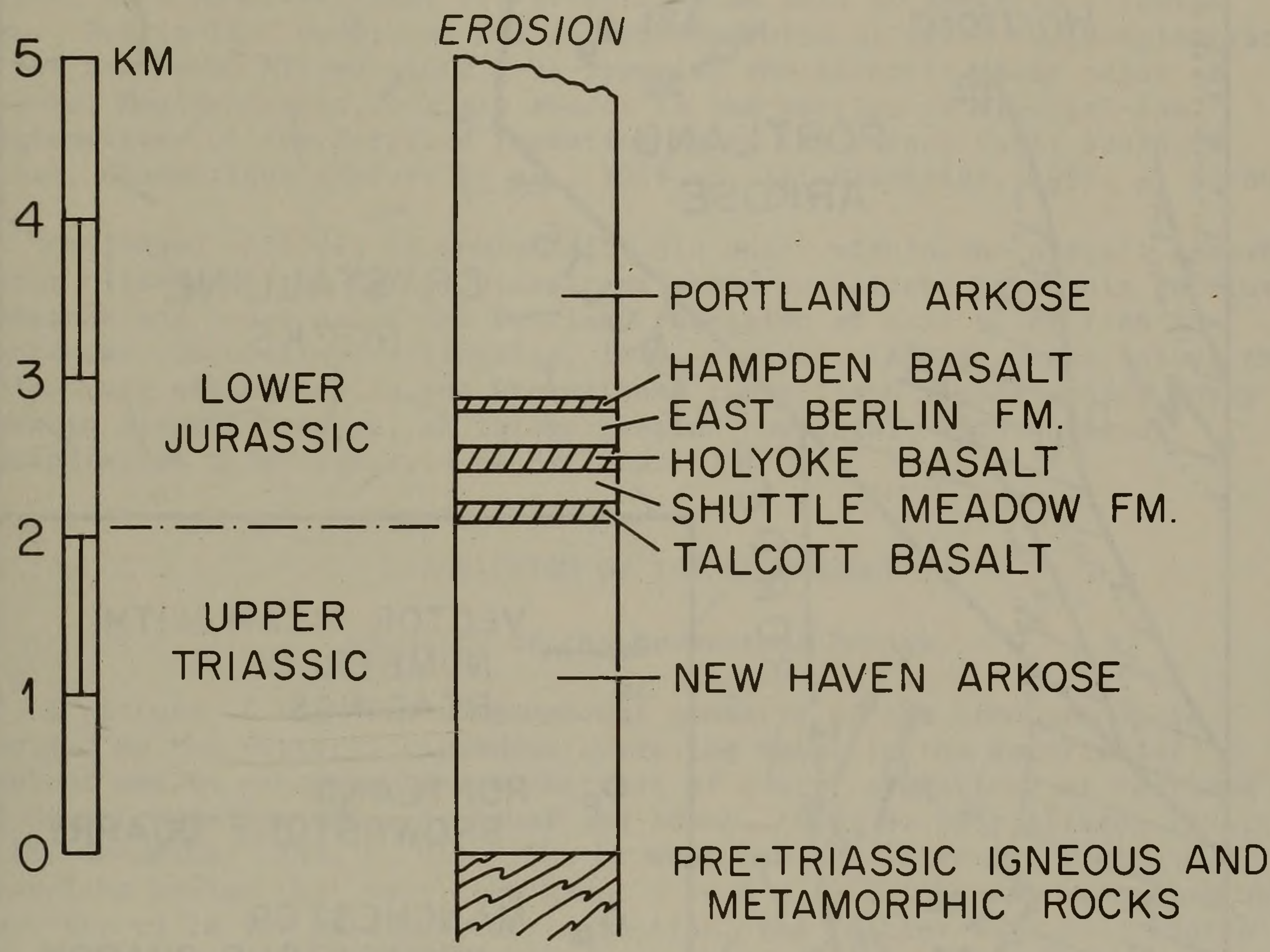


Fig. 3. Stratigraphic column for the Mesozoic rocks of central Connecticut with generalized thickness of the units.

Numerous horizons of caliche paleosols in the New Haven Arkose testify to Late Triassic semiaridity with perhaps 100 to 500 mm of seasonally distributed precipitation (Hubert, 1978, p. 164). With the onset of the Early Jurassic, the climate became wetter, as evidenced by multiple horizons of lacustrine gray mudstone and black shale in each of the Shuttle Meadow, East Berlin, and Portland Formations. The gray muds in some of these perennial, alkaline lakes mantled the valley floor from New Haven northward to the structural divide at Amherst between the Hartford and Deerfield basins and westward to the Pomperaug outlier (Hubert et al., 1978, p. 96). These lakes exceeded 5,000 $km^2$, a size comparable to Great Salt Lake. Spores, pollen, leaves, and stems are common in the lacustrine gray mudstone, defining three Jurassic palyno-floral zones (Cornet, 1977, p. 265). The flora shows that, in comparison with the Late Triassic, the climate in the Early Jurassic became progressively slightly cooler and wetter, perhaps due to northwest drifting of the American continental plate (Cornet, 1977, p. 269).

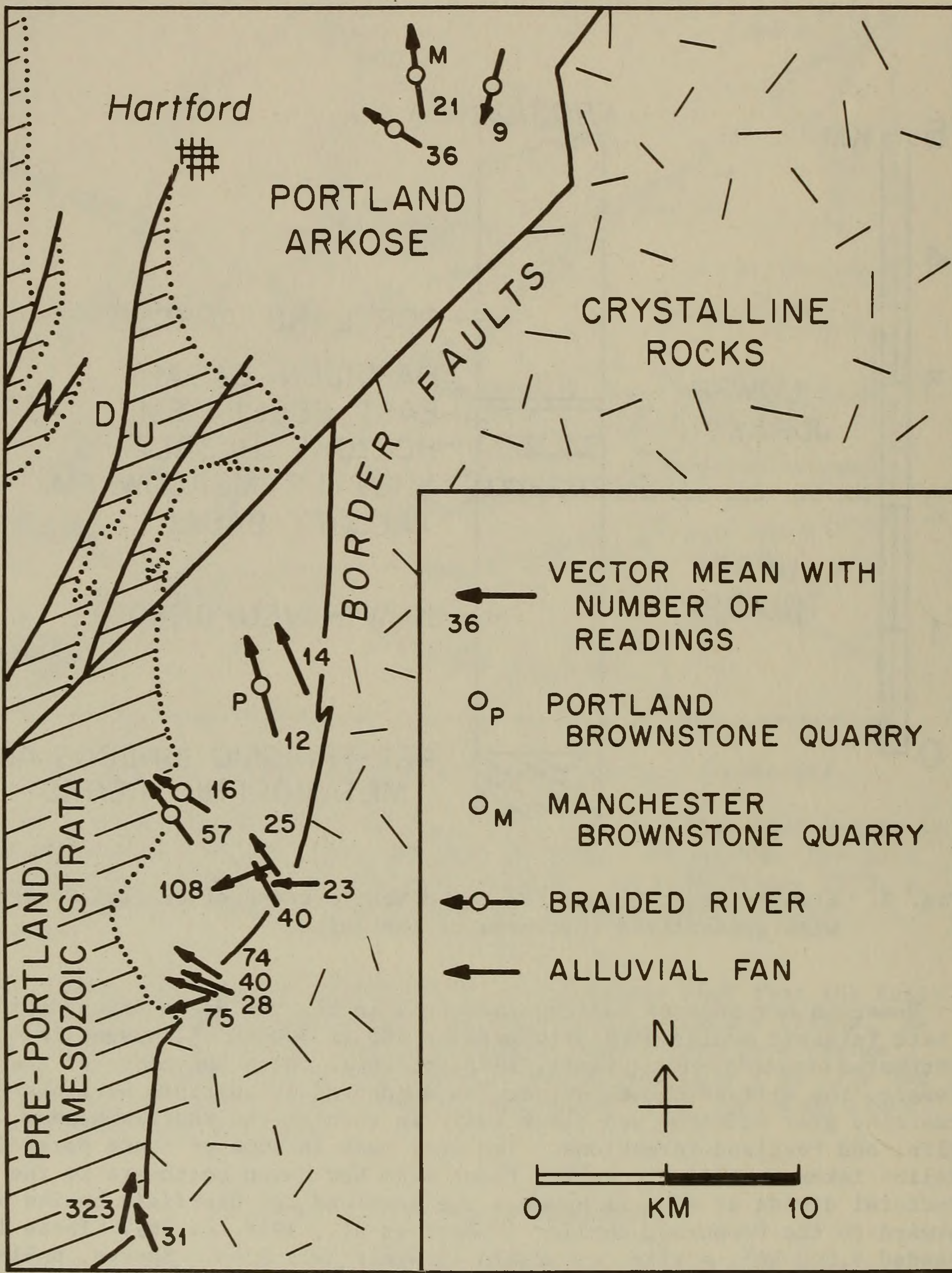


Fig. 4. Location of the brownstone quarries at Buckland in Manchester and at Portland. Each paleocurrent arrow is the vector mean for an outcrop of either alluvial-fan or braided-river facies. Each vector mean is significant at the 0.95 percent level when tested by the Rayleigh statistic L.

Increased precipitation in the Early Jurassic is further supported by the stratigraphic distribution of pebbly-sandy mudstones of debris-flow origin, such as occur today preferentially on arid to semiarid alluvial fans. Debris-flow mudstones are interbedded with alluvial-fan conglomerates of the New Haven Arkose along I-91 opposite the electric power palnt at Holyoke, Massachusetts, but are absent in the section of alluvial-fan conglomerates of the Portland Formation along the border fault south of Durham, Connecticut (Hubert et al., 1978, p. 11; Gilchrist, 1979, p. 65-80.

Prolonged episodes of semiaridity did occur within the overall somewhat wetter climate of the Early Jurassic as shown by caliche paleosols in fluvial sandstone and mudstone of the Portland Formation at exit 92 of I-86 in Manchester, Connecticut (Gilchrist, 1979, p. 151). As discussed below, the sedimentary structures in the brownstones imply flash floods and/or sharp peaks in river discharge, an interpretation compatible with seasonal precipitation under semiarid conditions.

## DESCRIPTION OF THE BROWNSTONE

### Geometry of the Brownstone Bodies

A picture of the three-dimensional geometry of the brownstones is provided by the vertical exposures above the water in the quarries at Portland and in photographs and sketches of quarry operations at Portland and East Longmeadow (Fig. 5; Asher and Adams, 1876, p. 185; Allbee, 1894, p. 21; Champlin, 1944, p. 91). The brownstones are laterally continuous, sheet-like bodies that vary from about 1 to 6 m in thickness, averaging about 2 m. Viewed in the paleo-upriver direction, the thicker sandstone bodies show about 2 m of lateral thinning across the quarry walls. The base of each sheet sandstone is fairly level with only shallow scours cut into the underlying strata. The ratio of sheet sandstone to overbank mudstone is about 20 to 1 with the thickest bed of mudstone less than a meter.

### Lithological Facies

The brownstone sequences at the Manchester and Portland quarries are made of eight lithological facies defined by sedimentary structures and grain size (Figs. 6, 7). A vertical succession made of a single facies is termed a unit. The colors cited are from the Munsell Color Chart. After the facies are introduced, we describe the individual flood sequences which are made of one or more of the facies.

Plane-bedded sandstone (facies Sh) is the characteristic and dominant facies in the brownstones, comprising 79 percent of the cumulative thickness of the sections (Figs. 8, 9, 10). They range from very fine to very coarse sandstone, sometimes pebbly, with medium and coarse sandstone most common. Parting lineation is present on some of the infrequent horizontal exposures. The units vary from 1 to 172 cm in thickness, averaging 30. They tend to be laterally continuous, commonly extending across the quarry walls for some tens of meters.

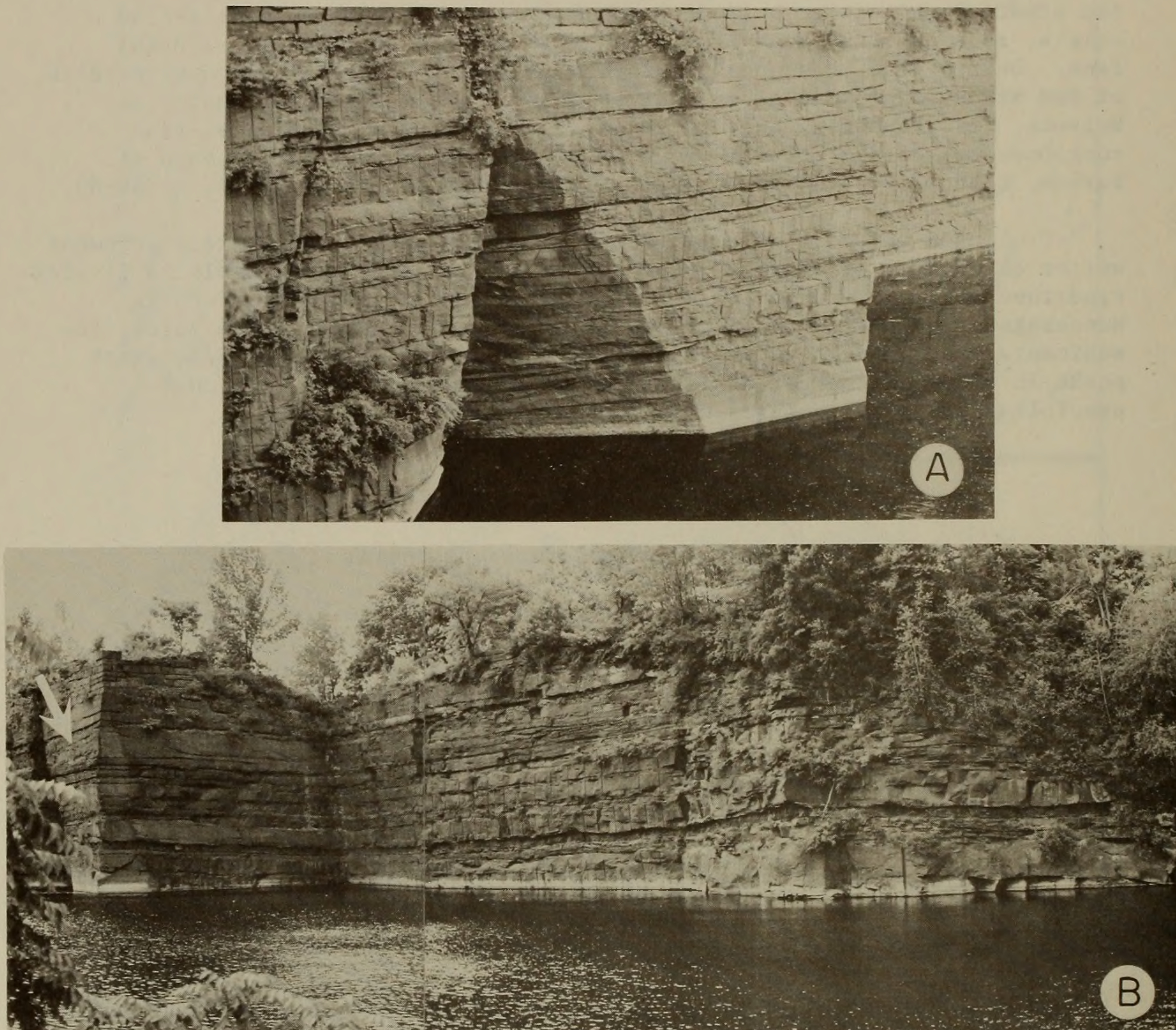


Fig. 5. Two views of a quarry in Portland, illustrating the lateral persistence of the brownstone layers. (A). View towards S66W almost perpendicular to the paleoflow direction, which is towards N18W (Fig. 7). The vertical rock wall is about 20 m high. (B). View towards S15E almost directly up the paleo-river system. The arrow points to the rock wall shown in (A).

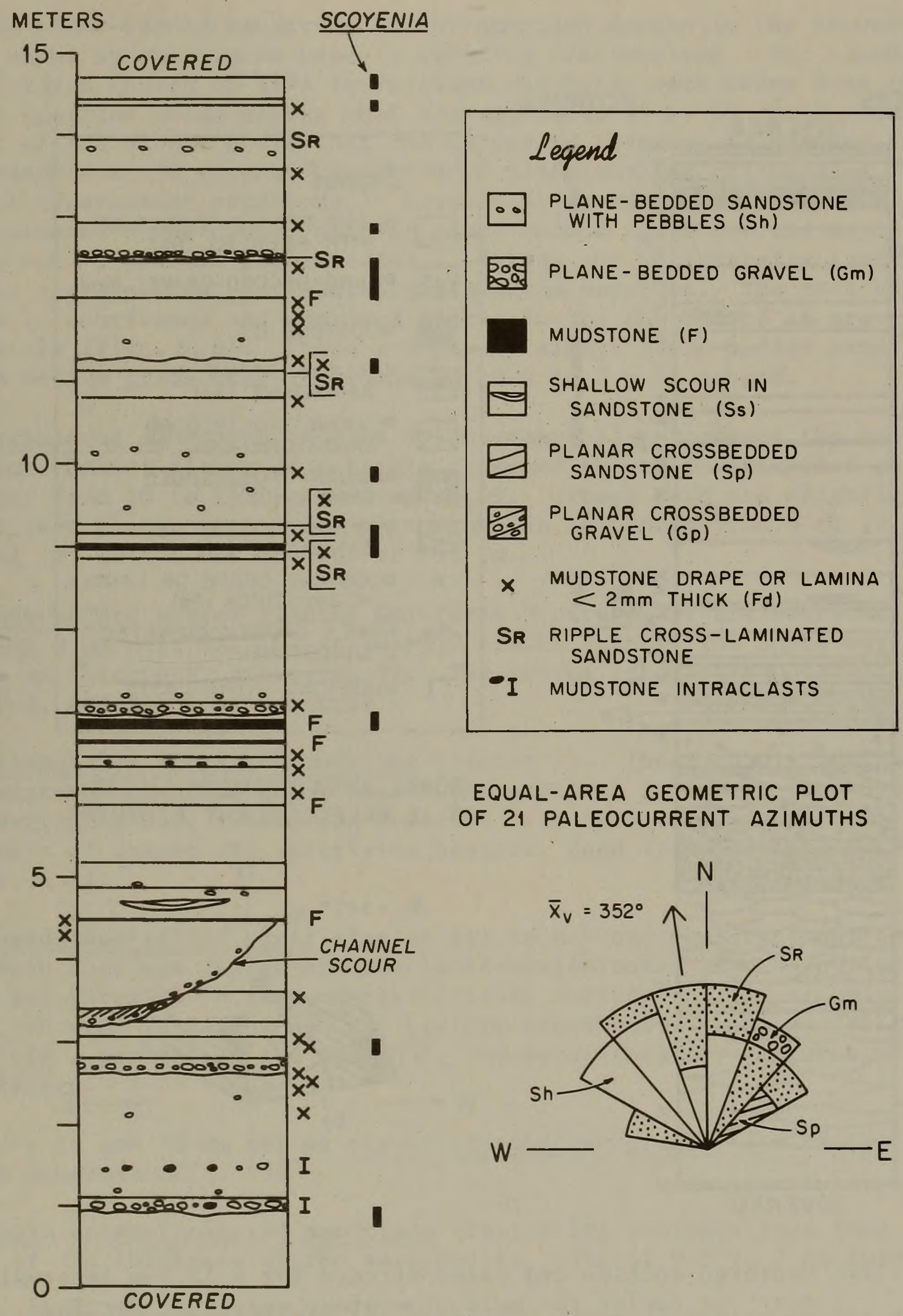


Fig. 6. Measured section and paleocurrents for the brownstone sequence at the Buckland quarry near Manchester.

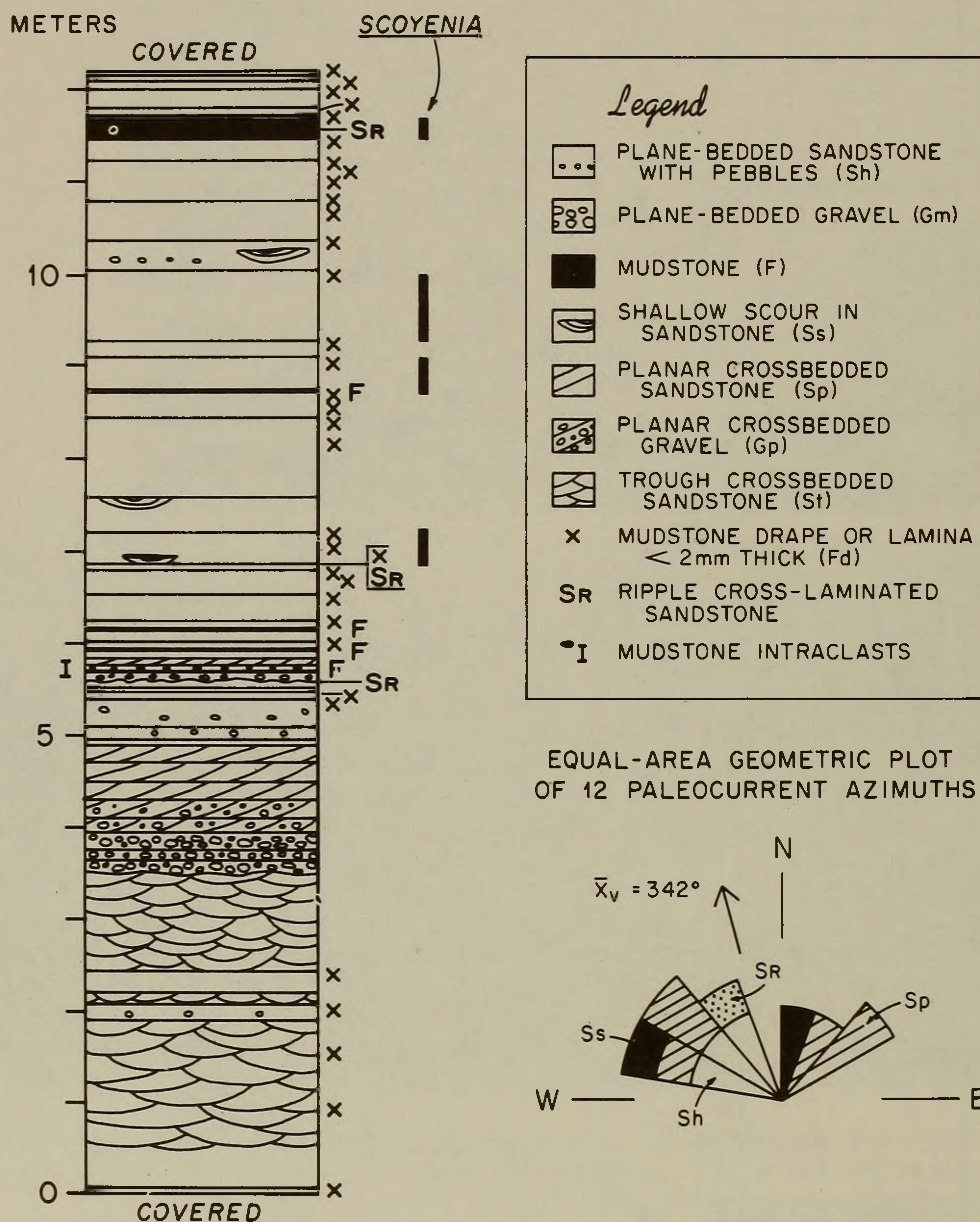


Fig. 7. Measured section and paleocurrents for a 12.2-m interval near the top of the main brownstone quarry at Portland.

That plane-bedded sandstone is the dominant facies in the brownstones is also shown by the blocks used in building construction. For example, the lovely Trinity Church of 1874 in Portland was built with stone from the Portland quarries using blocks that average about 30 by 50 cm in size. A sampling of 100 blocks shows that the facies in them are 57 percent plane-bedded sandstone, 32 percent plane-bedded sandstone and crossbedded sandstone, 6 percent crossbedded sandstone, 2 percent plane-bedded sandstone and ripple cross-laminated sandstone, 1 percent plane-bedded sandstone and sandstone-filled scour, 1 percent plane-bedded sandstone and horizontally laminated mudstone, and 1 percent horizontally laminated mudstone. The choicest stone was used in doorframes and engraved blocks in the church and as gravestones and obelisks (Figs. 8, 9). These are nearly always plane-bedded sandstone of fine and medium grain size in blocks up to 2 to 3 m in length.

Crossbedded sandstone (facies Sx) averages 13 percent of the sections in units that consist either of a single crossbed set or superimposed sets. The units vary from 10 to 111 cm, averaging 49. Trough sets are slightly more abundant than planar sets. The sets range in thickness from 6 to 28 cm averaging 16, except for one set of 111 cm.

Plane-bedded gravel (facies Gm) forms 3 percent of the sections. By definition a Gm unit must be at least 2 clasts thick. The units vary from 3 to 21 cm in thickness, averaging 11. The gravel is clast-supported, imbricated, and has a sand matrix.

Horizontally laminated mudstone (facies F). These thinly laminated sandy mudstones comprise 2 percent of the sections in layers from 0.1 to 17 cm, averaging 2.9. Where the mudstone is a thin (less than 2 mm) lamina that covers or drapes the underlying bedform, then it is designated facies Fd (Figs. 6, 7).

A sandstone-filled scour (facies Ss) is a broad shallow scour about 10 cm in depth that was filled by crudely cross-laminated sand. The inclined laminae are parallel to the underlying scour surface and dip at only a few degrees, showing that they are not bedform crossbeds. These sand-filled scours form 2 percent of the sections, always as solitary features within the Sh facies.

There is one 33-cm set of planar crossbedded gravel (facies Gp) in the Portland sequence (Fig. 7).

Ripple cross-laminated sandstone (facies Sr) averages less than 1 percent of the thickness of the sections in units of 0.5 to 2 cm thickness.

Densely packed burrows of the arthropod Scoyenia penetrate the sand and mud facies at numerous levels in both sections (Figs. 6, 7).

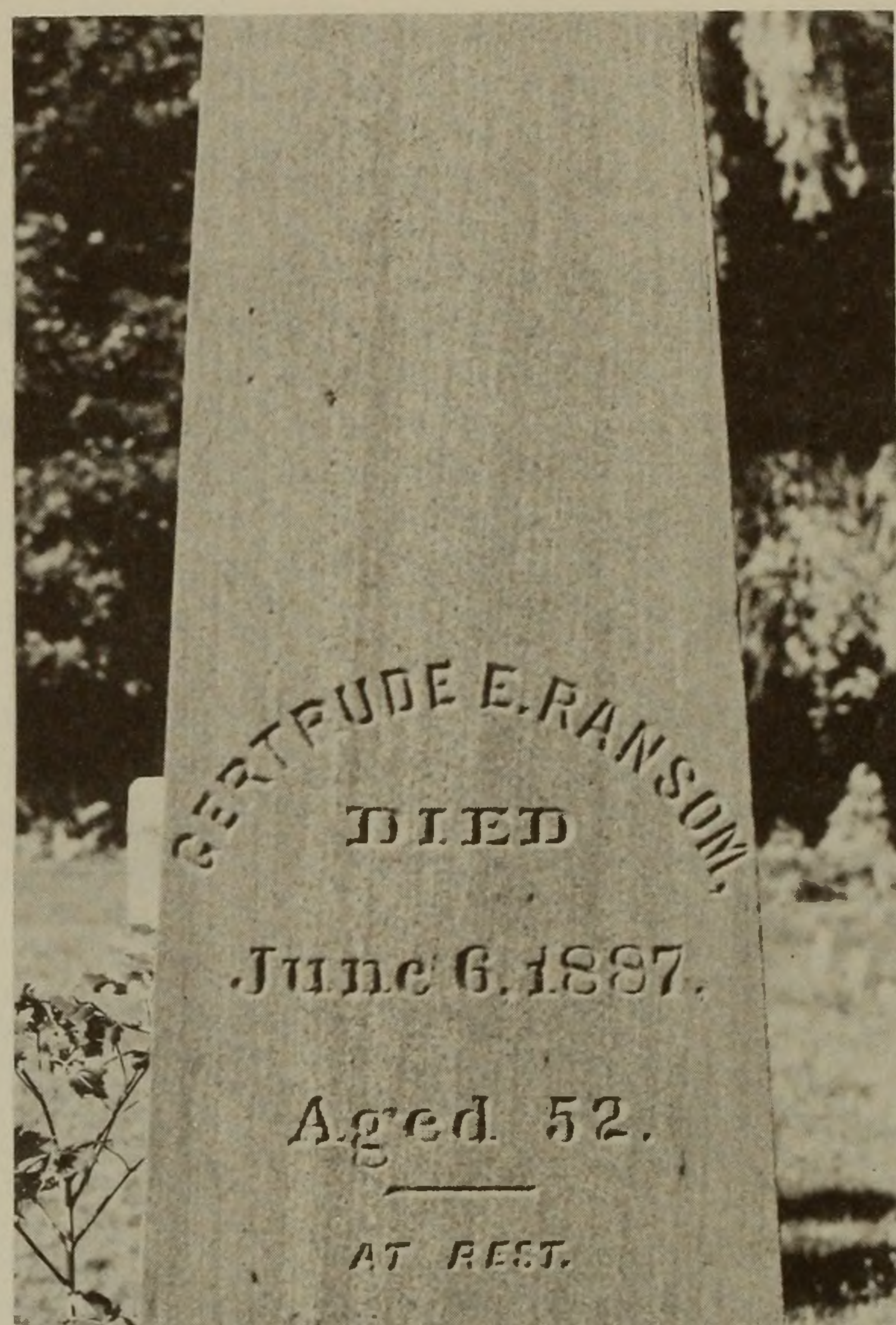


Fig. 8. Plane-bedded sandstone used as gravestone. Trinity Church, Portland.

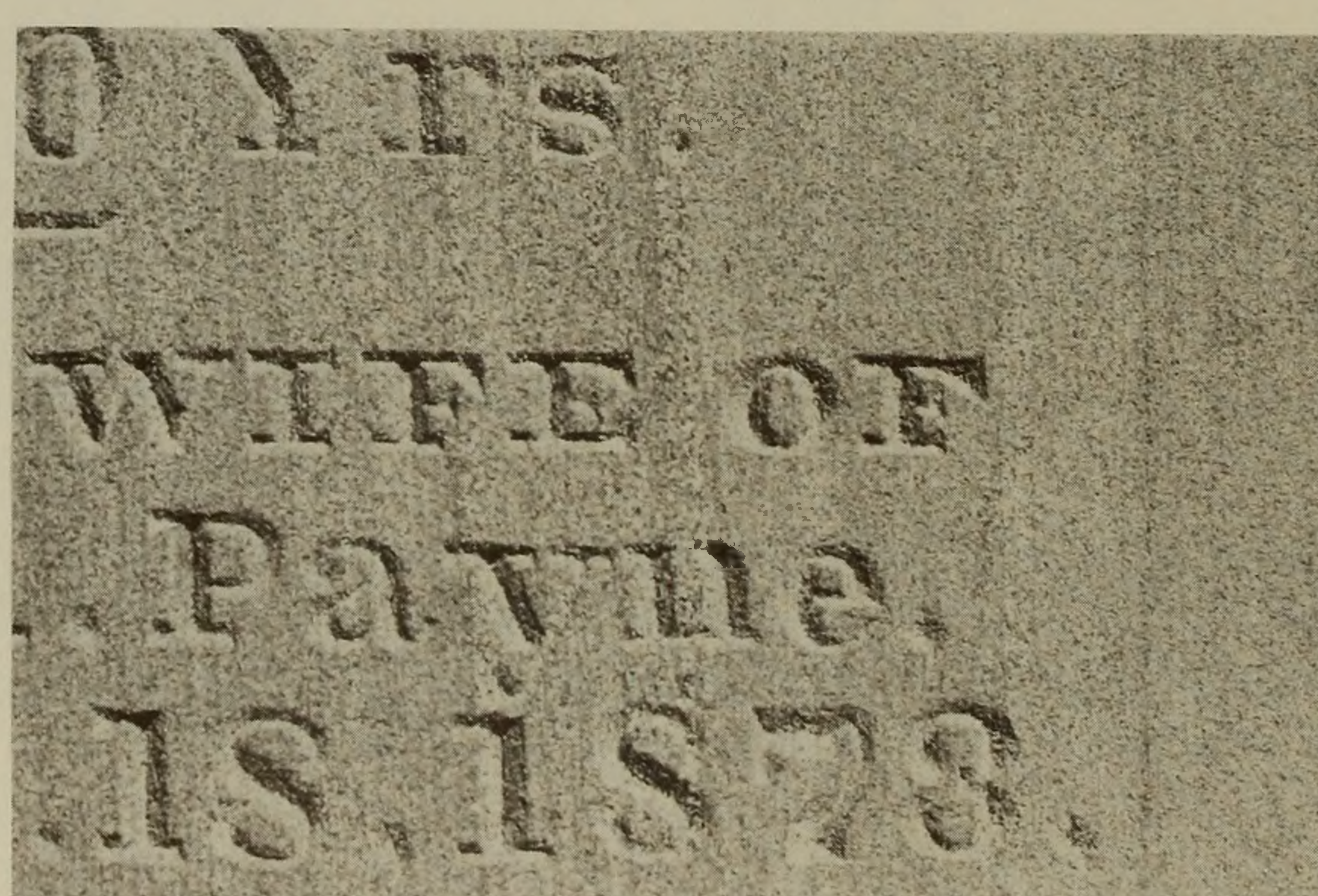


Fig. 9. Plane-bedded brownstone in graveyard at Trinity Church, Portland.

## Markov Chain Analysis of Facies Transitions

In order to determine preferred facies transitions in the fluvial sequences of the brownstone quarries at Manchester and Portland, the combined 26.8 m of the two sections were analyzed for the presence of the Markov property. When it is present, the probability of occurrence of any particular facies is not random, but is in part predictable from and thus "dependent on", the adjacent underlying facies. An embedded Markov chain was used, where each facies transition is tabulated, yielding a transition count matrix (Miall, 1973, p. 349).

The resulting Markov chain for the brownstone quarries is based on the positive probability values of the difference matrix (Fig. 11). These values are obtained by subtracting the independent trial probabilities (that is, the transition probabilities for a random sequence of these six facies when the Markov property is not present) from the transition probability matrix. The positive difference values cited in Figure 11 are the transitions that occurred more commonly than expected under a random selection process. A chi-square test shows that there is a greater than 99.9 percent probability that the Markov property is present in the brownstone sequences.

## Redstone Lake Quarry, East Longmeadow, Massachusetts

The brownstones in the Redstone Lake quarry, formerly known as the Maynard quarry (Fig. 12), are similar to the brownstones at Buckland and Portland, but are not included in the statistical calculations because only 3 m are exposed above the lake. Form 1965-1972, the Redstone Lake quarry was reopened to provide 20-ton blocks of brownstone for the library at New York University at Washington Square in New York City.

# DEPOSITION OF THE BROWNSTONES

Although separated in time and place, the rivers that deposited the brownstones at Buckland and Portland were sand-bed rivers subject to repeated floods. The measured sections average 95 percent sandstone, 3 percent conglomerate, and 2 percent mudstone (Fig. 10). The distinctive plane-bedded sandstones comprise 94 percent of the section at Buckland and 60 percent at Portland. As discussed next, the plane beds of sand accumulated from shallow, rapidly moving flows during the waning stages of floods.

## Flood Deposits

Here and there in the brownstones one can see distinctive sequences of sedimentary structures produced by the rapid waning of flood waters followed by fallout of mud from suspension. The sequences appear as preferred facies transitions in the Markov chain (Fig. 10). The most common sequences at the Buckland and Portland quarries, in order of decreasing abundance, are as follows.

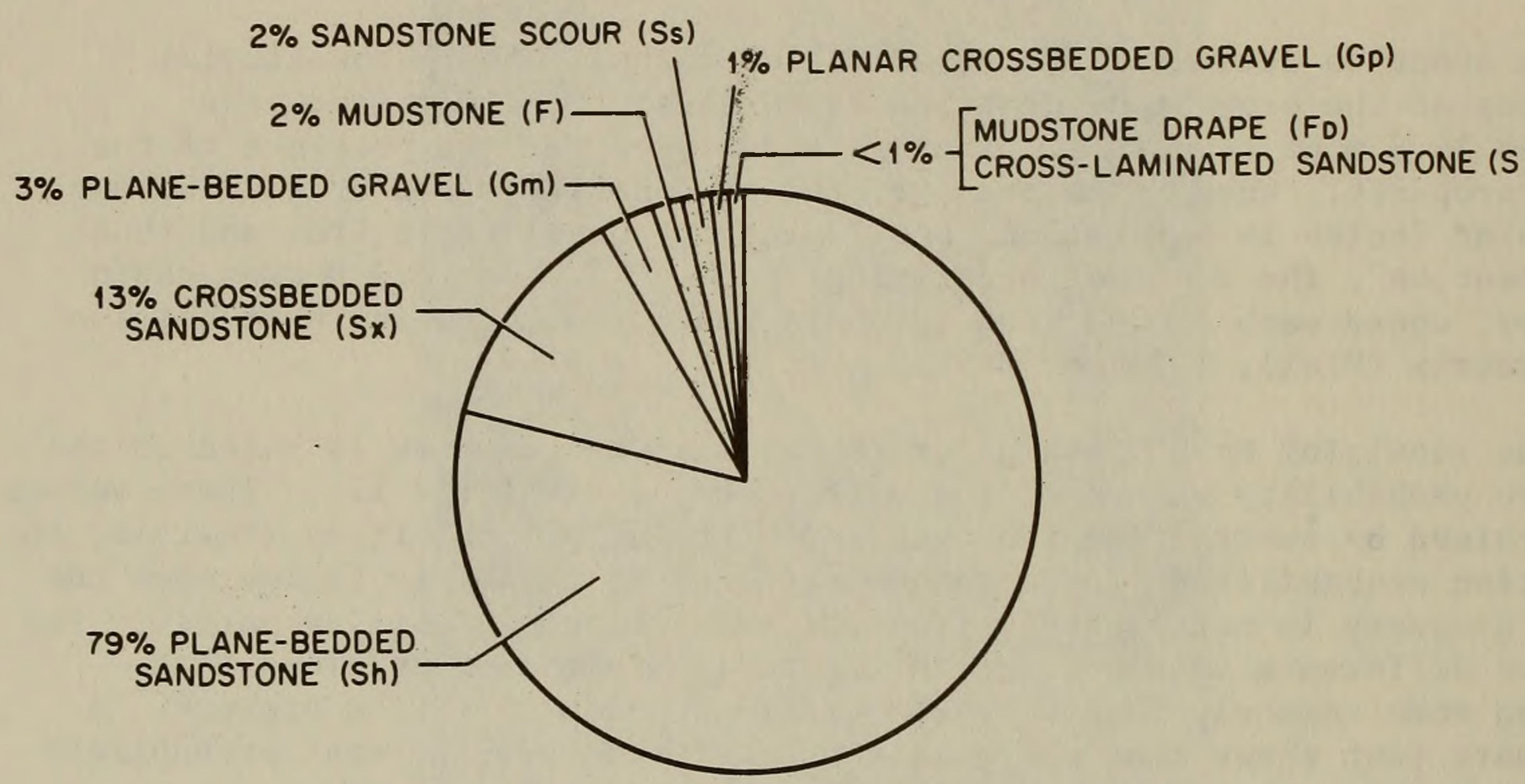


Fig. 10. Average proportions of the sedimentary structures in the combined brownstone sequences at Buckland and Portland (Figs. 6 and 7). The percentages are based on the cumulative thicknesses of the structures and not on the number frequence of occurrence.

1. The majority of the sequences are either plane-bedded sandstone (Sh), sometimes pebbly, → mudstone drape (Fd) or plane-bedded sandstone with thin lenses of mudstone → mudstone drape (Fd). Similar waning-flood sequences of 0.5 to 2 m thickness occur in the Trentishoe Formation of Middle Devonian age in Devon, England (Tunbridge, 1981, p. 84) and in the Lower Carboniferous of northwestern Ireland (Graham, 1981, p. 200). In both formations, a scour surface is overlain by plane-bedded sandstone and then a mudstone drape. Plane-bedded sandstone also dominates the distal alluvial-plain facies of the Lower Paleozoic Piekenier Formation in South Africa (Vos and Tankard, 1981, p. 190). In these three formations, the plane-bedded sandstone and mudstone drapes are attributed to channel floods with rapidly waning flow followed by fallout of mud from suspension.

2. Much less common are plane-bedded sandstone (Sh) → cross-laminated sandstone (Sr).

3. There are a few sequences of plane-bedded gravel (Gm) → plane-bedded sandstone (Sh) → mudstone drape (Fd). The mudstone drape is commonly partly removed by erosion before deposition of the succeeding sand layer.

4. Less common still are crossbedded sandstone (Sx) → plane-bedded sandstone (Sh). A mud lamina that settles from suspension has a low

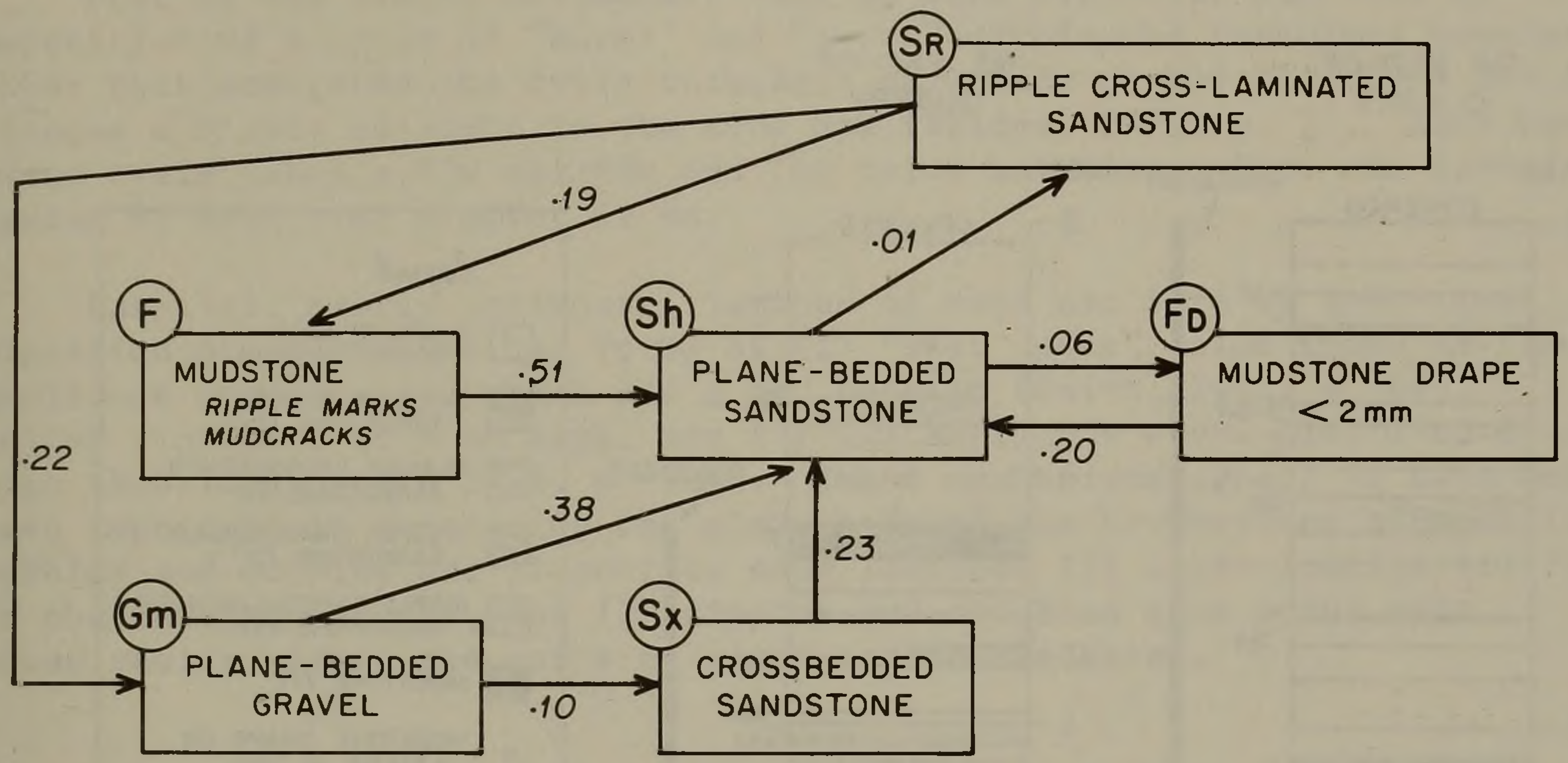


Fig. 11. Markov-chain analysis for the combined brownstone sequences in the Buckland and Portland quarries (Figs. 6 and 7). The probability values are the positive values from the difference matrix constructed by 197 facies transitions.

preservation potential. Although mud drapes do occur on some plane-bedded sandstones, many must be assumed to have been removed by the swirling rush of the succeeding flood.

Many units of plane-bedded sandstone are of nearly uniform color and grain size, suggesting that each accumulated in a single flood. Succeeding units differ slightly in color and grain size.

Some mud laminae within or between units of plane-bedded sandstone may be due to mud settling from suspension during one flood event, which then continued to deposit plane beds of sand (Fig. 13). The cause of these alternations may have been a pulsating supply of sediment due to large-scale eddies in the current. Another possibility is that local areas within a flow experienced temporary lower flow velocities.

One of the floods scoured a sequence of plane-bedded sandstone to produce a scarp 1.3 m high, as seen at the Buckland quarry (Figs. 6, 14). The scarp evidently reflects a shift in the location of the margin of a main channel. The base of the erosion surface is veneered by pebbles, which in turn are overlain by planar crossbed sets and then plane-bedded sandstone. The rarity of mudstone clasts in the brownstones is evidence of non-channelized sheet flow without undercutting and collapse of mud banks along the river.

Much of the time the river beds were dry. Floods of brief duration followed by desiccation are indicated by the waning flood sequences and the presence of mudcracks in some of the mudstone drapes.

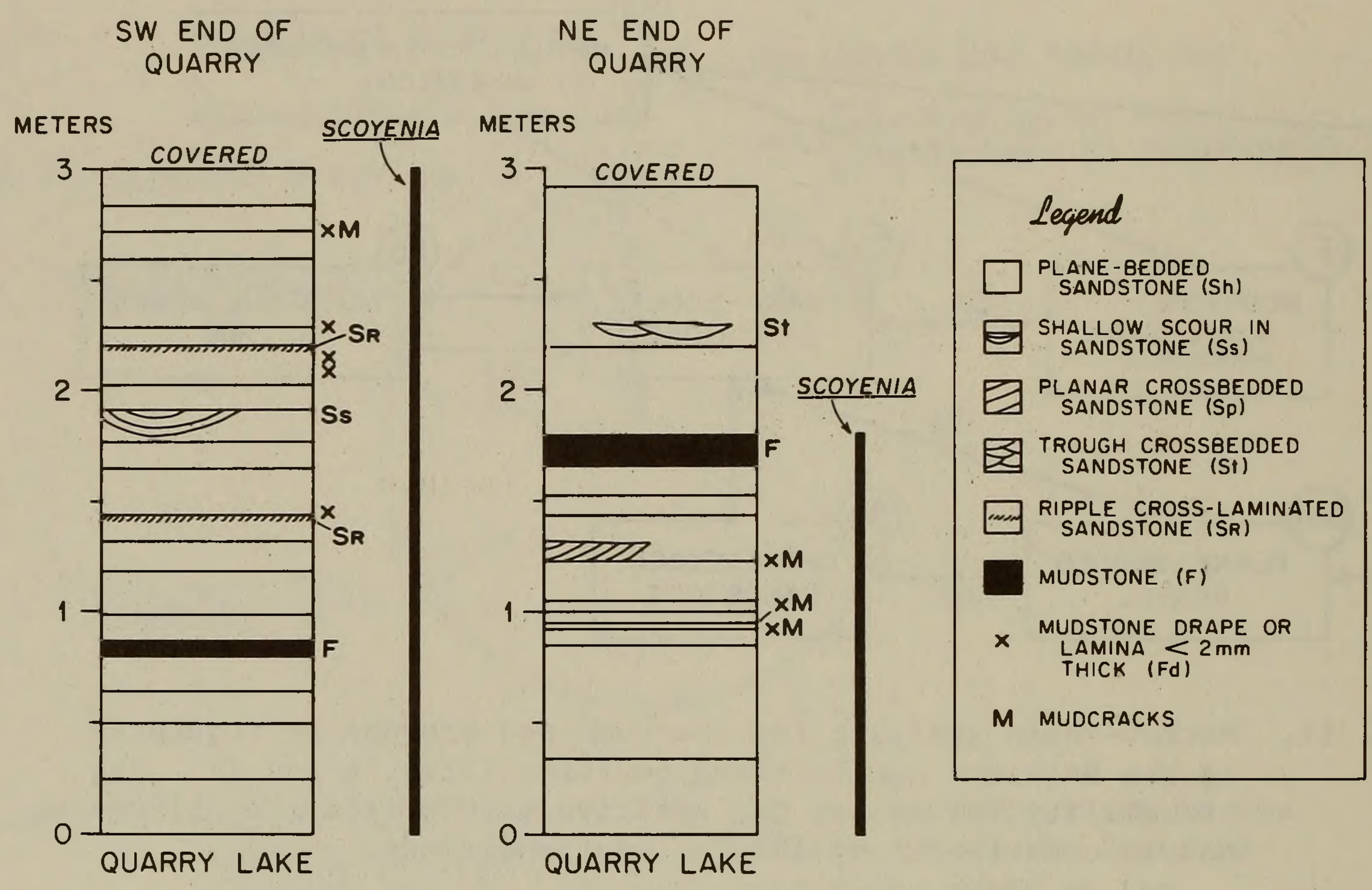


Fig. 12. Measured sections in the brownstone quarry at Redstone Lake in East Longmeadow, Massachusetts.

Bijou Creek in semiarid northeastern Colorado may provide an analog for the depositional processes that produced the brownstones. There, a flood in June, 1965, deposited a layer of sand mostly 60 to 90 cm in thickness with 90 percent plane beds (McKee et al., 1967). This sand layer not only mantled the 2 to 3-m deep channel of Bijou Creek, but extended for about a kilometer out onto the floodplain. Lenses of mud and ripple cross-laminated sand occur in the plane-bedded sand (McKee et al., 1967, p. 839). Superimposed 5 to 10-cm sets of trough crossbedded sand are confined to areas scoured by the flood in the channel. In general, recognition is growing of the importance of high energy, rare floods in depositing thick sedimentation layers of high preseva-tion potential.

That the plane beds of sand in the brownstones formed in shallow, vigorous flows is reflected by several observations. (1) An erosive scour occurs at the base of many units of plane-bedded sandstone. (2) The sand is of relatively coarse grade, mostly medium to very coarse. (3) There is primary current lineation in the plane-bedded sandstone. (4) Pebbles and cobbles of igneous and metamorphic rocks lie as isolated clasts in the laminae of many of the plane-bedded sandstones. Pebbles were not abundantly supplied to the rivers, but the strength of most of the flows was great enough to have swept along and deposited layers of gravel clasts if they had been available.

Most of the nearly horizontal laminae were evidently produced by repetition of a cycle of "burst" and "sweep" within the turbulent boundary layer that separates the fully turbulent main body of the flow from the thin viscous sublayer adjacent to the sand bed (Bridge, 1978, p. 7). Each burst-sweep cycle takes a few seconds and the major bursting events can spread a lamina of sand over a meter or so.

Parallel, nearly horizontal laminae of sand can form by down-river migration of repetitive bed forms of (1) "flat dunes", also known as "low amplitude sand waves", which are a few cm high (Smith, 1971, p. 69), (2) low relief ripples 2 to 8 mm high, and (3) low amplitude waves also 2 to 8 mm high (McBride et al., 1975, p. 136). These mechanisms appear to have been less important in generating the plane beds of the brownstones because (1) pebbles and cobbles are present in some laminae, (2) cross-laminae are rare in the thicker laminae, and (3) ripples and crossbed sets occur only occasionally within the units of plane-bedded sandstone.

## LIFE ALONG THE EARLY JURASSIC RIVERS

The Buckland quarry has been the most productive locality for dinosaur bones in the Connecticut Valley (Buckley, 1973, p. 7; Galton, 1976, p. 3). From 1884 to 1890, three well preserved skeletons of prosauropod dinosaurs were found here in the sandstones, namely two of Ammosaurus major and one of Anchisaurus polyzelus. Two fragmentary specimens also have been collected in the quarry. Prosauropod dinosaurs are widely known from several formations of Late Triassic age and Lower Jurassic age.

The first skeleton, Ammosaurus major Marsh, was discovered during quarrying operations in October 1884. Mr. Wolcott, owner of the quarry, set the fossil aside and sent word to Professor Othniel Charles Marsh of Yale University, who arranged for its purchase. Unfortunately, he found that the skull and fore quarters had been shipped from the quarry in a sandstone ("redstone") block destined for use in bridge construction. In 1967, John Ostrom of Yale University learned that a new highway, including bridges, was to be built through Manchester and he renewed the search for the missing bones. For years, some residents of Manchester had thought that possibly the bridge was the 12-m span of redstone over Hop Brook at Bridge Street in south Manchester (Spiess and Bidwell, 1924, p. 2). Ostrom surveyed more than 60 redstone bridges and was able to confirm that this was the bridge. In the summer of 1969, 85 years after its construction, the bridge was demolished. Ostrom's team hosed and cleaned more than 300 likely blocks and were rewarded with the missing half of the right femus in an abutment block of redstone weighing some 250 kg. The other bones remain unlocated, waiting for a future treasure hunt. A second abutment block contained several dinosaur bones not assignable to a specific genus (Time magazine, November 7, 1969, p. 53; Buckley, 1973, p. 7-8; Galton, 1976, p. 5).

Ammosaurus and Anchisaurus were herbivorous dinosaurs. Both were small, some 1.3 to 2 m in length, and lightly built, as illustrated in reconstructions (Lull, 1953, p. 119; Galton, 1976, p. 9). In his summary of their

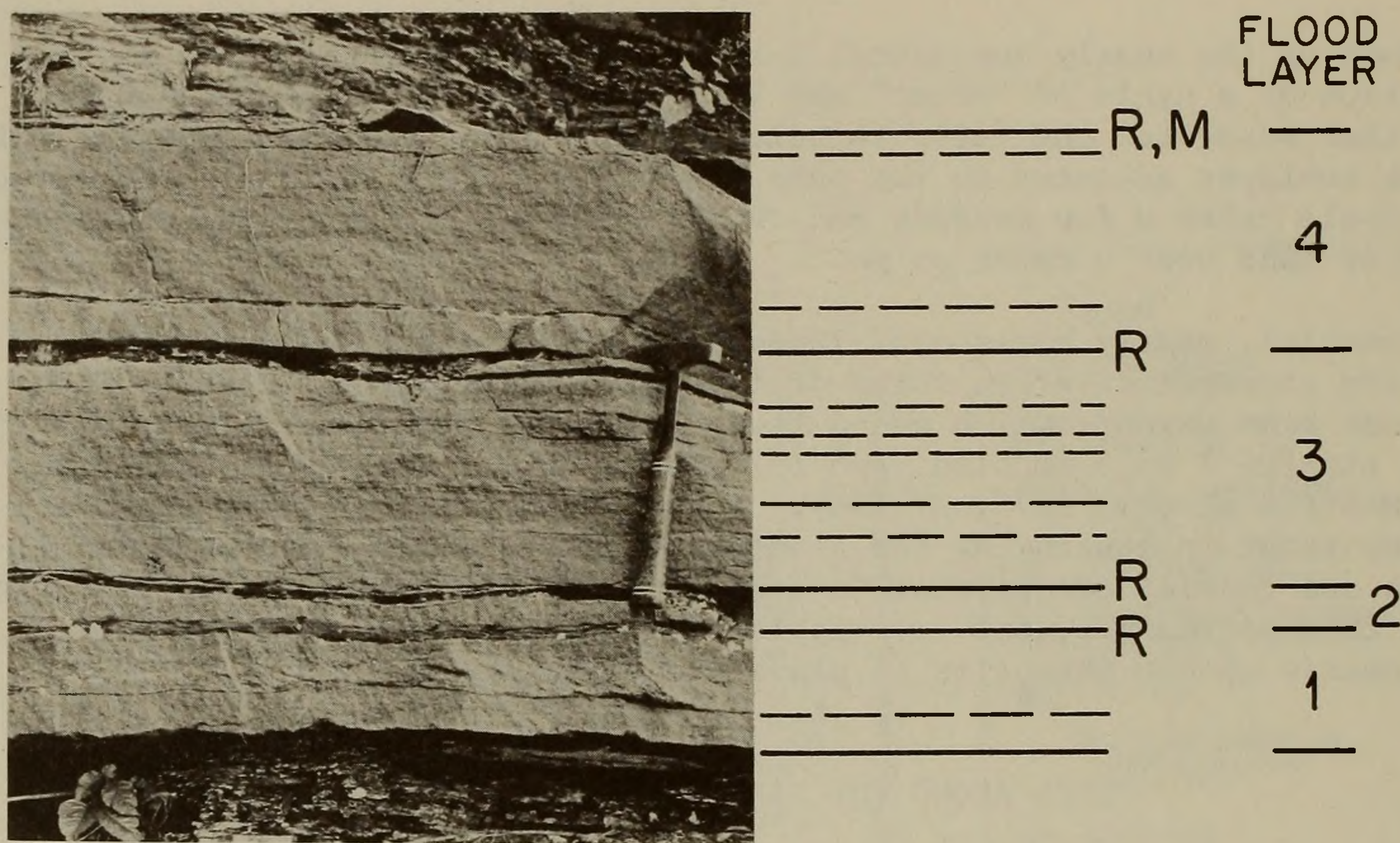


Fig. 13. Four sequences of sandstone and mudstone interpreted as four flood events (numbers 1 to 4) in a brownstone quarry at Portland. Sequence three has 5 laminae of mudstone (dashed lines) that were deposited during the flood. Each of the four flood events is mainly recorded by plane-bedded sandstone units and each flood event ends with ripple cross-laminated mudstone (letter R). The desiccation mudcracks (letter M) at the top of the fourth flood sequence show that the surface dried out after the flood. The thicker mudstones below the first and above the fourth sequence reflect overbank sedimentation, presumably during a number of floods.

biology, Galton (1976, p. 89-91) noted that Ammosaurus and Anchisaurus mostly travelled by quadrupedal locomotion, but could easily assume a bipedal stance, for example when necessary for defense. These dinosaurs lacked cheeks and self-sharpening teeth (tooth-to tooth occlusion) so that they chewed plant material inefficiently, especially coarse, tough fibers. Perhaps this is why they and the other prosauropods became extinct in the Jurassic and were replaced by the diverse and more efficient other kinds of dinosaurs (Galton, 1976, p. 90).

In 1897, Hine's quarry at East Longmeadow yielded a calcite-filled cast in brownstone of most of the skeleton of the crocodile Stegomosuchus longipes, reconstructed by Olsen (1980, p. 46, 49) to have been about 28 cm long.

Several taxa of reptile footprints, including dinosaurs, were encounted during quarrying of brownstones at Portland, Buckland, and East Longmeadow. Paul Olsen (personal communication) notes that the following forms were found

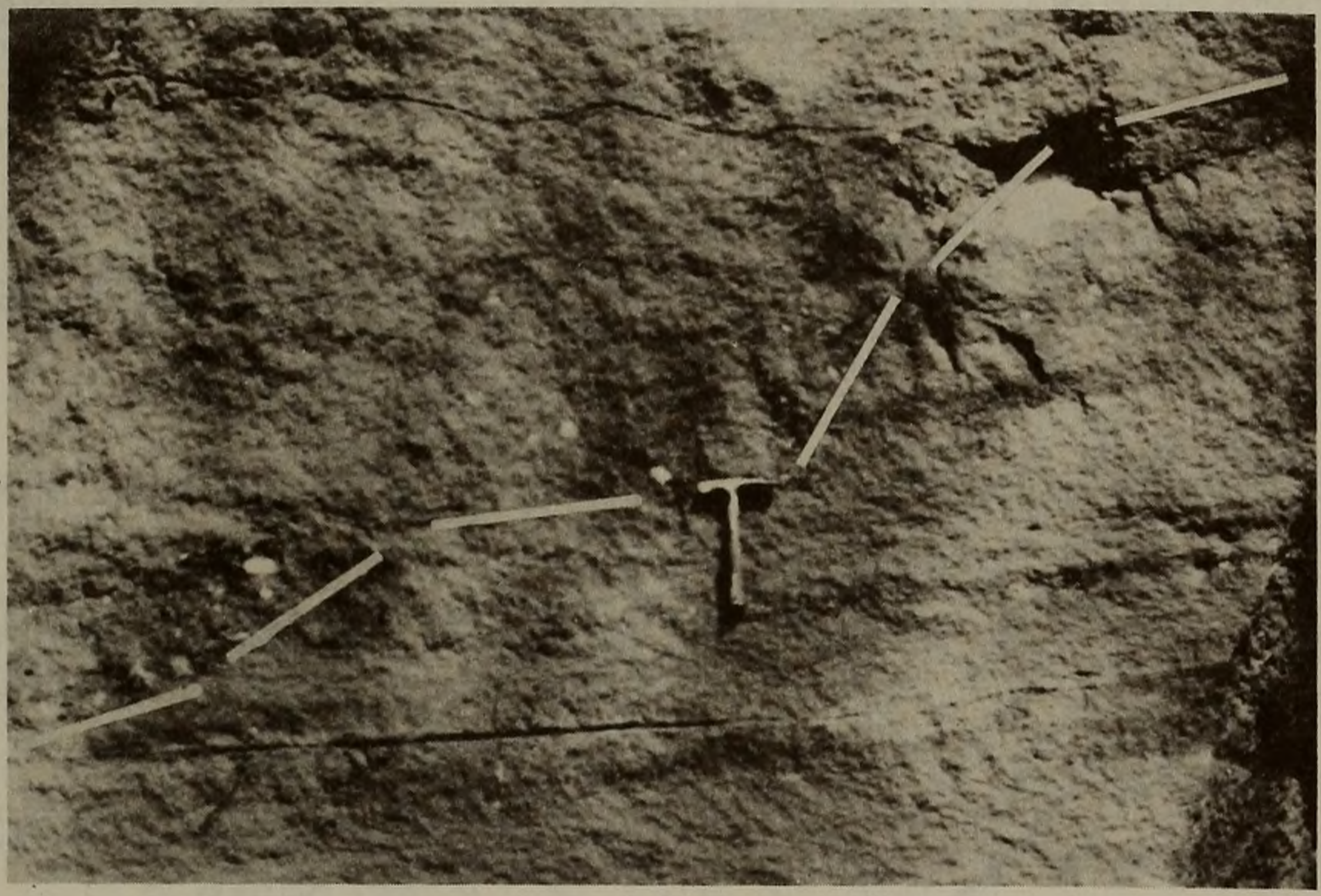

Fig. 14. Channel-margin scarp cut into plane-bedded sandstone between 3.2 and 4.5 m in the measured section at the Buckland quarry (Fig. 6).

at the Portland quarries; (1) small to large Grallator-type footprints (equals Grallator, Anchisauripus, and Eubrontes) made by carnivorous therotod dinosuars; (2) small tracks of the crocodiliomorph Batrachopus, of which one of the makers might be Stegomosuchus; (3) Anomoepus-type footprints made by herbivorous ornithischian dinosaurs, and (4) the large prints of the crocodiliomorph Otozoum.

Plants grew along the banks of the sand rivers and on the islands in the braided channels. Numerous casts of tree logs up to 30 cm in diameter and more than a meter long were found at the Portland quarries (Ward, 1900, p. 226; Rice and Foye, 1927, p. 61-62). There are fragments up to 45 cm in length of the tall horsetail Equisetites at Redstone Lake quarry in East Longmeadow.

Much of the time the water table was just below the sandy bed of the rivers, as evidenced by Scoyenia burrows that penetrate through the sand and mud (Figs. 6, 7, 12). These tubes are about 1 cm in diameter and comprise tunnel networks. In the Upper Triassic red mudstones of the Durham Basin of North Carolina, Scoyenia burrows are associated with the freshwater crayfish ?Clytiopsis sp., implying that these crayfish constructed the burrows (Olsen, 1977, p. 60). Scoyenia was evidently adapted to live in sand and mud flats saturated with water most of the time (William Baird, personal communication). The life cycle of crayfish requires that eggs be laid in water, but the burrows could have been filled with air during a prolonged drought or seasonally in a semiarid climate.

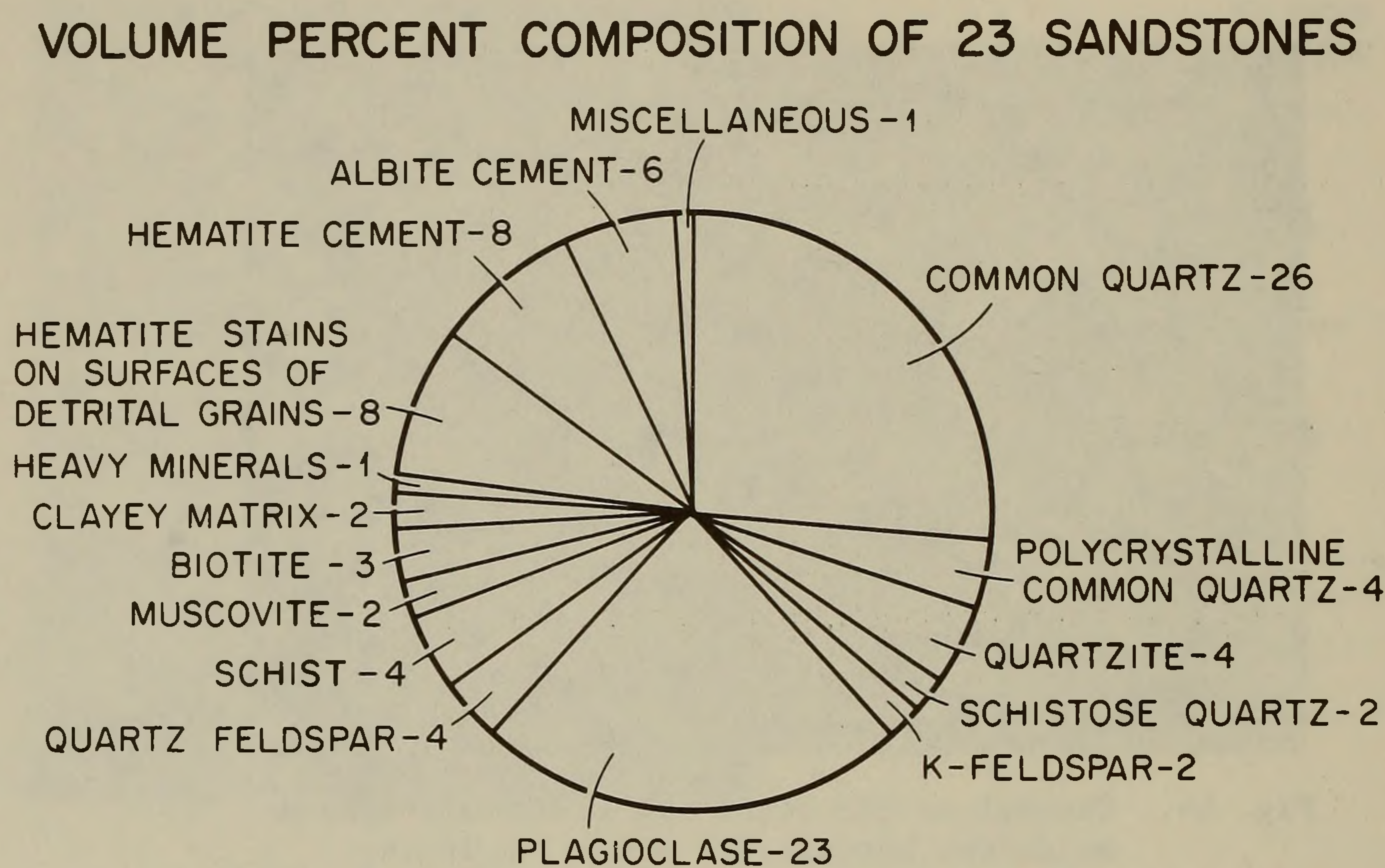


Fig. 15. Average composition of 23 brownstone samples.

## PETROLOGY OF THE BROWNSTONES

### Composition of the Sandstones

The petrographic composition of 23 sandstones was measured by point-count modal analysis. Each thin section was stained with sodium cobaltinitrite to differentiate K-feldspar from plagioclase and Alizarin red-S and potassium ferricyanide to distinguish carbonate minerals. Two hundred points were counted per thin section to determine the volumetric proportions of the petrographic components (Fig. 15). The detrital framework grains were then recalculated to 100 percent, omitting authigenic cements and clayey matrix less than 30 μm (Fig. 16).

When plotted on a classification triangle (Folk, 1968, p. 124), the brownstones are arkoses and lithic arkoses (Fig. 17). The sands were transported by rivers that flowed westward from the fault-bounded highlands on the east side of the valley (Fig. 4). The rocks exposed in the highlands were high-grade schists and feldspathic gneisses of Precambrian to Middle Paleozoic age with some granitic intrusives. The importance of metamorphic rocks is shown by the combined 20 percent of quartzite, schist, mica, and schistose quartz in the framework grains (Fig. 16). Feldspar comprises 34 percent of the framework grains, of which 92 percent is plagioclase, entirely albite to calcic oligoclase.

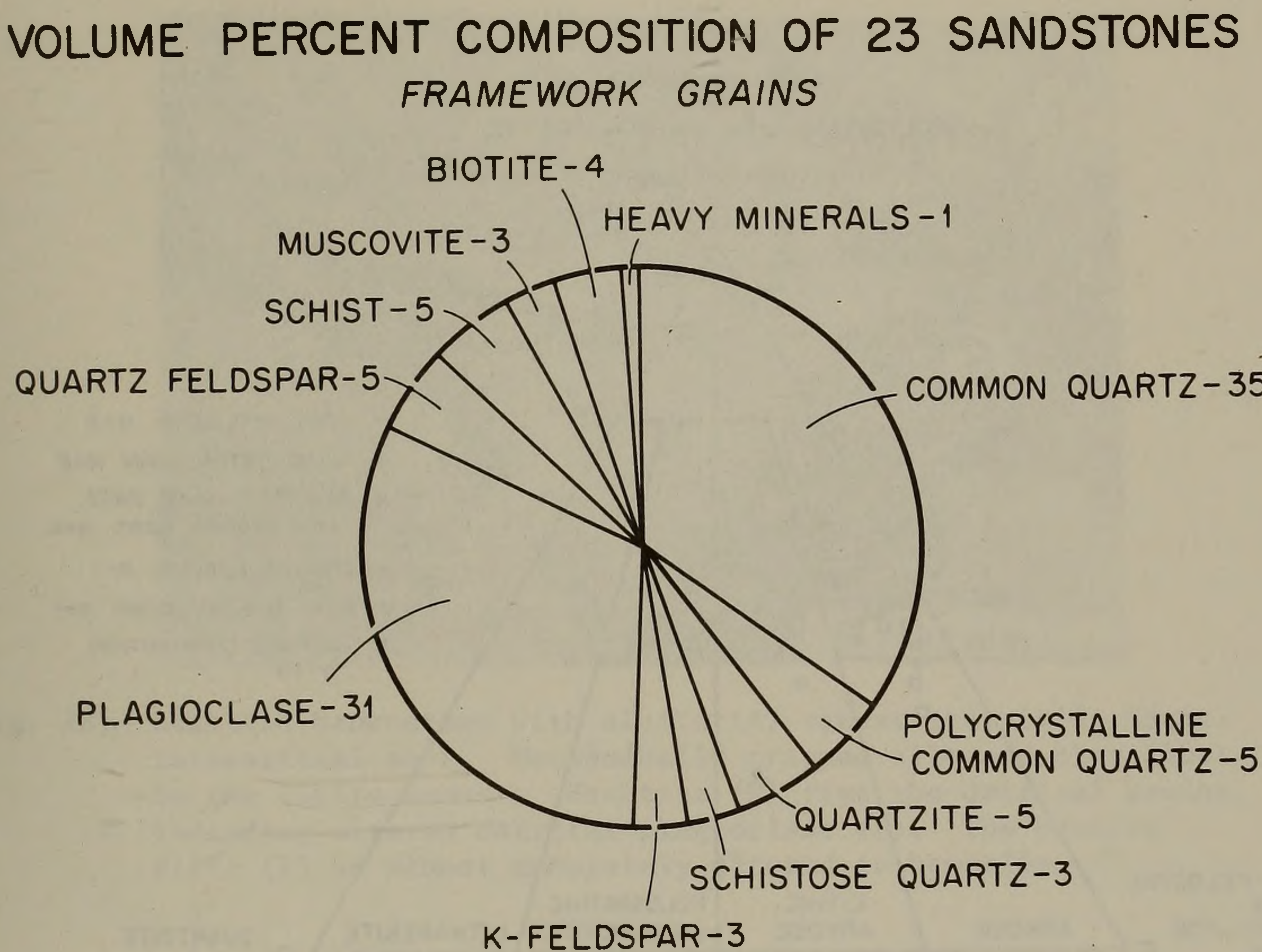


Fig. 16. Average composition of the framework grains of 23 brownstone samples.

The toughness and durability of the brownstones so useful in a building stone are provided by albite cement, which is abundant in every sample and averages 6 percent by volume (Fig. 15). The albite occurs as overgrowths on detrital plagioclase grains and as intergranular mosaics of crystals, some of which are idiomorphic (Figs. 18, 19; Heald, 1956, p. 1156). A few sandstones also contain from a trace to 3 percent of quartz overgrowths.

Albite was precipitated from groundwater enriched in sodium due to slow intrastratal solution of the detrital albite-oligoclase grains, which comprise 31 percent of the framework grains. The evidence consists of the pitting of the surfaces of many plagioclase grains. Furthermore, the interiors of almost all of the plagioclase grains are altered to clay, vacuoles, and minute bubbles, especially along the cleavages. The albite overgrowths and cement are not altered. Fresh plagioclase grains are rare, which is the opposite of what one expects in sand transported a few kilometers from rugged highlands east of the border fault. Albite cement is rare in terrestrial sandstones of all geologic ages because of the absence of marine pore water to provide sodium.

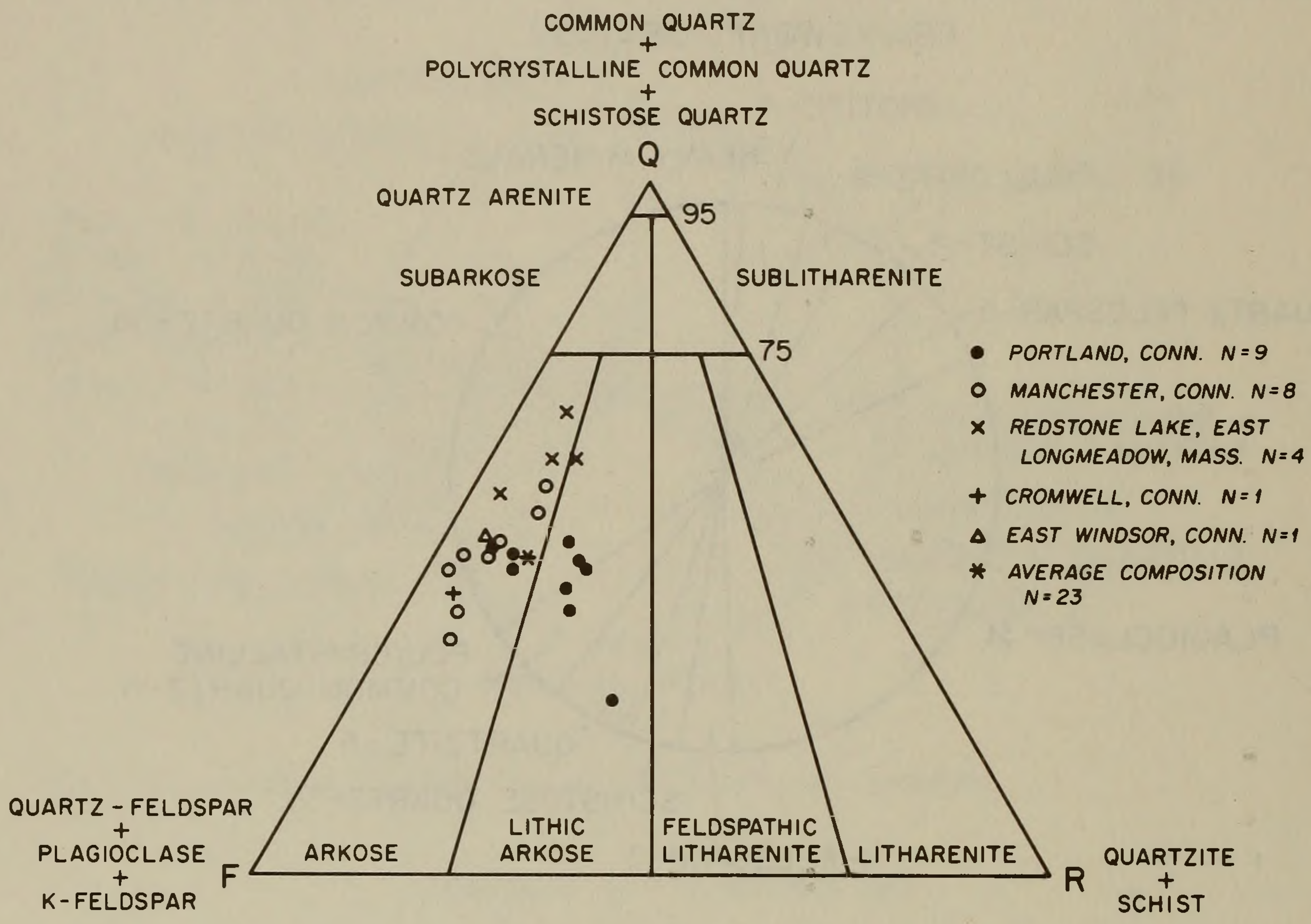


Fig. 17. Petrographic classification (Folk, 1968) of 23 brownstone samples.

## Color of the Building Stone

Brownstone has always been the popular name of the sandstone form the Mesozoic quarries of the Connecticut Valley (Fig. 1). In the quarrying and architectural trades, however, a distinction is made between brownstone and redstone. The Portland quarry produced typical brownstone, whereas the Buckland quarry in Manchester and Redstone Lake quarry in East Longmeadow yielded redstone.

The color of the dry, rough-cut surface of the brownstones averages pale red (10R 6/2) on the Munsell Color Chart. The Buckland redstone is also pale red (5R 6/2) with some laminae of grayish pink (5R 8/2). At East Longmeadow, the redstones are pale reddish brown (10R 5/4) with some beds grayish red (10R 4/2).

The letter R indicates that the sandstone is of red hue; 5R is the middle of the red hue and as the numbers increase to 10R there is more yellow and less red. The redstones have more red and less yellow than the brownstones. The value ("lightness") is shown by the number above the

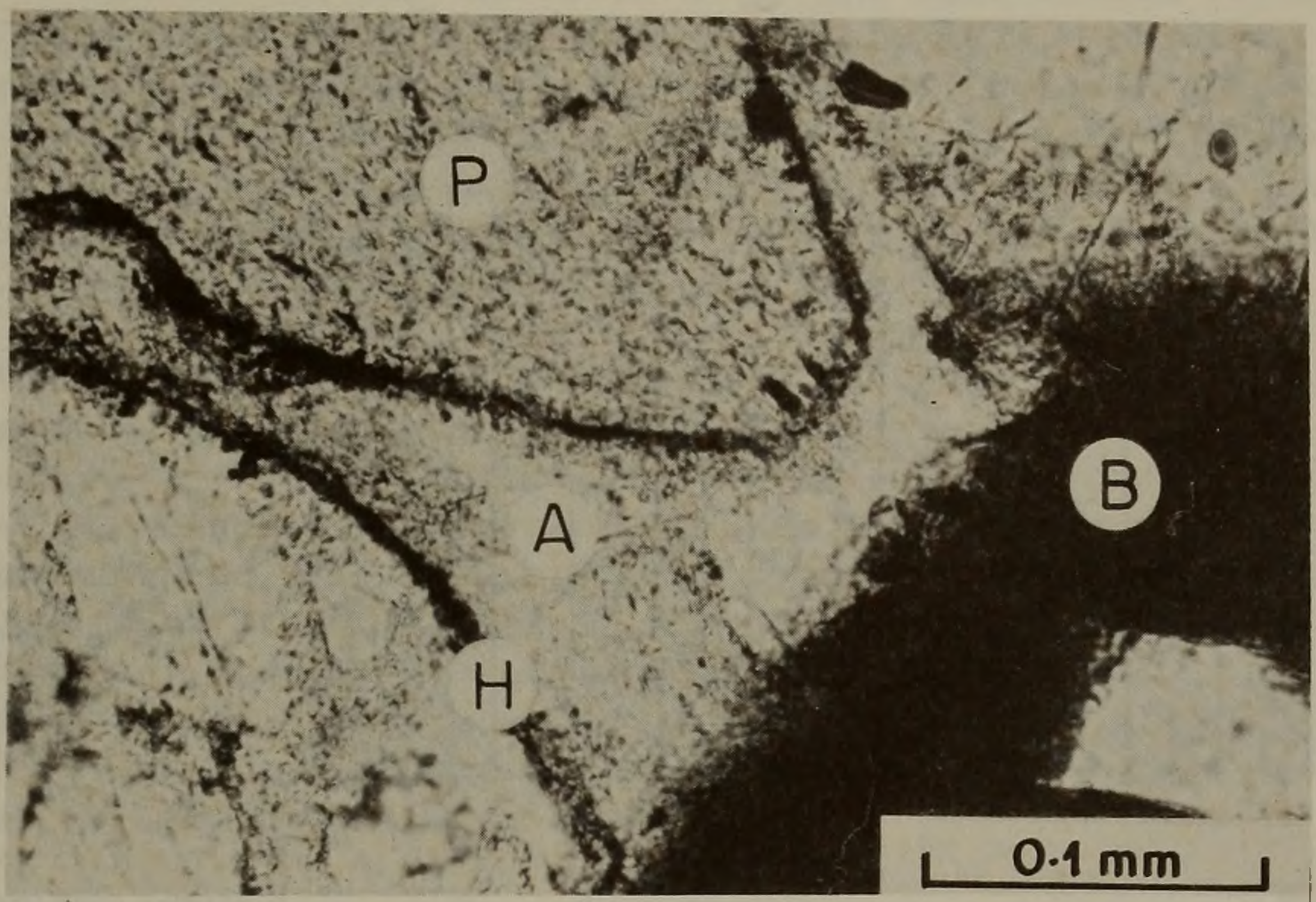


Fig. 18. Buckland brownstone with albite (A) cement that fills former interstitial pore. Mechanically trapped silt and clay float in the albite cement. Hematite (H) rims the detrital grains, including altered detrital plagioclase (P). The biotite flake (B) is almost completely altered to hematite.

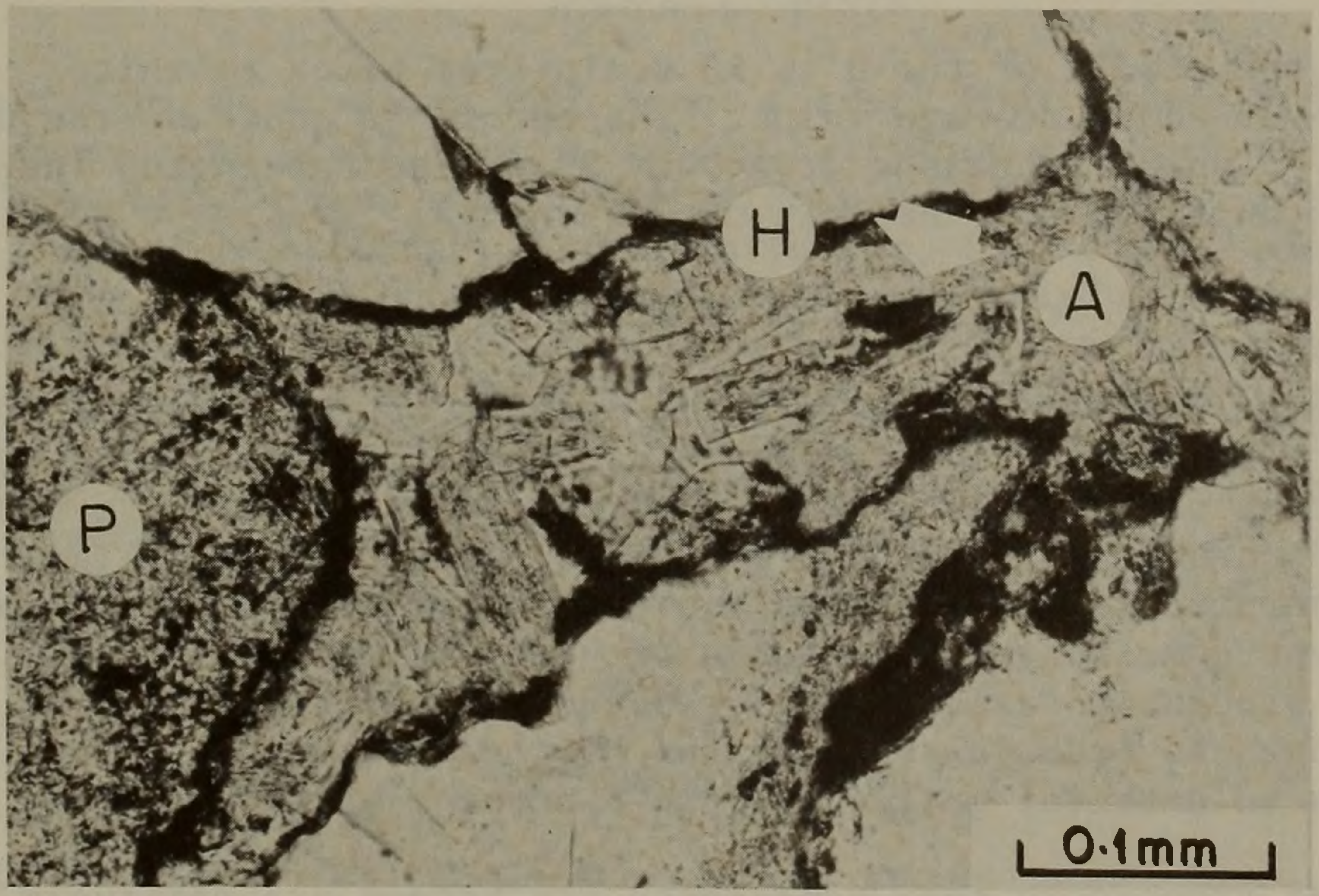


Fig. 19. Cement of albite (A), in part as crystals, fills former pore space in Buckland brownstone. The albite contains abundant dust inclusions. Hematite (H) stains occur on the detrital grains, including an altered plagioclase (P). "Late" authigenic hematite (arrow) stains some of the albite crystals.

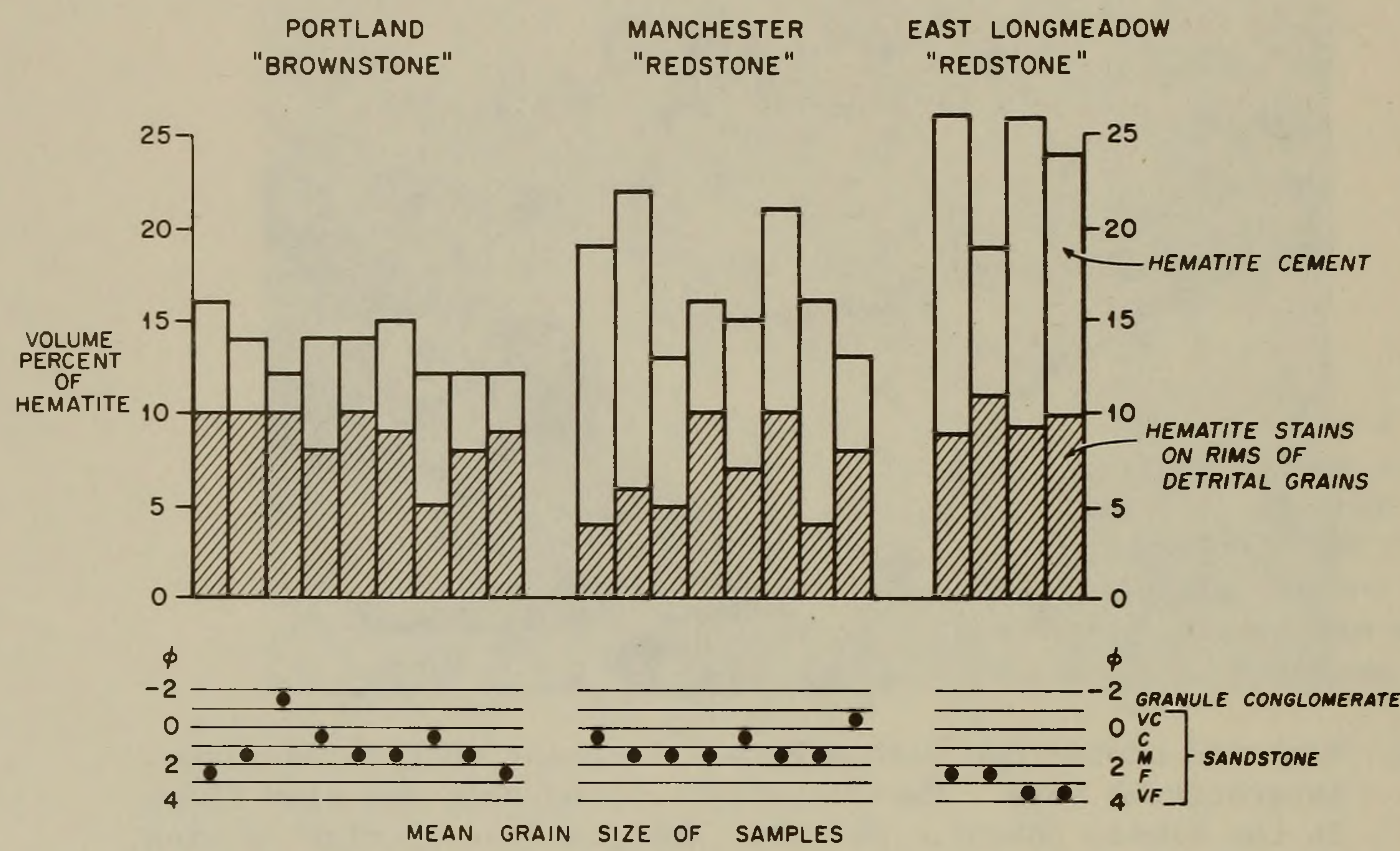


Fig. 20. Proportions of "late" authigenic hematite and hematite stains on rims of grains in modal analyses of 23 brownstone samples. The mean grain size of each brownstone is shown along the bottom of the diagram.

" / ", with 5 the middle of the 0 to 10 scale from black to white. The sandstones are of about average value. The chroma is shown by the number below the " / ", which increases from 0 to 20 as the "strength" intensifies. The building stones are consistently of low chroma.

## Origin of the Hematite Pigment

The hematite pigment that colors the redbeds of the Portland Formation was generated after deposition in two ways. The first depends on the fact that the surfaces of detrital grains in almost every climate are stained brown or yellow brown by hydrated iron oxides, collectively called limonite. These soil-generated limonite stains convert to hematite by aging and dehydration over some tens of thousands of years in oxidizing, alkaline pore waters. This process is universal in redbeds (Van Houten, 1961, p. 112). In the 23 sandstones from quarries in the Portland Formation, hematite surface stains on detrital grains average 8 percent by volume (Fig. 15).

The second process is that sandstones can become progressively reddened with hematite pigment over tens of millions of years by post-depositional dissolution of Fe-silicate grains, notably biotite, amphibole, pyroxene, and epidote (Walker, 1967). This mechanism generated about 3 volume-percent hematite cement in the red sandstones of the East Berlin Formation of central Connecticut (Hubert and Reed, 1978, p. 182). Hematite cement comprises 8 percent in the 23 sandstones of the Portland Formation and commonly coats the earlier albite cement (Fig. 19). An important source of the iron in the hematite cement was detrital biotite, which averages 4 percent of the framework grains; many biotite flakes are heavily altered to hematite. Quartzose biotite schists are also abundant.

The reason for the contrast between the redstones of the Buckland and East Longmeadow quarries and the brownstones of the Portland quarry is the greater amount of "late" hematite cement in the redstones, specifically 10 percent at Buckland and 14 percent at East Longmeadow, contrasted with 4 percent at Portland (Fig. 20). The average proportions of hematite surface stains dehydrated from limonite is about the same in redstones and brownstones, namely 7 percent at Buckland, 10 percent at East Longmeadow, and 9 percent at Portland. The redstones thus have more total hematite pigment, namely 17 percent at Buckland and 24 percent at East Longmeadow compared to 13 percent for the brownstones at Portland.

The greater amount of "late" hematite cement in the redstones compared to brownstones is not due to a finer grain size of the redstones with increased surface area for hematite stains. The 23 samples of redstone and brownstone are similar in average grain size, varying from very fine sandstone to granule conglomerate (Fig. 20). Seventeen of the samples are of fine, medium, or coarse sandstones, a group which includes both redstones and brownstones.

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## ROAD LOG

The road log starts at stop 1, continues through to the last stop (stop 8), and then returns to stop 1, forming a complete cycle. The user may start a trip at any stop and return to it using the log.

| MILES | | |
|---|---|---|
| 0.0 | 0.0 | STOP 1. PORTLAND FORMATION, DURHAM. |
| | | Park at two-story yellow house inside the Y-junction of routes 17 and 77 in Durham, Connecticut. At the Y-junction, walk east across the road and plunge into the woods. The 13-m rock ledge is abut 30 m east of the road. |
| | | Leave the parking area on the west side and turn left (south) on route 17. |
| 4.1 | 4.1 | The ridge on the right is the Holyoke Basalt. |
| 7.8 | 3.7 | Turn right on route 22. |
| 8.1 | 0.3 | Junction with route 150. Take left fork, following route 22. |
| 11.5 | 3.4 | Turn right on route 5. |
| 12.3 | 0.8 | Proceed through underpass; turn left onto I-91 and go south. |
| 14.2 | 1.9 | Leave I-91 at Exit 10 (route 40; Mt. Carmel, Hamden). |
| 16.3 | 2.1 | STOP 2. NEW HAVEN ARKOSE, NORTH HAVEN. |
| | | Stop in breakdown lane of route 40. The illustrations for stop 2 refer to the north side of the roadcut. Proceed west on route 40. |
| 17.1 | 0.8 | Turn left (south) on route 10. |

| | | |
|---|---|---|
| 17.3 | 0.2 | Turn around in parking lot of Our Lady of Mt. Carmel Church on left side of street and proceed north on route 10. |
| 17.5 | 0.2 | Turn right on route 40. |
| 19.9 | 2.4 | Take I-91 toward Hartford. As you enter I-91, the intrusive basalt of Sleeping Giant is ahead on the left. His head is on the west and feet on the east. |
| 23.1 | 3.2 | The roadcut on the right is New Haven Arkose with caliche horizons. |
| 25.1 | 2.0 | The roadcuts on both sides of I-91 are New Haven Arkose with caliche horizons. |
| 27.1 | 2.0 | New Haven Arkose on both sides of I-91. |
| 30.2 | 3.1 | New Haven Arkose along the center strip of I-91. |
| 30.5 | 0.3 | On the left are the Hanging Hills of Meriden (Holyoke Basalt). The TV installations are on West Peak. |
| 31.4 | 0.9 | The cliffs on the right are Holyoke Basalt. |
| 32.4 | 1.0 | Take exit 17 to the right following the sign to "route 66 west." |
| 33.1 | 0.7 | Take left fork toward route 66 west. |
| 34.4 | 1.3 | Go right toward route 66 west. |
| 34.7 | 0.3 | Junction with route 66 west. |
| 35.2 | 0.5 | New Haven Arkose on right in roadcut. |
| 35.6 | 0.4 | Leave route 66 at exit 6. Stop 3 is behind the G. Fox store seen on the north side of route 66. |
| 35.9 | 0.3 | Turn left into Meriden Square. |
| 36.0 | 0.1 | Turn left and drive around the perimeter of the parking lot to behind the G. Fox store, which is at the left end of the shopping center. |
| 36.4 | 0.4 | STOP 3. TALCOTT BASALT, MERIDEN. |
| | | The outcrop is directly behind the G. Fox store. Proceed to northwest corner of parking lot. |
| | | Turn left at stop sign and go up the hill. Holyoke Basalt is on the skyline. |

| | | |
|---|---|---|
| 36.9 | 0.5 | Turn right at traffic lights on route 71 (Capitol Avenue). |
| 37.3 | 0.4 | Holyoke Basalt is on the right and also ahead on left at bend in road. |
| 39.9 | 2.6 | Go left on Butler Street (note that there is no street sign at this end of Butler Street). |
| 40.1 | 0.2 | Turn left on Park Drive. |
| 41.0 | 0.9 | Cross first bridge; turn right and proceed over second bridge onto Percival Park Road. Drive carefully because this road is very narrow. You are passing the north end of Merimere Reservoir. |
| 41.6 | 0.6 | You are driving up the dip slope of the Holyoke Basalt. |
| 42.4 | 0.8 | Turn left on road to East Peak. The right fork leads to West Peak. |
| 42.8 | 0.4 | STOP 4. EAST PEAK OF THE HANGING HILLS OF MERIDEN. |
| | | Park in parking lot and ascend to top of stone tower. Leave parking lot by exit adjacent to stone tower in order to follow one-way loop. Return down Percival Park Road. |
| 43.3 | 0.5 | Drive past road on left that goes to West Peak. |
| 44.5 | 1.2 | Go past end of Merimere Reservoir. |
| 44.7 | 0.2 | Cross bridge and turn right on Reservoir Avenue. |
| 45.1 | 0.4 | Holyoke Basalt forms cliffs across lake on right. |
| 45.5 | 0.4 | View of stone tower on right. |
| 46.0 | 0.5 | Go through underpass below route 66. Turn right at second road into parking lot of Hubbard Park, Meriden. |
| | | LUNCH STOP |
| | | Leave parking lot by turning left on unnamed park road. Drive past Mirror Lake on the right. |
| 46.8 | 0.8 | Turn right at traffic lights on west Main Street. |
| 47.5 | 0.7 | Sign for junction with route 66. |
| 47.7 | 0.2 | Cross bridge and immediately past traffic lights turn left and park on unfinished access road. |

STOP 5. NEW HAVEN ARKOSE ALONG ROUTE 66, MERIDEN.

Proceed west on route 66, following sign to I-84.

| | | |
|---|---|---|
| 50.1 | 2.4 | Turn right at traffic lights on road leading to route 10. |
| 50.2 | 0.1 | Turn right on route 10. |
| 50.8 | 0.6 | Turn left on access road to I-84 and go east on I-84. |
| 52.6 | 1.8 | Hills on left are Lower Paleozoic crystalline rocks west of the Mesozoic redbeds. |
| 54.1 | 1.5 | New Haven Arkose with caliche horizons adjacent to and under bridge. |
| 55.8 | 1.7 | New Haven Arkose on both sides of I-84. |
| 57.1 | 1.3 | TV towers on Holyoke Basalt seen to the north. |
| 57.4 | 0.3 | Leave I-84 at Exit 34 leading to route 66 west. |
| 57.6 | 0.2 | Turn left at stop sign. Holyoke Basalt to right on skyline. |
| 58.1 | 0.5 | Turn right on route 72. Go past Getty Gas station and park on south side of road in pull-off just before entrance sign to Holiday Inn. |

STOP 6. SHUTTLE MEADOW FORMATION, PLAINVILLE.

The quarry is on the north side of the road. Please do not climb the rock faces. This is a working quarry and the blocks are loose. Do not examine rock face behind the Getty Gas station because the owner does not allow visitors and has two guard dogs. The Tomasso trap rock quarry in the Holyoke Basalt is on the south side of I-84. Proceed east on route 72.

| | | |
|---|---|---|
| 59.7 | 1.6 | Turn right to follow route 72 at the Texaco station. Go over the bridge and continue on route 72 east. |
| 64.8 | 5.1 | Bridge over routes 5/15. |
| 64.9 | 0.1 | Roadcuts with the type section of the East Berlin Formation (Lehmann, 1959, p. 16-21). The measured section (section 1 on Fig. 35) shows symmetrical lake cycles and river-channel sandstone and red mudstone. The contact with the overlying Hampden Basalt is especially well exposed. The measured section of the 33 m of exposed basalt details 8 lava flows (Chapman, 1965, Fig. 12). Watch out for high-speed cars - this is a major east-west road. |

| | | |
|---|---|---|
| 68.2 | 3.3 | Underpass beneath I-91 with Hampden Basalt on left. |
| 68.8 | 0.6 | Turn left at traffic lights on Coles Road (route 217). |
| 69:5 | 0.7 | Turn left on North Road. Just ahead is underpass beneath I-91. |
| 70.3 | 0.8 | Junction with Pasco Hill Road. Drive straight ahead on road marked "dead end". |
| 70.9 | 0.6 | Turn around at dead end of road. |
| 71.2 | 0.3 | Park on right just before bridge over brook. Trail to stop 7 begins on left (east) side of road about 10 m beyond (south) of bridge. Follow trail to large roadcuts in unfinished access lanes to I-91. |
| | | STOP 7. EAST BERLIN FORMATION, CROMWELL. |
| | | Proceed south again on "dead end" road. |
| 71.3 | 0.1 | Red sandstone and mudstone in the East Berlin Formation on left. |
| 71.6 | 0.3 | Junction with Pasco Hill Road. Proceed directly ahead on North Road. |
| 72.4 | 0.8 | Turn right on Coles Road. |
| 73.0 | 0.6 | Turn right at traffic lights onto route 72 west. |
| 73.4 | 0.4 | Turn right onto entrance ramp to I-91 north. On the right is the Hampton Basalt. |
| 76.5 | 3.1 | On the right you are passing Exit 23, which leads to West Street (go east) and the Dinosaur State Park. |
| 77.0 | 0.5 | Outcrop of Hampton Basalt on right. |
| 77.2 | 0.2 | Redbeds of the Portland Formation on right. |
| 77.6 | 0.4 | Fluvial channel sandstone and red mudstone of the East Berlin Formation. |
| 84.7 | 7.1 | Move over to right hand lane and turn right onto I-84. |
| 85.4 | 0.7 | Stay in right hand lane. |
| 85.7 | 0.3 | Take Exit 30 for I-84 east. |

| | | |
|---|---|---|
| 88.9 | 3.2 | I-84 ends and I-86 continues. |
| 90.5 | 1.6 | Straight ahead are hills of Paleozoic metamorphic rocks east of the border fault of the Connecticut Valley. |
| 91.4 | 0.9 | On left are pebbly sandstone and sandstone of the Portland Formation. |
| 92.4 | 1.0 | Leave I-86 by Exit 93. |
| 92.5 | 0.1 | Turn left at stop light across the street from McDonalds. |
| 92.6 | 0.1 | At traffic light turn sharp right onto Windsor Street. You are passing the J. C. Penney Catalog Distribution Center on the left. Note the entrance ramp to I-86 west on the right. |
| 93.2 | 0.6 | At the red tobacco barn turn right onto Pleasant Valley Road. |
| 94.0 | 0.8 | STOP 8. BUCKLAND BROWNSTONE QUARRY IN THE PORTLAND FORMATION, MANCHESTER. |

Park at intersection of Buckland Street and Pleasant Valley Road. The quarry is hidden in the woods east of Buckland Street. An historical marker for the quarry is located on Buckland Street about opposite to the south end of the quarry. To reach the quarry walk into the woods east of Buckland Street about 15 m northeast of the intersection of Buckland Street and Pleasant Valley Road.

Be careful crossing Buckland Street. It is a high speed road.

Do not climb the quarry walls.

Note the lush growth of poison ivy!

To leave stop 8, drive west on Pleasant Valley Road.

| | | |
|---|---|---|
| 94.2 | 0.2 | Turn left (south) onto Windsor Street. The sign for Windsor Street is hidden behind red tobacco barn number 25. You will pass the J. C. Penney Catalog Distribution Center on the right. |
| 94.8 | 0.6 | Turn left into the entrance to Exit 93 and proceed west on I-86. |
| 95.9 | 1.1 | Fluvial red sandstone and pebbly sandstone of the Portland Formation on the right. |

| | | |
|---|---|---|
| 96.2 | 0.3 | On the right you are passing red sandstones of the Portland Formation along the ramp for Exit 92. Incipient caliche paleosols can be examined along the north side of the exit ramp (Gilchrist, 1979, p. 151). |
| 98.5 | 2.3 | I-86 ends and I-84 begins. |
| 99.7 | 1.2 | Continue straight ahead on I-84. |
| 100.1 | 0.4 | Move to left lane to be ready to go south on I-91. |
| 100.8 | 0.7 | Take Exit 54 towards I-91 south. |
| 101.4 | 0.6 | Move to right lane to be ready to take Exit 1 leading to I-91. |
| 101.6 | 0.2 | Take Exit 1 and proceed south on I-91. |
| 103.3 | 1.7 | On the right is the Hampton Basalt. |
| 104.0 | 0.7 | On the right are fluvial channel sandstone and mudstone of the East Berlin Formation. |
| 104.2 | 0.2 | On the left is the Hampton Basalt. |
| 104.5 | 0.3 | Move to the left lane in preparation for left turn onto route 9 at Exit 22-S. |
| 105.6 | 1.1 | At Exit 22-S turn left onto divided route 9. |
| 107.2 | 1.6 | The hills on the horizon directly ahead are Paleozoic metamorphic rocks east of the border fault of the Connecticut Valley. |
| 111.9 | 4.7 | Turn right onto route 17. |
| 112.4 | 0.5 | Proceed around the traffic circle and continue south on route 17. |
| 113.2 | 0.8 | Sandstone of the Portland Formation on the right. |
| 114.6 | 1.4 | Durham Historical District with lovely old homes. |
| 115.8 | 1.2 | Take the right fork and continue on route 17. Escarpment on left follows the Mesozoic border fault that separates Paleozoic metamorphic rocks on the east from the Portland Formation on the west. |
| 116.0 | 0.2 | Turn left onto route 77. |

116. 1 0.1 STOP 1. PORTLAND FORMATION, DURHAM.

End of field trip.

## DISCUSSION OF PLAYA-PLAYA LAKE-OLIGOMICTIC LAKE SYSTEM

### Introduction

Since publication of our guidebook in 1978, great progress has been made in a process-products model for the stratigraphic sequences and primary sedimentary structures formed on playas in semiarid to arid rift valleys (Hardie et al., 1978). Also now well understood is the evolution of playa brines from dilute inflow waters during subsurface flow of groundwater from alluvial fans to the playa (Eugster and Hardie, 1978; Eugster, 1980). A further advance is the playa-playa lake-oligomictic lake system (Boyer, 1982).

In this model, a closed-basin playa can cover most of the floor of a rift valley when precipitation is consistently less than evaporation over many years. Storms in the fault-bounded highlands generate mud-laden flood waters that pass down alluvial fans, move over the adjoining sandflats, and pond on the playa where mud settles from suspension. With runoff amounts somewhat greater than evaporation, playa-lakes become established. These lakes are relatively short lived and shallow with oxidizing bottom water. Over time, dissolved ions become increasingly concentrated in the alkaline water. The preservation of limonite stains on the mud and sand leads to rebeds as the limonite slowly dehydrates to authigenic hematite. When precipitation consistently exceeds evaporation, an oligomictic lake will occupy the basin of the former playa. Over thousands of years, this relatively deep, nearly continuously stratified lake produces the characteristic record of gray and black mudstone, commonly with calcite or dolomite laminae.

### East Berlin Formation

In the East Berlin Formation at stop 6, we now recognize that the redbeds formerly interpreted by us as a fluvial system are playa and playa-lake mudstones and sandstones. The gray and black mudstones and sandstones remain interpreted as the deposits of oligomictic lakes. The evidence for a playa and playa-lake origin of the redbeds is as follows.

Stratigraphic Framework. These redbeds occur in a terrestrial sequence in a rift valley. Semiaridity dominated Late Triassic time as evidenced by numerous caliche paleosols in the New Haven Arkose.

Bedding Features. The beds of red mudstone extend completely across the outcrops for more than tens of meters with uniform thickness and only a few cm of relief along the bedding planes. Most of the beds are 1 to

3 m in thickness. They comprise about half of the total sequence.

Mudcracks and Raindrop Impressions. Many of the bedding planes have mudcracks, which attest to repeated wetting and drying. The deeper mudcracks exceed 50 cm. Raindrop impressions occur on a few bedding planes.

Sorting. The mudstones are poorly sorted mixtures of silt and clay with some sand.

Fossils. The insect burrows and other trace fossils are now being studied by Elisabeth Gierlowski Kordesch in her Ph.D. dissertation at Case Western Reserve University. Shelly fossils are absent.

Evaporite Minerals. Multiple horizons of dolomite and ferroan dolomite nodules and septarian nodules occur in the mudstones. Some nodules are deformed in synsedimentary slumps and others show compaction of mud laminae over them. The carbonate in the nodules commonly grew as acicular to stubby crystals oriented perpendicular to the surfaces of detrital grains, especially mica. This is a displacive fabric that reflects pushing aside of the unlithified mud. The original carbonate was presumably Mg-Calcite, later converted during burial diagenesis to dolomite and ferroan dolomite.

The carbonate in these nodules was evidently precipitated within the mud beneath former shallow, alkaline and somewhat saline lakes that had contracted and dried up due to inadequate annual runoff. This interpretation is favored by the restriction of the dolomite nodules to specific mudstone beds and the presence of dolomite that outlines mudcracks at the top of some of the nodule-bearing beds. Also, similar dolomite nodules occur in mudcracked gray mudstone that accumulated during wide lateral fluctuations of the shorelines of some of the oliogomictic lakes during their initial and final stages.

Small amounts of gypsum occur in some beds of red mudstone as thin layers and dispersed in the mud, especially in beds with dolomite concretions. Some of the crystals are in a more or less vertical orientation. Others have been dissolved to molds or are now dolomite pseudomorphs.

Absent are both bedded gypsum and pervasively disrupted fabrics in sandstone or mudstone that would be expected with extensive displacive precipitation of evaporite minerals within the vadose zone of a playa. Possibly much of the time the water table was too far beneath the playa surface to provide a steady flow of groundwater in nearsurface aquafers.

Analcime has not been found in the playa red mudstones, but small amounts do occur in some of the lacustrine gray mudstones (April, 1978, p. 100).

Graded Beds. The graded beds are a few to about 30 cm in thickness and have smooth lower surfaces, except rarely when there is 10 to 30 cm of basal scour. The graded beds are of various types, including climbing ripples with erosion of the stoss sides of the ripples. Others show planed-bedded sandstone followed by ripples. A few show planar or trough crossbed sets with mud drapes over and between dune crests. In some of these beds, the crossbeds are made of alternating laminae of sand and mud. The graded beds record the rapid deceleration of floodwaters on encountering the low gradient of the playa, with initial deposition of sand, followed by fallout of mud from suspension. Similar graded beds are an important component of the playa sequence of redbeds in the Upper Triassic Blomidon Formation, Nova Scotia (Hubert *et al.*, 1981; Hubert and Hyde, 1982).

Figure 35 on page 78 of the guidebook (Hubert *et al.*, 1978), shows these playa and playa-lake mudstones (labelled flood plain mudstone) with the graded beds and other flood units (labelled stream channel and shallow oxidized lake on flood plain). The paleocurrent data for these redbeds show that the low gradient surfaces of the playas sloped towards all four quadrants at various times during accumulation of the sequence. On the average, the playa surfaces sloped towards the northeast.

## Summary

The playa-playa lake-oligomictic lake continuum is a unifying concept for the cycles of lacustrine gray and black mudstone interbedded with red mudstone and sandstone in parts of the East Berlin, Shuttle Meadow, and Portland Formations in the Hartford Basin and the Turners Falls Sandstone in the Deerfield Basin. The playas with their internal drainage were situated in the subtropical rift valley at about 20°N paleolatitude. Given this setting, the control for the repeated cycles of playas and oligomictic lakes was long-term fluctuation in precipitation.

The laminite rock made of alternating laminae of kerogen-bearing gray to black mud and light-colored dolomite is a distinctive signature of these oligomictic lakes (Hubert *et al.*, 1976; Olsen *et al.*, 1982). Multiple horizons of these lacustrine laminites interbedded with playa red mudstones occur in the East Berlin Formation (Carey, 1974; Hubert *et al.*, 1978; Reed, 1976), Shuttle Meadow Formation, Portland Formation (Irwin, 1982), and the Turners Falls Sandstone (Handy, 1976; Hubert work in progress).

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