Comparison of Soil and Stratigraphy Structures in Similar Landforms at Selected Sites in the Amargosa River Valley, California

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Abstract

Soils and stratigraphy were recorded at selected sites and specific landforms along the Amargosa River near Tecopa, CA. Data were collated to compare sites for similarity of near-surface stratigraphy, as part of a larger study to support runoff modeling of the Amargosa Basin. Studied sites showed little correlation. Data is discussed and suggestions made for possible future study designs that might provide a better comparison of landform structures.

Problem Statement

In much of the Great Basin, extensive research has shown evidence of large scale climate variations during the Holocene and Pleistocene eras. In particular, evidence of long term lake stands has shown repeated development of lakes whose volume can only be accounted for by substantial changes in precipitation (Benson and Thompson, 1987). While many of these lakes formed during the Pleistocene, studies have also shown evidence of shorter duration perennial lake stands well into the late Holocene (Enzel et al, 1992). With the increase in human population in the Great Basin, and the development of permanent habitations in many dry lake basins, a better understanding of the pluvial and fluvial events that could create such lakes has become increasingly important.

The Death Valley, CA area has been the site of a series of lake stands, supported by the inflow of three rivers: the Owens, the Mojave and the Amargosa. All of these drainages are located on the Southern California / Southern Nevada border (Figure One). Of these, the Amargosa represents, in the modern era, the only drainage whose water flow reaches Death Valley. In addition, much of the Amargosa's precipitation derives from the continental climate pattern that affects large areas of the Great Basin. Research has shown that in dry climates such as that of the Amargosa, wet and dry periods can be tracked by studies of stratigraphy and soils development, using techniques such as chronicling changes from loess to sand penetration (Yair, 1990). In such studies, presence and thickness of silt layers indicate the presence of runoff. Loess (fine, wind-borne material) is common in wetter conditions, while sand penetration appears when the climate becomes drier.

Studies of soils and stratigraphy are also needed to support attempts to model basins such as the Amargosa. One area of interest is the response of basins to pluvial events, which are defined as geological episodes related to the effects of rain. Such modeling would create the basis to predict the basin’s response to such events. A knowledge of the structures that are common to the area’s landforms will aid in predicting the runoff characteristics of the drainage. Both the stratigraphic structures and soils affect permeability and infiltration responses of drainage areas. Soils moderate infiltration in complex ways, as do the strata under them, or the strata found in areas where soils are not present. The presence of hydrologically conductive layers, or conversely the presence of impervious layers, as well as their positions relative to the surface, have strong effects on the response of a surface to rainfall. Studies of these conditions can help to provide answers to questions including: what are the responses of the Amargosa drainage basin to various kinds of rainfall events? What effect would long term increases in precipitation have on the flow characteristics of the Amargosa? What changes in precipitation would be needed to produce flows sufficient to create lake stands?

Background Research

The following is a discussion of factors that support and affect this study. The goal of this discussion is to provide the reader with an outline of 1) work that supports or defines techniques used in this study and 2) factors outside the scope of this study that affect any conclusions that may be derived from this research.

Soil Formation as a Measurement Tool

Soil formation is a process that can vary in rate, but typically consumes long periods of time, so that soils can provide a record of slow landform changes occurring over thousands of years. In the investigation of landform changes related to pluvial events, geomorphologists often use studies of particle entrainment and downslope transport over periods of a few years to a few tens of years (McFadden and Knuepfer, 1990). In areas where landform changes are rapid, such studies are effective in providing a measurement of the processes. However, in areas where processes are slow, and particularly in arid areas, transport is often working too slowly to be measured in such a manner (Mc Fadden and Knuepfer, 1990).

For soils to form, the landform they are on must remain stable over long periods of time. The presence or absence of soils, their state of formation or destruction, and their position in a stratigraphic record can provide evidence of landform evolution in areas of slow (10^3 to 10^5 years) landscape change (Baker, 1988). In particular, thickness, texture, clay films and color correlate well in dating landforms (Birkeland et al., 1987).

Accordingly, studies of pluvial and fluvial (river flow) events in arid areas need to consider soils as found in the stratigraphic record.

Soil Development Rates in the Holocene and the Pleistocene

If soils are to be a part of stratigraphic studies, it is important to have an understanding of formation rates, and more importantly, the possibility of variations in formation rates. While it is often believed that physical processes operating in the present were also in operation in the past, it is also possible for the rate of such processes to be affected by climatic and tectonic conditions that were different from those in the present.

Evidence shows that soil formation rates in the Holocene are 10 to 50 times more rapid than in the Pleistocene, with a factor of 10 being the accepted difference in the Great Basin (Harden, 1990).

Also, soil development rates over long periods tend to be exponential or logarithmic, with rates decreasing with time (Birkeland, 1984a). Yet, when viewed on shorter time spans, soil development rates appear linear (Harden,1990). So, when used in chronological studies, it is important to consider the time spans in question. It also needs to be noted that some researchers feel that soil development in arid regions is more linear due to the large effect of eolian processes in the addition of material. In this view, eolian movement of dust is considered to be the limiting factor in development rates. Pedogenesis (soil formation) would be dominated by eolian additions of dust and such additions should be steady over time in a stable, arid climate (Reheis, 1987b, in Harden, 1990).

The Effect of Climatic Conditions on Soil Development Rates

As noted above, soil development rates vary strongly between the Pleistocene and the Holocene. Such variation may be related to differences in general climatic conditions between the two eras. Soil development rates also appear to be affected by climatic differences between different geographic areas within the same era. Moist areas appear to exhibit faster development rates than arid areas, due to the effects of moisture on erosion and mineral dissolution (Harden, 1988). Temperature also affects the rate of soil forming chemical reactions. While these rates do vary, the apparent effect is less than the effects measured between time periods, such as the Pleistocene and the Holocene. Therefore, it is felt that geographic comparisons from area to area are more accurate than temporal comparisons (Harden, 1990).

Eolian Processes, Desert Pavement Formation and Stability of Surfaces in Arid Climates

The formation of desert pavement patterns has been a subject of extensive discussion and curiosity. If such pavements are formed by erosion, and thus brought up from below the landscape, then the clasts that form them would reach the surface at different times. The same situation would apply under a second theory, in which the clasts "swim" to the surface through a fine-grained medium (Anderson, written communication). On the other hand, if formation occurs at the surface, then all clasts would be of the same age (Wells and McFadden, 1995). If the latter process were the case, then pavement development would provide an index of surface stability of an arid landform. This in turn would allow differentiation of relative age of landforms in a given area, based on degree of desert pavement formation.

Cosmogenic He^3 dating has provided good evidence that at least some desert pavement is, in fact, formed at the surface (Wells and McFadden, 1995). It is suggested that several processes may result in pavement-like surfaces, but that these can be differentiated. One process involves sheetflood effects, in which the movement of water over the surface transports fine material from between clasts and leaves the surface of the clasts slightly higher than the material between them, creating a pavement appearance. A second process involves the clasts "swimming" to the surface, as mentioned above. The other process involves the infiltration of eolian dust under the clasts, resulting in vertical lifting, or inflation, that maintains the position of the clasts above the surrounding material.

The processes can be differentiated by the presence or absence of a gravel-free dust layer under the surface clasts, known as an A_v (A vesicular) layer. If such a layer is present, then the pavement formation was by eolian processes.

In desert conditions, pavement surfaces develop a varnish that allows differentiation of age (McFadden et al, 1989). Such surfaces allow some judgement of the stability of landform surfaces in arid climates. The basic measure is that the darker the surface, the older the surface. A lighter varnish would indicate a surface that has not been in place as long. Since development of varnish takes long periods of time, disturbance of the surface changes the orientation of the pavement clasts as they are moved, thereby presenting unvarnished surfaces of the clasts . Also, the development of the underlying A_v layer allows some judgement as to the age of the pavement surface (Anderson, oral communication).

Lake Stands in the Mojave Desert as Evidence of Pleistocene and Holocene Climate Fluctuation

The term “lake stands” refers to the presence of perennial lakes in basins where the lakes may have existed for long periods of time, ceased to exist during dry cycles, and then reappeared, with this cycle possibly repeated a number of times. In these basins, sediment layers provide a record of the presence of lakes. Many of these basins occasionally display ephemeral lakes in the modern era, defined as lakes that may appear for a season following wet winters, then evaporate in the following few months. The creation of these ephemeral lakes provides information on water flows that would have been necessary to create and maintain lake stands in the past(Grasso, 1996).

In 1993, heavy winter runoff formed an ephemeral lake in Badwater Basin, Death Valley, CA. A similar lake had been formed in 1969, 1984 and 1992. Measurements by Grasso (1996) indicated that such lake formation was unlikely to be the result of single flood events, but rather the result of winter-long, above normal river flows. However, the region experiences evaporation rates of about 82 inches per year (Myers, 1962), which would suggest that an extreme change in climate would be necessary to maintain such lakes on rainfall alone.

Pleistocene lake stands in the southern Great Basin and the Mojave have been documented by a number of researchers. These lakes likely received inflow from the Mojave River (Enzel et al., 1992) and possibly from the Owens River (Smith and Street-Perrott, 1983, quoted in Grasso, 1996). These inflows were dependent on overflow from a series of lake basins that were part of the courses of these rivers. When these lakes subsided below the rims of their basins, inflow from these sources ceased. The Mojave probably ceased to flow 12 - 15 ka ago, while the Owens last overflowed into the area about 128 ka ago. When the inflow from the Mojave and the Owens rivers ceased, the Amargosa became the major water source affecting the Death Valley area (Anderson, oral communication). Figure two shows the locations of lake stands that are believed to have occurred in the southern Great Basin and Mojave Desert during the Pleistocene and Holocene eras.

Following the end of Mojave and Owens River inflow, a series of Holocene era neoglaciations have been documented in the western United States and western Canada. Dates for these neoglaciations have varied, but accepted dates indicate one neoglaciation about 4.0 ka, another at about 1.8 - 1.0 ka and a final period around 0.3 - 0.1 ka. (Benedict, 1973). In the geographic area closest to the Amargosa, Enzel (1992) provided evidence of lake stands in the Silver - Soda Lake basins that occured 3.6 and 0.39 ka ago. In the Sierra Nevada, to the northwest of Silver and Soda Lakes, documented glaciations from 3.0 ka (Recess Peak glaciation) and 0.35 ka (Matthes glaciation) approximately correlate with the Silver - Soda Lake lake stands. Enzel (1992) calculated that floods as large as the largest modern Mojave flood may have occurred annually to maintain the Silver and Soda Lakes (Enzel, 1992).

The combination of conditions that could produce lake stands is a matter of ongoing discussion. Enzel (1992) concluded that atmospheric circulation shifts would have caused increased high intensity winter storms sufficient to support desert lake stands, and that increased summer precipitation or decreased summer evaporation would have had only a small effect. On the other hand, Grasso (1996) suggested that maintenance of lakes stands would have required a 50% decrease in summer evaporation. Further, Grasso felt that higher groundwater levels may have also been necessary to support perennial lake stands. Because of the uncertainty of the parameters necessary to create lake stands, better modeling of the runoff capabilities of drainage basins would be of considerable help.

Description of the Drainages of the Amargosa, Mojave and Owens Rivers

In the present era, the Amargosa makes up 66.7% of the Death Valley drainage (Grasso, 1996). The Death Valley area also receives drainage from the Salt Creek basin, which is a complex of ephemeral streams, and from the alluvial fans on both sides of the valley itself. Figure two provides a general schematic of these drainage patterns. As noted earlier, the Mojave and Owens Rivers once also drained into Death Valley, but that input ceased approximately 15 ka ago. Figure three shows a general map of the drainage areas that affect Death Valley.

The sources of precipitation and runoff for each river system are different. Figure one shows the general directions of storm paths that affect the study area. It is felt that the Owens generally received much of its input from snow and glacial melt in the Sierra Nevada mountains. The Mojave is primarily affected by Pacific Ocean storms from the Southeastern Pacific. The Amargosa's input derives largely from a more inland, continental weather pattern (Anderson, oral communication). This would have the effect of making the Amargosa more rapidly responsive to local climate changes, and in turn affect the soils and stratigraphy development of the basin.

Hypothesis

Modeling of a drainage basin should be based on easily measurable parameters. Such measures should be selected so that their presence or absence can be used as a reliable indicator of the response of the basin to specific stimuli. For this study:

n within the geographically contiguous and limited area of the Amargosa River basin, similar landforms should have been acted on by similar pluvial and/or fluvial events. Soil and stratigraphy structures in specific landforms, such as alluvial fans of approximately the same age, and derived from the same parent material, should display similar patterns. In turn, similarities in soil and stratigraphy structures should indicate landforms of similar ages and sources.

n if landforms, and the soils or sediments of their surfaces, are similar, their infiltration and runoff responses to precipitation should be similar.

The data reported in this paper will test the first of the above hypothesis. Data collected by this team and others in the research group, when collated by the principal investigator, will be used to test the second hypothesis.

Procedures

Study sites in the Amargosa Valley had been preselected by the principal investigator. All sites were located on the Amargosa River and ranged geographically from a site about 20 miles north of Tecopa, CA to a site about ten miles south of Tecopa.

At each site, specific landforms were chosen for analysis. In general, sites representing young, intermediate and old alluvial fans were chosen, as well as sites representing river terraces. At some locations, certain landforms were either unavailable or inaccessible and were not studied.

For each study site, the following stratigraphy procedures were carried out:

1. The surface of the area to be studied was cut back using shovels, then cleaned and smoothed with brush and trowel.

2. Strata were identified, marked with small flags and measured for thickness. The prepared site was sketched and photographed.

3. Each layer was analyzed for:

    - percent gravel
    - clast shape
    - structure
    - color
    - texture
    - boundary type between layers
    - maximum clast size

Where soils were present, the above measurements were taken, as well as:

- horizon thickness and type
- consistency (hard, loose, etc.)
- presence of clay films
- roots / coarse organic material
- pores
- presence of carbonate deposits

Since this was a primarily qualitative study, no statistical analysis of the data was attempted. Comparative illustrations of the strata are attached to this paper.

Results

Comparisons of stratigraphy showed some basic similarities, but few strong patterns. Clasts at all sites were classified as subangular, and general repeated patterns of alternating sand, silt and gravel were seen. Below are specific comments as they relate to landform categories. Stratigraphy drawings for each category of landform are appended to this paper.

Old Alluvial Fans (Qfo)

Each studied site generally contained few similarities. Site 3 showed some soils development and site 5 contained evidence of surface pavement that had been buried. All clasts were subangular and larger clasts were observed distributed throughout the layers. Otherwise, very little correlation existed among the sites.

Intermediate Alluvial Fan (Qfi)

Only one good study was done. The study is included here for comparison to information recorded from other landforms. These strata had less clasts and more loam than was general for other sites, but the results may have been affected by the parent material of the site.

Young Alluvial Fan (Qfy)

The young alluvial fan sites showed some correlation. With the exception of site 3, all showed a predominance of larger clasts in the upper strata. The common texture in the strata was sand with some silty sand. Site 3 and 5 were similar in that they displayed numerous narrow layers in their structure.

Terrace

Terrace structures showed little correlation except that the texture of most layers was silty sand. Site 4, however, consisted of silty clay.

Soils Structures

Few soil layers were found at the sites studied. The stratigraphy drawings appended to this paper include schematics of soil layers at sites where they existed. In general, all soils were poorly or partially developed. The soils displayed A and B layers of varying consistency.

The data from this study displayed few correlations in stratigraphic sequence. Some similarities were found in soil texture and clast distribution. Clast shapes were similar in most strata.

Discussion

While this study showed few correlations, it should not be concluded that stratigraphic similarities do not exist among similar landforms in the Amargosa. This study was preliminary in nature, and did not take into account such factors as hillslope (angle), geographic orientation (i.e., compass direction), size of drainage area above the structures studied, or the nature and source of the parent material making up the structures.

By way of illustration, alluvial fans of different angle might be expected to experience different flow speeds during runoff events, and therefore different levels of particle entrainment and deposition. Fan structures angled at different compass headings might also be affected in different ways by prevailing storm winds. Obviously, availability of runoff (size of drainage area above the structure) would affect rapidity of material movement. Finally, the physical characteristics of parent material will affect the formation of soils, silt, clay, sand and clast sizes within the structures studied. At least two study sites included ancient lake bottom sediments that strongly affected the texture and color of study sites.

Conclusions

Mild correlations between structures were found, but correlation did not appear strong enough that this study could be used to predict responses to pluvial or fluvial events with any accuracy. The study did provide an insight to the nature of soils and sedimentology variation in the area, and revealed the common presence of subangular clasts through the area. As such it served to familiarize the research team with common layers and soils of that part of the Amargosa drainage. When combined with permeability studies done by other teams in the project, the data recorded by this team may allow some insights into the permeability results.

Recommendations for Future Work

A further study that might clarify this situation would be a more intense comparison of two or more similar-age structures within the drainage of the Amargosa. In a study of this type, a landform, such as young or old alluvial fans, would be selected as a sole subject. Based on maps and photographs of the drainage, a set of fans with similar orientation, size and drainage sources would be selected. Each fan would then be examined on the ground and fans without similar hillslope angles and parent material would be eliminated from the study.

The remaining fans in the study would then be examined at multiple sites to record soils and stratigraphy structures. Data would need to be compared two ways. First, internal comparisons within each studied fan would provide an index of consistency within the structure. Second, comparisons between structures, and particularly internally consistent structures, would allow a better conclusion about predictability of the structural nature of landforms. If such structural comparisons were shown to be predictable, modeling of drainage basins would become simpler.

Procedurally, few problems occurred in this study. All equipment worked well. In some cases, soil faces were difficult to access and some structures presented problems in cutting them back with shovels so that they could be studied. Studies done during a wetter and cooler time of the year might be more easily carried out.

References

Arkley, R.J., 1962, Calculation of carbonate and water movement in soil from climatic data: Soil Science, vol. 96, p. 239-248.

Baker, V.R., 1988, Geological fluvial geomorphology: Geol. Soc. Am. Bull., vol.100, p. 1157-1167.

Benedict, J.B., 1973, Chronology of cirque glaciation, Colorado Front Range: Quaternary Research, vol. 3, no. 4, p. 584-589.

Benson, L.V. and Thompson, R.S., 1987, The physical record of lakes in the Great Basin. *In* “North America and adjacent oceans during the last deglaciation” (W.F. Ruddiman, and H.E. Wright, Jr., eds.). P. 241-260. Geological Society of America, Boulder, CO.

Birkeland, P.W. 1984a, Holocene soil chronofunctions, southern Alps, New Zealand, Geoderma, vol. 34, p.115-134.

Birkeland, P.W., *et al.*, 1987, Holocene alpine soils in gneissic cirque deposits. Colorado Front Range. U.S. Geologic Survey Bulletin 1590-E.

Enzel, Y. *et al.*, 1992, Short-duration Holocene lakes in the Mojave river drainage, southern California, Quaternary Research, vol. 38, p. 60-73.

Enzel, Y., 1992, Flood frequency of the Mojave River and the formation of late Holocene playa lakes, southern California, Holocene, vol. 2, no. 1, p. 11-18.

Grasso, D.N., 1996, Hydrology of modern and late Holocene lakes, Death Valley, CA, U.S. Geological Survey Water Resources Investigation Report 95-4237.

Harden, J.W., 1988, Genetic interpretations of elemental and chemical differences in a soil chronosequence, California, Geoderma, vol. 43, p. 179-193.

Harden, J.W., 1990, Soil development on stable landformsand implications for landscape studies, Geomorphology, vol. 3, p. 391-398.

McFadden, L.D., *et al.*, 1989, Use of multiparameter relative-age methods for age-determination and correlation of alluvial -fan surfaces on a desert piedmont, eastern Mojave Desert, CA, Quaternary Research, vol. 32, p. 276-290.

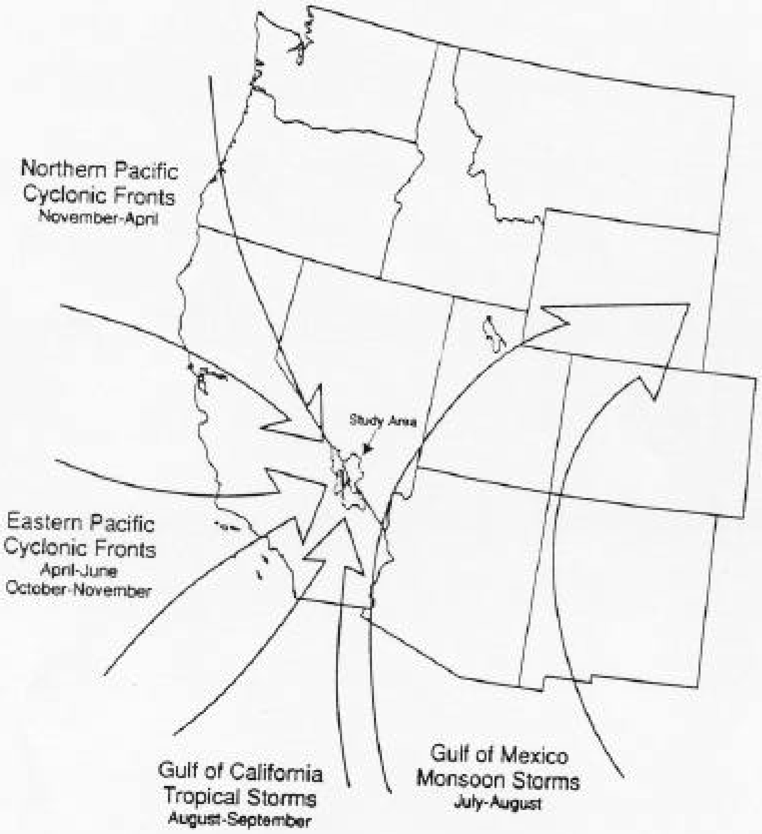
McFadden, L.D. and Knuepfer, L.K., 1990, Soil Geomorphology: the linkage of pedology and surficial processes, Geomorphology, vol. 3, p. 197-205.

Meyers. J.S., 1962, Evaporation from the 17 Western States, U.S. Geological Survey Professional Paper 272-D, p. 71-80.

Wells, S.G. and McFadden, L.D., 1995, Cosmogenic He^3 surface-exposure dating of stone pavements: inplications for landscape evolution in deserts, Geology, vol. 23, p. 613-616.

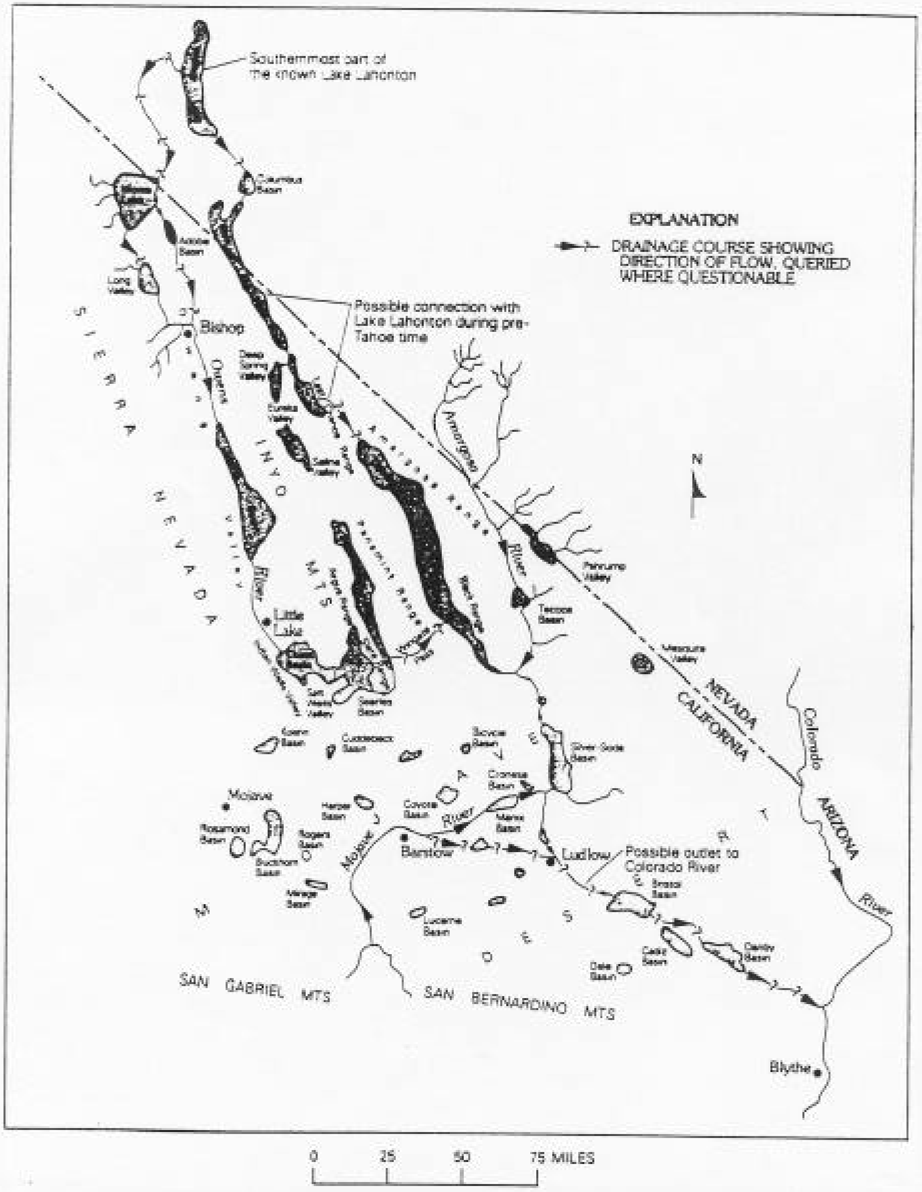
Yair, A., 1990, The role of topography and surface cover upon soil formation along hilltops in arid climates, Geomorphology, vol. 3, p. 287-299.

Figure One



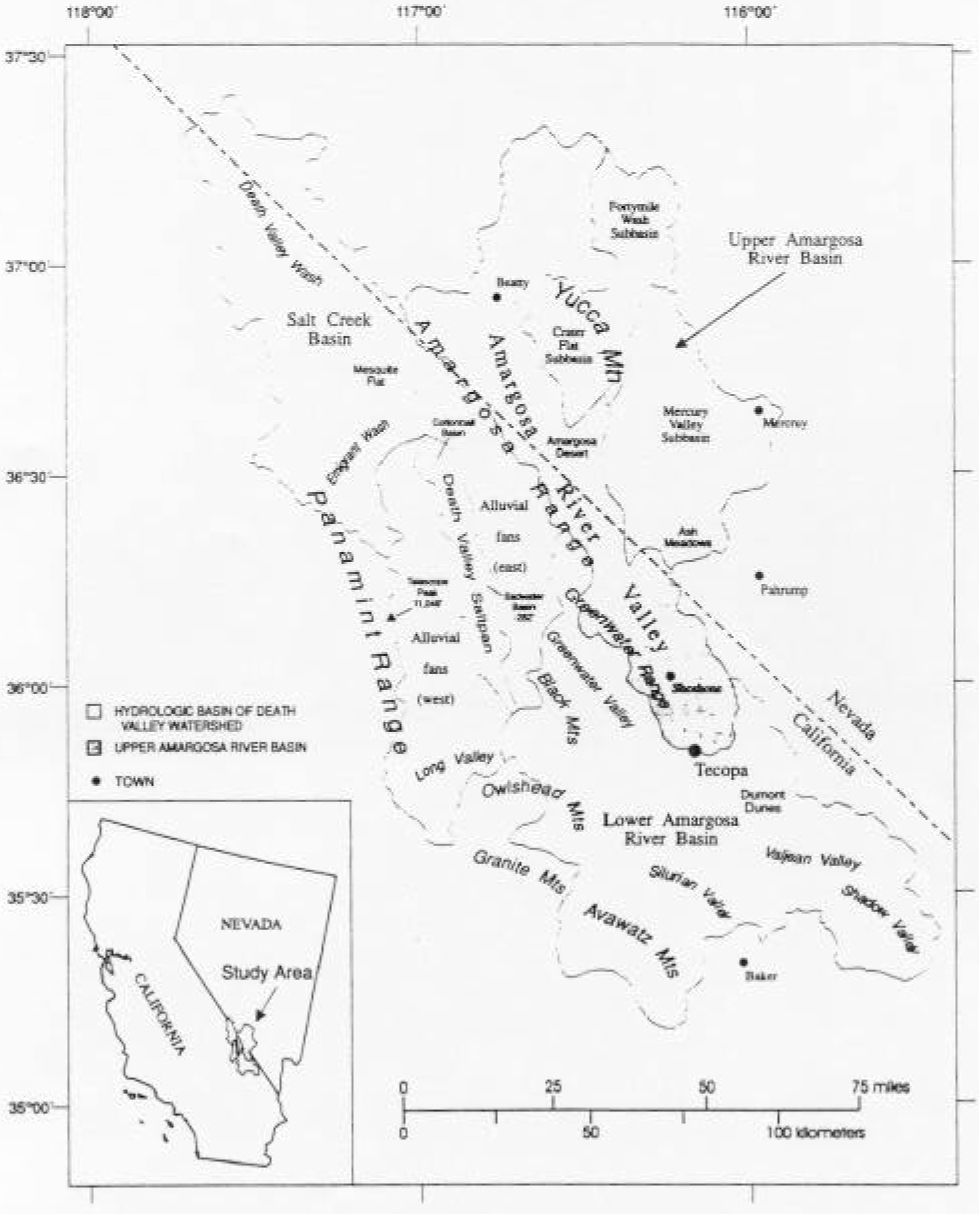
Map of the western United States showing the general study area and directions of prevailing modern-day storm paths. (Adapted from Grasso, 1996)

Figure Two



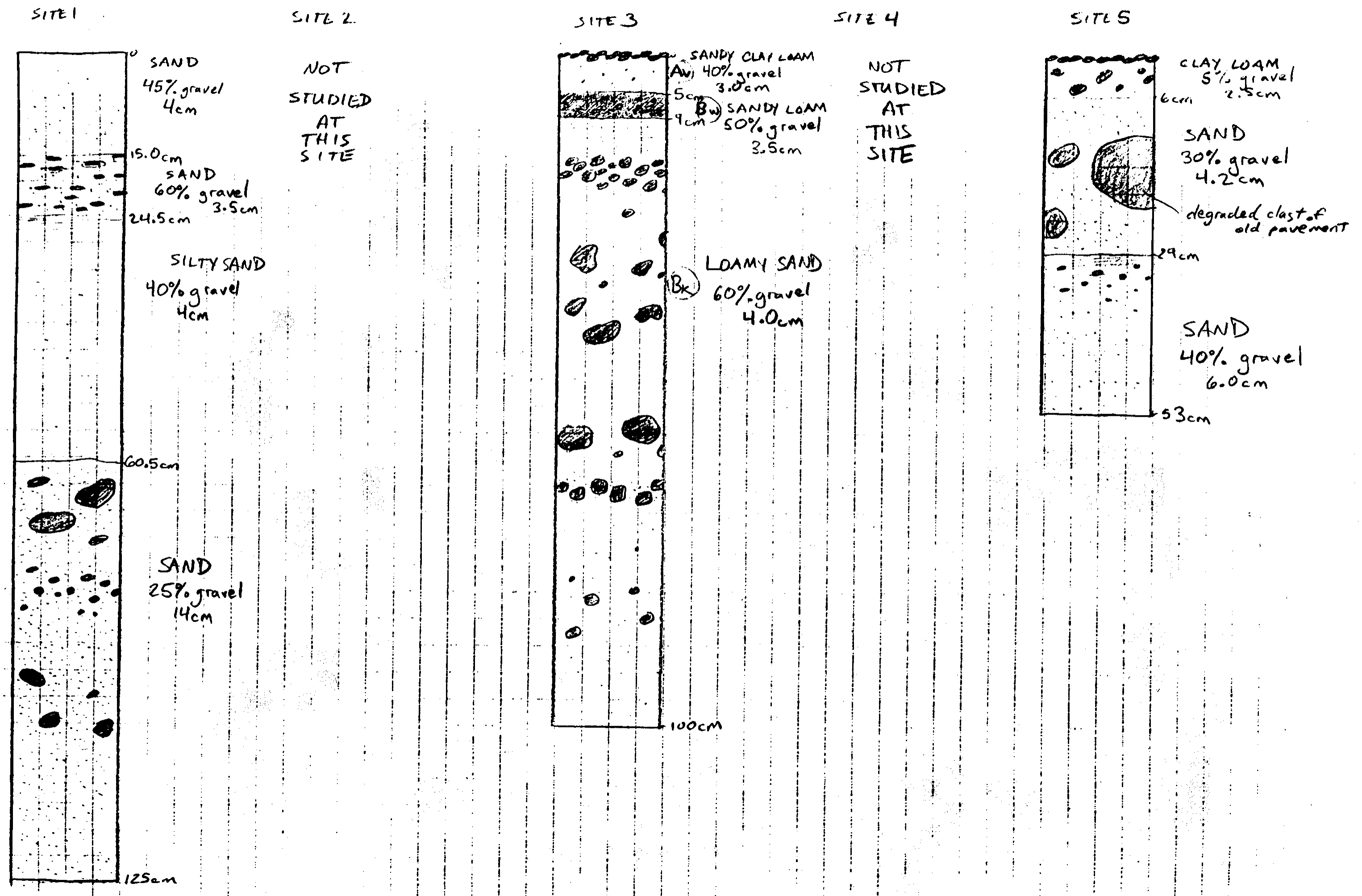
Approximate locations of late Pleistocene lakes in the southern Great Basin and the Mojave Desert. Possible river channels and connections are indicated as lines with arrows indicating direction of flow (Adapted from Grasso, 1996)

Figure Three



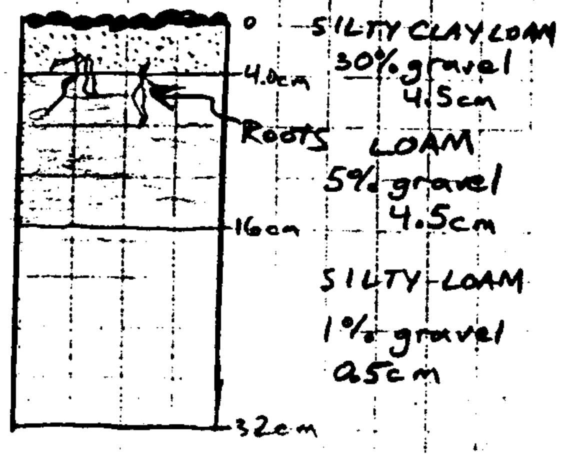
Map of the major drainage basins affecting Death Valley.
(Adapted from Grasso, 1996)

OLD ALLUVIAL FAN

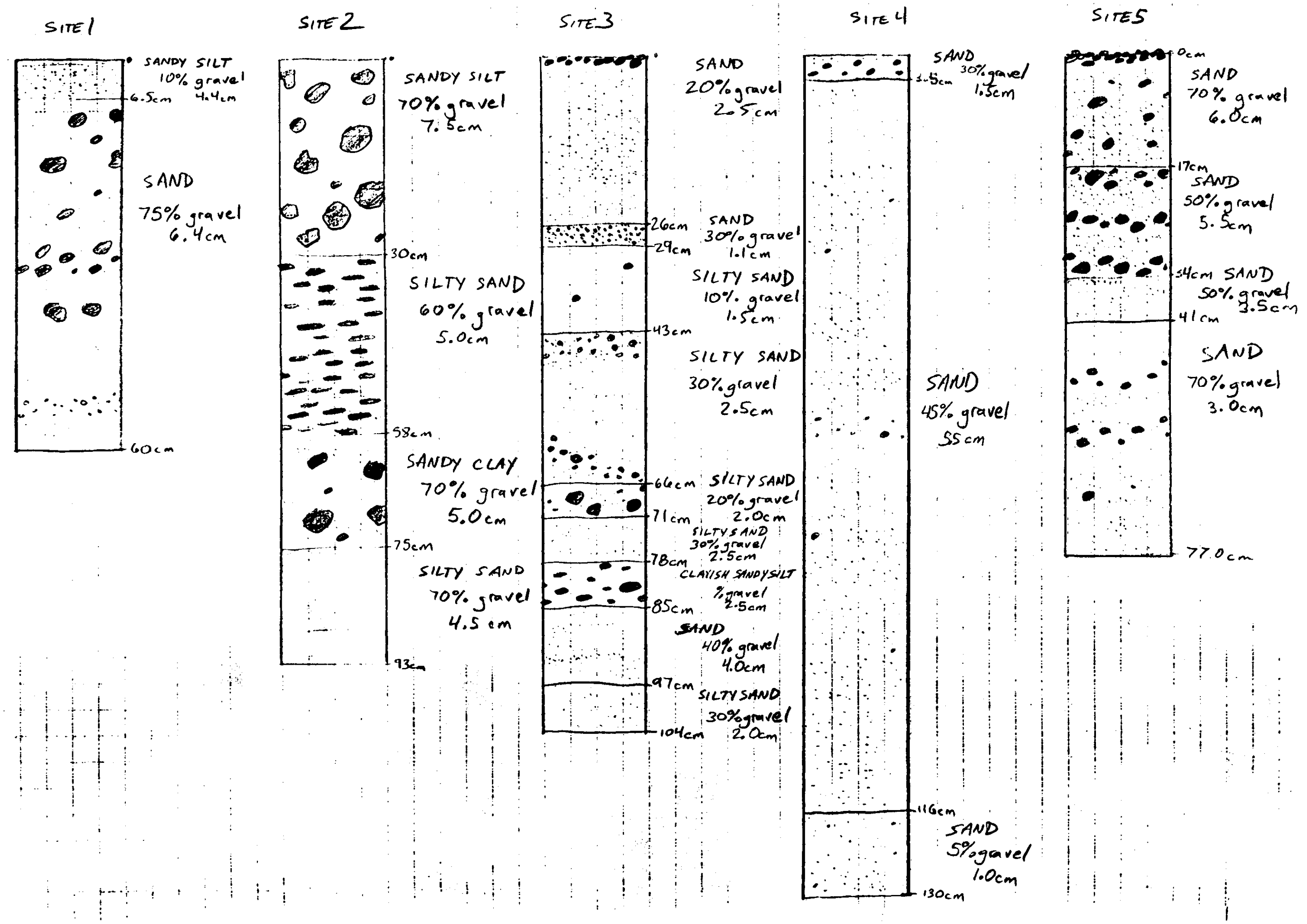


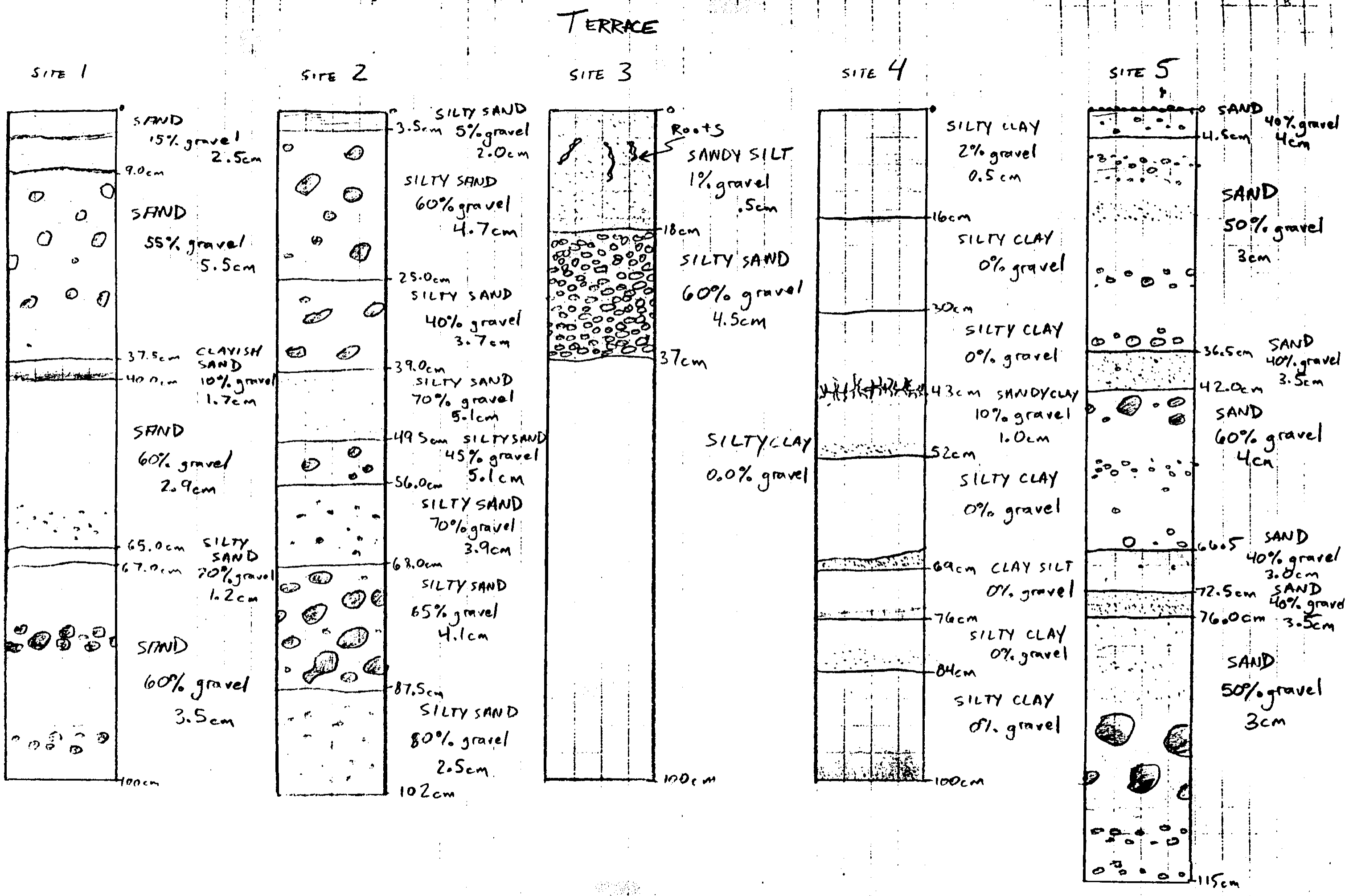
INTERMEDIATE ALLUVIAL FAN

SITE 5



YOUNG ALLUVIAL FAN




TERRACE
SITE 1
SAND 15% gravel 2.5cm
9.0cm
SAND 55% gravel 5.5cm
37.5cm
CLAYISH SAND 10% gravel 1.7cm
40.0cm
SAND 60% gravel 2.9cm
65.0cm
SILTY SAND 70% gravel 1.2cm
67.0cm
SAND 60% gravel 3.5cm
100cm
SITE 2
0
SILTY SAND 5% gravel 2.0cm
3.5cm
SILTY SAND 60% gravel 4.7cm
25.0cm
SILTY SAND 40% gravel 3.7cm
39.0cm
SILTY SAND 70% gravel 5.1cm
49.5cm
SILTY SAND 45% gravel 5.1cm
56.0cm
SILTY SAND 70% gravel 3.9cm
68.0cm
SILTY SAND 65% gravel 4.1cm
87.5cm
SILTY SAND 80% gravel 2.5cm
102cm
SITE 3
0
Roots
SANDY SILT 1% gravel .5cm
18cm
SILTY SAND 60% gravel 4.5cm
37cm
SILTY CLAY 0.0% gravel
100cm
SITE 4
SILTY CLAY 2% gravel 0.5cm
16cm
SILTY CLAY 0% gravel
30cm
SILTY CLAY 0% gravel
43cm
SANDY CLAY 10% gravel 1.0cm
52cm
SILTY CLAY 0% gravel
69cm
CLAY SILT 0% gravel
76cm
SILTY CLAY 0% gravel
84cm
SILTY CLAY 0% gravel
100cm
SITE 5
0
SAND 40% gravel 4cm
4.5cm
SAND 50% gravel 3cm
36.5cm
SAND 40% gravel 3.5cm
42.0cm
SAND 60% gravel 4cm
66.5
SAND 40% gravel 3.0cm
72.5cm
SAND 40% gravel 3.5cm
76.0cm
SAND 50% gravel 3cm
115cm