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CORRELATION OF ALLUVIAL DEPOSITS AT THE NEVADA TEST SITE

Brian Grothaus
Nancy Howard

MASTER

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LAWRENCE
LIVERMORE
LABORATORY

University of California/Livermore

LAWRENCE LIVERMORE LABORATORY

University of California, Livermore, California, 94550

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***Present address: University of South Carolina, Columbia, SC.**

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CORRELATION OF ALLUVIAL DEPOSITS AT THE NEVADA TEST SITE

ABSTRACT

Because characteristics of rock layers and problems in drilling must be studied before radioactive waste can be safely contained, an evaluation was made of methods for correlating alluvial deposits at Yucca Flat of the Nevada Test Site (NTS). Although correlation of Tertiary volcanic tuff beds at the NTS has been successfully achieved, correlation of stratigraphic zones in the overlying alluvium has posed technical difficulties. We have evaluated several methods for correlating alluvial deposits from drillholes, including electric resistivity logs (E logs), visual examination of sidewall samples and comparison of their carbonate (CO_2) content, downhole stereo photography for identifying debris flow deposits, caliche age-dating, and specific yield and permeability measurements of deposits. For predicting the thickness of zones having similar physical properties in the alluvium, E log measurements were found to be the most useful of these methods.

INTRODUCTION

The late Tertiary and Quaternary colluvial and alluvial deposits at the Nevada Test Site (NTS) consist predominately of waterlaid sands and gravels with occasional debris-flow deposits. The alluvial deposits in this area are comprised of mainly Tertiary volcanic tuffs and Paleozoic and Precambrian clastics and carbonates.

A major task of persons responsible for the containment of radioactivity from underground nuclear explosions at the NTS has been to correlate stratigraphic zones in the alluvium that possess similar physical properties (e.g., CO_2 content). This is done so that the physical-chemical characteristics of rock layers can be predicted. In turn, more accurate forecasting of potential drilling problems will be possible at proposed sites. A knowledge of the alluvial stratigraphy and its correlation will also

help us to better understand the geologic history of Yucca Flat.

Correlation of the overlying alluvium in the northern part of Yucca Flat has posed considerable technical difficulties. In this study, we have reviewed the applicability of resistivity log data for correlating zones of alluvial deposits, and explored the potential of other methods of correlation, some of which have been successfully used by others elsewhere. For this project, we studied Area 2 of the NTS (Fig. 1). It lies in the north-central portion of Yucca Flat, and is bordered on the east by Yucca fault and on the west by the Carpetbag fault. West of the Carpetbag fault is a north-south subsurface ridge of Paleozoic rocks covered by less than 250 ft of alluvium in some places (Fig. 2).¹ We obtained our data from the deposits in holes drilled east of this ridge where the alluvium abruptly thickens.

METHODS

A wide variety of data were used for correlating alluvial deposits: electric resistivity logs (E logs), gamma-gamma density logs, lithologic descriptions

from sidewall samples and downhole photos, and CO_2 analyses from sidewall samples. The best results were obtained by examining both electric

Fig. 1. Location of Area 2 near Yucca Flat of the Nevada Test Site showing the three cross sections studied by authors. Numbers around the map are Nevada coordinates.

logs and sidewall photos. Unfortunately, the investigation was limited to the few holes where alluvial resistivity was logged and to the scattered depth intervals from which sidewall photos were taken.

Correlation of Alluvial Layers With Resistivity Logs

Examination of Electric Logs and Sidewall Samples

In correlating the alluvial stratigraphy at NTS, our best results were achieved with E logs. The logs used were plotted with a 5-ft smoothing interval,

and were correlated chiefly by a "best fit" method. This method is an overall comparison of one log to another by sliding it to meet the other until the best fit for the resistivity curves is achieved. The alluvium surface and the tuff-alluvium contact were the only real datum planes that could be used because there are no distinctive continuous marker horizons within the alluvium itself. Nevertheless, the curves do match up well in many cases. The problem, however, is in understanding what these traceable zones of matching resistivity actually indicate.

In working with E logs from oil and coal fields, there is usually no major problem in identifying the rock types (sands, shales, carbonates) before correlating them. Subsequently, when correlating the data, one can envision how the stratigraphic profile should look on the basis of paleoenvironmental models, and a more accurate picture of the subsurface can therefore be made. At the NTS, we are not working with well-defined rock types, but rather an agglomeration of volcanic, nonvolcanic clastic, and carbonate fragments. On E log traces, it is therefore difficult to know the lithologic differences between peaks even though they can often be traced from one hole to another. One should therefore construct lithologic models from such correlations with caution.

Originally, it was thought that the problem of correlating predominant layers could simply be solved by making preliminary correlations with the E logs and then examining the sidewall samples to determine the actual causes of the zones with comparable resistivity. It was hoped that carbonate pebble layers, silty zones, and other distinct layers would show unique resistivity signatures, and once these were established, the units could then be recognized simply by analyzing the E logs. After examining a large number of samples, this was found not to be true. If there are distinct changes in the lithology where these kicks occur, they are not readily distinguishable by visual analysis of the sidewall samples. Possibly, x-ray diffraction analysis would show imperceptible mineralogical differences.

There are several explanations for this apparently poor correlation between resistivity curves and samples. Rather than distinct changes in rock type, the E logs may be primarily affected by diagenetic effects such as varying degrees of clay alteration or zeolitization of the tuff fragments. A marked response of resistivity logs to the degree of alteration has been demonstrated in the underlying tuff. Perhaps the dominant factor governing the resistivity of alluvium is its proportion of tuff and,

Fig. 2. A three-dimensional diagram of the northern portion of Yucca Flat showing major faults and rock layers. Insert shows horizontal section of B-B' cross section.

more importantly, the percentage of altered vs unaltered tuff. Limited examination of samples with a binocular microscope has not confirmed this. If the amount of tuff does contribute to alluvium resistivity, analysis of x-ray diffraction patterns together with E logs may be the best method of correlating deposits.

However, E logs may reflect other changes that are not identifiable in the sidewall samples. Alluvium consists largely of loose gravels, representing many rock types in varying proportions. Many of the sidewall samples may not be representative of alluvium since they consist only of a cup full of sand-sized alluvium and several small pebbles. In obtaining sidewall samples, the sampler

is lowered to a known depth, but it often does not catch the side of the hole immediately. Sidewall photos from the same depths indicate that the sampler often scrapes the wall for several feet rather than taking a sample from a specific point. Through examination of sidewall samples and photos, we may produce a detailed lithologic description. No matter how accurate the description is, however, its accuracy is only as good as a sample is representative of the level from which it was taken. At one extreme, the sample may be perfectly representative, while at the opposite extreme, the sample may have been taken only from one boulder set in a different matrix. Also, the sample may consist only of matrix if the pebbles are too large for the sampler. If

possible, stereo photos should be taken within the hole to enable one to determine how representative the sidewall samples are.

The E log resistivity curves probably represent the interaction of many factors. When logging holes in unsaturated material like the alluvium at the NTS, porosity is the main determinant of resistivity. However, the degree of porosity is governed by such variables as lithology, grain size, particle sphericity, orientation, sorting, sediment compaction, fracture zones, and cementation. Therefore, although the sidewall rock samples or photos may be used in some ways to correlate alluvial strata, they are difficult to correlate with actual resistivity values.

Trends in Resistivity Logs

Comparing E log values with sidewall samples does not always indicate a correlation: between the two, and it is therefore difficult to assess how sensitive E logs are to detecting small-scale lithologic and textural changes (boulder beds, silt layers, etc.). However, they may be used in a broader way to infer relative changes in density and saturation.

Examination of approximately 40 resistivity log plots from Area 2 has shown that the overall profile of the resistivity curve is broadly convex to the right (Fig. 3). Although this is a widely recognized phenomena, there does not seem to be any generally accepted explanation for why this occurs. In working with average water content, grain density, and bulk density values, Germain also observed a similar zonation with depth in alluvium. The zones he defined—the surface down to about 800 ft, 800 to 1100 ft, and below 1100 ft—correspond well to the major inflections in the resistivity curves.

In inspecting Germain's data, we found that down to ~800 ft, the grain density gradually decreases with depth, and the water content reaches a minimum at ~600 ft. Over the same depth, bulk density increases to a maximum between 700 and 800 ft. This produces a decrease in porosity and corresponding increase in saturation with depth. From 800 to 1100 ft, the grain and bulk densities decrease with depth while the water content and porosity increase. Below 1100 ft, the densities are fairly constant, the water content continues to increase slowly, and the porosity increases slightly.

The high degree of correlation between this zonation based on physical properties and the bowl-shaped resistivity profiles commonly observed in Area 2 electric log traces indicates that the interaction of water content, grain density, and bulk density values is likely the most influencing factor in determining the main changes in resistivity with depth. If this is true, the zonal interactions among

these 3 parameters is probably universal throughout Area 2.

Cross Sections

Three cross sections have been prepared for Area 2 based upon digitized E logs (Fig. 4). Two of these, A-A' and B-B' (Figs. 5 and 6), are north-south profiles, whereas C-C' is oriented east to west (Fig. 7). Although only those E logs that have been digitized were actually incorporated into these cross sections, all other pertinent exploratory and emplacement holes for which resistivity data exists were used in determining the final correlations. In Figs. 5-7, question marks were placed at those portions of the cross sections where there is either a lack of data, or where it is difficult to correlate the data without further information.

As we illustrated in Fig. 3, many of these logs possess a similar pattern in the overall resistivity with depth. On a smaller scale, however, there is considerable fluctuation in the resistivity values, and this can also be correlated. If one were working with log data from more conventional sand and shale sequences, these small scale changes could be used to pick beds where there are lithological changes. The continuity of various major rock types could then be traced between holes. In dealing with alluvium, however, these small-scale changes cannot be assigned to a particular lithology because the material has a complex composition and texture. Therefore, the correlation lines between holes shown in Figs. 5-7 do not necessarily mark boundaries between beds or distinctive lithologies. Such lines represent only distinct horizons characterized by similar resistivity patterns and have been chosen because it is easy to recognize these horizons from one hole to another. Since the exact reason for these comparable peaks is not fully understood, we cannot effectively evaluate the accuracy of these correlations; however, they do appear to be strikingly continuous with only minor changes occurring over the area we examined.

In cross section A-A', the resistivity profile from drillhole U2dy (far right, Fig. 5) is especially difficult to correlate with the other logs because of the small variation in resistivity with depth. Examination of other resistivity data indicates that this is probably due to problems encountered during logging and does not necessarily reflect major changes in the alluvium. However, geologic cross sections also indicate a fault that may extend through the tuffs into the alluvium of U2dy at ~430 ft. This may further account for the difficulty in trying to correlate this drillhole with the adjacent one, U2do.

An average resistivity log for
Area 2

Zonation observed by Germain (1976)
in areas 2 and 10.

- Grain density and water content approximately constant; some tendency for grain density to fall with depth.
- Shallow minimum in H_2O content at ≈ 600 ft.
- Bulk density increase with depth, peaking $\approx 700 - 800$ ft.
- Decrease with depth in porosity and gas filled porosity.
- Grain and bulk density decrease rapidly with depth, while water content increases.
- Porosity increases sharply with depth; saturation and gas filled porosity flatten out.
- Densities remain constant for several hundred feet, but fall as water table is approached; H_2O content increases with depth until effect of static H_2O level is felt at about 1800 ft.
- All these changes appear to cancel out in that saturation and gas-filled porosity are constant while porosity increases somewhat with depth.

Fig. 3. Profile of resistivity curve from log plots of Area 2 of the NTS.

In cross section B-B', hole Ue2ek (far right, Fig. 6) is equally difficult to correlate with adjacent holes, but this is because it is an induction log run in a dry hole as opposed to the others, which are run in wet holes. Nevertheless, there do not appear to be

any major faults closely associated with U2ek. Based upon these correlations, inspection of all three resistivity profiles in Figs. 5-7 indicates that the alluvium is generally continuous since no major offsets from faulting are apparent, except for U2dy.

Fig. 4. Location of boreholes studied in this report. Lines connected by letters represent the cross sections studied in this area. Open circles represent boreholes not yet investigated.

Fig. 5. Resistivity profiles from boreholes along cross section A-A'.

Fig. 6. Resistivity profiles from boreholes along cross section B-B'.

Fig. 7. Resistivity profiles from boreholes along cross section C-C'.

If this is true, then the gravity-inferred faults on the Paleozoic surface and faults identified or proposed in the underlying tuffs probably do not penetrate into the alluvium any appreciable distance, if at all.

There does seem to be a greater ease of correlation in a north-south direction than in an east-west direction, at least in the southern part of Area 2, based on our limited number of observations. This phenomenon is interesting in view of the present drainage patterns for Area 2 at Yucca Flat (Fig. 8). Those holes we studied are all within the present drainage boundaries of a large fan originating in Rainier Mesa (A in Fig. 8). The massive area of this fan reflects an equally large drainage-basin area.³ If we assume that conditions of deposition have been generally the same in the past inasmuch as this fan has been contributing the greatest flux of sediment to this area, then correlating alluvium is much easier north-south than east-west. Bull⁴ has shown that the stratigraphy along radial sections of a fan is

Fig. 8. General surficial drainage pattern for Area 2 interpreted from aerial photographs. Numbers around map are Nevada coordinates.

continuous for greater distances than for sections across a fan.

A much more detailed study of the surficial alluvium divides Yucca Flat into several groups.⁵ They are playa, alluvium, and alluvial-colluvial areas (Fig. 9). The playa deposits are in the area

numbered I, and the alluvial deposits are labeled II through IX. The alluvial-colluvial units are assigned letters A-G.

The drainage pattern for Yucca Flat as a whole is similar to that of Area 2. There are two components to the direction of flow: one toward the distal

Fig. 9 Map of Yucca Flat showing surficial units. Roman numerals represent alluvial units, letters represent alluvial-colluvial units. Numbers around map are Nevada coordinates.

portions of all contributing arms (towards the center of the basin), and on a larger scale, one main component towards the south-east, approaching Yucca Playa. We can therefore expect that this drainage pattern will decrease the size of particles in the fan at the center and southeast of Yucca Flat. Studies of particle size in alluvial fans of arid regions have shown that the particle size decreases with increasing distance from the fan apex.⁶ The evidence to support this lies in the Area 3 "sandpile", southeast of Area 2. Here, particles are much finer in average clast size and are more uniform than those from Area 2.

Other Methods for Correlating Alluvial Layers

Comparison of CO₂ Percentages

The distribution of various pebble types in the alluvial strata may be such that distinct lithologies cannot be correlated between holes, but the relative percentage of different rock types may vary enough between fans that a comparison of mineral contents could be used to distinguish fans. Alluvial fans commonly contain minerals such as gypsum and calcite. These are deposited along with the fan either as limestone and dolomite fragments, or as carbonates from surface weathering and reprecipitation from downward-moving surface water (caliche). CO₂ wt% analyses reflect the combined amount of carbonate contributed to the fans from both sources. Since each fan is the product of a single stream, the mineral content of even adjacent fans may vary greatly from each other if the lithology of their respective source areas is different.⁷

If fans were buried below the water table, the zonation of minerals could be altered, but this is a

rare occurrence at the NTS because the water table is deep. Figure 10 roughly illustrates how a series of buried fans might look along a vertical plane normal to the main fan axes. The question has arisen whether or not CO₂ sample analyses from drillholes could be used to delineate the subsurface boundaries of fans at the NTS. Several CO₂ samples are commonly taken from each hole, and therefore data is available. However, except for the most recently logged holes, the analyses were run only within those zones we were interested in at the time.

Aside from the work by Carlson and McKague⁸ and Germain,⁹ there has been little work with determining subsurface trends in the CO₂ content. By averaging the values from each hole and plotting them on a location map, Germain found that there was an overall increase in CO₂ toward the north of Yucca Flat. By contrast, the research of Carlson and McKague in Area 2 indicates increasing CO₂ concentrations in the deeper tuffaceous alluvium, towards the west and south of Yucca Flat. Even if either of these situations reflects the accurate subsurface conditions, they still do not help us in understanding the stratigraphic geometry of individual fans. As illustrated in Fig. 10, an average CO₂ value (wt%) from vertical sampling may be the result of an average value from two or more buried fans. Thus, we could not rely upon the information to aid us in distinguishing individual alluvial fans.

To use the CO₂ data for correlating alluvium strata, another approach would be to arrange the CO₂ values from the data bank for each hole in columns, as they are listed on computer printouts. Each data point in the column should indicate both the value and the depth from which the reading was made. The values could then be used like a vertical sequence of rock types, and in a correlation (Fig. 11), one may be able to delineate the 3-dimensional limits of distinctive alluvial layers. It is unlikely that

Fig. 10. Schematic representation of how buried fans might be identified based on their CO₂ content. Numbers are CO₂ content in wt%.

Fig. 11. Hypothetical method of correlating fans by their CO₂ wt% values.

these values could be contoured as easily as illustrated in Fig. 11, but through examination of the data, we found percentage intervals (0 to 2.5%, 2.5 to 5%, etc.) that can be traced between holes. However, a wider coverage of CO₂ sampling will be needed before this method can be adequately evaluated.

Caliche Dating

Uranium age-dating of caliche deposits as a method of correlating strata is currently being evaluated.¹⁰ This process has been successful in dating carbonate coatings from alluvium pebbles, and it has been suggested that the method may be useful in correlating subsurface alluvial fan strata. However, caliche dating poses problems. Without physically testing its applicability, the method may be limited. One limitation is that the carbonate to be tested cannot be greater than 300,000 years old since the products of radioactive decay reach equilibrium after that time.

Aside from this, there are other problems to consider. Because a number of adjacent fans can experience the same climatic influences at the same time, it is logical that they would all be relatively close in age at any designated horizon. This method would then be of little value in differentiating lateral fan boundaries, although the dating would serve as a paleogeomorphic marker. However, an alluvial fan is deposited such that only a small portion of its surface is active at any time. Thus, the fan head may develop a caliche soil horizon while its distal portion accumulates sediment. This process and the fact that the locus of fan deposition tends to shift with time, may cause different portions of the fan to develop caliche deposits of different ages at the same stratigraphic level. This problem could be further compounded by the retention of previously formed carbonate rinds on pebbles eroded from older fans and redeposited in younger ones. Because of these phenomena, this method would provide similar dates for fans of different ages.

Debris-Flow Deposits

Another source of data that may be generally useful in correlating fans would be the occurrence of debris-flow deposits. The rationale in using this method is that the occurrence of such deposits would reflect an overall climatic trend and thus serve as a type of local time horizon. By their nature, debris flows are deposited in a short time (minutes to hours) over a relatively large area. In the context of our problem debris flows are produced by short, irregular periods of intense rain-

fall along with steep, poorly vegetated slopes and a source that provides a mud matrix.⁴ These deposits are most prevalent near the fan apexes, and have a high density and viscosity compared with streamlaid deposits. Commonly, debris-flow deposits have the following criteria: poorly sorted material, angular and randomly oriented clasts floating in a much finer matrix, and occasionally cracked fragments transported without much displacement. Examination of sidewall stereo photographs allows us to identify such deposits in some cases. Photographs were taken using a downhole camera specifically developed at the Lawrence Livermore Laboratory for large holes (Fig. 12). This system takes color stereo photographs either of the sidewall or downhole, and can be oriented by its magnetic compass. Color and stereographic photographs are invaluable to the geologist in determining the lithologic characteristics of the drillhole. Although this system has been in use for more than 10 years, only recently has it been used routinely for all large-diameter drillholes.

Fig. 12. The downhole stereo camera developed at Lawrence Livermore Laboratory.

Fig. 13. Four views 90° apart of hole U2dv at approximately 1600 ft showing debris flow deposits.

Deposits with most of the criteria of a debris-flow have been seen in at least two and possibly three of five holes in the U2d area from which sidewall photos were available. Pictures from the bottom of hole U2dv at approximately 1600 ft. indicate debris flow deposits (Fig. 13). The lower right photograph in this figure shows this particularly well. A large cobble at the bottom of the photograph appears to have been broken and transported with little displacement. In hole U2do, cobbles of Paleozoic carbonates are prevalent from 854 to 110 ft, and most

look like a debris flow at 914 ft (Fig. 14). In hole U2dh-3, (Fig. 15) large clasts occur between 800 and 900 ft and are especially coarse between 850 and 860 ft. Based on the limited number of sidewall photos available from the older holes, it is difficult to assess whether plotting the occurrence of such deposits is a useful correlation method. The few sidewall photographs we have prevent us from determining whether flows intersect many of the holes. From the photographs we have, it appears that debris flows are limited to the west side of the Area 2, implying

Fig. 14. Three views of hole U2do at approximately 914 ft showing debris flow deposits.

that nearby the Paleozoic ridge was the source of the deposit. This suggests that the Carpetbag fault was active during the Quaternary period, and supplied the necessary gradient.

In the northern part of Area 2, some anomalous CO_2 values have been obtained.⁸ Two abnormally high CO_2 values of 23% (U2bv) and 30% (Ue2dj) were obtained from analysis of total drill cuttings. At hole U2fa, a cutting sample from one horizon had a CO_2 value of 31%. In this sample, the corresponding sidewall samples showed low CO_2 content. This suggests that a Paleozoic carbonate boulder was encountered at this depth that was too

hard or too large for the sidewall tool to penetrate. The occurrence of such high values from these holes may be attributed to similar zones.

Specific Yield and Permeability

Another possible method of correlating subsurface alluvium is by specific yield and permeability measurements. Specific yield is the ratio of gravity-yielded water from a saturated rock to the volume of the rock. There has been some success in accomplishing this by Magleby and Klein.¹¹ These workers were able to correlate alluvial fan deposits in Central California by using these parameters.

Fig. 15. Views at increasing depths to 360 ft of hole U2dh-3 showing outlines of tuff and limestone (L.S) clasts.

Croft¹² developed a method for extracting specific yield and permeability data from electric logs taken in the conventional manner, but this process cannot be applied to the electric log data of Yucca Flat because of a lack of formation saturating fluid and the hole drilling techniques used at the Test Site.

Normally, values of spontaneous potential would provide sufficient permeability data. However, even though spontaneous potential is commonly logged together with resistivity at the NTS, this information is not helpful as there is so little variability in the readings.

SUMMARY AND CONCLUSIONS

Although not an easy task, correlation of the alluvium at the NTS is possible, and zones within the alluvium appears to be more continuous than thought before. Comparison of large changes in the shape of resistivity curves with an alluvium zonation devised by Germain using water content, grain density, and bulk density indicates a similarity in certain zones. This suggests that the occurrence of such bow-shaped resistivity curves can be used to predict relative changes in density and saturation with depth. Further, from the similarity of such curves, the zonal interactions among these three parameters must be similar throughout the study area.

On a smaller scale, even the kicks in resistivity logs can be correlated easily in most cases, but the complexity of the alluvium makes it difficult to interpret the meaning of these correlations. Small-scale fluctuations may be due mainly to the interaction of these three parameters, but the many factors that determine the effective porosity (lithology, grain size, particle roundness, etc.) all contribute to the resistivity values. Although the major trends in resistivity may be determined mainly by the interaction of water content, grain density, and bulk density, minor changes in resistivity trends probably represent the interaction of many other factors as well.

Based on resistivity logs from Area 2, we found that the major vertical zones of alluvium are con-

tinuous with only minor changes occurring over great distances, especially in a north-south direction. Other than the major Yucca and Carpetbag faults, tectonic activity in this area was minor or occurred prior to deposition of the alluvium.

Two other methods for correlating the Yucca Flat alluvium layers appear promising. One of these—comparison of CO₂ percentages—is worth pursuing for two reasons. First, alluvial fans are characteristically fed by single streams with a definite drainage area. Thus, the mineral content precipitating from their waters as they reach the fans should be unique from one fan to another. Second, even if the CO₂ content cannot be used to distinguish fan boundaries, any information on subsurface trends in CO₂ would be valuable for future site selection.

Another method that may help in correlating alluvial fans is comparison of the stratigraphic levels at which debris flow deposits occur. Such deposits have been seen in Area 2 boreholes by use of stereo photography. Photo coverage is sparse, however, and more data will be needed before the efficiency of the method can be determined.

Although we may never be able to precisely correlate the alluvium of Yucca Flat, we are closer now to this goal than before, and further research into these methods is needed to complete our task.

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