U.S. DEPARTMENT OF THE INTERIOR

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SEDIMENTARY FABRICS OF STRATIFIED SLOPE DEPOSITS AT A SITE NEAR HOOVER'S CAMP, SHENANDOAH NATIONAL PARK, VIRGINIA

by

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ABSTRACT

An outcrop of stratified slope deposits in Shenandoah National Park is described in detail. The Pleistocene age deposits are comprised of a mixture of clay to cobbles defining a series of offlapping wedges. Elongate clasts are oriented parallel to wedge boundaries except at the toe of the wedge, where they are oriented nearly vertical. The wedges represent sedimentation by freeze-thaw of ground ice. Thin layers of pebbly sand separate matrix-rich wedge deposits, which represent sheetfloods during periods of thaw. Thicker sand layers and lenses of clay are placed upslope of coarse-grained wedge fronts. This association represents ponding of water around the solifluction lobe topography during warm periods. Stratified slope deposits at an outcrop at a higher elevation lack the sandy sheetflood and pond deposits, whereas sheetflood fabrics dominate deposits at a lower elevation. These variations are attributed to differences in temperature at the different elevations.

INTRODUCTION

Stratified slope deposits are rhythmically layered pebbly deposits that occur on steep slopes with no obvious drainage patterns (DeWolf, 1988). They are attributed to solifluction and sheetflood processes associated with seasonally frozen ground and permafrost. Eaton and others (2003) have described stratified slope deposits from exposures in the Blue Ridge Mountains of central Virginia. The age range of these deposits is within the late Pleistocene as determined from carbon dating of wood fragments (Eaton and others, 2003; Litwin and others, in review). The dates all lie within the age of the last glacial advance or older. This report provides a detailed sedimentological description of one of these exposures with less detailed reference to observations in other localities. These data are used to provide constraints on depositional mechanisms and possible scenarios for the environment at that time.

Solifluction is defined as the slow mass movement of water-saturated material down a slope (Washburn, 1980; Lewkowicz, 1988; Ballantyne and Harris, 1994; French, 1996). When the movement is controlled by the freeze-thaw cycles of ground ice, the solifluction is referred to as frost creep and gelifluction. Frost creep is the slow "ratchet" movement of particles down a slope due to expansion of the sediment with ice and the gravitational offset as the ice thaws. Gelifluction is the gravitational sliding of water-saturated sediment as the surface of frozen ground thaws. The underlying frozen ground prevents water movement so pore-pressures increase, leading to failure of the overlying sediment even on low slopes. Rapid movement of a surface layer, called skin flow, is similar to a debris flow. Differential movement of sediment on the surface creates the step-like topography of solifluction sheets and lobes. Isolated boulders may act as obstructions to movement initiating step development.

Sediment sorting by frost heave segregates larger grain sizes from finer sediment because finer sediment is entrained in expanding ice more easily. When combined with gravitational segregation of larger grain sizes, this leads to patterns of boulder, cobble, and pebble distributions that are components of the solifluction sheets and lobes. The step-like topography may have relief varying from a few centimeters to several meters on a riser. The fronts of risers may be comprised of tightly packed boulders and cobbles (stone-banked) or they may be comprised of an unsorted mixture of coarse and fine sediment (turf-banked) (Benedict, 1970, 1976).

Migration of solifluction sheets and lobes results in aggradation of material, and the front of one feature may overrun that of another. Benedict (1970) noted that the fronts of turf-banked lobes in Colorado moved slower than the axis. Francou and Bertran (1997) noted that the fronts of stone-banked solifluction lobes in Bolivia were moving slower (around 30 cm/yr) than the sheets of fine material behind them (around 100 cm/yr). These observations support the hypothesis that the lobes move in a top-fed fashion, so that the front is continuously buried by the back (Francou, 1990; Van Steijn and others, 1995).

Classical gelifluction movement is similar to laminar flow with steadily decreasing velocity from the surface, but plug flow (similar to that of a debris flow) may occur if water saturated-sediment occurs below a frozen surface (Mackay, 1981). This is important in areas of permafrost where two-sided freezing occurs from the base and top of the active layer. In areas of sufficient moisture and summer warming, sheetflooding may wash fine-grained sediment from solifluction deposits, particularly from lobe-fronts of stone-banked lobes.

STUDY AREA

The main outcrop described in this report occurs along the headwaters of the Rapidan River in the Shenandoah National Park near Big Meadows (Figure 1) at an elevation of about 2300 feet. This is called the Hoover Camp site because of its proximity to the former U.S. president's cabins. A nearly vertical cut bank, as much as 5 m high, is exposed for about 40 m along the stream edge beneath a bench covered with a fairly recent debris flow deposit. The outcrop is oriented roughly east-west at the base of a southeast-dipping hollow with steeper slopes to the northeast and southwest. Although bedding inclination is variable, there is a general dip to the southwest that is parallel to the steeper portions of the slopes to the northeast.

Two additional sites will be mentioned in this report (Figure 1). The first occurs just below the eastern margin of Big Meadows at an elevation of 3500 feet. It is a small gravel pit operated by the National Park Service. The other is a large exposure formed during the 1995 floods along Kinsey Run near the eastern border of Shenandoah National Park, west of Graves Mill at an elevation of about 1200 feet. The latter exposure was described in Eaton and others (2003).

METHODS

The Hoover Camp outcrop initially was cleared of loose debris and cut back to nearly vertical using pick and shovel. A rectangular grid framework (Figure 2) was formed using string, with each segment 1 m wide and 1.5 meters high. The surface of each grid segment was carefully scraped clean with a sharp knife (the larger clasts cut into relief), then cleared with a leaf blower.   The cleaned grid section was photographed in overlapping 30 cm sections, and then logged in a notebook at a tenth scale. The clasts and other sedimentary features were projected onto a vertical surface for logging with no attempt to correct for bedding dip or the actual dip of the outcrop face. The orientation, sizes, and shape of clasts larger than 5 cm were drawn to scale. Orientation and shape of smaller pebbles and sand grains were noted and indicated schematically.

The log of each grid panel was overlapped by 10 cm with adjacent grids to ensure continuity of description. Twenty panels were logged (Figure 3), then combined into a single composite section (Figure 4). Description took several months, so some portions of the outcrop collapsed or became covered, and had to be cleaned again. As a result, some layers and clasts are only approximately aligned in adjacent grids.   The uniformity of description was checked using the photos.

SEDIMENT DESCRIPTIONS

Grain sizes in the outcrop vary from boulders over a meter in diameter to relatively pure clay. Clasts vary from moderately well rounded to angular in shape. Some angular clasts have rounded sides, and in one place angular fragments of a rounded clast were separated by a small amount of matrix, suggesting fragmentation in place. Clasts are a mixture of granite and metabasalt (greenstone) with minor vein quartz, reflecting rocks in the immediate vicinity (Gaithright, 1976). The clay is predominately kaolinite with less abundant illite that is consistent with local bedrock weathering (Daniel Webster, U.S. Geological Survey, Reston, Virginia, personal communication).

Most of the sediment in the exposure contains some portion of muddy matrix comprised of a mixture of clay, silt, sand, and granules. This muddy matrix may occur as pore-filling material in framework gravel and sand or may dominate a sediment layer with randomly distributed pebbles and cobbles. Fine- to coarse-grained sand layers, dominated by rock fragments, quartz, and mica, may be matrix free. The upper contacts of thin sand beds overlain by beds with muddy matrix are often diffuse, suggesting eluviation or mixing of clay-rich material. Beds of nearly pure clay with discrete layers of sand or scattered pebbles and cobbles occur as thin lenses. These clays have a similar composition to those of the muddy matrix, but have a significantly more smectite that is only trace in the matrix (Daniel Webster, U.S. Geological Survey, Reston, Virginia, personal communication).

Layering of sediment is defined by varying amounts of muddy matrix, abundance and sizes of clasts, clast orientations, and layers free of muddy matrix. Layers mostly are discontinuous and highly variable in thickness, defining lenses, pods, and wedges. As progressive layers were scraped from the outcrop, it was established that some of the variation in shape is due to different orientations of cross-sections with similar features.

A dense root mat extends downward from the forested surface that comprises the top of the outcrop (Figure 3, Grids 1, 5, 8, and 11). Live roots, mostly with diameters of less than one cm; extend more than 50 cm below the surface. There is a greenish cast to the sediment immediately below the surface that fades out about 30 cm below it. There are only hints of layering defined by horizons of similar-sized clasts in the sediments containing the root mats. A yellowish zone of higher clay content that cuts across bedding has a series of vertical partings that roughly parallel the outcrop face. The zone probably represents a B-horizon eluviated clay. Iron oxides rim the yellowish clay and also unevenly cement sandy layers. Open casts of former roots and casts filled with iron-oxide-stained clay are present within the yellowish clay-rich zone. Yellowish clay with sediment-filled root casts was observed in two other places within the section, but only as small patches (Figure 3, Grids 6 and 12).

BOULDER-COBBLE CLUSTERS - Clusters of cobble- to boulder sized material comprise distinctive features within the exposure (Figure 3, Grid 13). The clasts commonly are in grain contact with long axes oriented near vertical or shingled with other clasts, commonly with inclination downslope (opposite that of stream imbrication).

Areas between the clasts are filled with muddy matrix, particularly in the lower parts of clusters. The clusters appear to be elongate and arcuate or sinuous roughly perpendicular to the regional slope, but there is considerable variation in the orientation.

MATRIX-RICH PEBBLE AND COBBLE LAYERS - The most common layers in the outcrop are beds dominated by muddy matrix that contain layers rich in pebbles or cobbles. The pebbles and cobbles commonly have long axes oriented in similar directions more or less parallel to bedding (Figure 3, Grid 14). Clasts tend to have similar sizes within a bed, but may change in size along a bedding plane. Lenses that appear to have randomly oriented clasts actually are cross-sections of layers whose clasts are aligned out of the outcrop plane. Larger clasts generally occur towards the top of beds, and clasts within beds tend to become coarser and more closely packed where they pinch out downslope. Variations in sand abundance within the matrix help to define decimeter-scale layers. A common type of layer consists of a few centimeters of muddy matrix with isolated cobbles protruding out of the top (Figure 3, Grid 10). The cobbles tend to have similar sizes and their long axes commonly are nearly vertical.

SAND AND GRAVEL PARTINGS - An important component of stratification is mm- to cm-scale layers of poorly sorted medium- to coarse-sand or sandy pebble layers (Figure 3, Grid 18). The sand layers have sharp basal contacts with scattered small pebbles common. The upper contacts also may be sharp, but they are commonly more diffuse if the overlying layer is mud-rich. Sand layers of this type vary in thickness laterally and commonly show concentrations of larger grains upslope of clasts protruding from the underlying layer and thickening of finer sand in the downslope side (shadow fabric). Pebbles layers have similar clast sizes (0.5- 2 cm long) that are imbricated upslope. In places, the sand-rich beds laterally become more clay rich and grade into matrix-rich layers (Figure 3, Grid 19).

STRATIFIED SAND - Coarse to fine sand forms tabular foresets that may intertongue with or overlie clays (Figure 3, Grid 12). These sediment bodies rarely are more than a 1-2 meters long before pinching out or abutting against another sedimentary fabric. The foresets range from a few cm high to a maximum height of about 20 cm. Where clays are intercalated with sand foresets, they are interleaved with the base of the foresets, thickening as the foresets thin. Also, foresets commonly have pebbly layers in the upflow portion grading to finer sand and clay in the downflow direction.

CLAY LAYERS - Unlike the typical mixture of sand, silt, and clay that comprise the muddy matrix, clay layers are dominated by clay. Thick clay layers may have laminae of fine sand or silt (Figure 3, Grid 20). Pebbles and cobbles may be distributed randomly within a clay matrix. Typically, the long axes of clasts are parallel to layering, particularly the larger clasts. Clay layers grade into sandy beds with tabular foresets through increasing thickness and abundance of sandy layers. In these cases, the opposing side of a clay lens will drape over or abut against boulder-cobble clusters. Scattered cobbles and pebbles within the clay matrix are more abundant near those contacts.

DEFORMATION FEATURES - Layering is folded and oversteepened in many places. Deformation is most evident in sand and clay layers, but pebbly and cobbly layers commonly are included in the deformation (Figure 3, Grids 4 and 20). The deformed zones are limited to a few decimeters laterally before dying out into flat bedding. In places the folding appears to overturn beds, but this may be an artifact of the cross-section. Distinctive flame-like deformation features were observed along the contact between matrix-rich and sandier beds in two places (Figure 3, Grids 2 and 6). The flame-like structures are flattened in the plane of bedding with upslope extension of flames.

SEDIMENT PACKAGING

The primary form of sediment packaging appears to be a series of 10-to-50-cm-thick sigmoidal wedges that offlap downslope, creating crude cross-stratification (Figure 4). The orientations of these inclined wedges change stratigraphically in at least three zones (Figure 5). The middle zone features primary dip that is parallel to the outcrop, whereas the upper and lower zones are oriented more out of the outcrop plane. The latter two cases produce lenticular or wavy beds with both convex and concave contacts. There are two themes of wedges that characterize the outcrop. Thick wedges rich in muddy matrix tend to coarsen downslope to a cobble cluster at the nose (Figure 4 inset). Thick clusters of larger cobbles or boulders may have more than one wedge terminate against it. The clasts within the body of the wedge are oriented parallel to the surface and become more concentrated toward the downslope end. The upper part of the wedge is coarser than the base. The other wedge style commonly occurs upslope of the first type on any horizon (Figure 4 inset). These wedges are thin and taper to a point, which is finer grained than the upslope part. Matrix-rich layers are coarser at the top and alternate with sandier layers.

Lenses of clay are equivalent laterally to and overlain by stratified sand beds. They occur upslope of large boulder cobble clusters (for instance, the lower right-hand corner of the composite section in Figure 4). The thickest clay lenses are visible where the outcrop cross-sections are more perpendicular to the wedge dips. The clay layers drape over matrix-rich sediment and fill in some of the spaces between clasts in clusters. Stratified sand forms wedges that intertongue downslope into clays and overlie them. Some stratified sands have only thin layers of clay, probably reflecting a cross-section upslope of thicker clay. Oversteepened folds are restricted to the upper part of the downslope termination of clay and sand lenses. The overlying material appears to be thrust over the deformed sediment.

OTHER OUTCROPS

The gravel pit near Big Meadows exposes about three vertical meters of section in several walls. Clasts are exclusively greenstone, reflecting the surrounding bedrock, and they vary from subrounded to angular in character. These deposits are more matrix-rich and less obviously bedded than the deposits described above. Most clasts appear to be oriented horizontal with layering defined by differences in clast concentration. Clusters of cobbles are uncommon and no sandy layers were observed.

The outcrop on Kinsey Run exposed as much as 6.5 m of vertical section. The major lithology is granite with some greenstone and includes highly sheared clasts of both rock types. This exposure is sandier and more distinctly bedded than the other two. There are indications of similar sediment styles including matrix-supported pebbly layers and clusters of cobbles. Sand layers are thicker and more common at the Kinsey Run site, and boulder-sized clasts are uncommon. Sandy units appear to be continuous, but this is partly due to their dip out of the outcrop face. The basal 60 cm of the outcrop is very clay rich with numerous root casts and pieces of carbonized wood. This zone is sharply overlain by lenticular cobble units, then planar sandy beds with muddy pebble interbeds. A partial section right angles to the outcrop face reveals steeply dipping sandy foresets about 1.5 m high overlying more gently dipping cobble-rich muddy sediment.

COMPARISON TO SOLIFLUCTION DEPOSITS

The sedimentary features of the main outcrop are similar to those formed by solifluction as illustrated in the literature (Benedict, 1970, 1976; DeWolf, 1988; Francou, 1990; Bertran and others, 1992; Ballantyne and Harris, 1994; Van Steijn and others, 1995). The variability and packaging of the sediments, however, appear to be much more complex than any published descriptions. This discussion will emphasize first the features that are consistent with solifluction deposits in the literature, then will elaborate on possible causes for variations and complexities.

A common observation of stone-banked solifluction lobes is that the body of the deposit consists of matrix-supported clasts whose long axes are oriented parallel to slope and the front consists of grain-supported clasts with more vertical or random orientations. This geometry dominates the wedges observed in the measured section. The clasts with long axes parallel to slope are developed by the laminar flow of gelifluction. The grain-supported clasts represent a more complex combination of factors including steepening of clast fabrics in the slower-moving lobe front that leads to dips more steeply downslope. This is the most common arrangement for the coarser clasts towards the downslope end of wedges. Frost heave of clasts produces vertical orientations. This may account for more randomly distributed vertical clasts, although some of these observations also may be due to the plane of cross-section. Francou (1990) noted that frost heave caused coarse clasts to migrate to the top and front of stone-banked lobes causing a reverse grading in layers in conjunction with a downslope coarsening. This type of sorting is common in the matrix-rich wedges, although similar sorting can be caused by other mechanisms. Entrapment of coarse clasts upslope of impediments (shadow fabric) causes imbrication of clasts more steeply upslope. A commonly mentioned cause of these impediments is large isolated boulders called ploughing blocks that move very slowly compared to finer-grained materials. Shadow fabric and upslope imbrication is associated with the larger boulders in the section and probably represents those conditions.

Plug flow in solifluction results in matrix-supported fabrics with more random orientation of clasts. In the case of skin flows, the sedimentary fabric should resemble that of a thin debris flow. There are many layers with apparent random clast orientation, although they may be an artifact of orientation, because the cross-sections are invariably parallel to the wedge fronts. There are some thin beds with larger clasts protruding out of the upper contact that resemble thin debris flows. Thin debris flows also may show coarse-grained lobate ends and internal reverse grading (i.e. Costa, 1984) that would be difficult to distinguish from the features produced by solifluction.

Sheetwash commonly is mentioned in descriptions of solifluction deposits. For the most part, sheetwash is believed to remove matrix with little net deposition. Several authors note the common loss of matrix in stone-banked lobe fronts by sheetwash. Francou (1990) and van Steijn and others (1995) emphasize that removal of matrix from the nose of solifluction lobes is important in producing matrix-poor layers that alternate with matrix-rich layers as the matrix-rich treads override the fronts. Thin sand layers with little matrix in this study area probably are produced by sheetwash. The pebbles in these layers commonly display typical imbrication and shadow fabrics of pebbles and sand that are consistent with shallow flow. Some of the boulder-cobble pods have a sandy matrix filling between clasts that probably was introduced by sheetflow.

Unlike the Hoover Camp outcrop, the descriptions of solifluction deposits suggest relatively planar bedding, or thickness to length ratios that are small in downslope cross-sections. A higher degree of lenticularity was attributed to rainfall and sheetwash by van Steijn and others (1995) for deposits in the French Alps. Ozouf and others (1995) argue that debris flow action accounts for higher lenticularity of solifluction deposits in the northern Aquitain. Benedict (1970) indicates that source rock variability controls the complexity of lobe fronts and variability of deposits, with more range of grain sizes favoring more complex features. The high mud content and large range of grain sizes in the Hoover Camp deposits probably dictate a more lenticular geometry reflecting irregular lobe-front morphology and mixtures of gelifluction and skin-flow deposits. The level of intercalated sheetwash deposits also probably affected local grain-size distribution and relief at Hoover Camp.

The inclusion of cross-stratified sand and thick clay lenses in the Hoover Camp deposit is quite unlike anything reported in the literature. These deposits appear to reflect small ponds developed at the toes of solifluction terraces that are fed by the melt water. The cross-stratified sands resemble small Gilbert-type deltas (as in Jopling and Walker, 1968) rather than cross beds from streamflow bedforms. The water depths involved were similar to the thickness of the foresets, or only a few cm to less than 30 cm deep. The clay deposits represent the ponds. Isolated cobbles within the clays distort lamination as drop stones do. The bedding-parallel orientation of elongate clasts differs from classic drop stones, whose long axes are more vertical, but are consistent with very shallow water.

The direct evidence of ice formation in the sediments is not strong. Thin sections have not been made to look for structures formed by ice lenses (Harris and Ellis, 1980), but parting fabrics are consistent with their presence (see Ballantyne and Harris, 1994, figure 6.30). The unusual flame-like deformation features are very similar to features illustrated by Bertran and others (1992, figure 11), which they attribute to overthrusting of lobe-front festoons. The deformation presumably is related to solifluction creep. The other deformation features also are consistent with downslope creep of sediment blocks. The folding of clay-rich, sandy, and pebbly sediment suggests cohesion of materials inconsistent with their present rheology. There is no evidence of ice wedges or other cryoturbation features.

The deposits in the Big Meadows gravel pit exposure resemble the poorly sorted fabrics associated with turf-banked lobes sectioned by Benedict (1970, 1976). Although detailed analysis is incomplete, there appears to be strong evidence of shattered clasts and platy partings as seen in solifluction deposits. The lack of structure and sandy material, as seen at the Hoover Camp exposure, is consistent with low-relief lobes with little modification by sheetwash.

The deposits along Kinsey Run most closely resemble the stratified colluvium illustrated by Francou (1990), Bertran and others (1992), and Van Steijn and others (1995). The apparent continuity of layers and undulatory contacts are directly comparable. These deposits are much sandier and contain more flat, pebble-sized clasts and less mud than the other deposits. The platy, granitic source material for the deposits is similar to that in the Andes (Francou, 1990) and the Pyrenees (Bertran and others, 1992). The meter-scale tabular sets of sandier material are not like the stratified slope deposits described in the literature. Speculation on the significance of these features awaits completion of a more detailed description of the outcrop.

DISCUSSION

The combination of shapes and fabrics in the Hoover Camp outcrop strongly suggest accumulation occurred through a combination of solifluction and sheetwash. The geometry of the features was influenced by the mud-rich source material and a mixture of clast sizes. The absence of obvious cryoturbation features may reflect the relatively wet and warm conditions during accumulation. Francou (1990) and Van Steijn and others (1995) noted that ice wedges and pingos developed better in very cold dry conditions, whereas solifluction bedding was better developed in areas with seasonal freeze-thaw conditions and abundant moisture. This also is consistent with the presence of sheetflood sand and small ponds. There is no direct evidence of permafrost having formed at this locale. The dearth of root casts and presence of beds suggesting plug flow may be indicators of at least periods of permafrost development. Angular, *in situ* fractured clasts and platy muddy matrix are consistent with frozen ground. The association of some root casts with muddy pond deposits may indicate warmer conditions occurred intermittently during accumulation of the deposit. There is a hint of a stratigraphic separation of more sheetflood and pond deposits, but this also is coincident with a shift in the orientation of lobe fronts.

The differences between the Big Meadows and Kinsey Run exposures and the one at Hoover Camp provide a tantalizing suggestion of correlation between elevation differences and temperature during accumulation of these deposits. The higher elevation deposits at Big Meadows lack sheetflood overprints and are only poorly sorted, suggesting a dominance of slow creep during freeze-thaw cycles. The lower elevation Kinsey Run deposits show repeated influence of sheetflow and overprinting by vegetation. Hoover Camp may represent an intermediate condition. Radiocarbon ages from the Kinsey Run and Hoover Camp outcrops and from a core near the Big Meadows outcrop indicate some overlap in age of deposits (Eaton and others, 2003; Litwin and others, in review). The apparent change in lobe morphology, including steep-fronted sandy terraces in the lower elevation, is similar to regional variation observed in periglacial deposits in Britain (Ballantyne and Harris, 1994, Figure 11.1).

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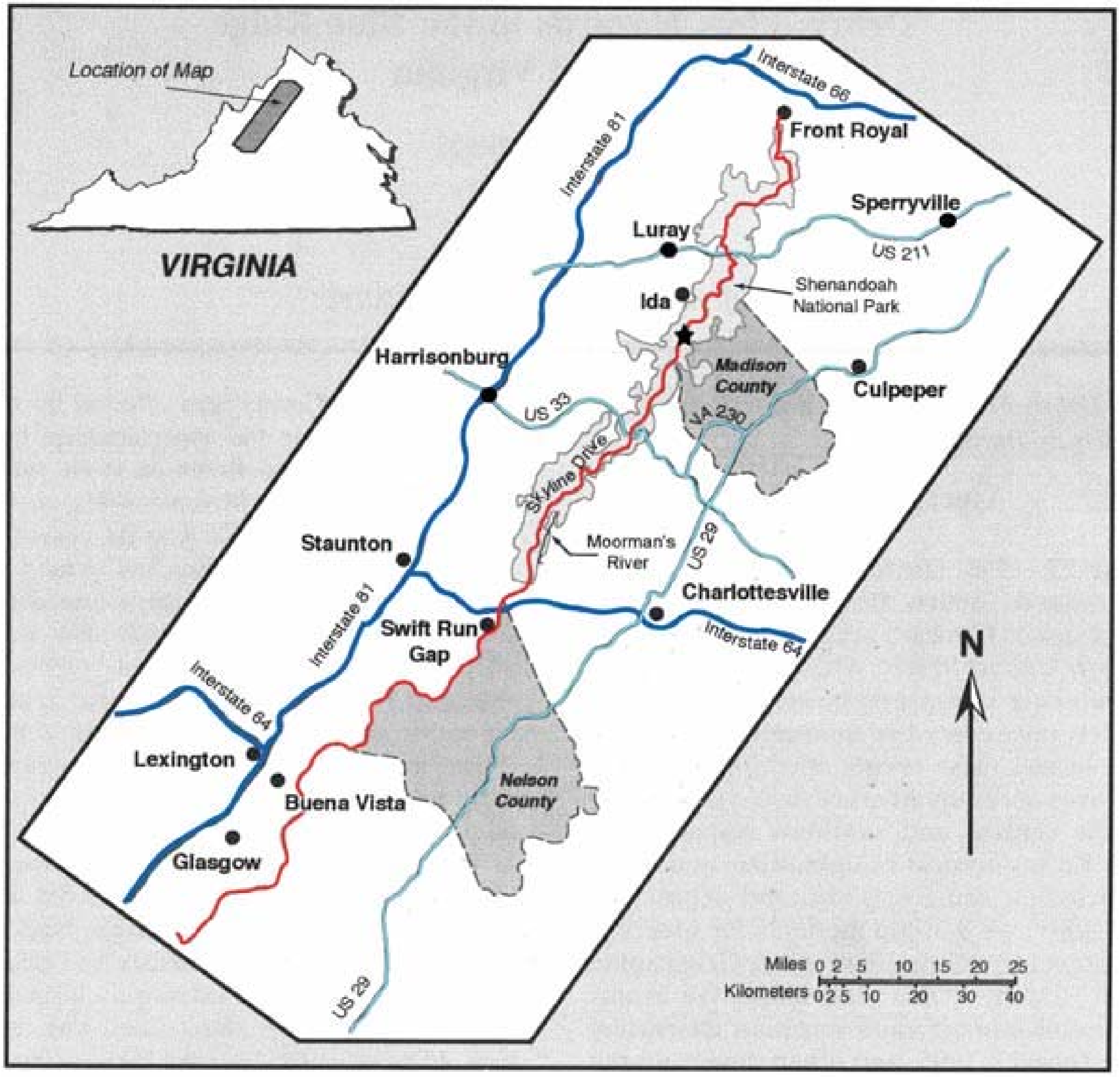
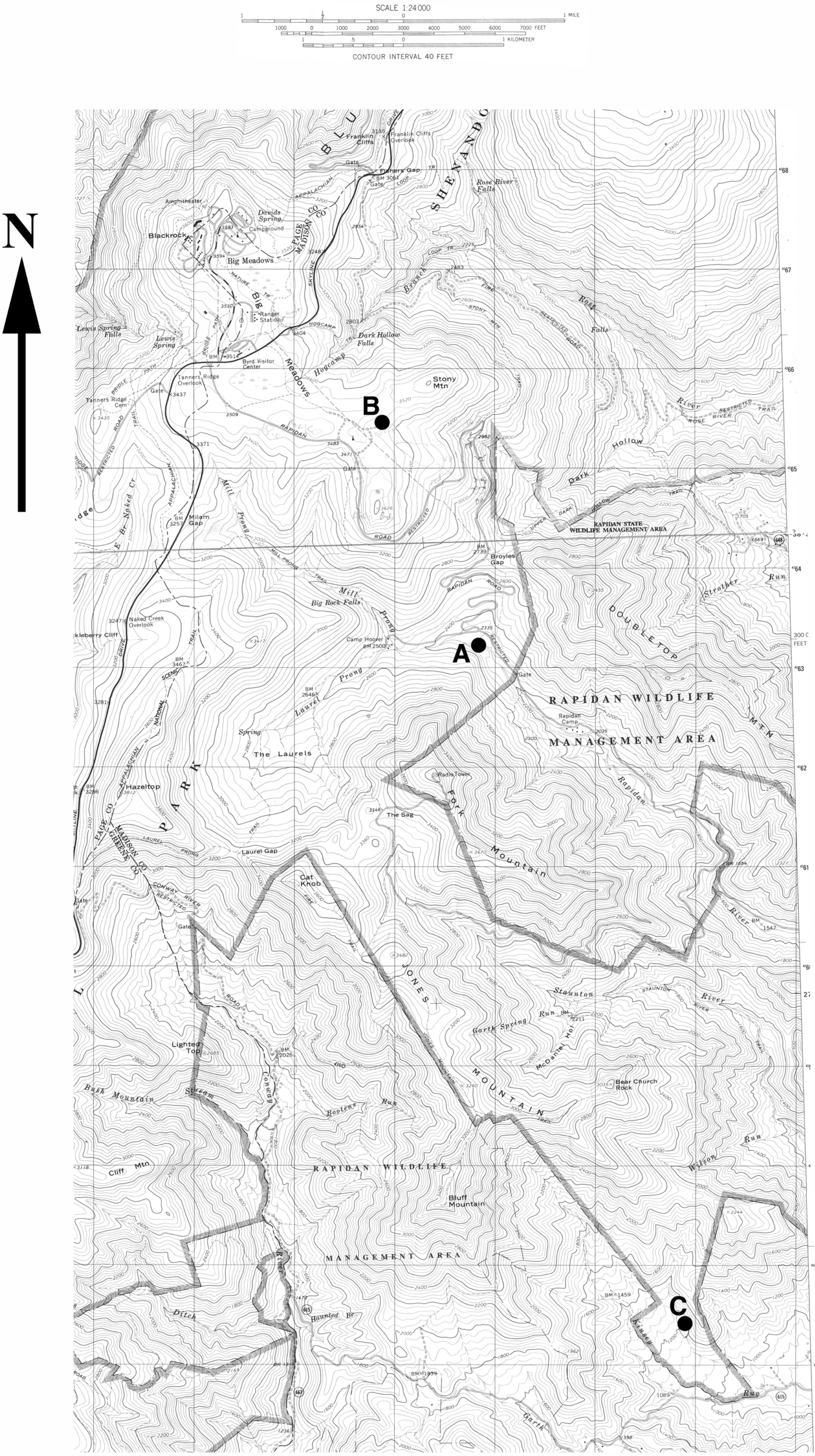


Figure 1. A. Map showing Shenandoah National Park in Virginia and location of Big Meadows (star). Madison and Nelson Counties are sites of study for debris flow hazards by the USGS. B. Topographic map showing location of Hoover Camp site (A), the Big Meadows gravel pit (B), and the Kinsey Run site (C).



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1 MILE
1000 0 1000 2000 3000 4000 5000 6000 7000 FEET
1 .5 0 1 KILOMETER
CONTOUR INTERVAL 40 FEET
N
A
B
C
Franklin Cliffs
Fishers Gap
Rose River Falls
Big Meadows
Blackrock
Davids Spring
Campground
Amphitheater
Ranger Station
Byrd Visitor Center
Dark Hollow Falls
Lewis Spring Falls
Tanners Ridge Overlook
Stony Mtn
Milam Gap
Broyles Gap
Rapidan Road
Big Rock Falls
Camp Hoover
Naked Creek Overlook
Doubletop
Rapidan State Wildlife Management Area
Rapidan Wildlife Management Area
Rapidan Camp
Laurel Prong
The Laurels
Hazeltop
Radio Tower
The Sag
Fork Mountain
Laurel Gap
Cat Knob
Jones Mountain
Staunton River
Garth Spring Run
Bear Church Rock
Lighted Top
Bush Mountain
Conway
Bootens Run
Cliff Mtn
Bluff Mountain
Management Area
Wilson Run
Kinsey Run
Ditch
Haunted Br
Garth

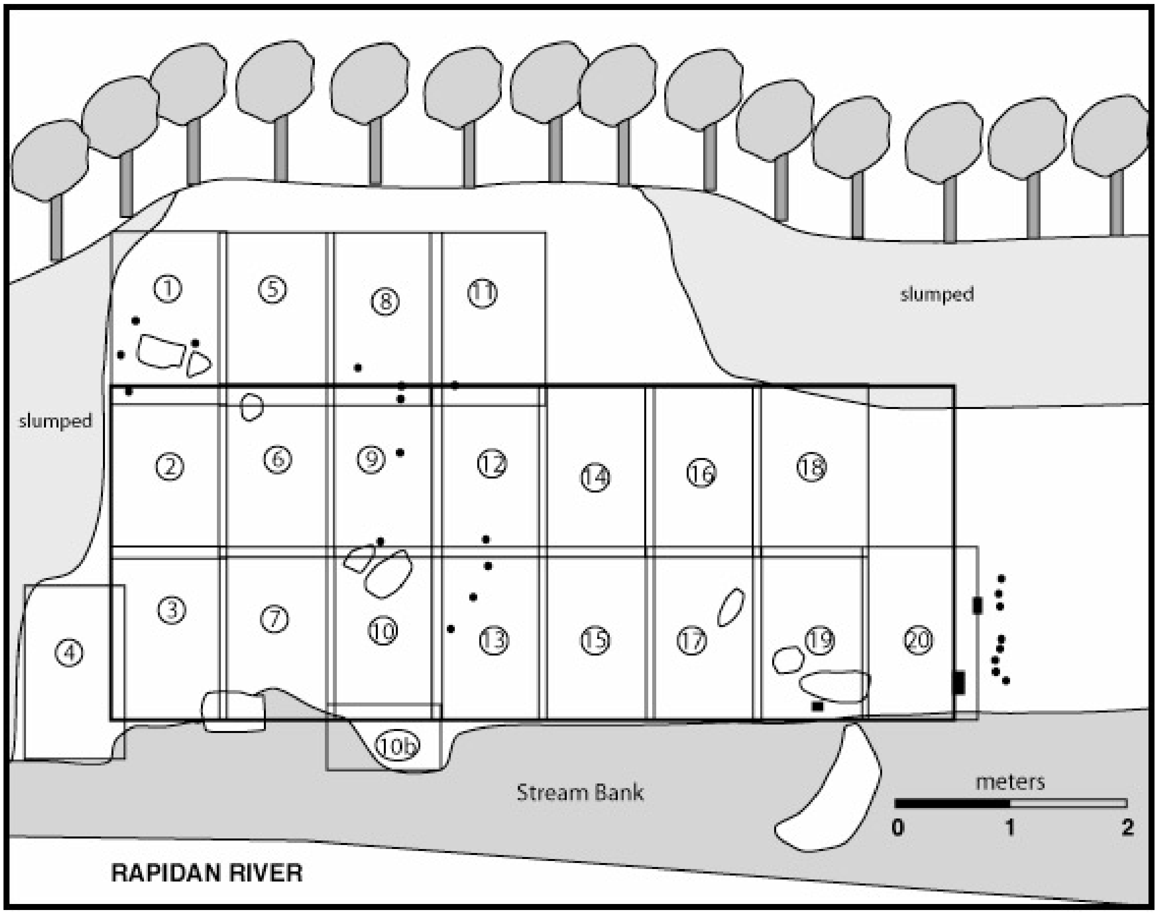

Figure 2. Generalized sketch of the Hoover Camp site showing distribution of overlapping grids shown in Figure 3. Circles and blocks show sample locations for pollen and carbon dates (Litwin and others, in press). Larger box with heavy lines is area of the composite section in Figure 4.

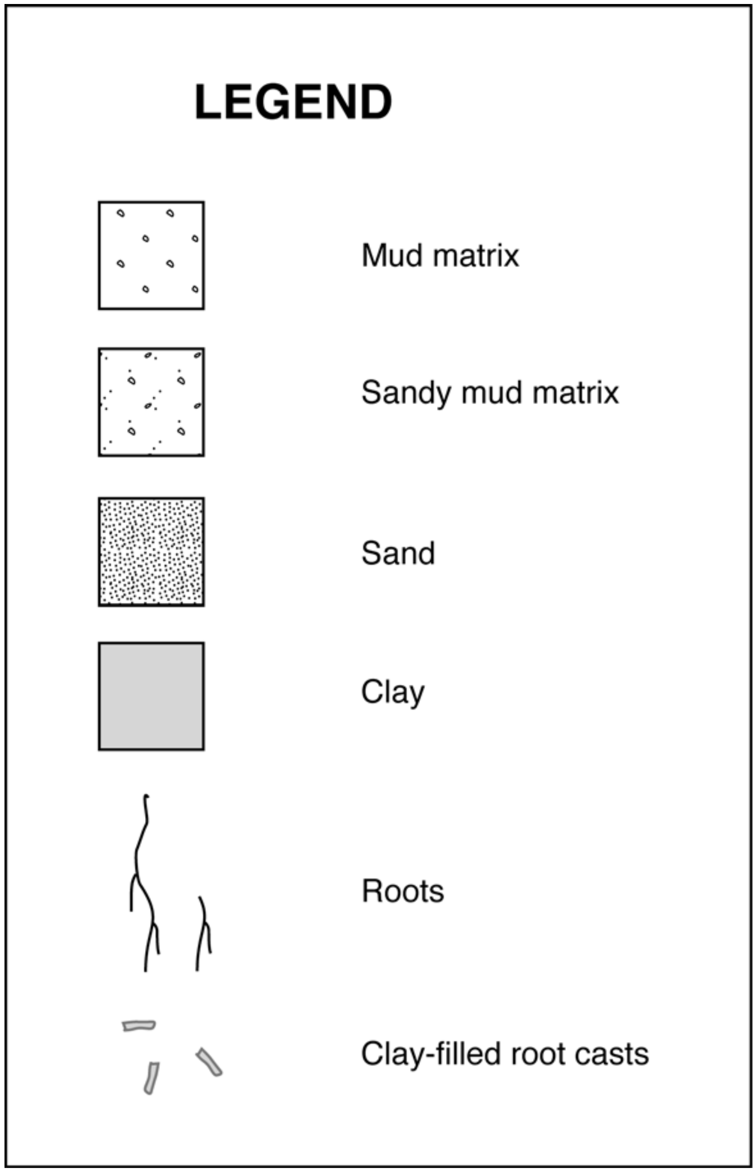

Figure 3. Field sketches of 20 grids shown in Figure 2. Outlines of clasts greater than 5 cm in length are shown exactly to scale, whereas smaller clasts are shown schematically. Lettered boxes refer to specific parts of text.

A. Flame-like deformation features comprised of sand overlain by muddy matrix. (Grid2)

B. Deformation of a clay lens and adjacent cobbles, pebbles, and sand. (Grid 4)

C. Flame-like deformation features muddy matrix overlain by sand. Root casts filled with iron-stained clay are also present. (Grid 6)

D. Thin beds of matrix-rich pebble deposits with sand partings. Note protrusion of larger clasts above contacts. (Grid 10)

E. Stratified sand forming cross beds with intercalated lenses of clay. Note that bed sets are coarser upflow of clay (to the right). (Grid 12)

F. Root casts filled with iron-stained clay. (Grid 12)

G. Cluster of boulders and cobbles at toe of wedge. Note inclination of elongate clasts is up slope (to the right). (Grid 13)

H. Matrix-rich wedge with cobbles and pebbles oriented parallel to slope. Note larger clasts toward top of wedge and crude layering defined by upward-coarsening sequences. (Grid 14)

I. Pebbly sand trapped upslope (to the right) of cobble projecting from muddy matrix. (Grid 18)

J. Lateral gradation from muddy matrix (left) to sand. (Grid 19)

K. Deformed clay lens with thin sandy laminae (light lines) and scattered cobbles and pebbles. Note orientation of the clast long axes parallel to layering. (Grid 20)

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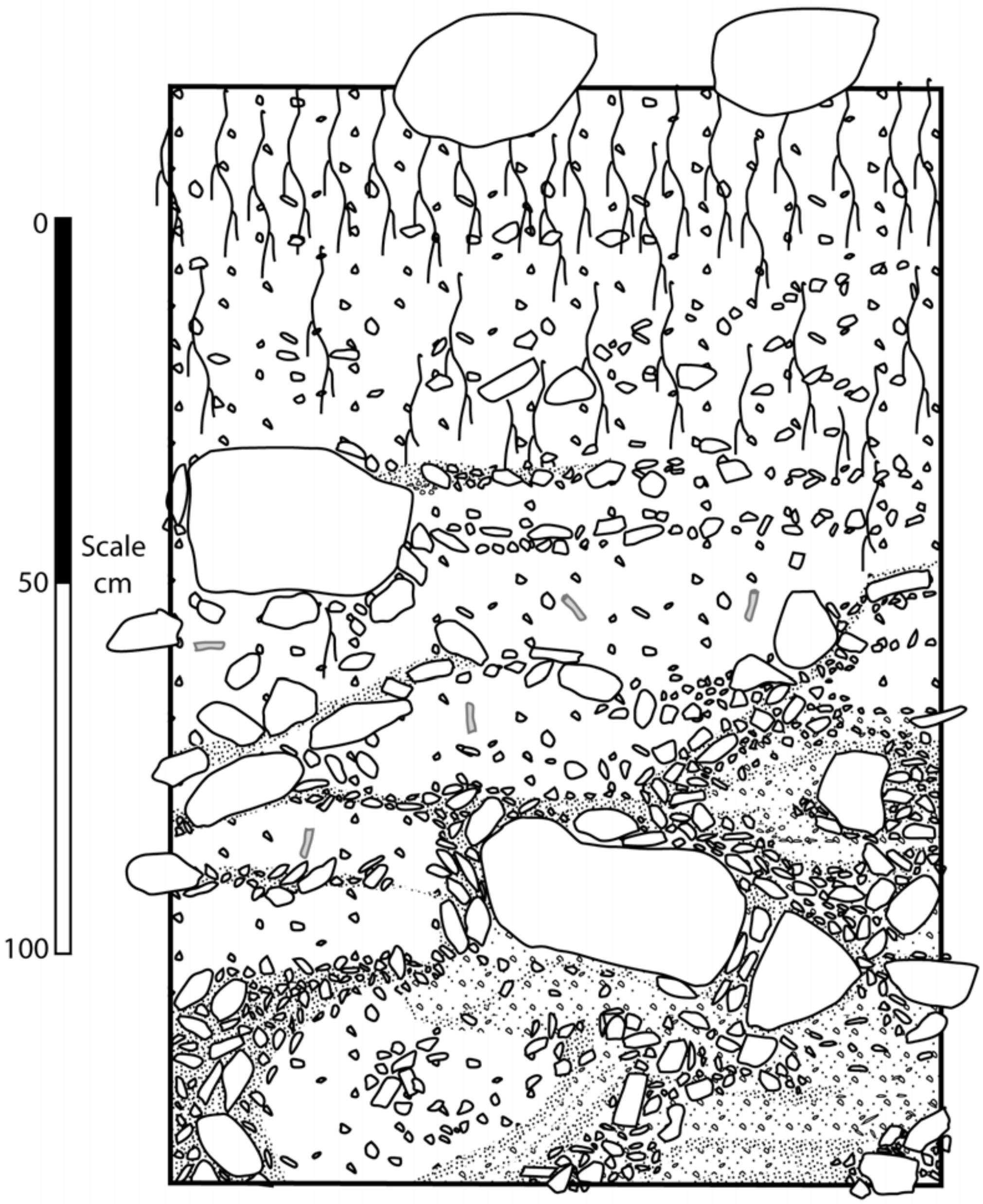

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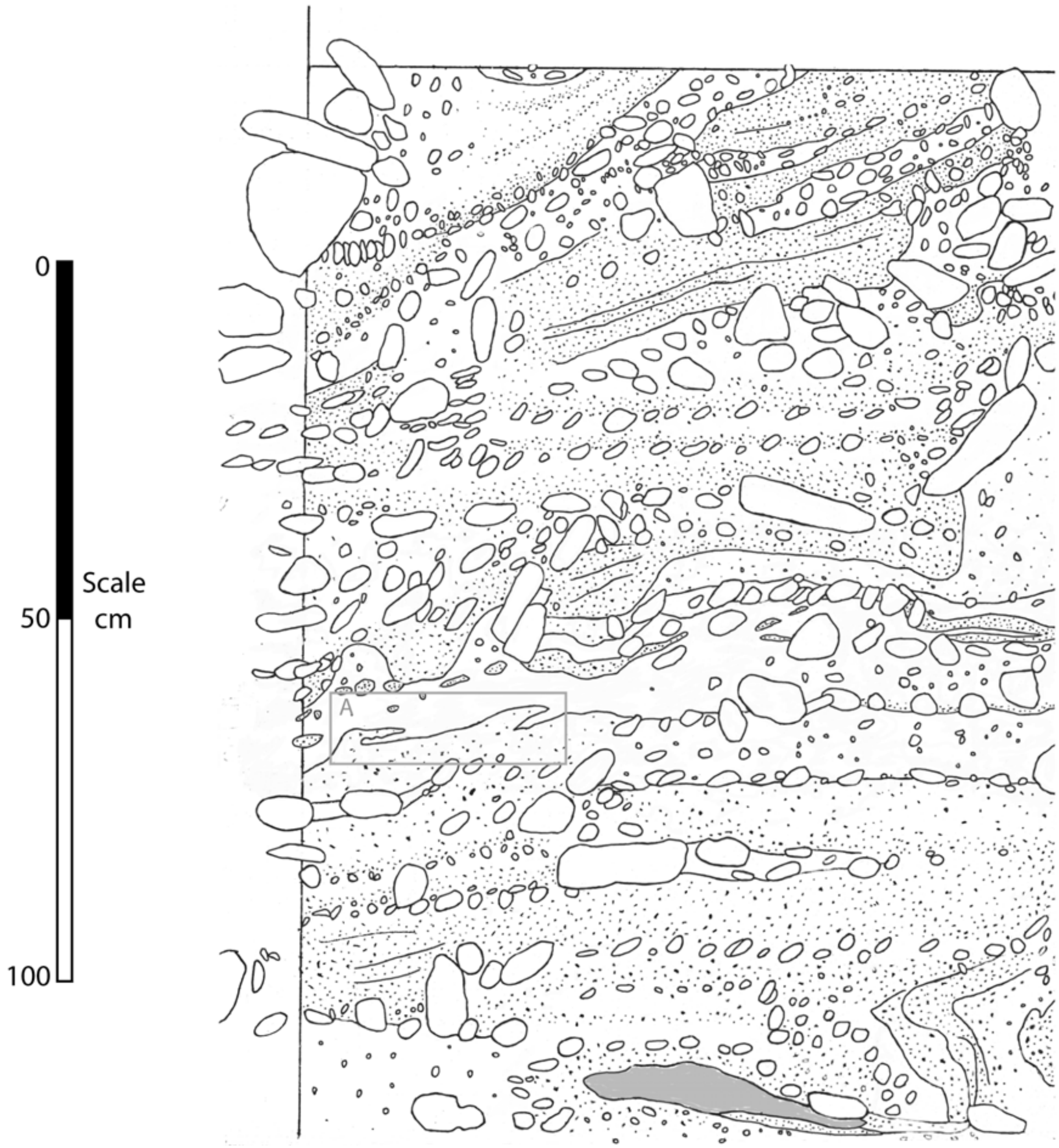

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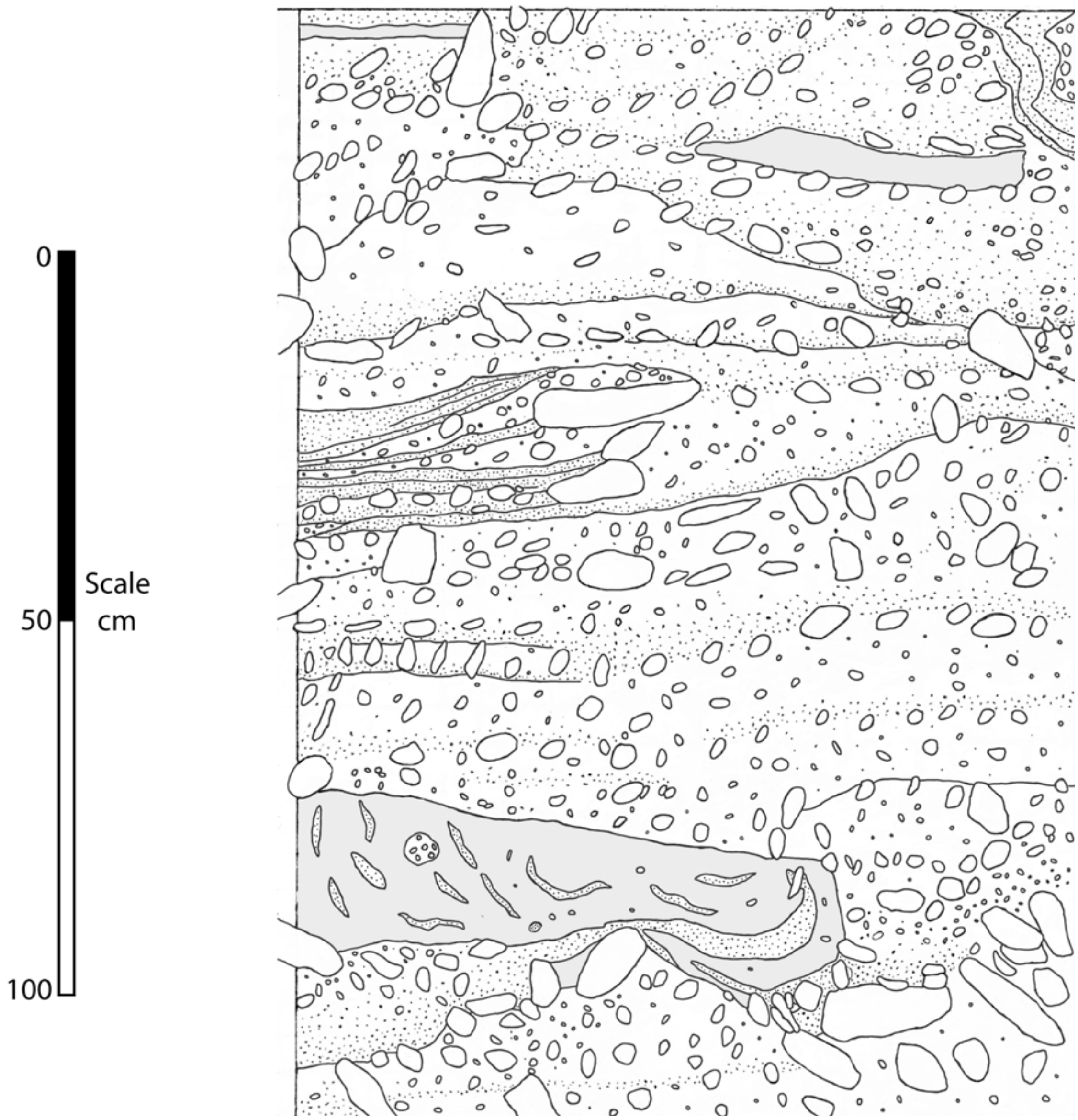

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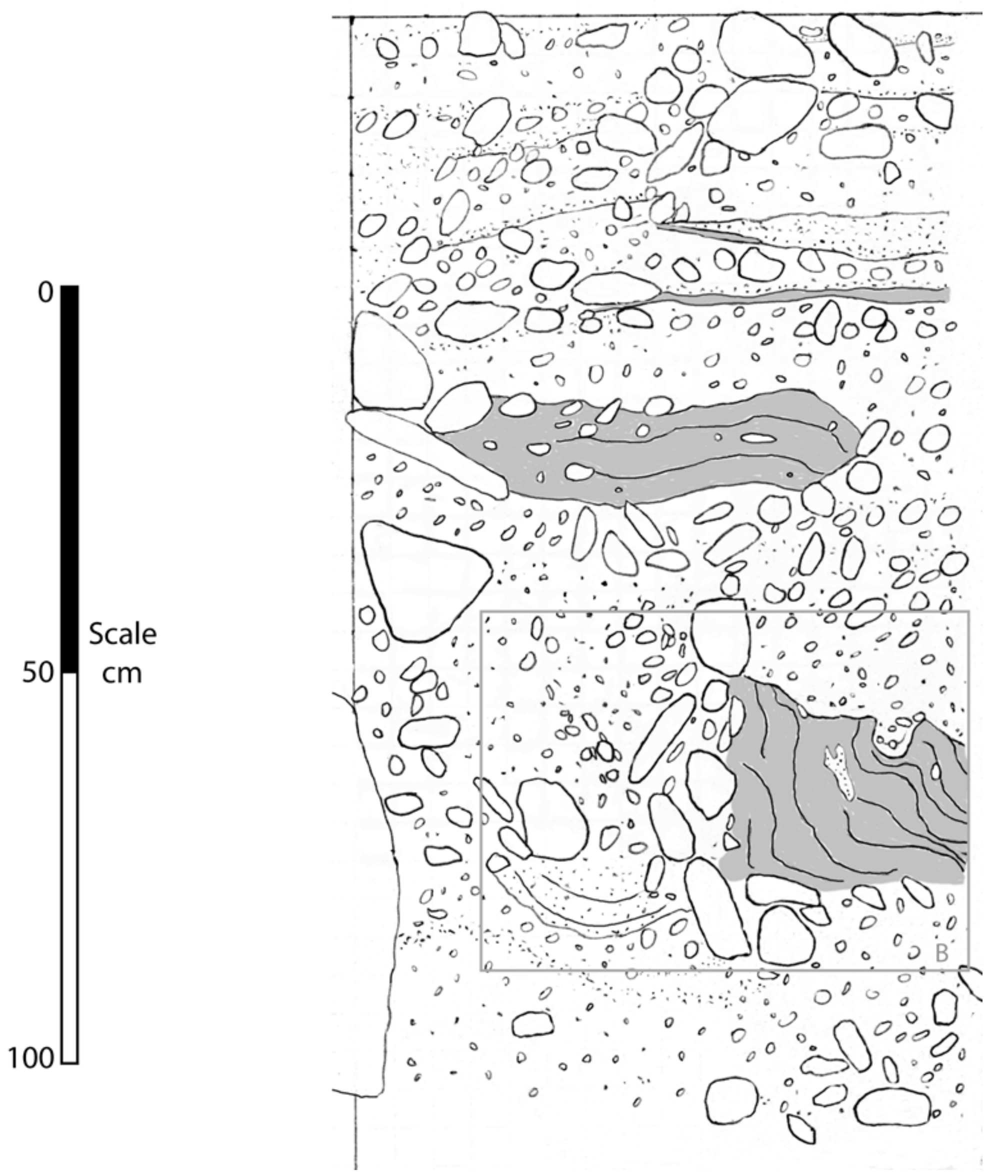

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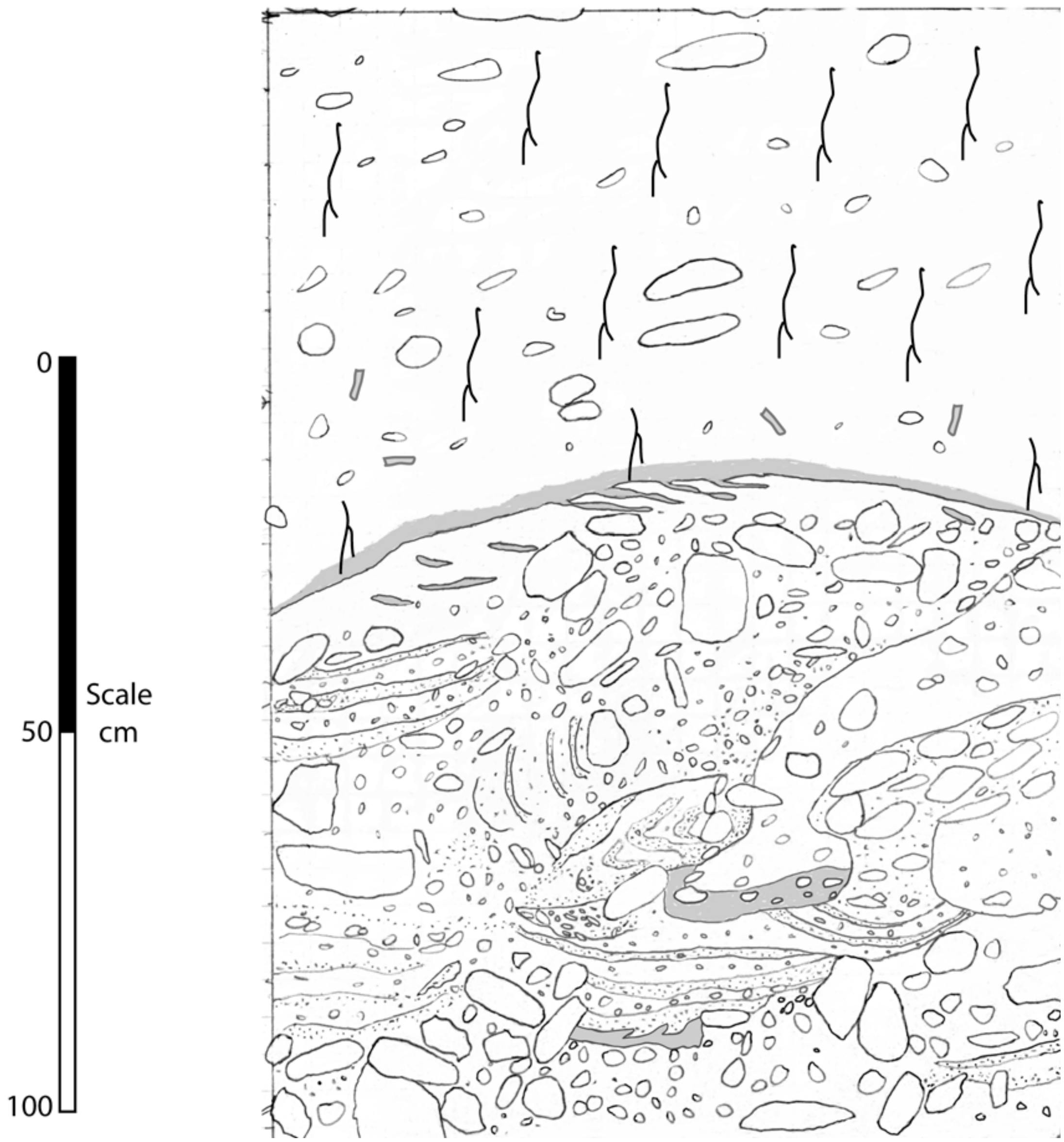

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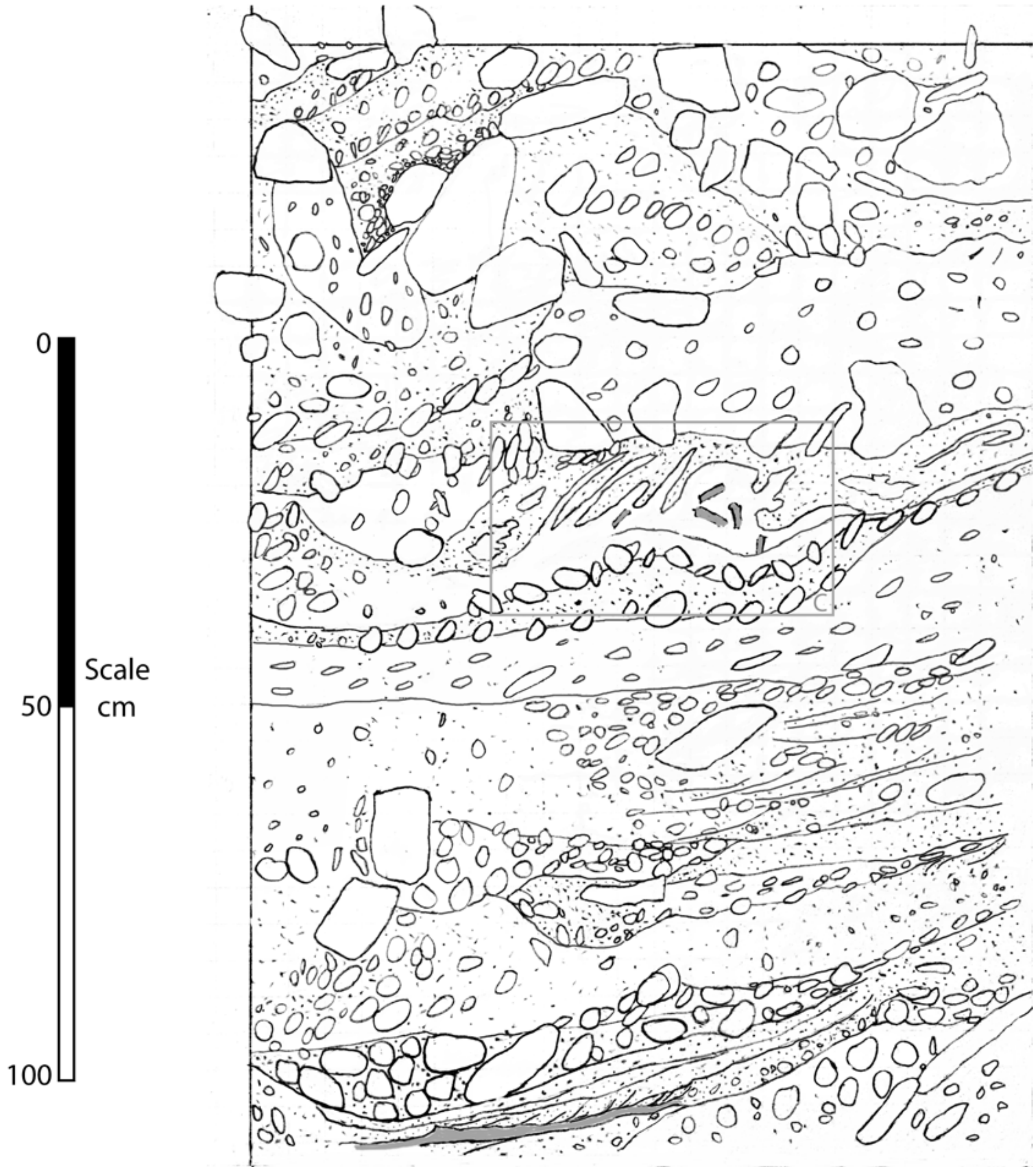

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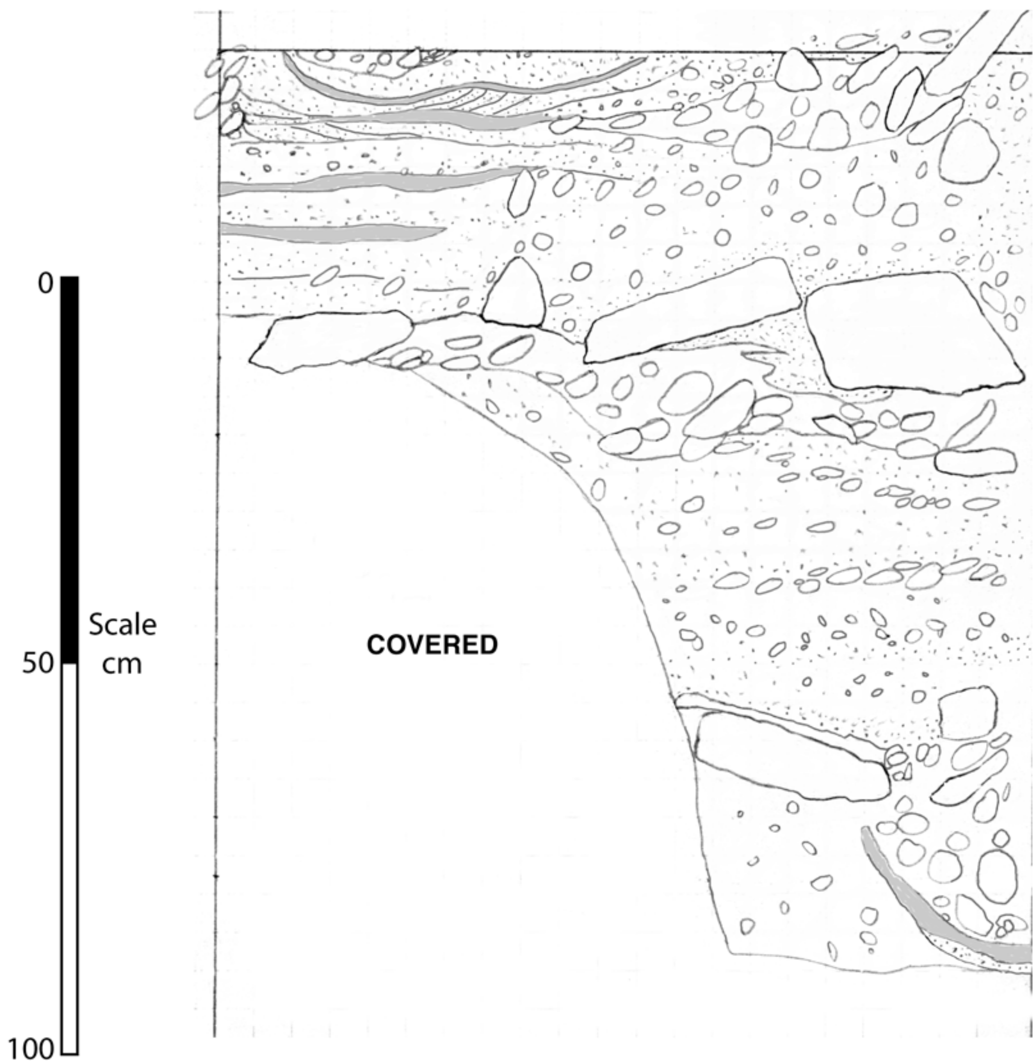

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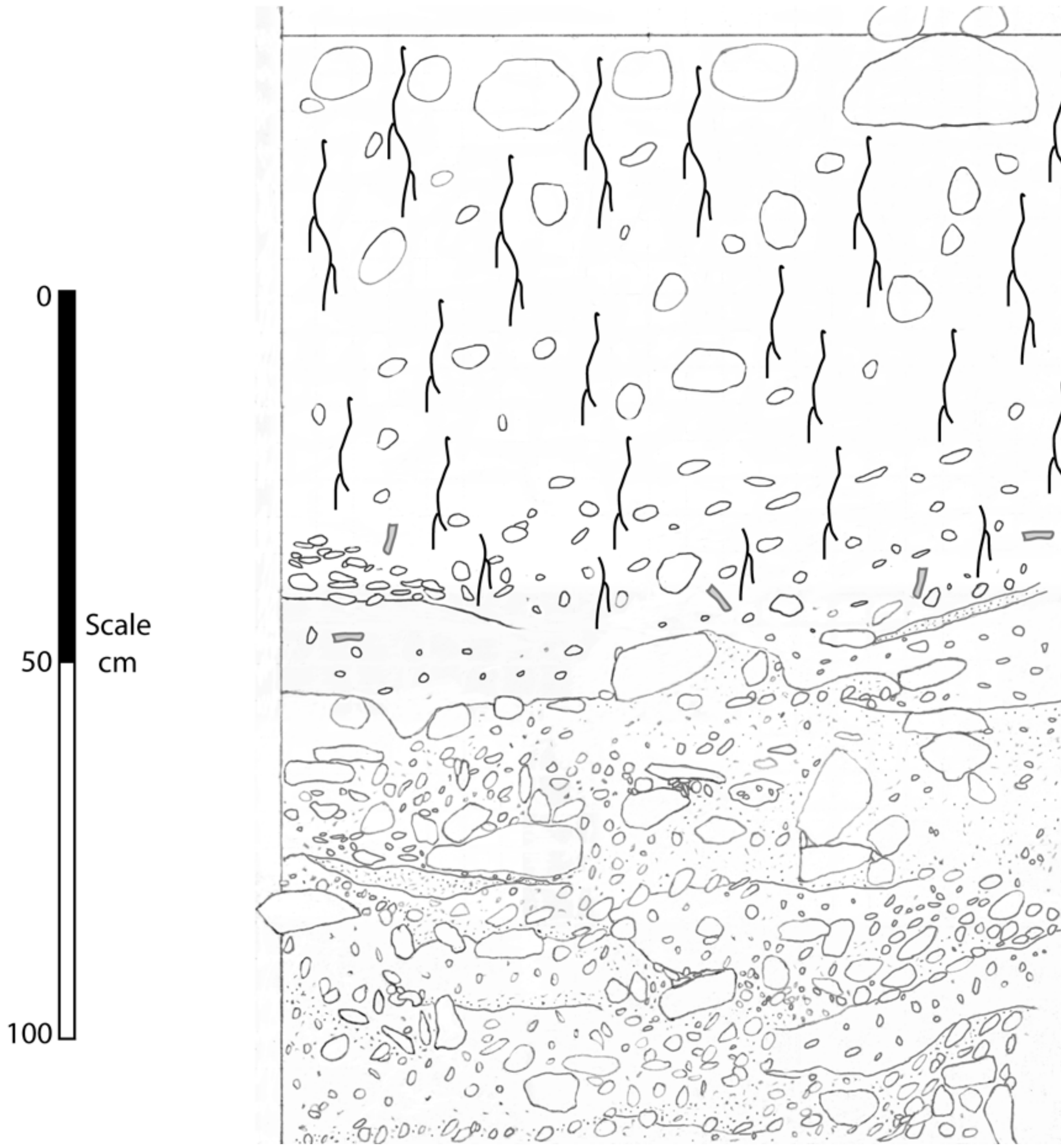

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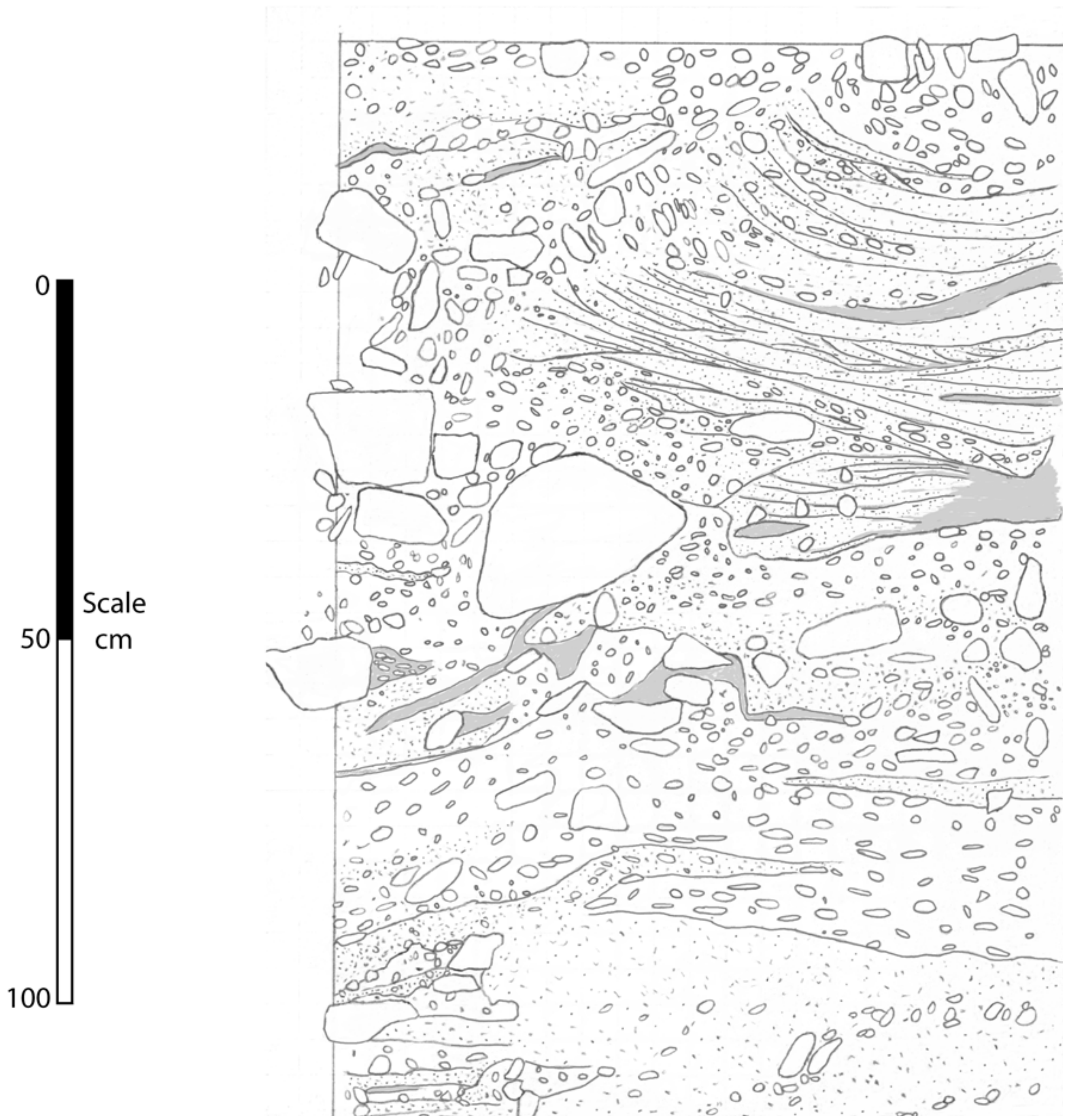

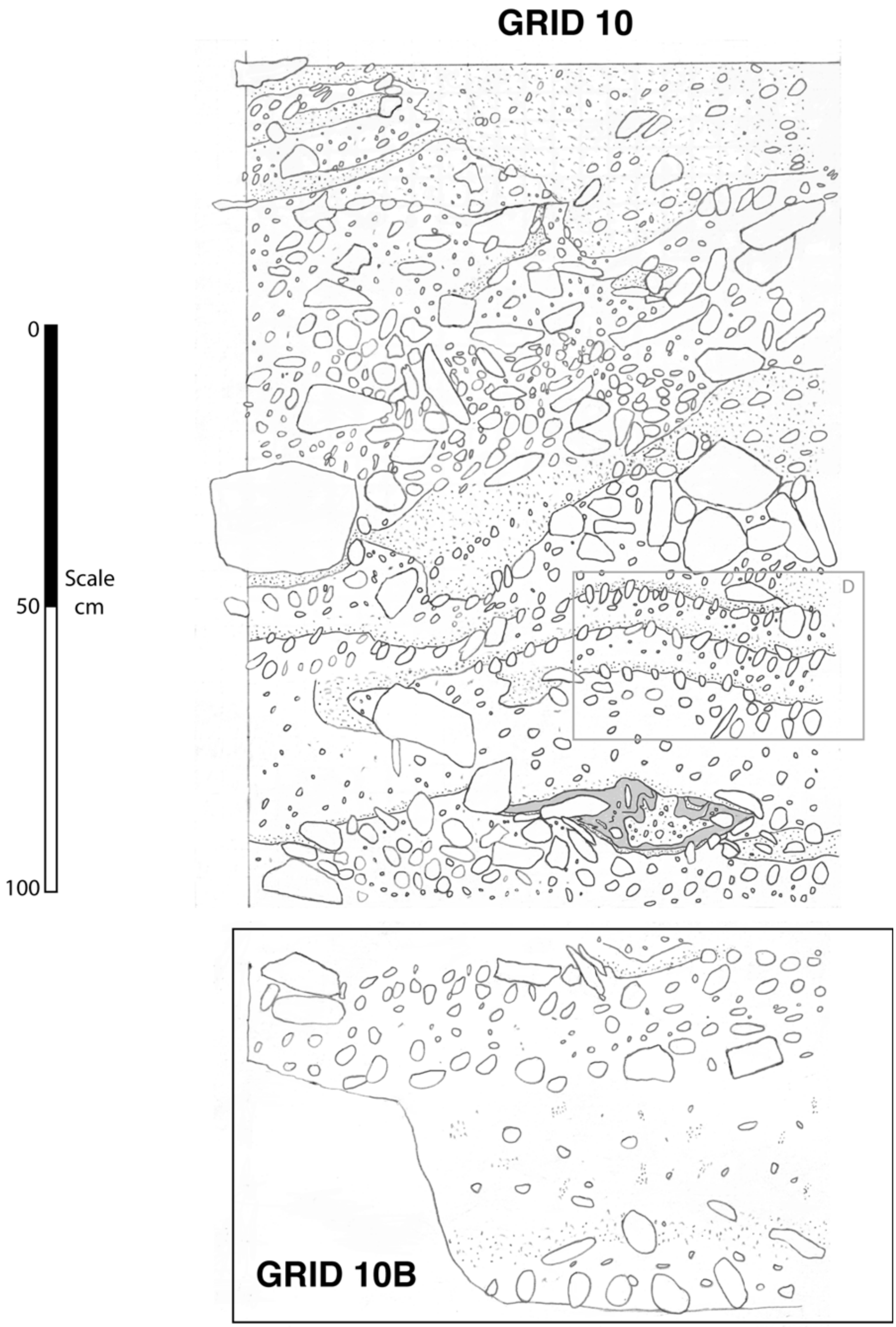
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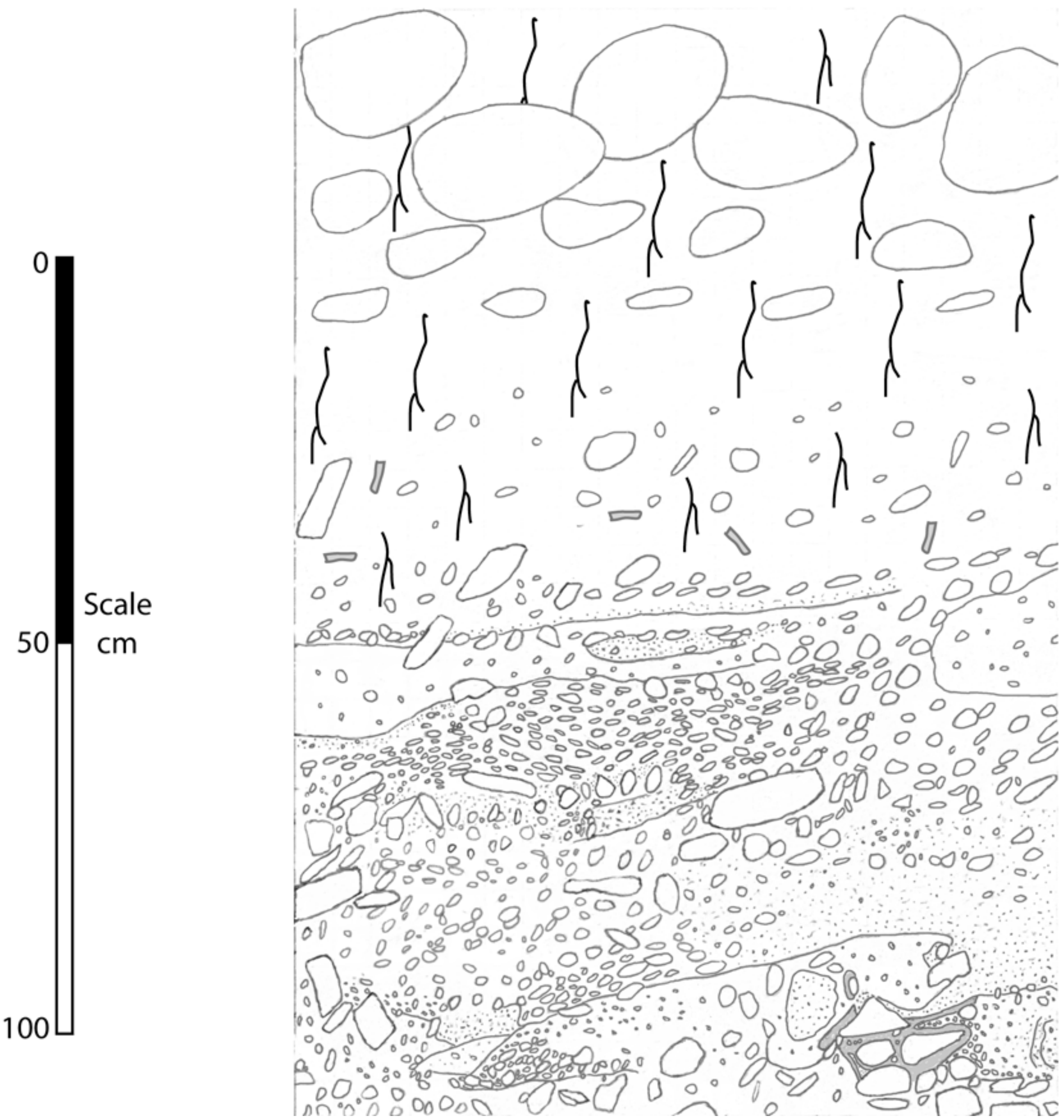

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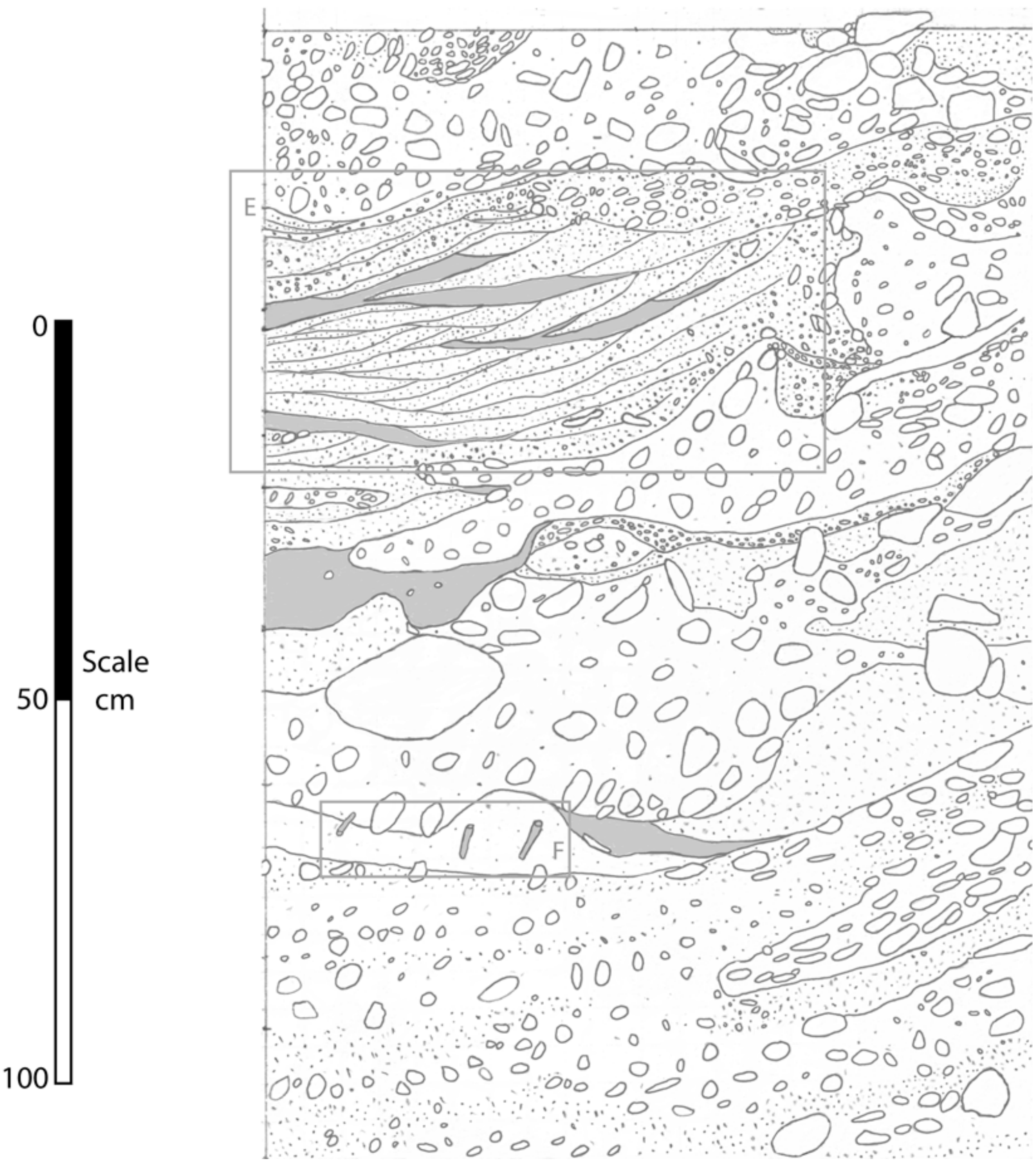

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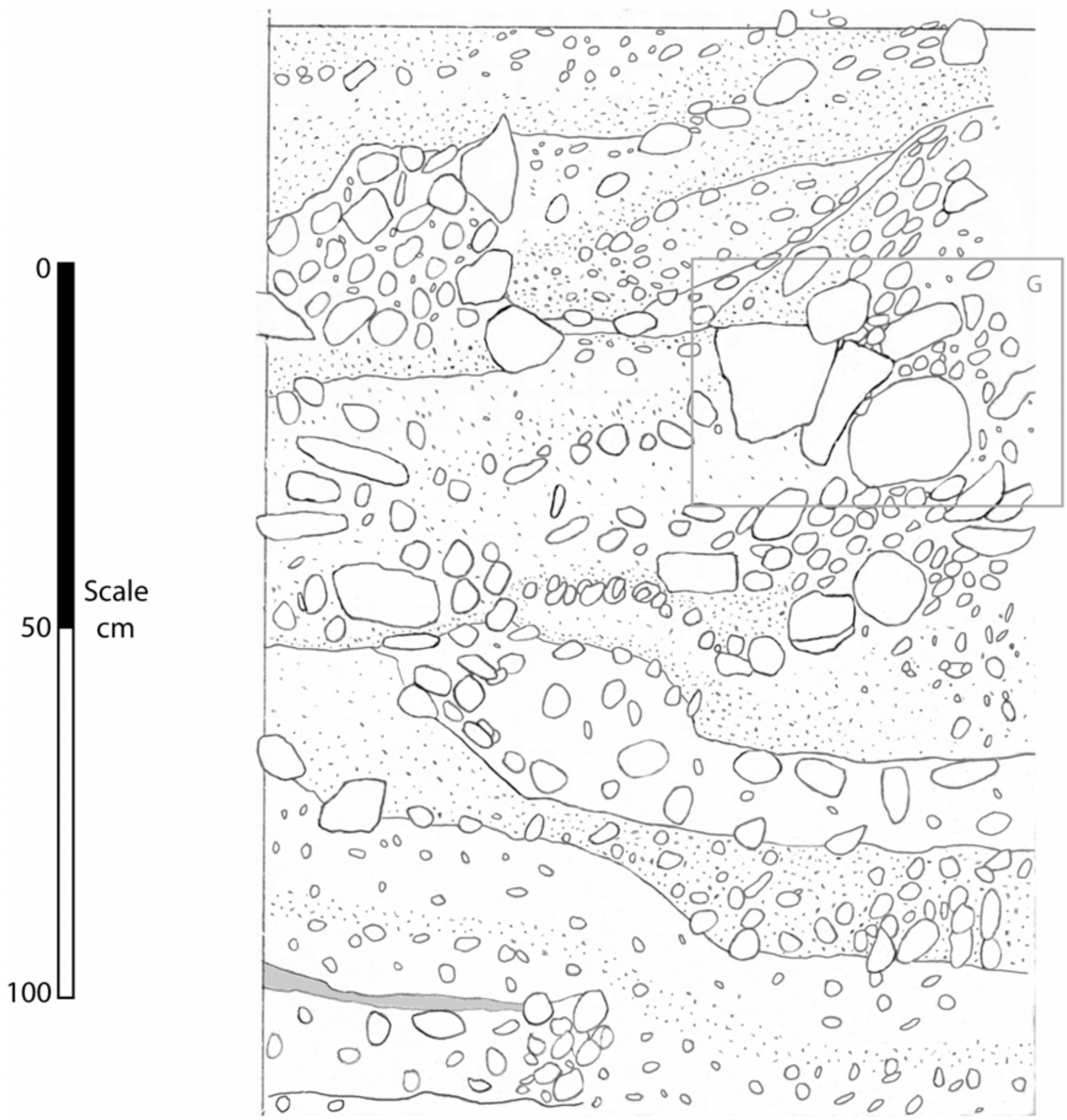

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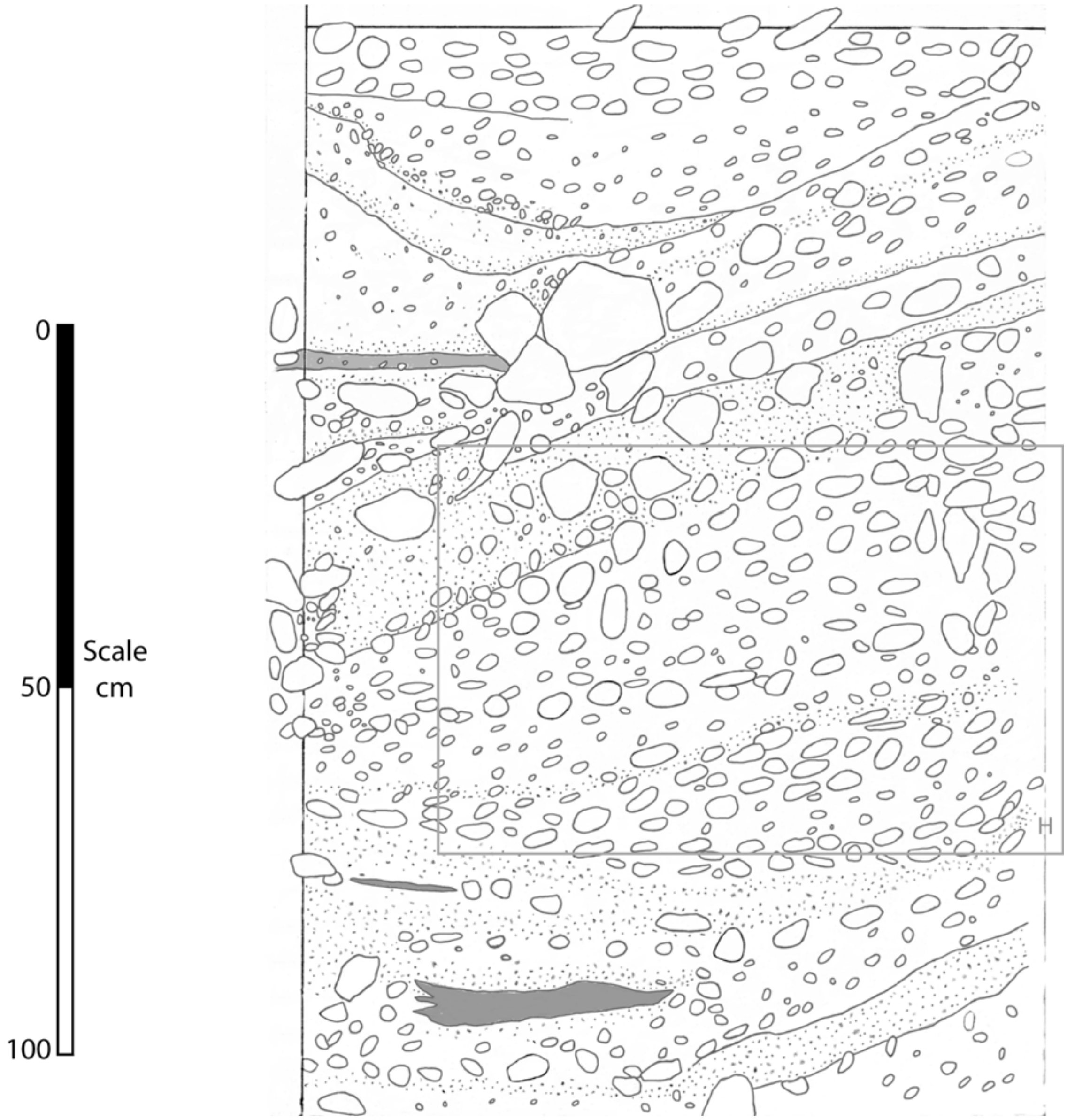

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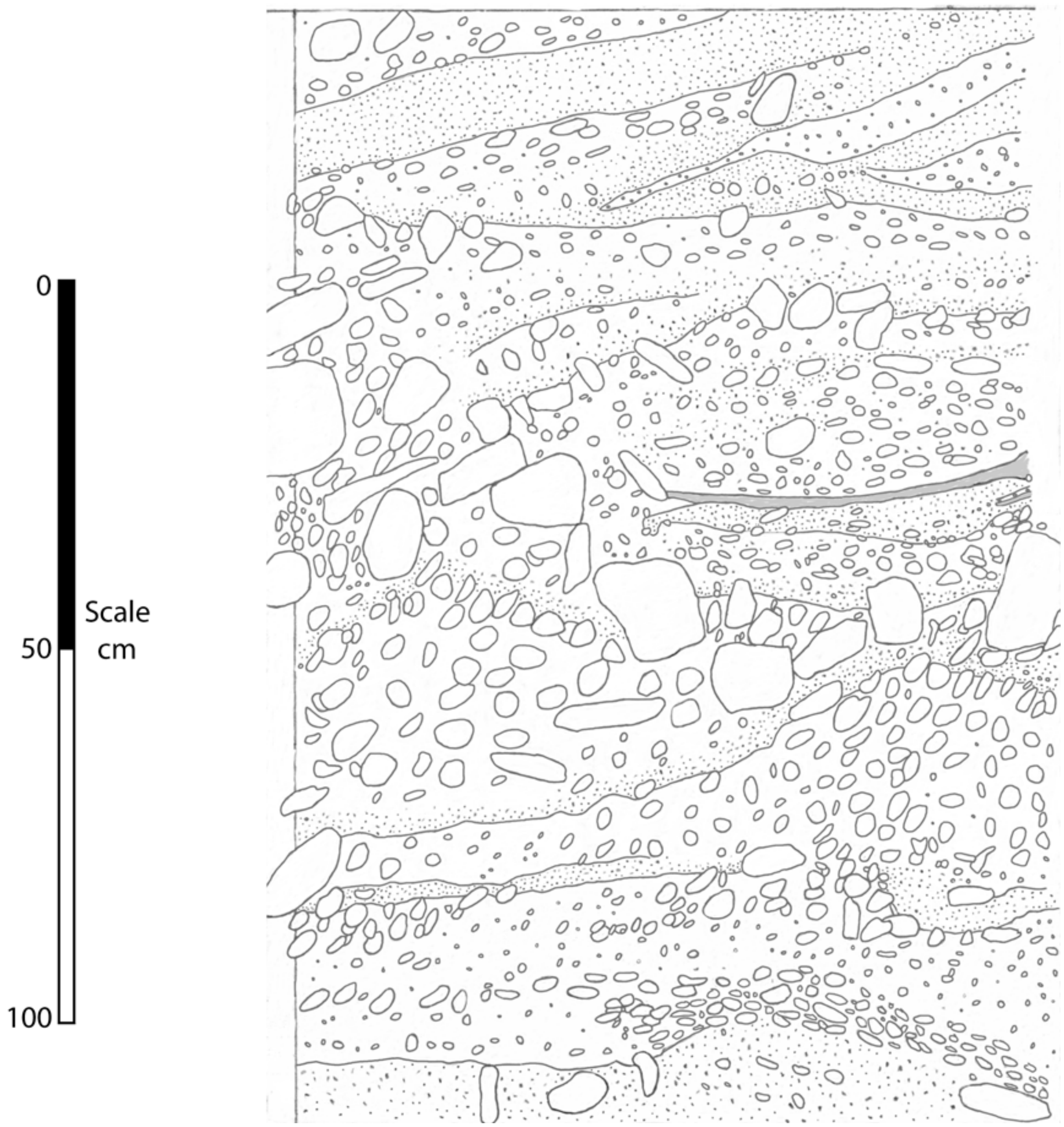

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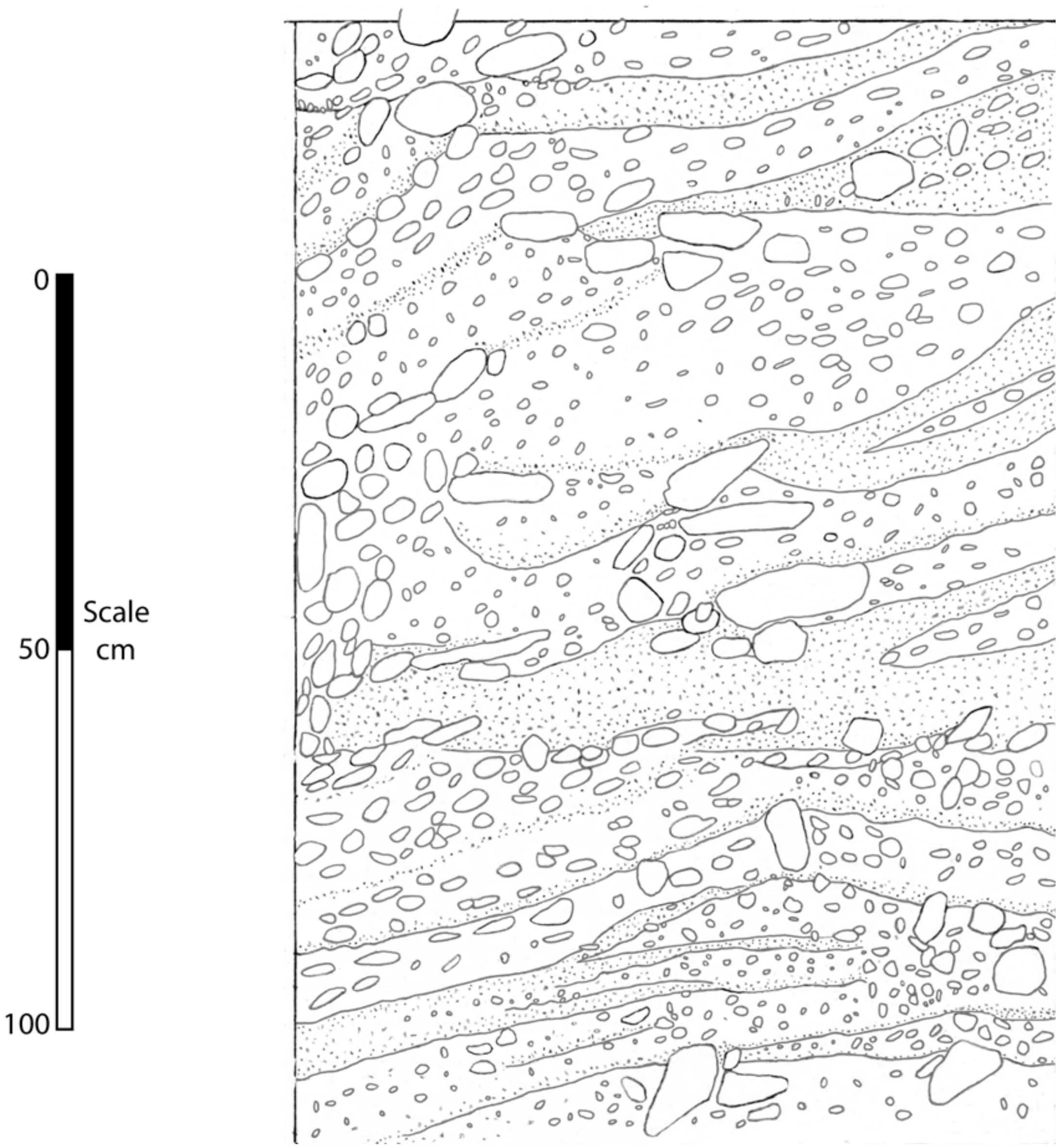

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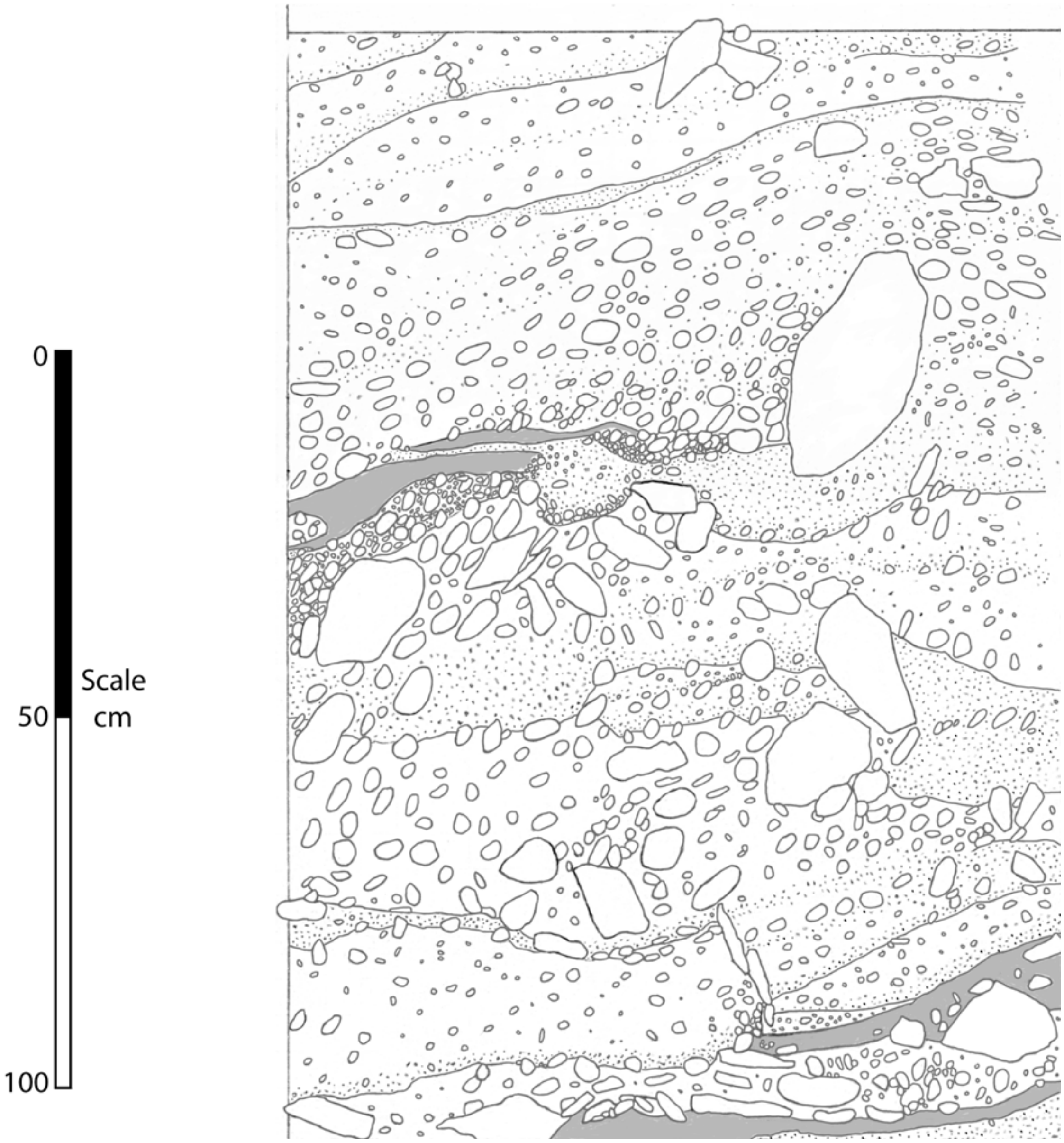

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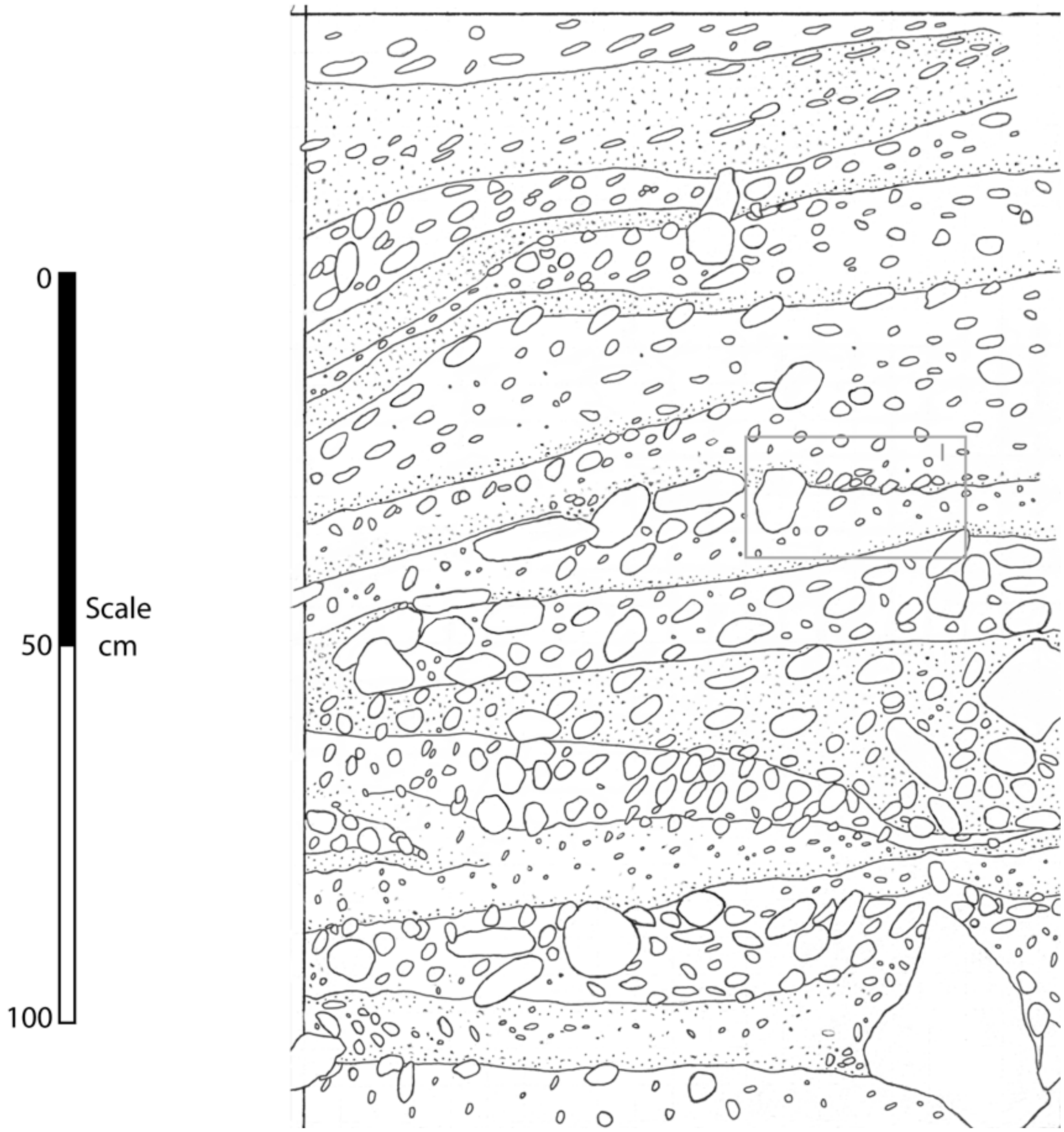

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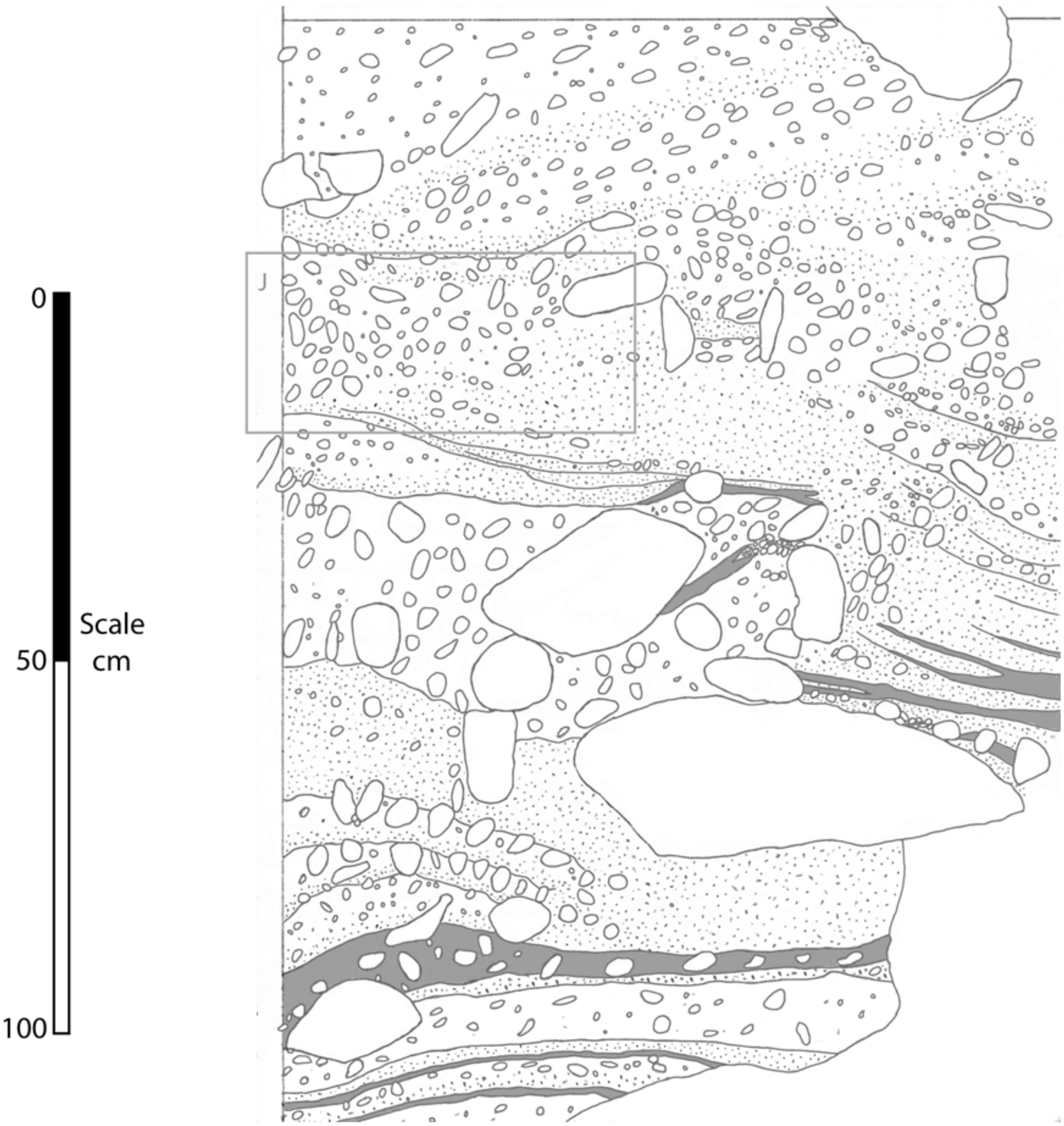

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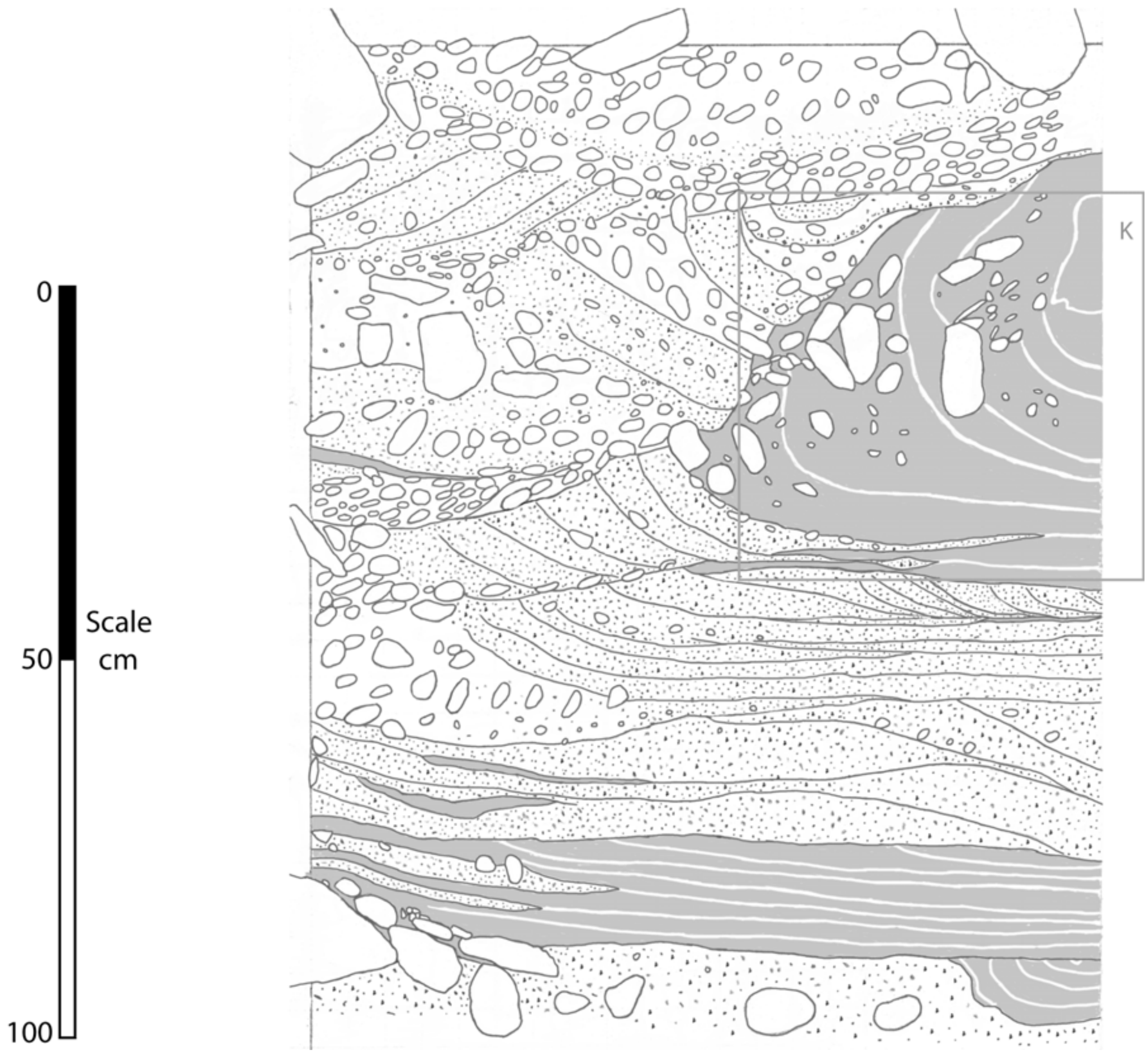

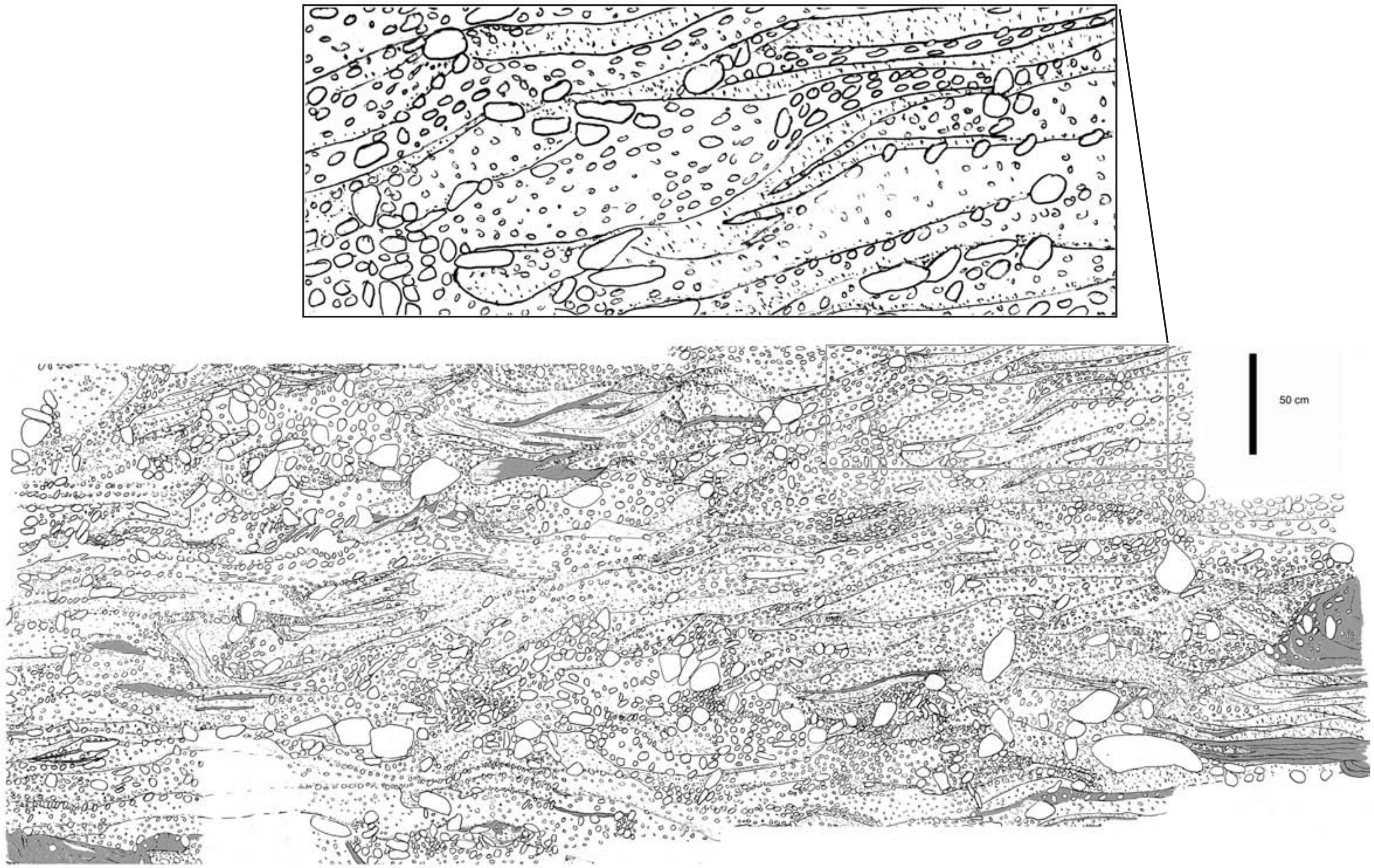

Figure 4. Composite sketch of grids showing large scale fabric of outcrop. Inset is an enlargement of box area showing offlapping wedges that dip right to left.

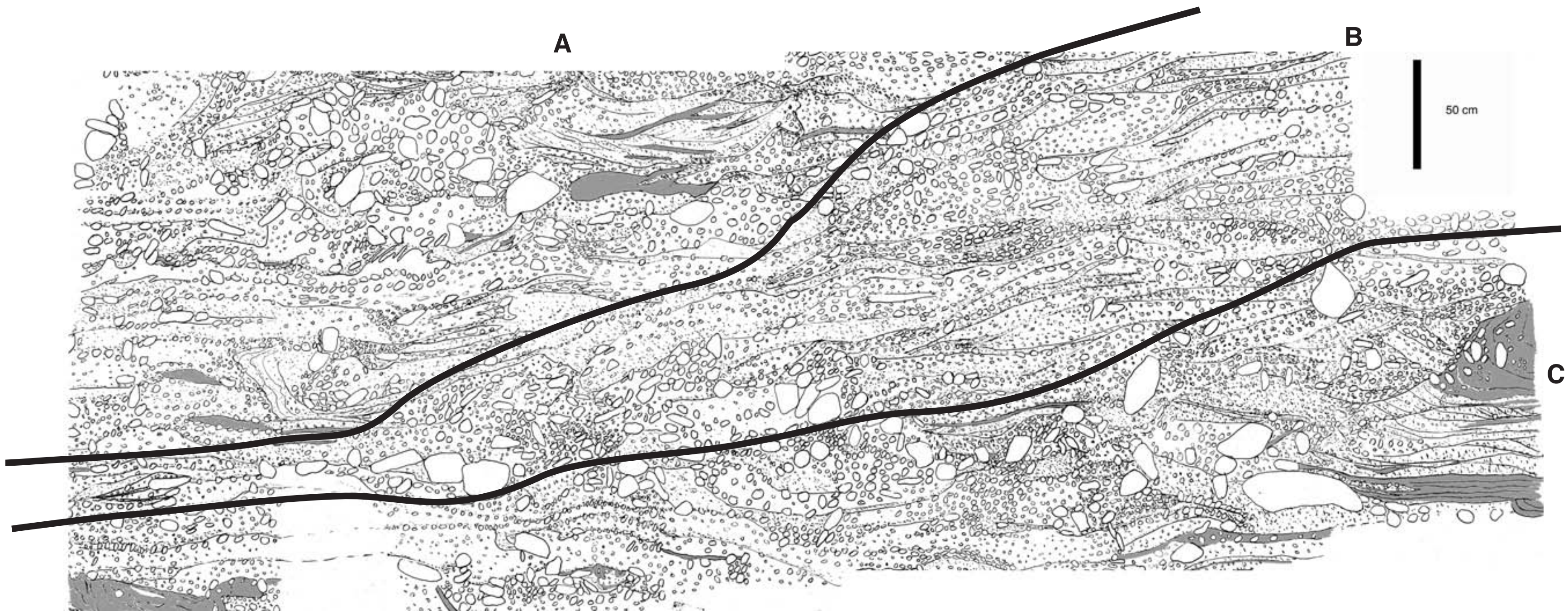

Figure 5. Composite diagram illustrated in Figure 4 with dark lines indicating zones where dip direction of wedges change. Wedges in zones A and C primarily dip out of the plane of view. Wedges in zone B dip from right to left.