Analysis of Sediment Dynamics in the Bill Williams River, Arizona:

Hydroacoustic Surveys and Sediment Coring

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Submitted to:

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Note on Data Sources

This report provides data and analysis relevant to understanding sediment dynamics in the Bill Williams River system. Funding for this report supported field activities to collect sediment cores in Alamo Lake and the Bill Williams delta of Lake Havasu in May 2011, and subsequently to analyze and report those samples and to prepare bathymetric maps of these lakes. This report includes data on seismic profiling which were collected in June 2009 as part of an unfunded study on this lake system. The authors also contributed sediment core samples from Alamo Lake which were collected in 2004 as part of a funded study of that lake.

1 Introduction

Alamo Dam was constructed in 1968 on the Bill Williams River to limit the delivery of sediment to the Parker Dam area of Lake Havasu. As a result the sediment dynamics of the river corridor between Alamo Dam and Lake Havasu was altered. The objective of this study was to use several strategies to understand the sediment dynamics of this river system. Seismic profiling was used to provide information on the spatial distribution of sediment in Alamo Lake and the Bill Williams delta of Lake Havasu. Bathymetric mapping of these lakes was conducted as a first step in determining sediment distribution in the lakes. Sediment coring was conducted to determine fine-scale changes in sediment characteristics over time.

2 Methods

2.1 Field Methods

Field activities consisted of bathymetric and seismic surveys and sediment coring. This section describes the procedures used to collect data and ensure data quality.

2.1.1 Position Control

Bathymetric maps and seismic profiles were collected along transects parallel and perpendicular to the long axis of each lake. For navigation to maintain a course along transects, we used a consumer-grade Garmin GPS 76 with 3D differential GPS capability. For bathymetry and seismic profiling, a Trimble GEO XT was connected to the seismic profiling unit, or to a sonar depth finder. The Garmin unit had a horizontal precision within 3 meters and the Trimble unit had sub-meter horizontal precision. For sediment coring, the Garmin GPS unit provided position data.

2.1.2 Seismic Profiling

Acoustic seismic profiling was conducted using an EdgeTech SB 424 profiler with an EdgeTech 3200 P topside unit[1]. The profiler was towed behind a boat with a 15 meter layback and a consistent speed of 3 to 6 knots was maintained. Figures 1 and 2 show the transects along which seismic profiles were collected. The seismic data were processed using Triton SB-Interpreter software. Horizontal positions of tracks were recorded as well as depth data for bathymetric mapping.

2.1.3 Bathymetric Mapping

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[1] http://www.edgetech.com/edgetech/gallery/category/sub-bottom-profiling-systems

The seismic profiling equipment provided depth data accurate within 5 cm. Triton SB-Interpreter[2] software processed the seismic data to identify the sediment water interface and make corrections to the horizontal position for layback, which is the horizontal distance behind the boat of the towed seismic vehicle. The depth measured was the vertical distance from the tow vehicle to the sediment-water interface. These depths needed to be corrected to true depth, since the tow vehicle traveled underwater. This vertical correction was made by passing the tow vehicle at normal cruising speed alongside bouys which marked locations of known depth. This was done separately for Alamo Lake and Lake Havasu because depths were lower in Lake Havasu and a shorter layback distance was used there to permit operations in shallower water. Figures 3 and 4 show the depth correction regression equation. Resulting depths in meters were converted to feet and subtracted from the lake elevations at the time of the surveys. The bathymetric data were interpolated into a digital elevation model of the lake beds using ArcGIS 3D Analyst software. Both Kriging and Nearest Neighbor interpolation procedures were tested and the approach that produced the lowest level of distortion of depth contours was selected.

2.1.4 Sediment Coring

Two coring devices were used. To collect cores from the sediment water interface to about one meter below the interface, a 5-cm diameter pistonless corer was used, attached to a solid rod. This device has a check valve in the coring head, rather than a piston, to suspend the core in the coring tube by vacuum. This device was used to collect the surface cores SC 1 through SC 5 in both lakes. Cores collected with this device were sampled in the field at one to five cm intervals. Longer cores were collected using a Wright-Livingstone square-rod piston corer (Wright, et al., 1984). This device is also attached to a solid rod and collects cores in one-meter segments. These segments were extruded intact in the field, wrapped in plastic wrap and aluminum foil, and stored in split-PVC pipe segments.

2.2 Laboratory Methods

Sediment cores were analyzed for a suite of parameters to provide both qualitative descriptions and quantitative analysis of sediment constituents. These consisted of a physical description and magnetic susceptibility analysis of the Wright-Livingstone cores, and a variety of physical and chemical analyses of all cores.

2.2.1 Initial Sample Preparation

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[2] http://www.tritonimaginginc.com/site/content/products/sbinterpreter/

Once sediment cores were recovered from the field, they were stored in a locked walk-in cooler at 4^{o} C until analysis. Intact Livingstone cores were split and observations were made on the appearance of the cores. These lithologic descriptions are provided in Appendix A. For each core drive, the datum was the top of the drive and measurements were made in cm from the top.

All data from surface cores are reported as cm from the sediment water interface. Data from the Wright-Livingstone cores are reported as cm from the top of the first drive. For example, the first drive in Lake Havasu Core 1 (Havasu C1D1) was 89.5 cm in length. Measurements in Lake Havasu Core 1 Drive 2 (Havasu C1D2) started at 89.5 cm.

After the lithologic description was performed, the split core halves were then analyzed for magnetic susceptibility at 5-mm intervals using a Bartington Magnetic Susceptibility analyzer with units reported in the cgs system. The split cores were the returned to cold storage to await sampling. The surface cores did not undergo any preliminary analysis.

2.2.2 Core Sampling

Field sampling resulted in the recovery of ten surface cores ranging in length from 30 to 80 cm and six Livingston cores, ranging in length from 96 to 414 cm. Each surface core was sampled at five intervals roughly equally spaced through the core length. The entire length of each Livingstone core was sampled by collecting strips of sediment 10 to 15 cm in length along each core drive. For example, the sample, AL C3D1 10-15 represents a sample collected along the core from 10 cm to 15 cm from the top of the drive.

Approximately 20 grams of wet sediment were collected for each sample and were weighed and dried overnight at 70^{o}C. Dry samples were weighed again to determine moisture content and were crushed to powder using a Spex 8000 ball mill.

2.2.3 Total Digestion for Metals

To prepare samples for metals analysis by inductively-coupled plasma mass-spectrometry (ICP-MS), a total digestion was necessary. First, 0.20 +/- 0.01 grams of dry sediment were weighed into tared and labeled glass vials. The vials were weighed then placed in a furnace at 400^{o}C overnight to drive off organic matter (dry ashing). The vials were then re-weighed to determine loss-on-ignition and the sediment was transferred to labeled 50-mL plastic centrifuge tubes.

Total digestion of the ashed sediment residue was performed consistent with US EPA Method 3052[3] by adding to each 50-mL centrifuge tube 2.5 mL concentrated HNO_3 and 1.5 mL HF. The

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[3] http://www.epa.gov/osw/hazard/testmethods/sw846/pdfs/3052.pdf

centrifuge tubes were capped and placed in a vented convection oven overnight at 80^{o}C. Afterward, the samples were diluted to 15 mL with deionized water (DIW) and a solution containing 0.7 grams of boric acid was added to neutralize any remaining HF in solution. Samples were brought to 50 mL by adding DIW.

Prior to analysis, 80 uL of the sample digest was added to a 5 mL plastic test tube. A diluent containing HNO_3 and 5 ug/L each of the internal standards rhodium (Rh) and iridium (Ir) was added to each tube to bring the volume to 4 mL.

Samples were then analyzed using a Thermo Scientific quadrupole ICP-MS for the following metals: Cu, Zn, As, Cd, and Pb. For quality control, duplicate analyses were performed on every 10 samples and the following standard reference materials (SRMs) were used: USGS AGV-2 and USGS SoNE-1. A summary of the quality assurance data is provided in Table 1.

2.2.4 Mercury Analysis

Dry samples were analyzed for total Hg using a Teledyne Leeman Hydra-C instrument. This instrument is designed to detect only total Hg. Aliquots of 0.2 to 0.5 grams of dry sediment were loaded into nickel boats and introduced to the instrument. The instrument combusted the sample and collected Hg vapor onto a gold-coated sand. The vapor was then released as a pulse on heating and Hg was quantified using a cold-vapor atomic absorption cell. This analysis is consistent with US EPA Method 245.7 (US EPA, 2005) As with the metals samples above, for quality control, duplicate analyses were performed on every 10 samples and the following standard reference materials (SRMs) were used: a marine sediment (MESS-3), peach leaves (NIST 1547), and fish tissue (DORM-3). A summary of the quality assurance data is provided in Table 1.

2.2.5 Plutonium Analysis

The mass 239 and 240 isotopes of plutonium were measured using an acid extraction technique. For each sample, 10.0 +/- 0.1 grams of dry sediment were weighed into glass vials and ashed at 600^{o}C overnight. After the samples had cooled, a spike solution containing 4.06 x 10^{-14} g ^{242}Pu (5.93 x 10^{-6} Bq ^{242}Pu) was added. Extraction of the Pu was performed by adding 20 mL concentrated HNO_3, capping the vials, and placing the samples in a vented convection oven overnight at 80^{o}C. Afterward, the samples were quantitatively transferred to plastic 50 mL centrifuge tubes and diluted to 50 mL. The samples were then centrifuged to separate particulates from the liquid, and the liquid was decanted through columns containing cotton filters and collected into labeled plastic cups. This liquid was then poured into a column containing TEVA resin. This resin captures uranium and plutonium. The columns were then rinsed with 2M HNO_3 to remove excess uranium and 8M HCl to remove thorium. Elution of plutonium from the resin consisted of placing a labeled 5 mL plastic vial under each column, then adding the following solutions to each column: 0.6 mL DIW, 0.6 mL ammonium oxalate, and 0.6 mL DIW.

Samples were analyzed using a Thermo Scientific quadropole ICP-MS set to detect the following elements: ^{238}U, ^{239}Pu, ^{240}Pu, and ^{242}Pu. A 0.5 ug/L uranium solution for instrument tuning. To process the data, a mass correction was made for the presence of UH^{+} in the mass 239 channel. A mass-dependent fractionation correction was also made using a marine carbonate (coral) sample. Finally, the measurement of ^{242}Pu was used to correct for any loss of plutonium in the sample analysis process.

3 Results

This project yielded data in four basic areas: seismic profiling, bathymetric mapping, dating of the sediment cores, and changes in concentrations of selected metals in the sediment cores.

3.1 Seismic Profiles

Seismic data were collected in June 2009 on Alamo Lake and the Bill Williams delta of Lake Havasu in June 2009, resulting in profiles for 103 separate transects with files occupying 3.25 gigabytes of data. Figures 1 and 2 show the locations of the transects. Of these, seven segments of transects have been extracted and are shown in Figures 5 through 11. Acoustic seismic profiling operates on the principle that pressure signals transmitted downward from the tow vehicle are reflected back to the vehicle with intensity and timing that vary with the density of the material encountered. The best reflectors in the sediment package of lakes and reservoirs are interfaces between zones of differing density. Of the transects shown in Figures 5 through 11, this is best demonstrated in Figures and 6, where there are faint reflectors in the surface sediments of Alamo Lake and Figures 9, 10, and 11 in Havasu Lake.

It should be noted that Figure 11 also shows multiples, one of which meets the right axis of the plot at about 10 meters depth. Multiples result from a seismic signal which has reflected from a sub-surface feature, then reflected back against the air-water interface, back downward, and upward again. These have no physical meaning in the interpretation of seismic profiles.

3.2 Bathymetric Mapping

Seismic profiling data were used to produce a digital elevation model (DEM) for Alamo Lake and the Bill Williams delta area of Lake Havasu. The DEM was then used to prepare the maps shown in Figures 12 and 13.

These maps show the current configuration of sediment in the lake basins. Comparisons with previous bathymetric studies would be useful in determining the patterns of sedimentation in the lake. The US Army Corps of Engineers (USACE) conducted a bathymetric survey of Alamo Lake in 1985. This survey existed only as paper copies of the bathymetric map and supporting data. An example of part of one of the five sheets of the map is shown in Figure 14. To evaluate sedimentation in Alamo Lake, we digitized the entire 1985 USACE map, which consisted of nearly ten thousand individually digitized data points. Using these data, we produced a DEM of the 1985 bathymetric contours using the same approaches described previously. The map of 1985 bathymetric contours appears in Figure 15.

3.3 Sediment Coring and Chronometry

A total of 16 cores were collected for this study and are summarized in Table 2. Coring locations are shown for Alamo Lake in Figure 16 and for Havasu in Figure 2. Lithologic descriptions of the cores appear in Appendix A and an example of the description for one core drive (Lake Havasu Core 2 Drive 2) is shown in Figure 17. All cores except Alamo Core 2 were collected in May 2011. Alamo Core 2 and surface core SC 1 were collected as part of a previous study in August 2004 and were recovered from an archive for sampling. With regard to core numbering, The three cores for Alamo referenced in this study are numbered 2, 3, and 4.

Chronometry for the cores can be estimated from known date markers and by markers for atmospheric fallout of above-ground atomic testing. The only known date markers available for Alamo and Havasu are dates of impoundment, which are 1968 for Alamo and 1938 for Havasu. Cores collected in Alamo and Havasu, with the exception of Havasu Core 3, were all assumed to extend to the native pre-impoundment lake bed. This assumption is based on observations made of the material at the bottom of each core. Using these markers, average sedimentation rates at the core locations were estimated (Table 3 averages) and vary from 2.2 to 11.5 cm/year. These rates fall within the range for large western USA reservoirs (Graf et al., 2010; Gremillion and Toney, 2005).

Radioisotope dating provides date markers for the onset of above-ground atomic testing in 1954 and the enactment of the nuclear test-ban treaty in 1964, which marks the peak of above-ground atomic testing and the highest rate of global radioactive fallout. The radioisotope cesium-137 (^{137}Cs) has been the most commonly used fallout indicator. However the relatively short half life (about 30 years) of ^{137}Cs means that the supply of bomb cesium is diminishing. In addition the analysis is time consuming and requires relatively large sample sizes. An attractive alternative is the analysis of two plutonium isotopes, ^{239}Pu and ^{240}Pu. Recent advances in instrumental techniques enable the analysis for these isotopes using mass spectrometry.

Plutonium analysis was performed on the Lake Havasu cores, since this reservoir was impounded before 1963. The Alamo Lake cores were not analyzed for radioisotopes since it was impounded in 1968. Figure 18 shows the $^{239+240}$Pu records for the Lake Havasu cores. Also plotted is magnetic susceptibility (MS), which can be used as a proxy for particle size (Evans and Heller, 2003). Of the Pu records, Havasu Core 1 has the best resolved shape. There is a clear peak at 98 cm which can be associated with 1963 and a clear onset of the presence of Pu at 150 cm which can be associated with 1954. There is a second peak at about 40 cm, which may indicate reworking of sediment. The Pu record for Havasu Core 2 does show a distinct peak at 40 cm, but there is not a gradual buildup from the onset of Pu at about125 cm upward to the peak. Havasu Core 3 was collected near the inflow from the Bill Williams River. This core shows an abrupt onset of Pu at 130 cm followed by high and erratic Pu upward in the core. It is certain that sediment below 130 cm was deposited prior to 1954, but it is unclear to what extent this part of the lake was subjected to erosion and reworking of sediment. As a result, only the 1954 marker at 130 cm was used for this core.

The only available markers for the Alamo cores were the dates of impoundment. The average sedimentation rates resulted in an estimate of high sedimentation toward the lacustrine end of the lake at about 11 cm/year and much lower sedimentation (< 4 cm/yr) toward the riverine end.

3.4 Physical and Chemical Analyses

Sediment samples were analyzed for a suite of metals. The results are plotted in Figures 19 through 26 and the data listings are provided in Appendix B. Variations in the concentrations of physical and chemical parameters, as well as magnetic susceptibility (MS), appear to track with changes in the characteristics of sedimentation as indicated by the lithologic logs. Loss on ignition (LOI), a proxy for organic carbon content, tracked generally with regions of cores that were darker in color. The appearance of coarser or sandier material in the core lithology correlated strongly with increases in MS.

4 Discussion

4.1 Seismic Profiles

Seismic profiling can be a powerful tool in determining sedimentation characteristics. In reservoirs, which are subject to episodes of sediment deposition associated with storm events, the delivery of coarse mineral sediments can create an interface in the sediment record, overlying fine sediments deposited during quiescent periods. These interfaces create strong reflectors and can be counted like varves in seismic records. Of particular value is the capability of seismic profiles to confirm that patterns shown in individual cores are valid at a larger spatial scale.

An interference can exist, though, if lake sediments are high in organic content. Organic matter can absorb seismic signals and in the absence of reflected acoustic signals, create black regions in the record. The presence of organic material can obscure patterns in sediment deposition. For example, Figure 10 indicates that there are about 50 cm of sediment overlying a strong reflector, which could be the native hard material in the pre-impoundment reservoir. However this profile was taken between Cores 1 and 2 in Lake Havasu (Figure 2). Both cores extended more than 300 cm before reaching hard material.

Seismic profiling in Alamo Lake and Lake Havasu has been useful in producing high-resolution, accurate records to support bathymetric mapping, but has limited use in interpreting sedimentation. Instruments better suited to this type of material may produce better results. It may also be possible to re-process the existing data records to reduce the opacity created by organic matter in the sediments.

4.2 Bathymetric Mapping

Bathymetric maps were prepared using recent data collected on Alamo Lake and the Bill Williams delta of Lake Havasu. Additionally we prepared a DEM from a bathymetric survey of Alamo Lake conducted in 1985 by the USACE for comparisons of sedimentation characteristics in Alamo Lake.

Before making direct comparisons between the two DEMs for Alamo Lake, an analysis of data resolution is necessary. In the 1985 survey there was a very high density of observations in a uniform square pattern with a spacing of about 100 ft. between points in the south region of the lake. In the north region of the lake data observations had a rectangular pattern with a spacing of about 100 by 200 ft. For our survey we collected elevation observations about every 25 feet along transects in a roughly square pattern with spacing between transects of 500 to 1,000 ft.

To test whether the two surveys produced comparable results, we started with the DEM for the 1985 data and considered this the "dense grid" (Figure 27, left). We used the DEM to produce an elevation vs. storage table (Figure 28, top). We then deleted datapoints until the remaining pattern of observations resembled the NAU dataset (Figure 27, right), which we called the "sparse grid", and prepared a DEM and elevations vs. storage table similarly. The plot of Figure 28, top shows the two storage relationships. The results are similar and the greatest magnitude of error is at the highest elevation (1,130 ft NGVD 1929) with a difference of 2.16% between the sparse and dense grids.

To examine the data more carefully, we plotted the lake volume (acre-ft) for every one-foot thick slice of elevation. The results are shown on Figure 28, bottom left. Figure 28, bottom right, shows the error expressed as the volume predicted by the dense grid minus the volume predicted by the sparse grid for each foot of elevation. The difference varied from about minus 30 acre-ft to about plus 70 acre-ft per foot of elevation.

From these comparisons of data from the 1985 survey, we conclude that the error associated with our larger spacing for the transects does not introduce significant error to the estimation of elevation vs. storage relationships in the 2009 survey. Additionally, storage loss is likely associated with regions of low slope which would not necessitate high resolution in transect spacing for accurate characterization.

A comparison of the 1985 and current bathymetric maps is shown in Figure 29. There appear to be some differences in the shoreline from the 1985 (Figure 29, left) to the current (Figure 29, right) surveys. This is an artifact of the methods used in handing the data. The limits of data from the 1985 survey were ends of transects, which varied in elevation. The limits of data for the current survey were points digitized from a 2007 ortho-rectified aerial image of the lake. We determined the elevation of the lake on the day the photo was taken and assumed that shoreline points all were associated with that elevation.

The final elevation vs. storage data for the current survey are plotted with the 1985 survey data on Figure 30. The results indicate that the deepest parts of the lake lost about 15 feet of depth in the 24 years between the studies, or about 7.8 inches per year. As a comparison, in 2004 we collected a sediment core in Alamo Lake which was 13.8 feet long and extended to the pre-impoundment lake bed. This corresponds to an average sedimentation rate of about 4.2 inches/year from impoundment in 1965 until coring in 2004. At that location (*e.g.,* Figure 29) the DEMs for the 1985 and 2009 surveys indicated that in the 24 years between surveys the lake lost about 7.4 feet of storage at that location, or about 3.7 inches per year.

To make a preliminary estimate of the spatial extent of storage change we compared the DEMs from 1985 and 2009. Because the data were collected at different densities and using different methods, we limited the extent of this comparison to a region we refer to as *lake bed* and excluded the sloped sides of the lake basin. This excludes about half of the lake area (Table 4), but focuses on the area where the greatest storage change likely occurred. Figure 31 shows the extent of the DEM comparison as an outline overlayed on the extents of the 1985 (Figure 31, left) and 2009 (Figure 31, right) surveys. Using the raster algebra feature in ArgGIS Toolbox, we subtracted the elevation of the 1985 surface from the elevation of the 2009 surface. The resulting map (Figure 32) show the spatial change in elevation from 1985 to 2009. These results show that a storage loss of three to seven feet occurred over most of the basin with increasing loss of storage toward the inflow of the lake.

The 2009 survey did not extend as far toward the inflow as the 1985 survey (Figure 31). This is shown more explicitly on Figure 33, which shows the portion of the lake excluded in the 2009 survey (Un-surveyed) compared with the extent of the 2009 survey. This amounts to about 15 percent of the total 1985 lake surface area (Table 4). The high magnitude of storage loss at this end of the lake makes this un-surveyed area important as a location of high storage loss.

In summary, the bathymetric survey we have completed to date is accurate but incomplete. The lake bed elevation along the upstream boundary of the 2009 survey ranged from 1,100 to 1,114 ft. NGVD 1929, so we can conclude that the elevation vs. storage table below the elevation of 1,100 ft. is accurate and complete. We can also conclude that the elevation vs. storage table between elevations of 1,100 and 1,130 ft. is accurate and incomplete.

With regard to the Bill Williams delta of Lake Havasu, we consider the map to be reasonably accurate, but requires additional observations. Both lakes generally have gentle bathymetric contours, but areas around the shorelines are not well represented by the current map. Additional field work is necessary in both lakes to improve the quality of the bathymetric DEMs. Time limitations in completing the study prevented additional field work necessary to bring this map to the level of accuracy desired by the authors. The data grid used to produce the DEM is less dense than in Alamo Lake.

4.3 Sediment Core Chronometry and Sedimentation

The Lake Havasu cores contain a record of sedimentation from 1938 to 1968, capturing the last 30 years of the pre-impoundment period of the Bill Williams River, and from 1968 to 2001, representing the 38 year record of impoundment of Alamo Lake. In terms of absolute sedimentation, the period from 1938 to 2011 resulted in the accumulation of about 310 cm of sediment in the Core 1 region of Lake Havasu and 330 cm of sediment in the Core 2 region. This represents 76% and 90%, respectively, of the total sediment accumulation in these cores. We did not conduct this analysis for Lake Havasu Core 3, since this core was collected in a more depositionally unstable environment.

It is clear from the sedimentation rates that impoundment of Alamo Lake resulted in lower sedimentation rates in the Bill Williams delta of Lake Havasu. Another important aspect is that the character of the sediment that was delivered to the delta changed as well. The magnetic susceptibility records for Lake Havasu Cores 1 and 2 (Figures 23 and 24) show low values with low variability, compared with the higher values and higher variability earlier in the lake’s history. This indicates the delivery of sediment with smaller particle size in recent decades. This is in contrast with the MS records of Alamo Lake Cores 2 and 3, (Figures 19 and 20) which show high variability throughout their records.

Photo images of the cores support the lithologic and MS data which indicate a change in sedimentation characteristics in the Bill Williams delta of Lake Havasu after the impoundment of Alamo Lake. For example Figure 34 shows the MS record and photos of Lake Havasu Core drives C1D1 and C1D3. The core drive on the left represents roughly the time period of impoundment of Alamo Lake. The core drive on the right shows at about 203 cm absolute depth a zone of coarse material that indicates delivery of sediment from a significant storm event. Zones of coarse material can be found in the Alamo cores. Coarse material, however is absent from the sediment record in Lake Havasu after impoundment of Alamo Lake.

The Alamo Lake cores (Figures 19 through 21) show high sedimentation rates and regular delivery of coarse sediment. The average sedimentation rate for Alamo Lake Core 2 was 11.5 cm/year compared with a sedimentation rate during that same time period in Lake Havasu of about 2 cm/year (Table 3). Sedimentation in Alamo Lake Cores 3 were both less than 4 cm/year. Although these are still high sedimentation rates, even for reservoirs, they are much lower than in the lacustrine zone of Alamo Lake. It is possible that during high-magnitude storm events, sediment is rearranged in the lake. Anecdotal information indicates that during major storm events, the level of the lake rises quickly enough that a water velocity is actually observed in the lake. This can impart sufficient energy to move sediments toward the lacustrine end of the lake. Figure 32 supports this contention, to some extent. Change in bathymetry from 1985 to 2009 shows that most of the increase in bottom elevation occurred in the upper riverine and lacustrine zones of the lake, rather than the middle. It is possible that sediments fine enough in diameter to be transported during major storm events relocated to the lacustrine zone and that larger particles remained in the riverine zone. It is also possible that the material in the riverine zone was therefore so coarse that the hand-driven coring equipment used for this study was unable to penetrate to the pre-impoundment sediments in the Core 4 region of the lake.

4.4 Physical and Chemical Analyses

The metals data for both Alamo Lake and Lake Havasu show that most metals show some degree of covariation. It is possible that larger-magnitude storm events result in the mobilization of more erodible minerals. The variations in types of minerals delivered may then be reflected in co-varying changes in the analytes plotted in Figures 19 through 26. Mercury appears to vary independently of the other metals. This has been observed in other reservoirs in Arizona (Gremillion 2011a, Gremillion 2011b, Gremillion and Toney 2005) and indicates an atmospheric source of Hg superimposed on the signal of mineral Hg delivery.

Changes in concentrations of physical and chemical parameters track closely with the lithologic features described in Appendix A and shown in Figure 34. The cores recovered from Alamo Lake and Lake Havasu contain much information on environmental change in the Bill Williams watershed that can be interpreted with further study.

5 Conclusions and Recommendations

The three primary areas of study in Alamo Lake and the Bill Williams delta of Lake Havasu were seismic profiling, bathymetric mapping, and sediment coring. Seismic profiling was successful in providing accurate bathymetric data, but had limited utility in providing a spatially resolved picture of sediment stratigraphy in the lakes. This was likely due to high concentrations of organic matter which obscured the seismic signal. If a more complete analysis of sedimentation characteristics is desired, a second seismic study with equipment better suited for organic materials is recommended.

The bathymetric mapping component of the study produced accurate digital elevation models of Alamo Lake for the years 1985 and 2009 and for the Bill Williams delta of Lake Havasu in 2009. Both 2009 maps, however can be improved with additional field work to provide better resolution in shoreline areas and other areas of high relief.

The sediment coring component of the study produced a set of well-resolved high-resolution cores, which have been sampled and analyzed to produce a synoptic description of sedimentation in both lake systems. Analysis of the cores for bomb fallout radioisotopes resulted in reliable chronologies for the Lake Havasu Cores 1 and 2. The recent impoundment of Alamo Lake precludes use of bomb radioisotopes. Analysis of the cores for physical and chemical parameters indicates that changes in concentrations of analytes track closely with lithologic features. The cores contain much unexploited information and should be re-sampled at finer resolution and analyzed for changes in the environment of the Bill Williams River over the course of the 20th century.

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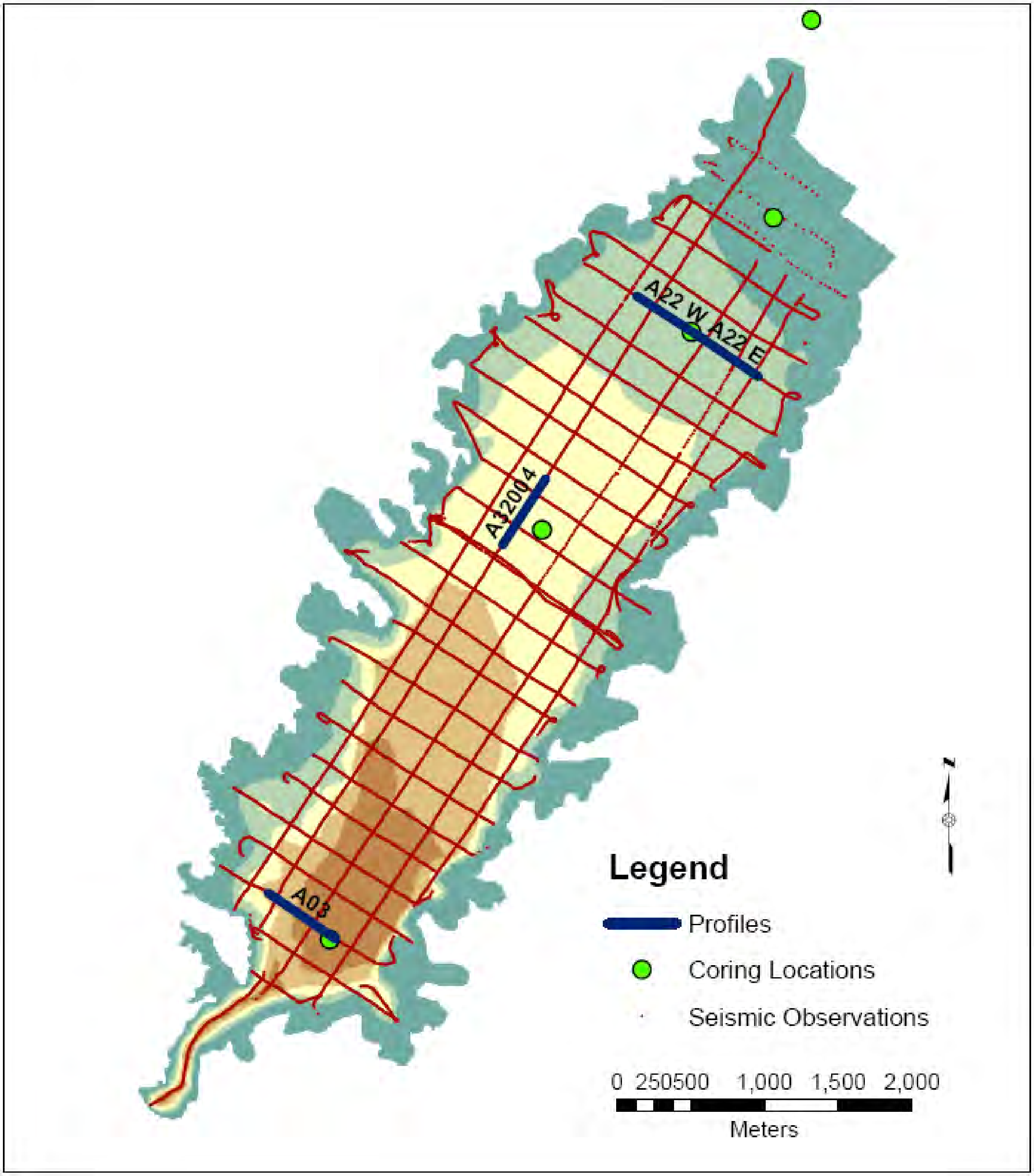


Figure 1. Transects for seismic profiling on Alamo Lake, Arizona.

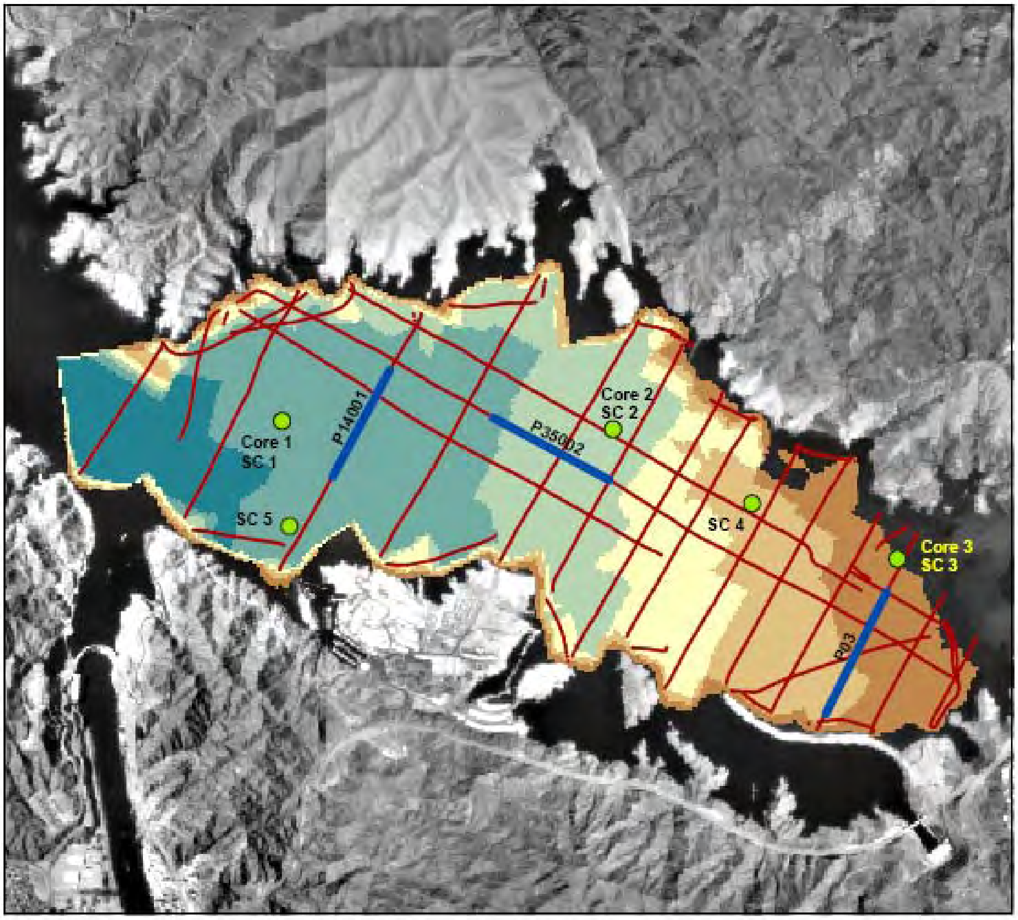


Figure 2. Seismic tracks for the Bill Williams delta area of Lake Havasu, Arizona.

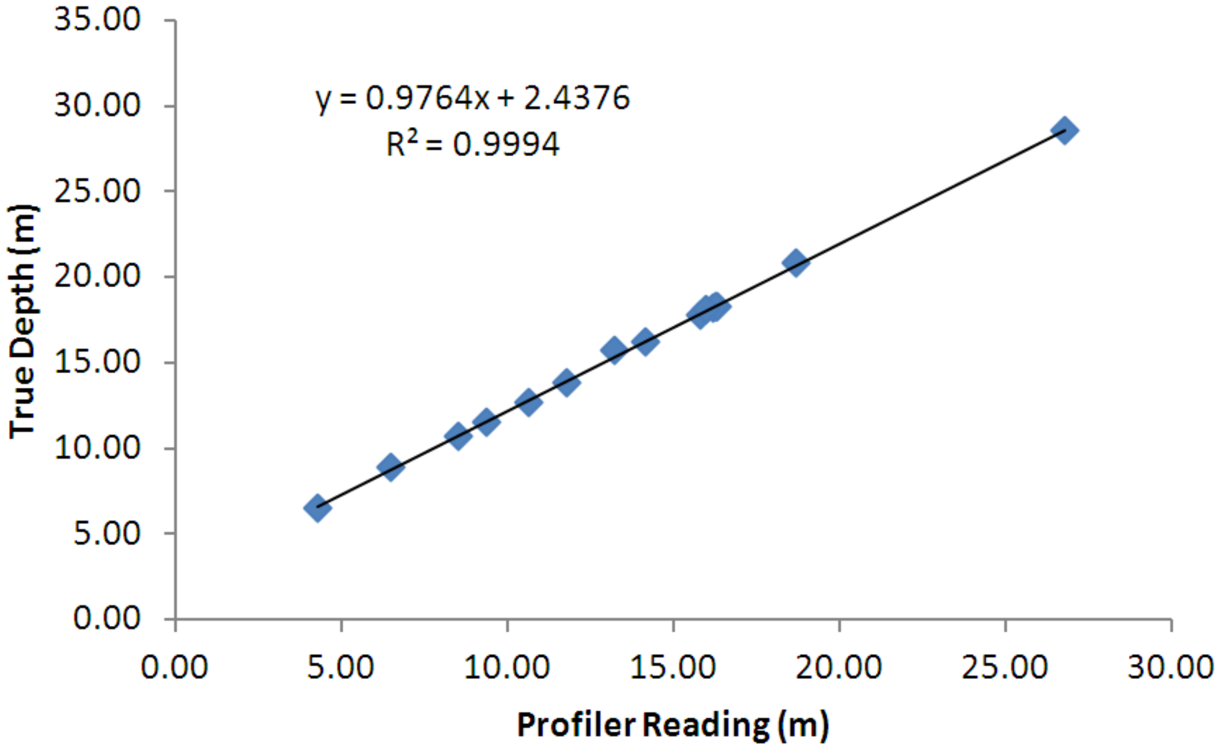


Figure 3. Calibration of seismic profiler depth measurements to true depth for Alamo Lake.

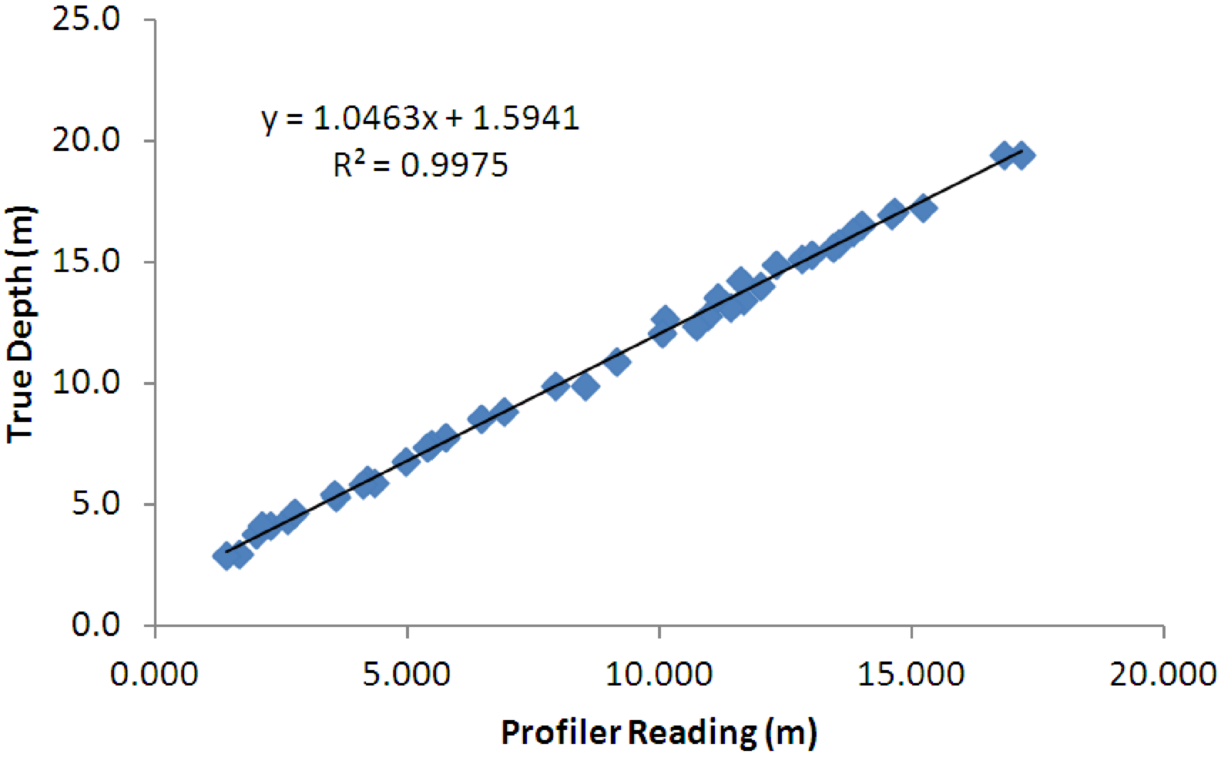
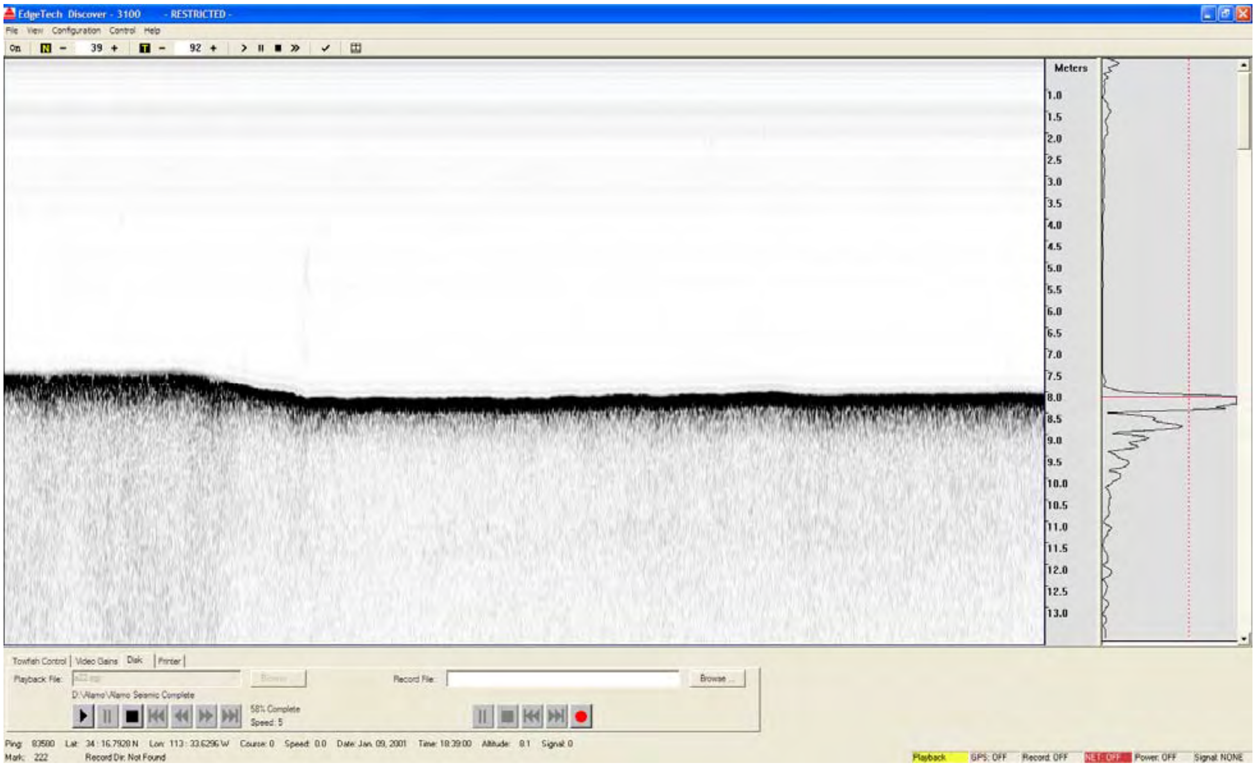


Figure 4. Calibration of seismic profiler depth measurements to true depth for Lake Havasu.



Playback File: a22.sgy

D:\Alamo\Alamo Seismic Complete

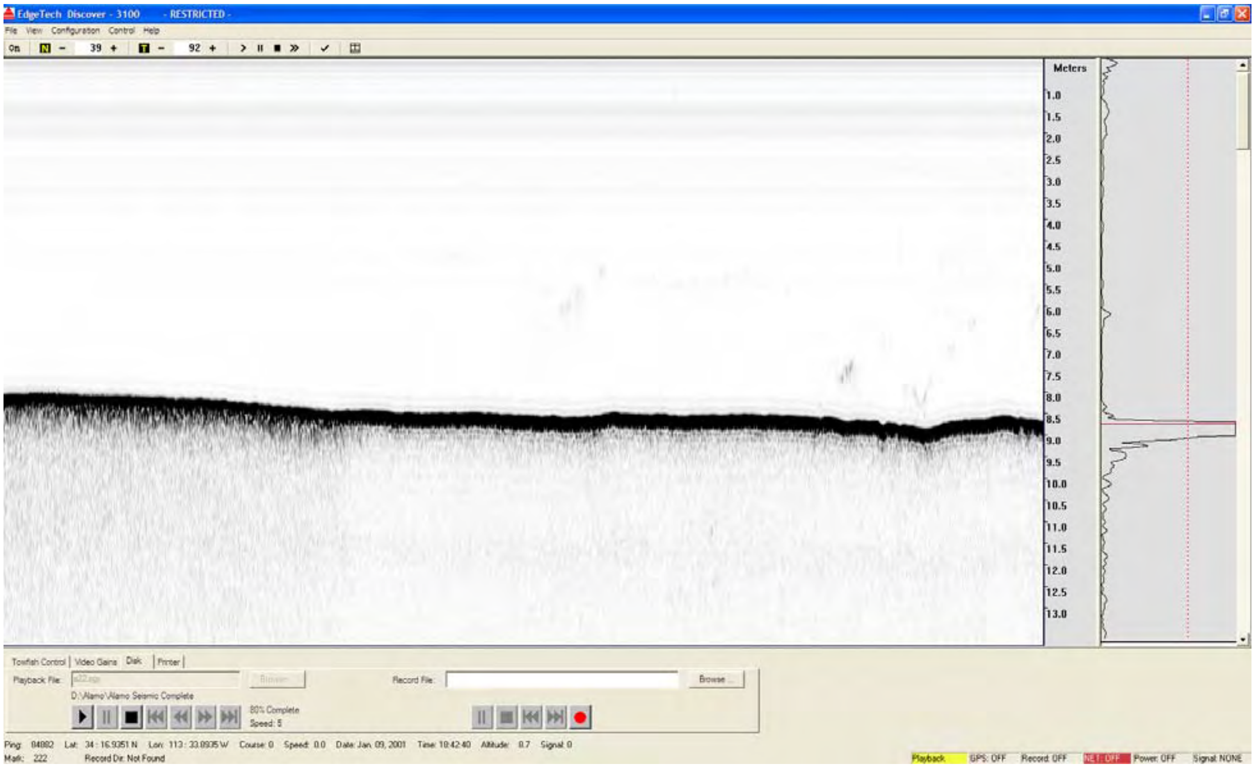
58% Complete
Speed: 5

Record File:

Ping: 83580 Lat: 34 : 16.7928 N Lon: 113 : 33.6296 W Course: 0 Speed: 0.0 Date: Jan. 09, 2001 Time: 18:39:00 Altitude: 8.1 Signal: 0
Mark: 222 Record Dir. Not Found

Playback GPS: OFF Record: OFF NET: OFF Power: OFF Signal: NONE

Figure 5. Profile of Transect A22 (east side) in Alamo Lake.

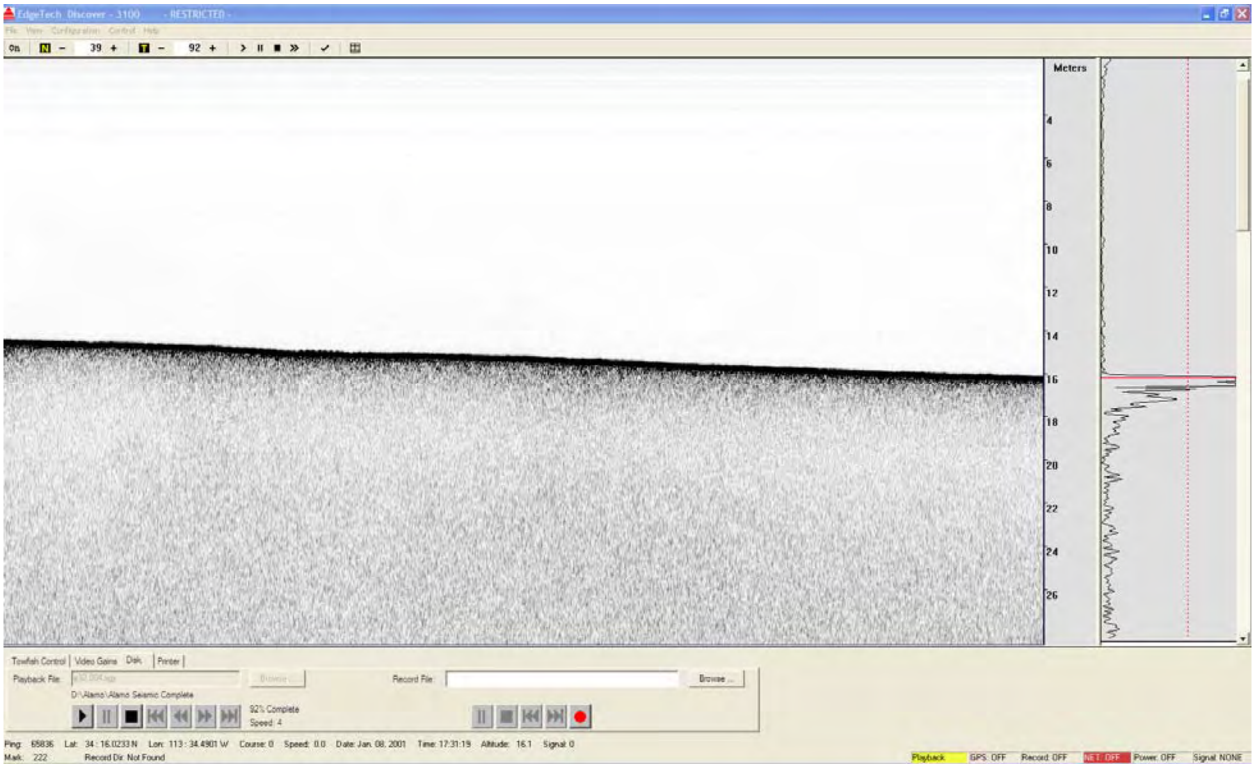


Playback File: a22.sgy
D:\Alamo\Alamo Seismic Complete
80% Complete
Speed: 5
Record File:

Ping: 04882 Lat: 34 : 16.9351 N Lon: 113 : 33.0935 W Course: 0 Speed: 0.0 Date: Jan. 09, 2001 Time: 18:42:40 Altitude: 0.7 Signal: 0
Mark: 222 Record Dir: Not Found

Playback GPS: OFF Record: OFF NET: OFF Power: OFF Signal: NONE

Figure 6. Profile of Transect A22 (west side) in Alamo Lake.



Playback File: a32.004.sgy

D:\Alamo\Alamo Seismic Complete

92% Complete

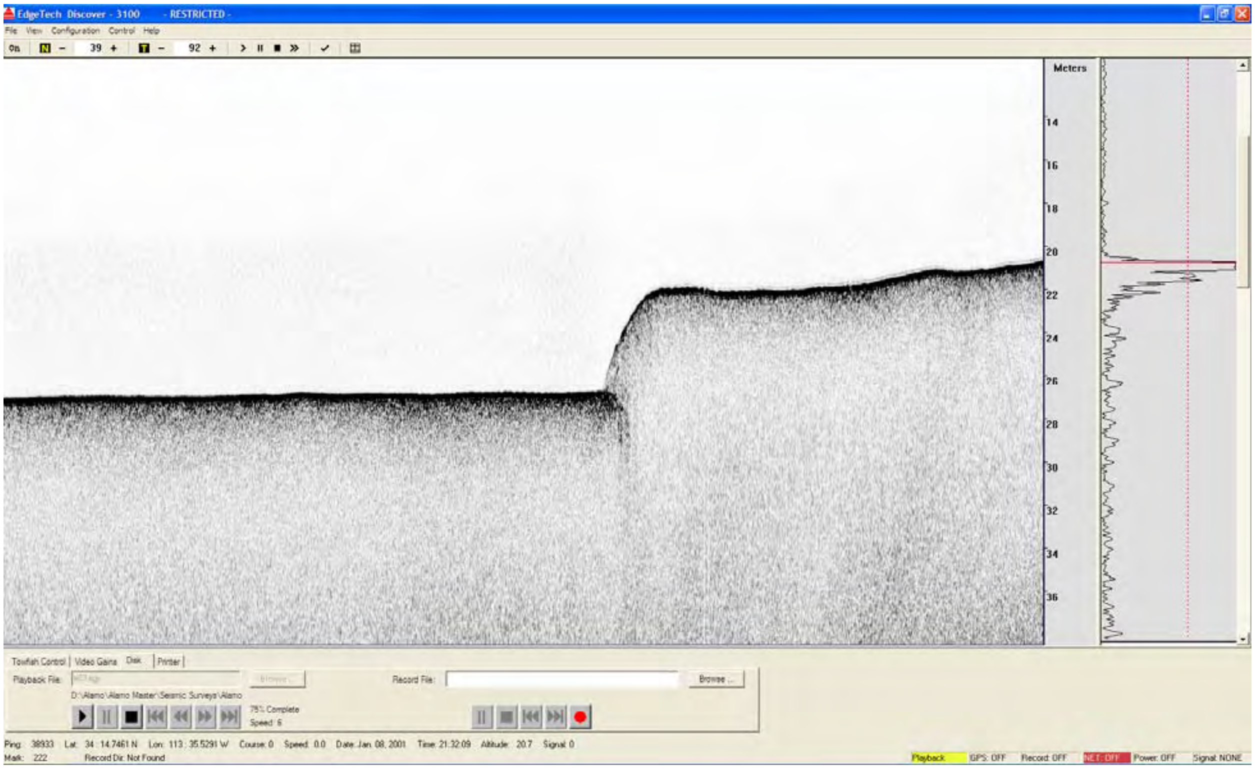
Speed: 4

Record File:

Ping: 65836 Lat: 34 : 16.0233 N Lon: 113 : 34.4901 W Course: 0 Speed: 0.0 Date: Jan. 08, 2001 Time: 17:31:19 Altitude: 16.1 Signal: 0

Mark: 222 Record Dir: Not Found

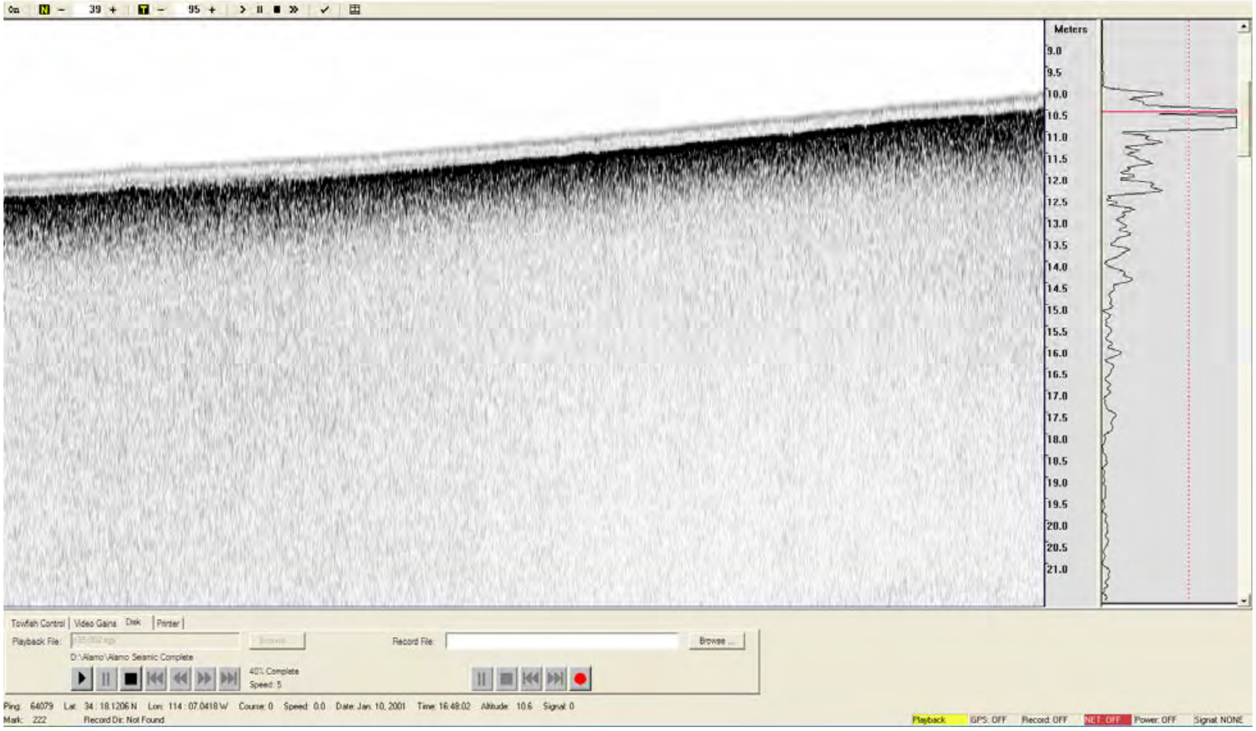
Figure 7. Profile of Transect A32.004 in Alamo Lake.



Playback File: A03.sgy
D:\Alamo\Alamo Master\Seismic Surveys\Alamo
75% Complete
Speed: 6
Record File:

Ping: 38933 Lat: 34 : 14.7461 N Lon: 113 : 35.5291 W Course: 0 Speed: 0.0 Date: Jan 08, 2001 Time: 21:32:09 Altitude: 20.7 Signal: 0
Mark: 222 Record Dir: Not Found

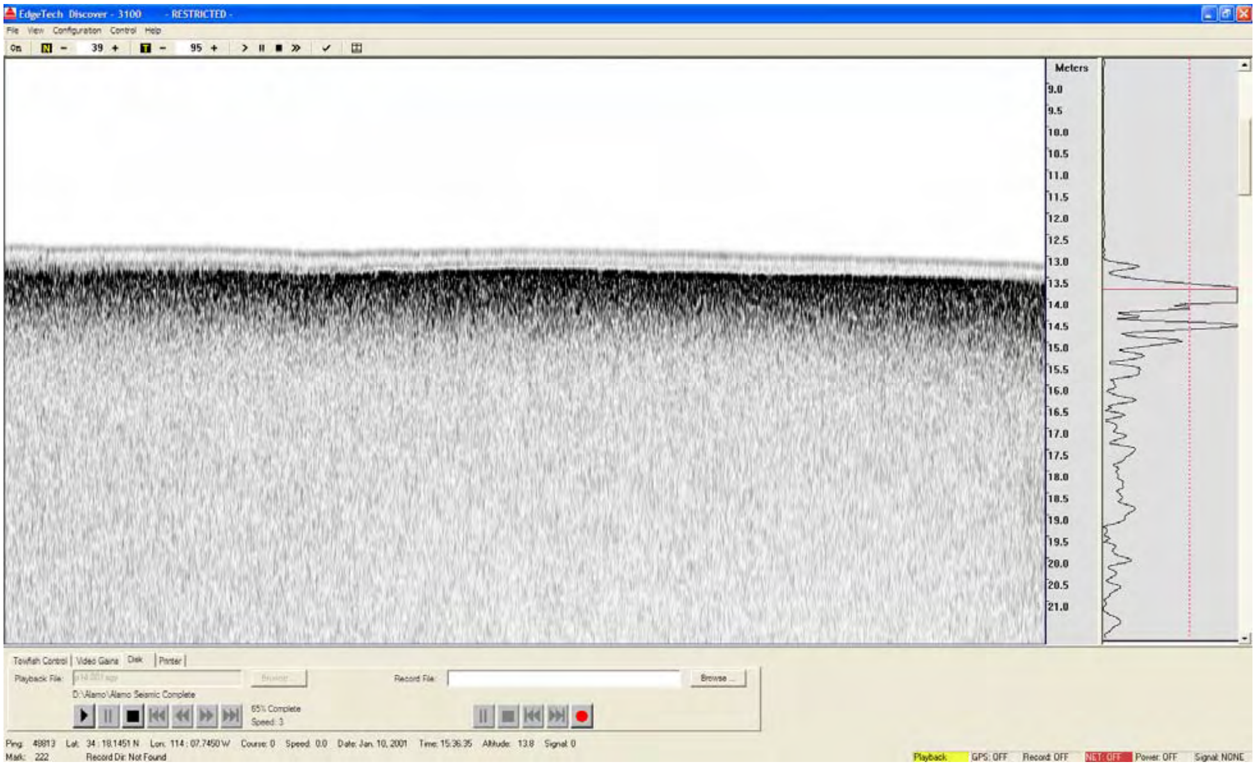
Figure 8. Profile of Transect A03 in Alamo Lake.



Playback File:
D:\Alamo\Alamo Seismic Complete
Record File:

Ping: 64079 Lat: 34 : 18.1206 N Lon: 114 : 07.0418 W Course: 0 Speed: 0.0 Date: Jan. 10, 2001 Time: 16:48:02 Altitude: 10.6 Signal: 0
Mark: 222 Record Dir: Not Found

Figure 9. Profile of Transect P35.002 in Havasu Lake.

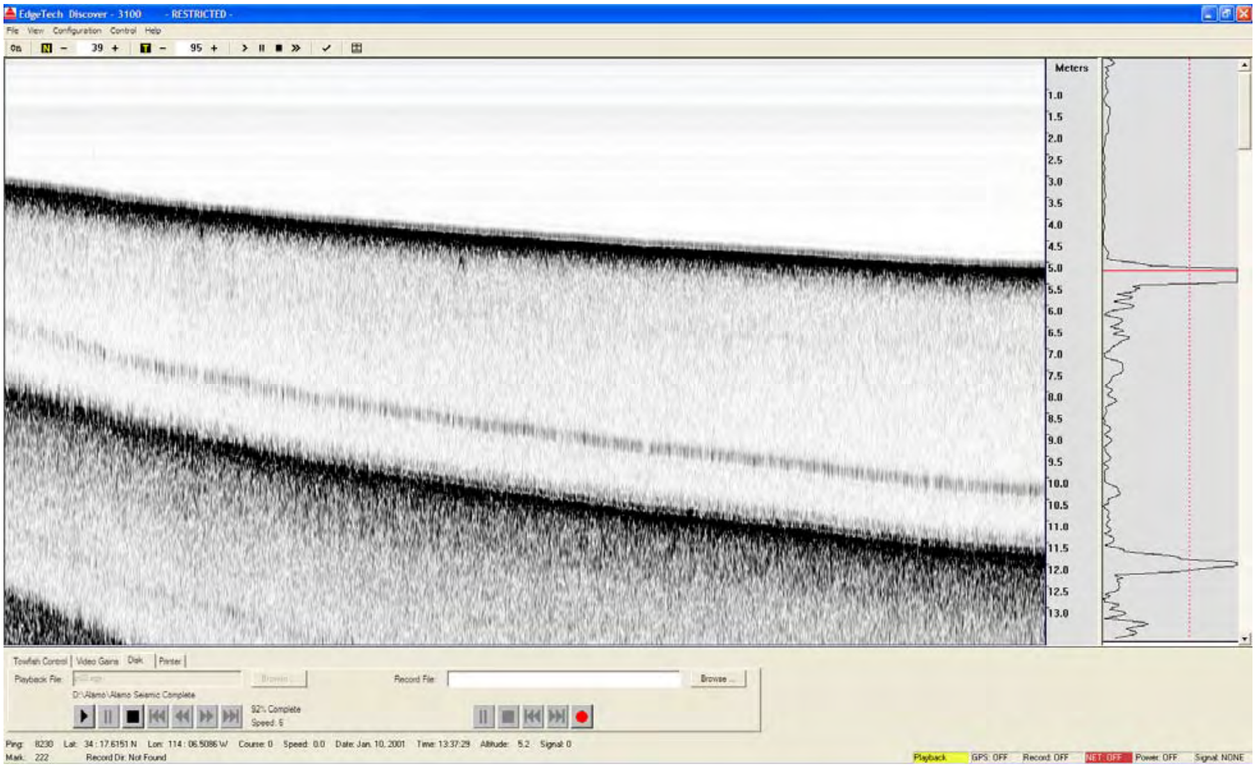


Playback File: p14.001.sgy
D:\Alamo\Alamo Seismic Complete
65% Complete
Speed: 3
Record File:

Ping: 48813 Lat: 34 : 18.1451 N Lon: 114 : 07.7450 W Course: 0 Speed: 0.0 Date: Jan. 10, 2001 Time: 15:36:35 Altitude: 13.8 Signal: 0
Mark: 222 Record Dir: Not Found

Playback GPS: OFF Record: OFF NET: OFF Power: OFF Signal: NONE

Figure 10. Profile of Transect P14.001 in Havasu Lake.



Playback File:
D:\Alamo\Alamo Seismic Complete
92% Complete
Speed: 6
Record File:
Ping: 8230 Lat: 34 : 17.6151 N Lon: 114 : 06.5086 W Course: 0 Speed: 0.0 Date: Jan. 10, 2001 Time: 13:37:29 Altitude: 5.2 Signal: 0
Mark: 222 Record Dir: Not Found

Figure 11. Profile of Transect P03 in Havasu Lake.

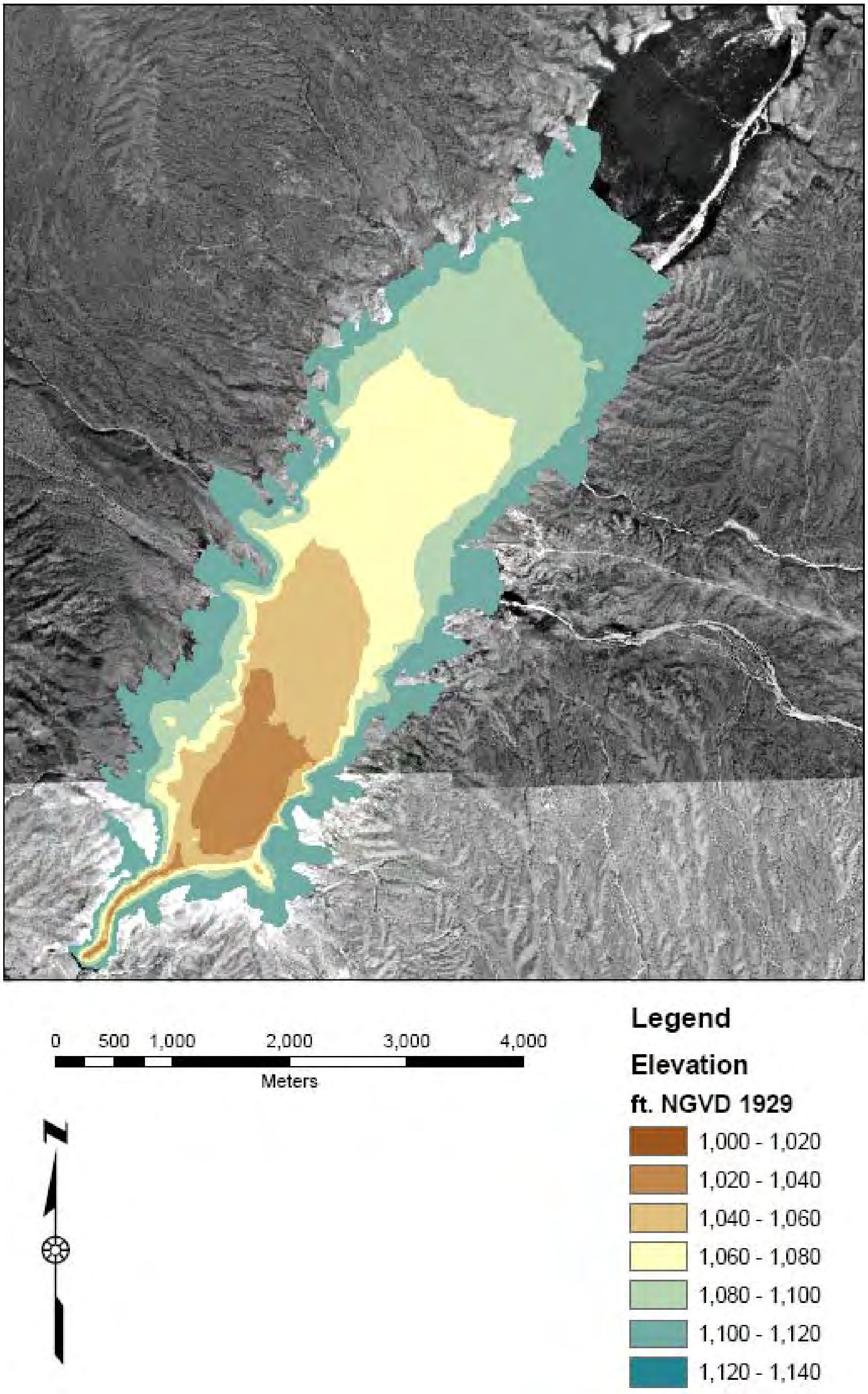


Figure 12. Bathymetric map of Alamo Lake.

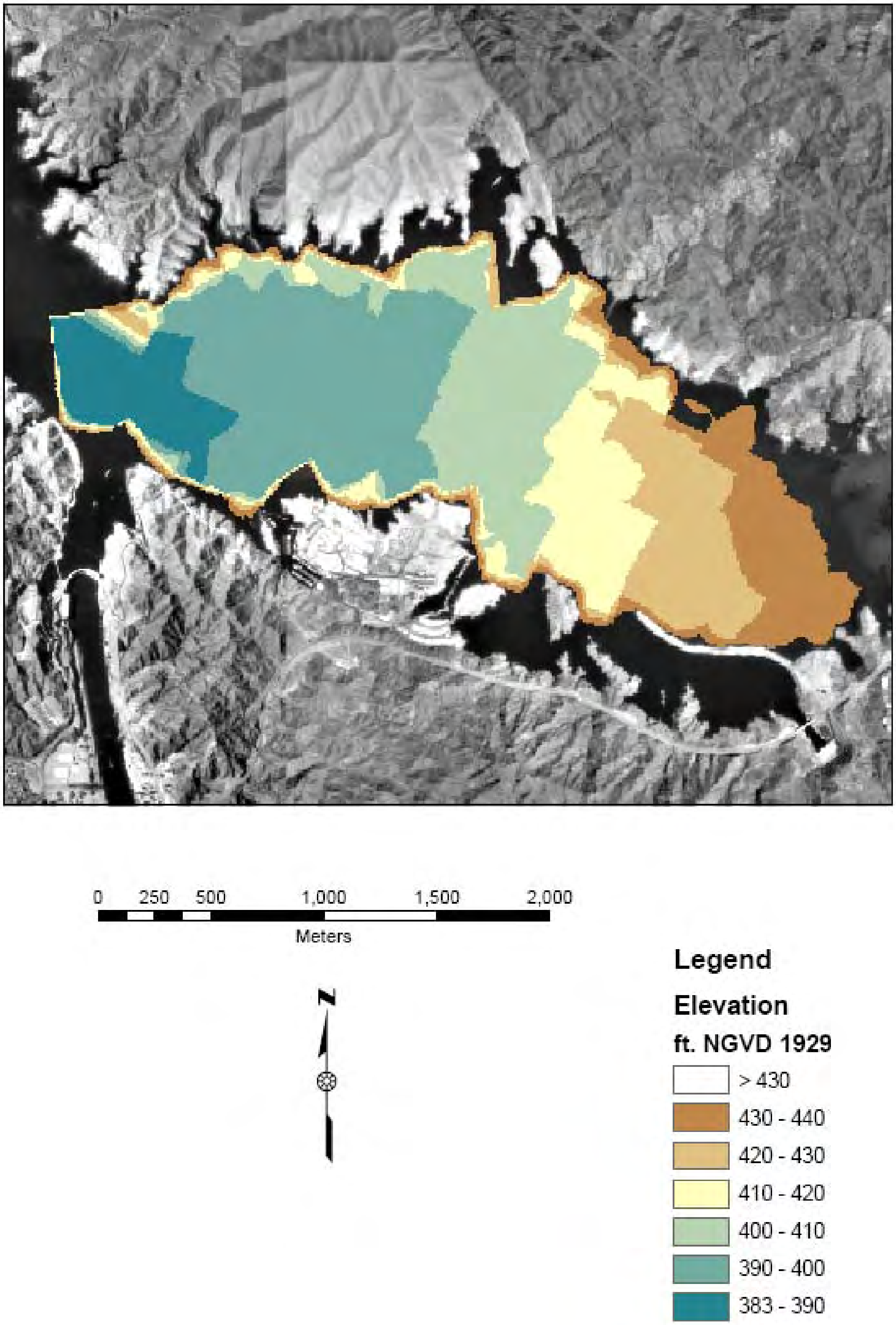


Figure 13. Bathymetric map of the Bill Williams delta of Lake Havasu.

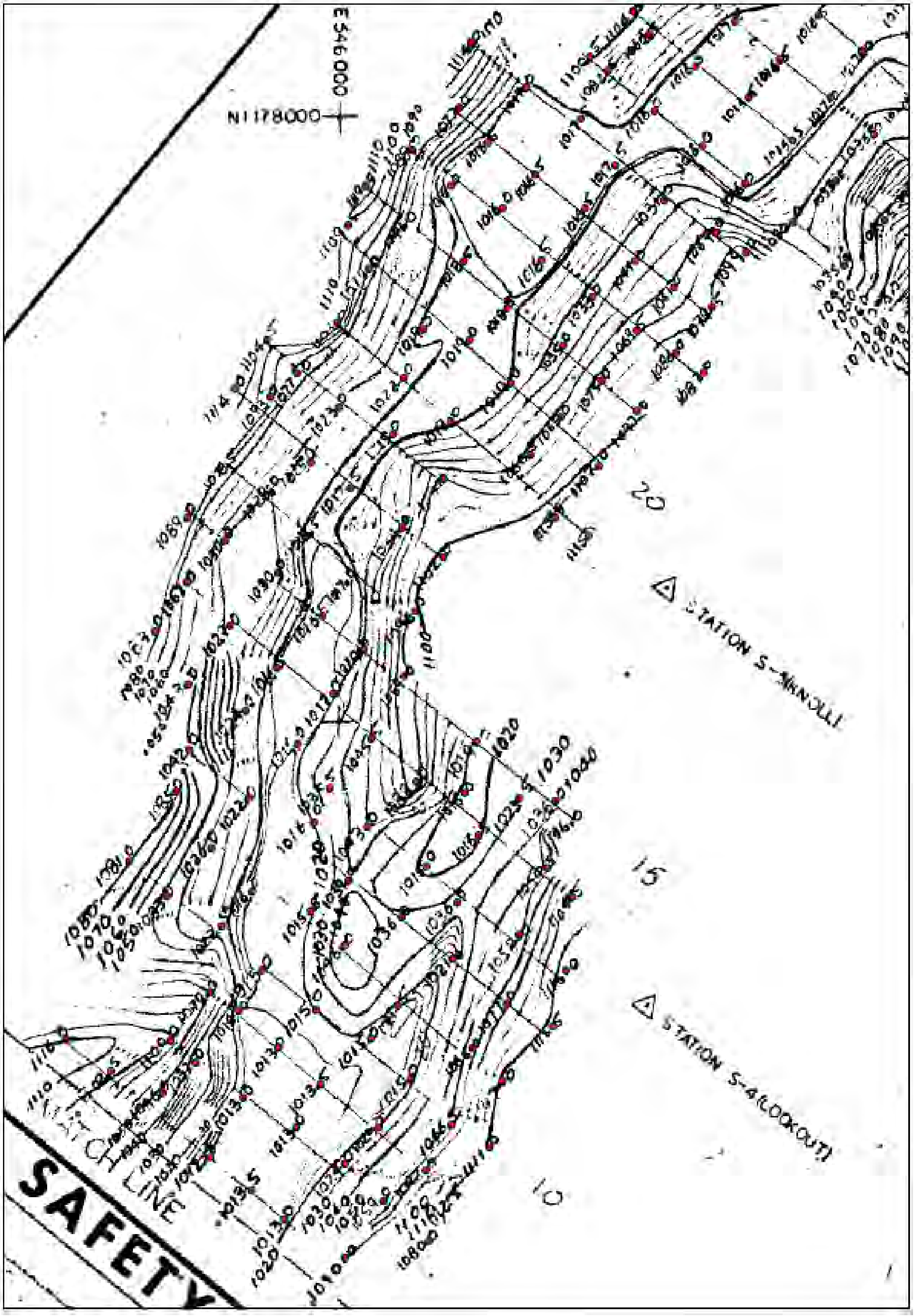


Figure 14. Part of Sheet 5 of the 1985 US Army Corps of Engineers survey of Alamo Lake.

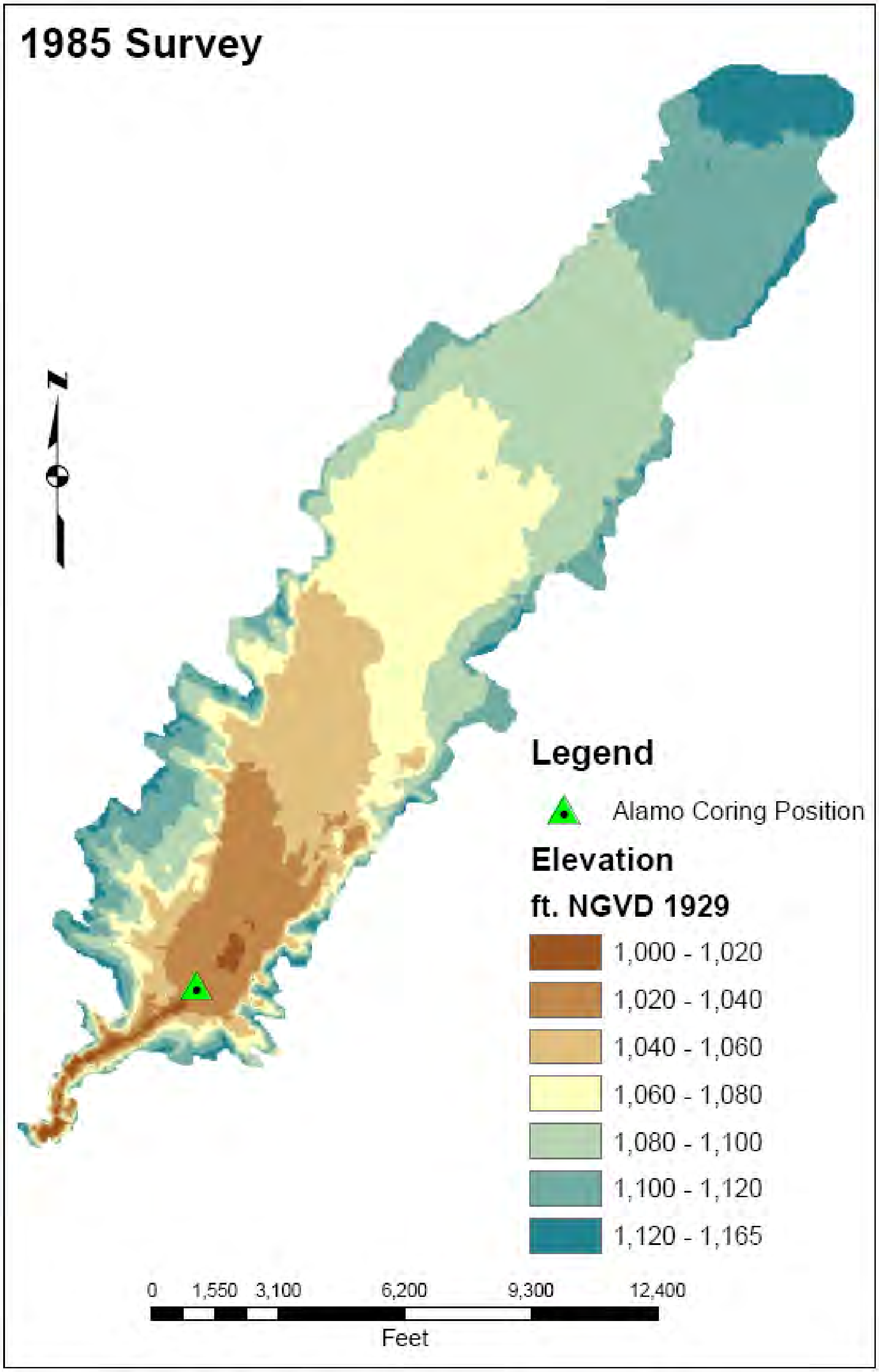


Figure 15. Bathymetric map of 1985 survey of Alamo Lake.

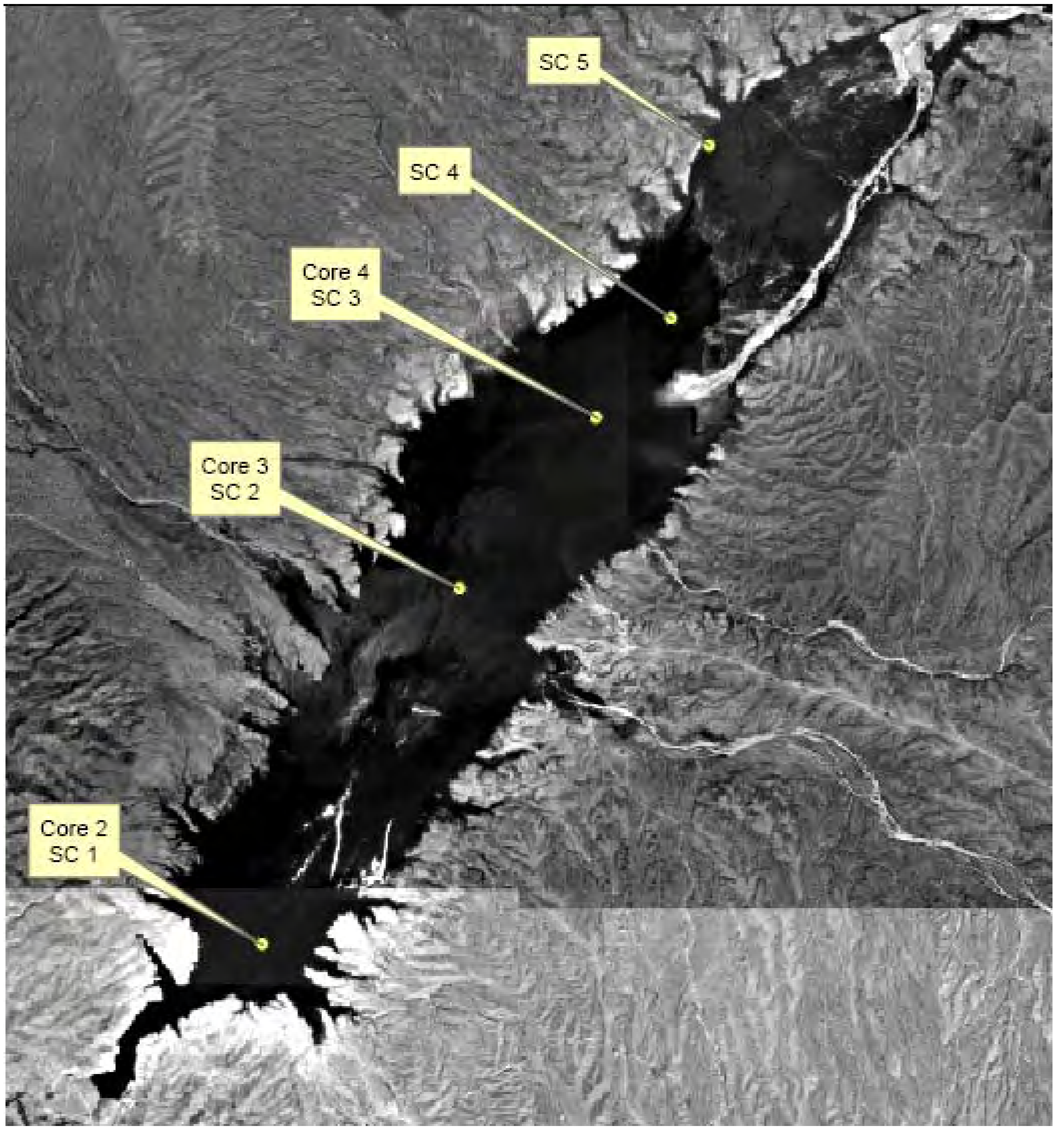
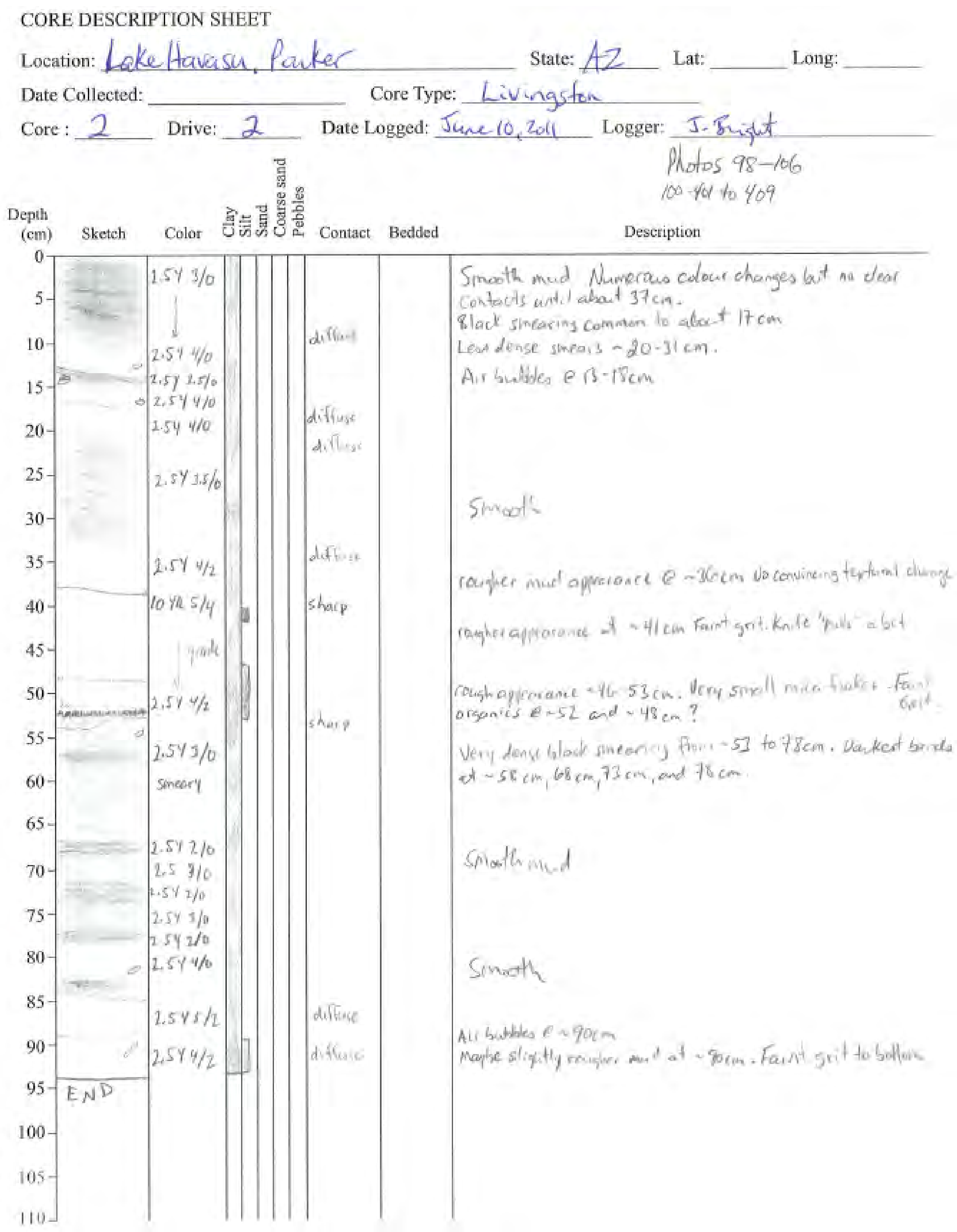


Figure 16. Coring locations for Alamo Lake.



CORE DESCRIPTION SHEET

Location: Lake Havasu, Parker State: AZ Lat: ______ Long: ______

Date Collected: ______ Core Type: Livingston

Core : 2 Drive: 2 Date Logged: June 10, 2011 Logger: J. Bright

Photos 98–106
100-401 to 409

Depth (cm)	Sketch	Color	Clay	Silt	Sand	Coarse sand	Pebbles	Contact	Bedded	Description
0		1.5Y 3/0								Smooth mud Numerous colour changes but no clear contacts until about 37cm.
5										Black smearing common to about 17cm
10		2.5Y 4/0						diffuse		Less dense smears ~20-31 cm.
15		2.5Y 2.5/0 2.5Y 4/0								Air bubbles @ 13-18cm
20		2.5Y 4/0						diffuse diffuse		
25		2.5Y 3.5/0								
30										Smooth
35		2.5Y 4/2						diffuse		rougher mud appearance @ ~36cm No convincing textural change
40		10YR 5/4						sharp		rougher appearance at ~41cm Faint grit. Knife "pulls" a bit
45		grade								
50		2.5Y 4/2								rough appearance ~46-53cm. Very small mica flakes. Faint grit organics @~52 and ~48cm ?
55		2.5Y 3/0						sharp		Very dense black smearing from ~53 to 78cm. Darkest bands at ~58 cm, 68 cm, 73 cm, and 78 cm.
60		smeary								
65		2.5Y 2/0								
70		2.5 3/0 2.5Y 2/0								Smooth mud
75		2.5Y 3/0 2.5Y 2/0								
80		2.5Y 4/0								Smooth
85		2.5Y 5/2						diffuse		
90		2.5Y 4/2						diffuse		Air bubbles @ ~90cm Maybe slightly rougher mud at ~90cm. Faint grit to bottom
95	END									
100										
105										
110										

Figure 17. Lithologic core description sheet.

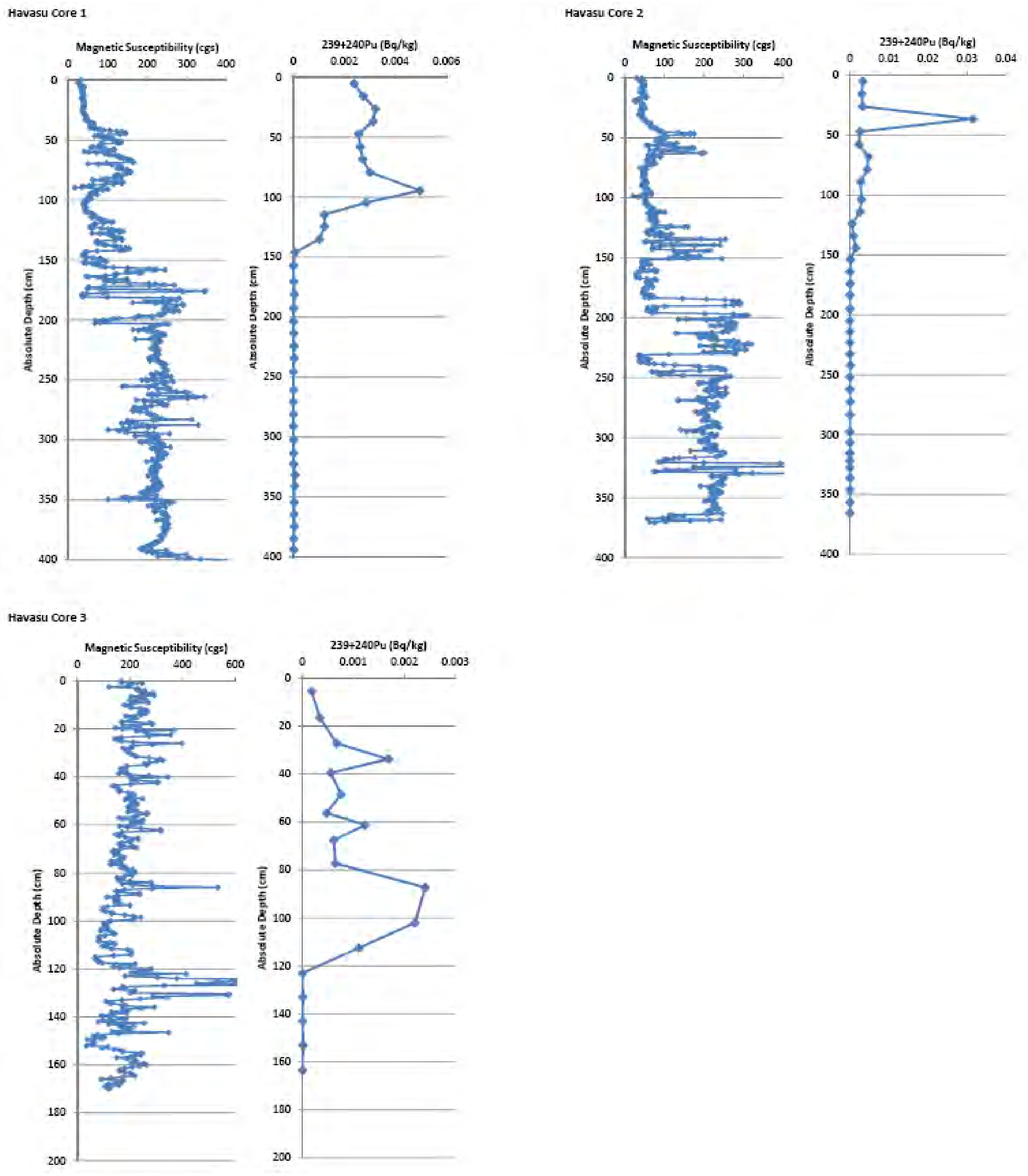


Figure 18. Magnetic susceptibility and plutonium curves for Lake Havasu cores.

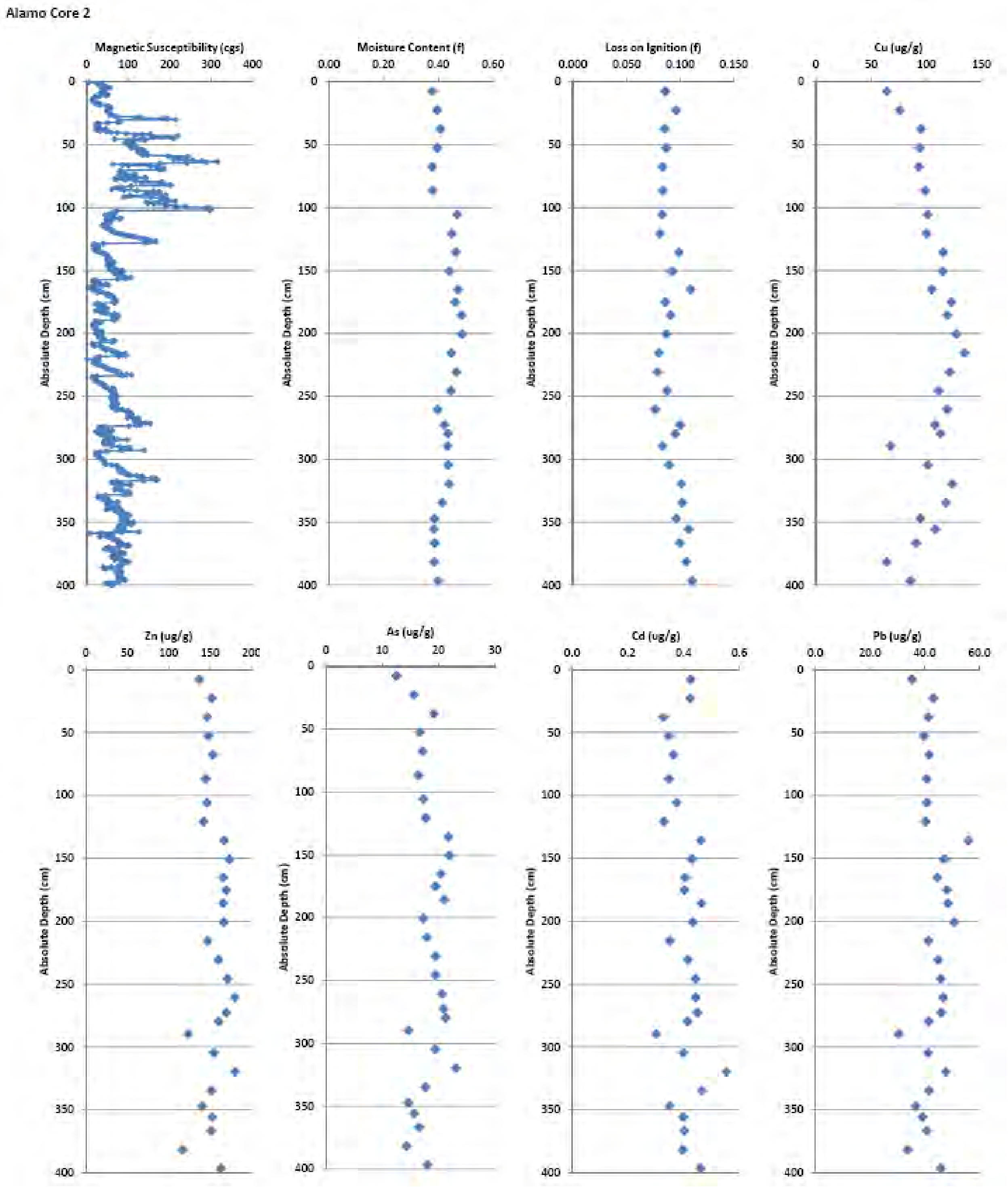


Figure 19. Metals data for Alamo Lake Core 2.

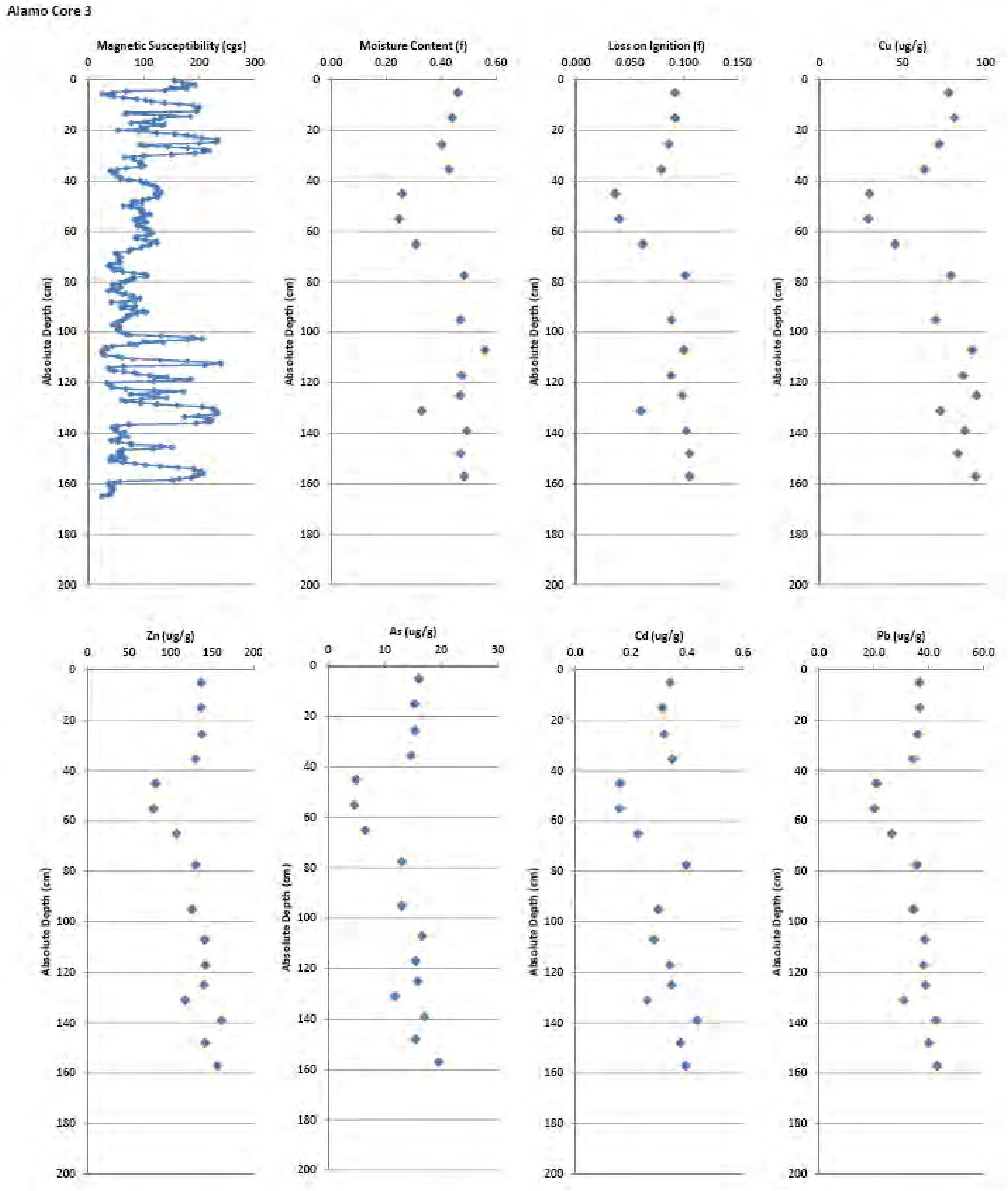


Figure 20. Metals data for Alamo Lake Core 3.

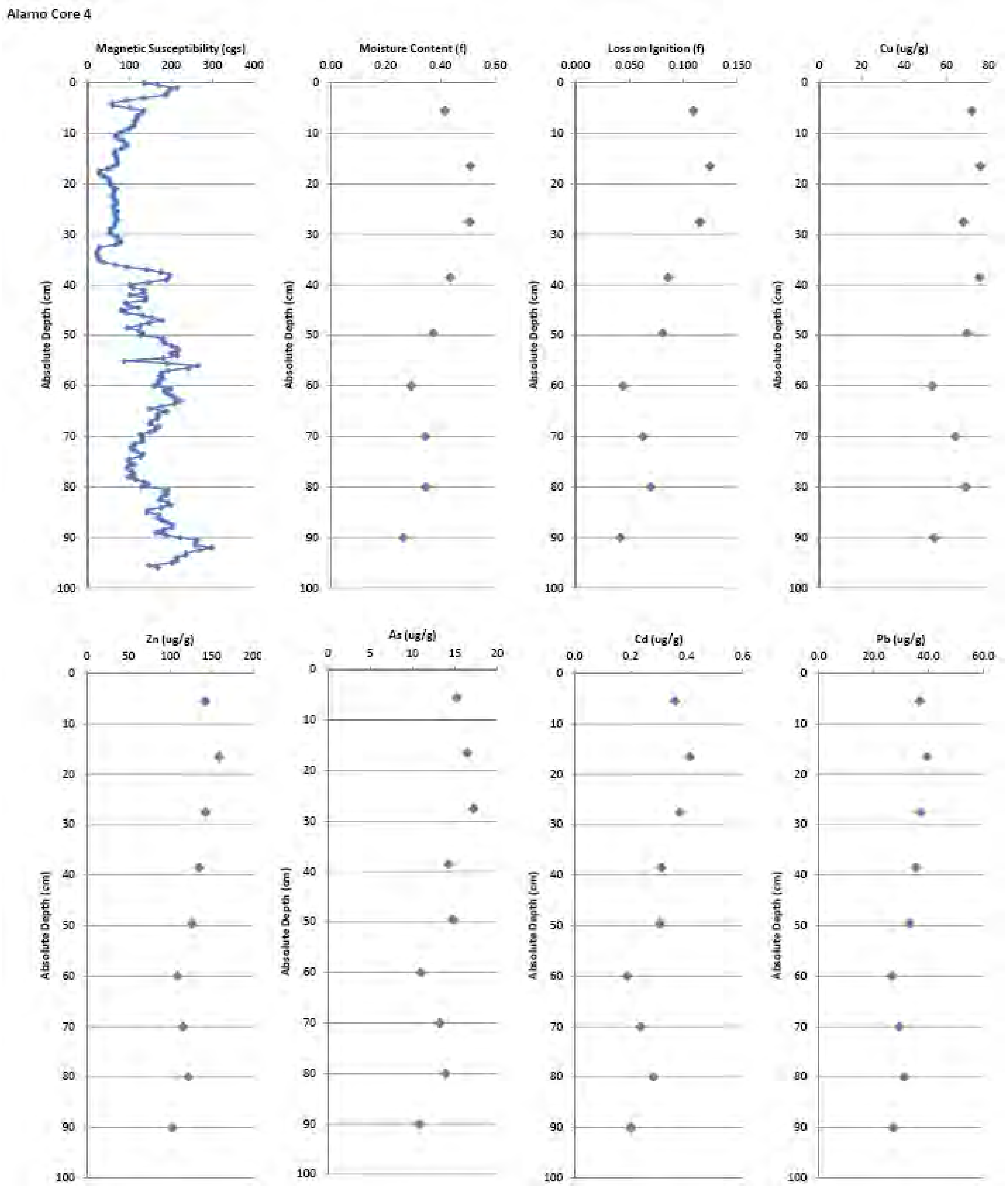


Figure 21. Metals data for Alamo Lake Core 4.

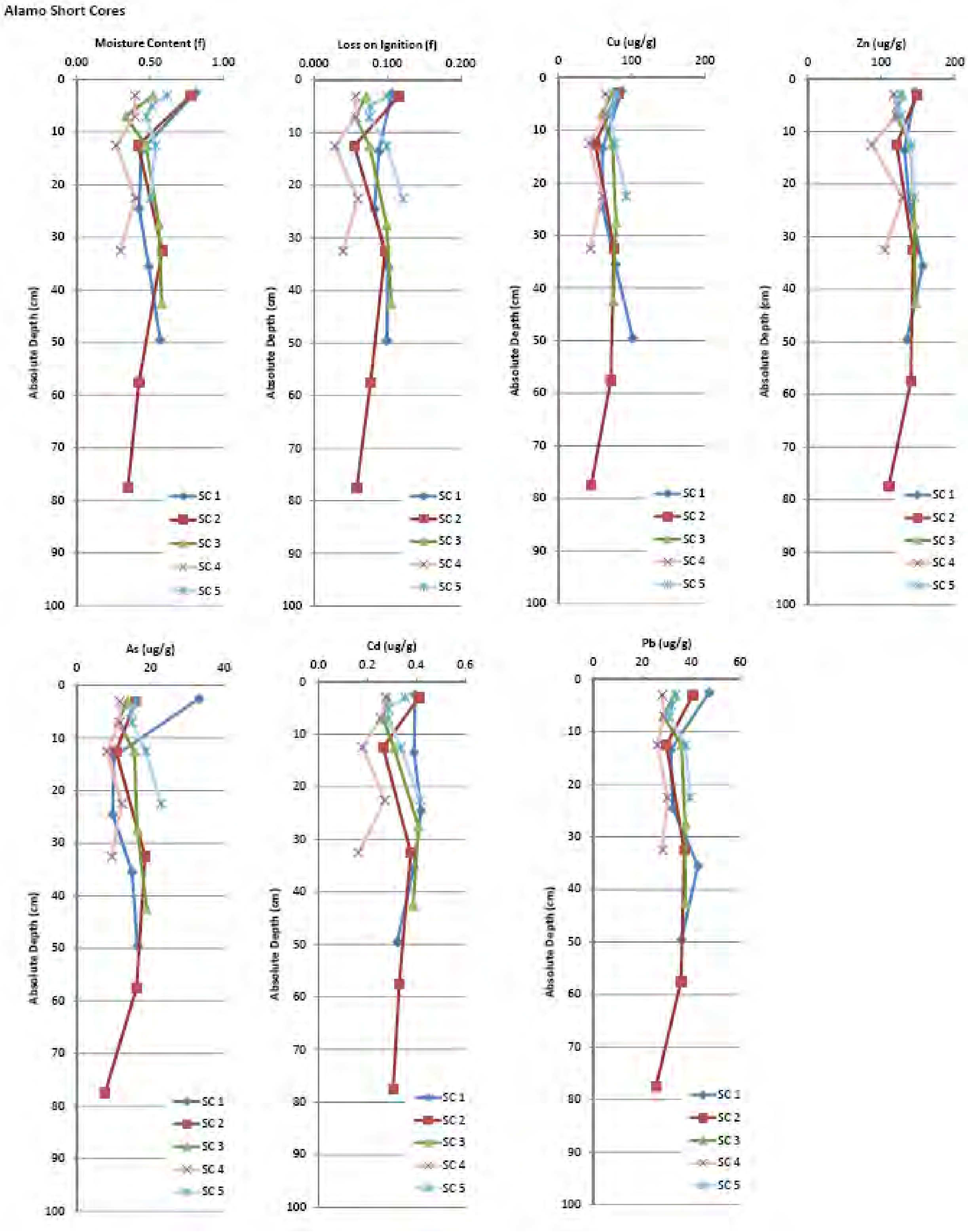


Figure 22. Metals data for Alamo Lake surface cores.

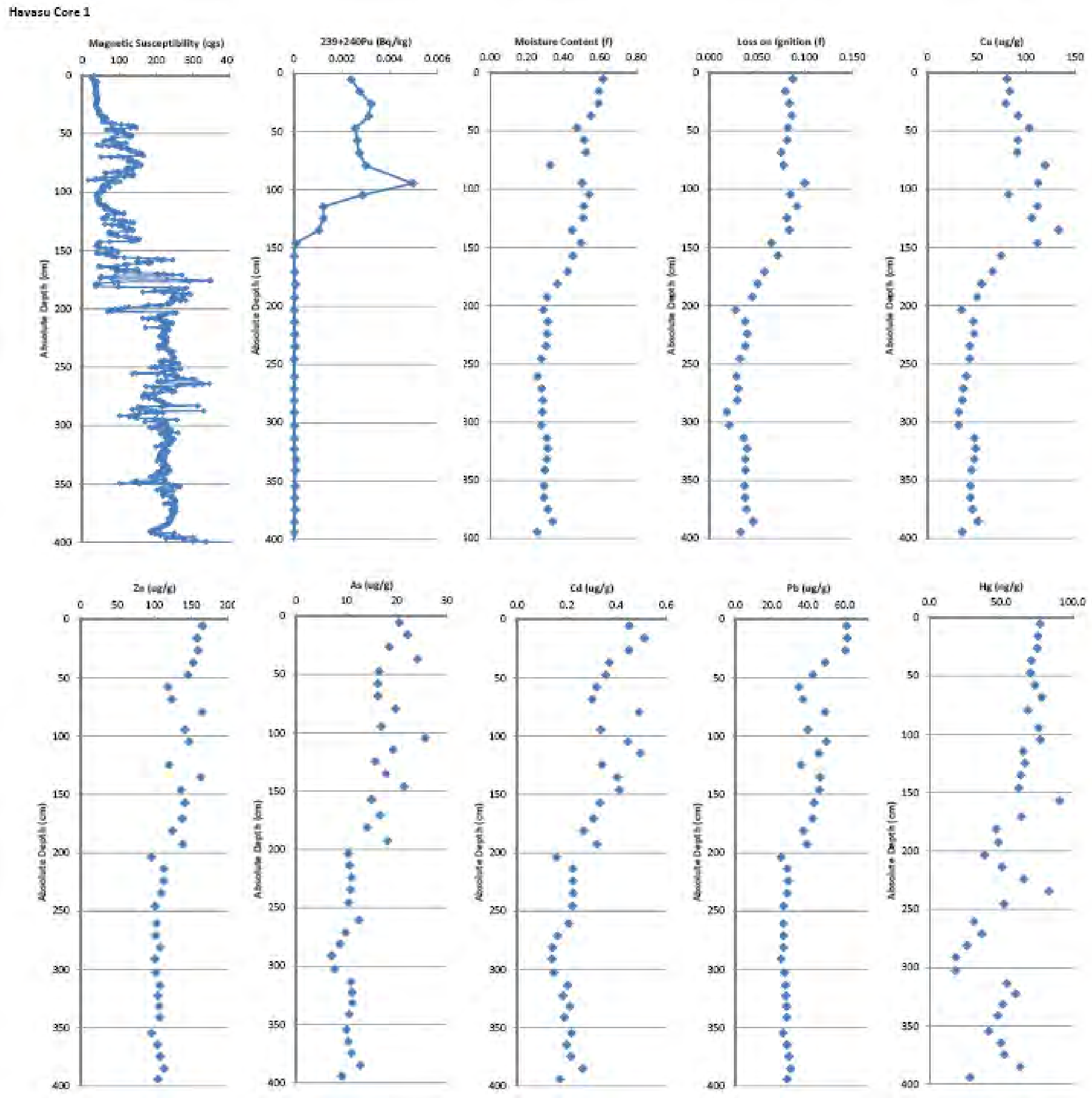


Figure 23. Metals data for Lake Havasu Core 1.

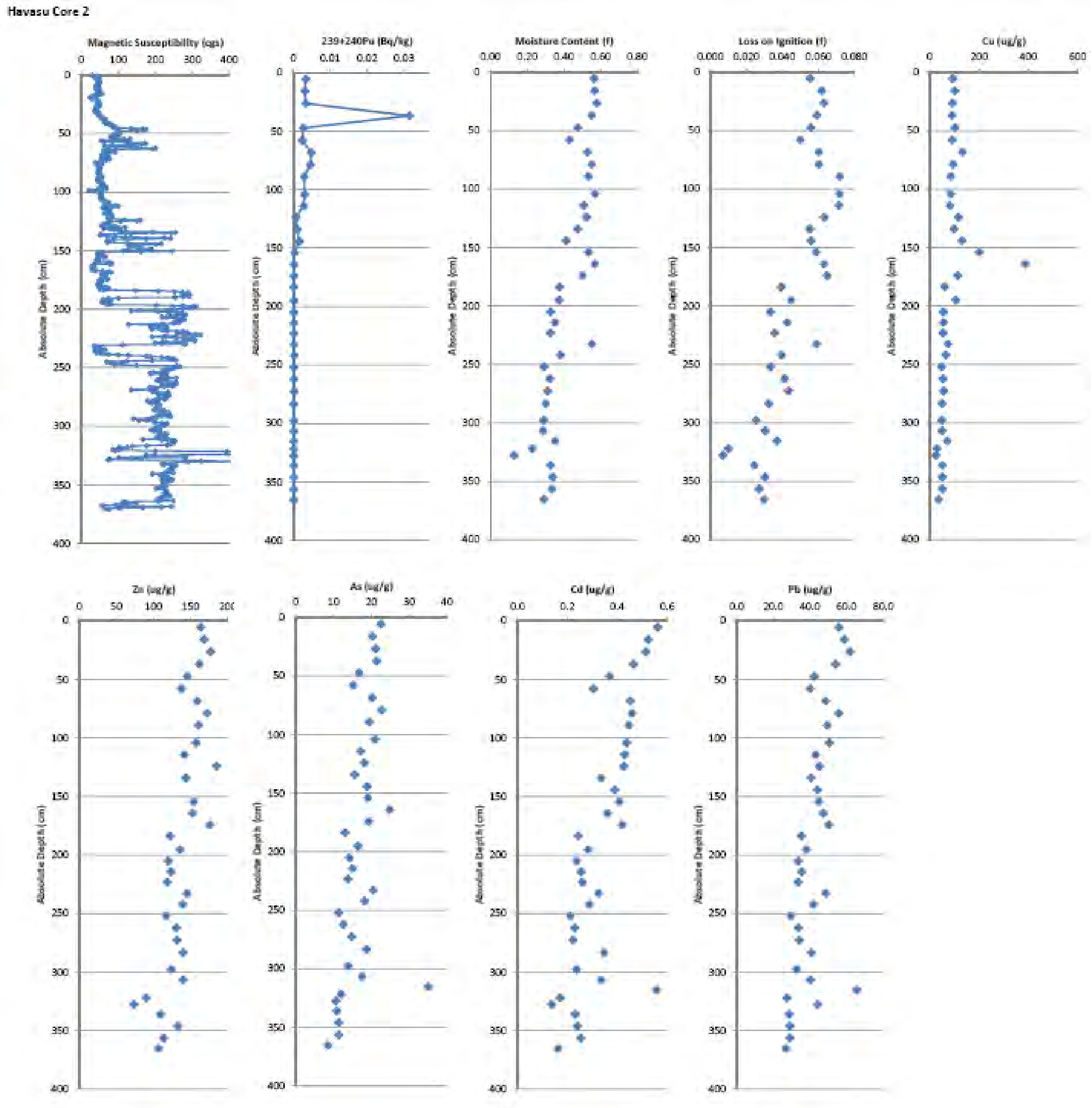


Figure 24. Metals data for Lake Havasu Core 2.

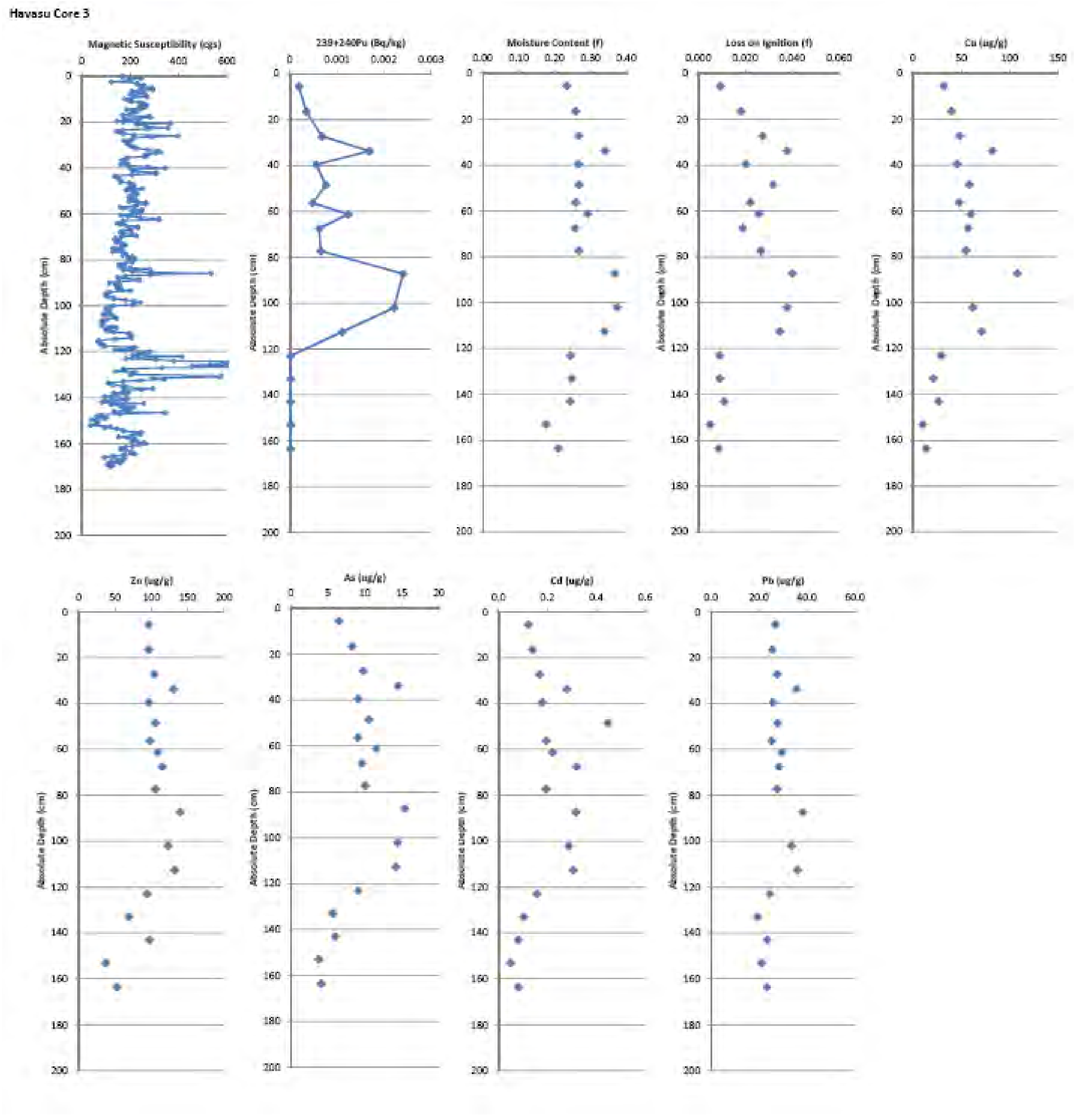


Figure 25. Metals data for Lake Havasu Core 3.

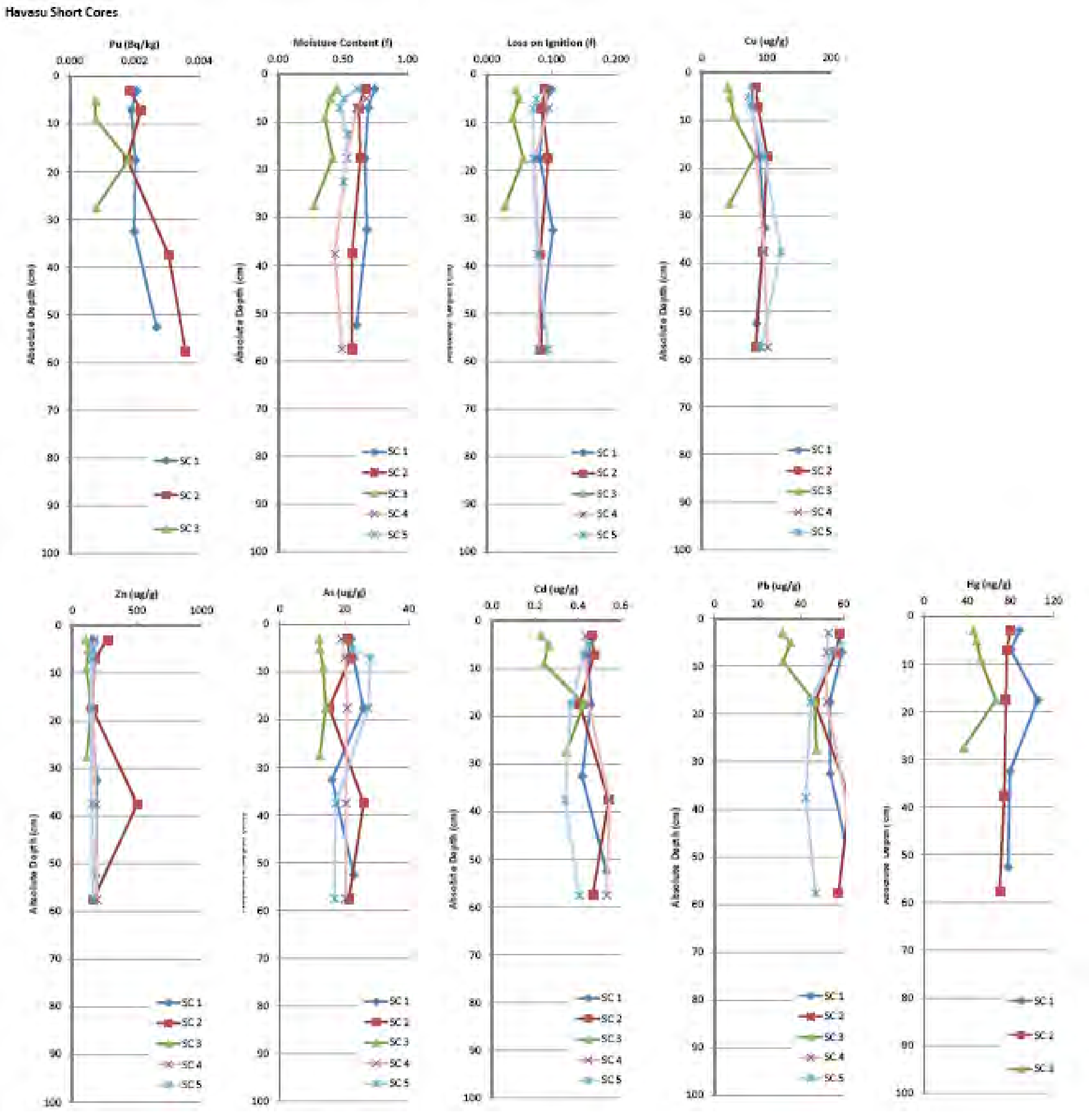


Figure 26. Metals data for Lake Havasu surface cores.

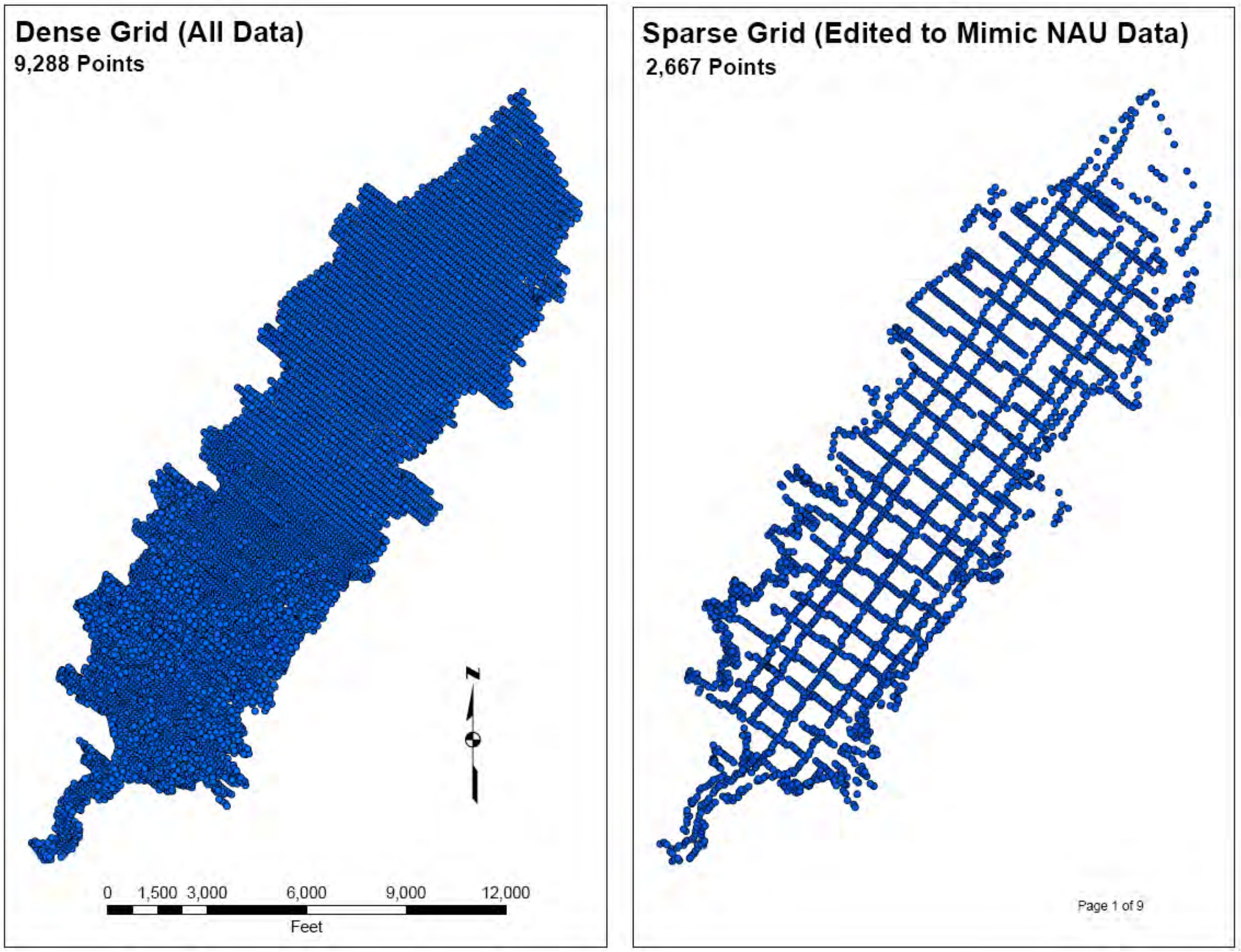


Figure 27. The original dataset for the 1985 bathymetric map (left). The modified dataset was produced from the original dataset (left) with data deleted to mimic the data density of the current survey.

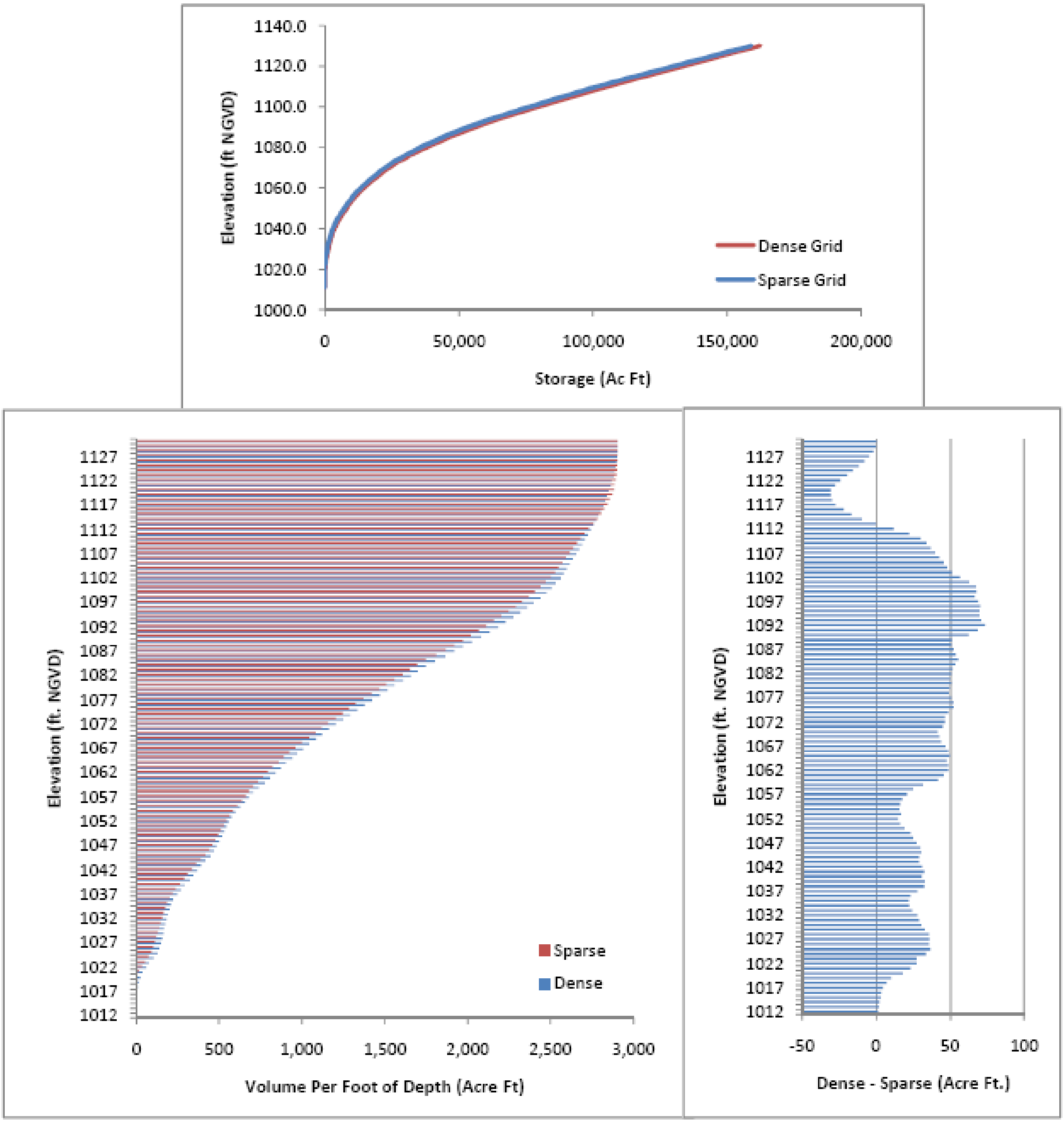


Figure 28. Elevation vs storage relationships for dense and sparse grids (top), elevation vs volume relationships for sparse and dense grids (bottom left), and the difference between the elevation vs volume relationships (bottom right).

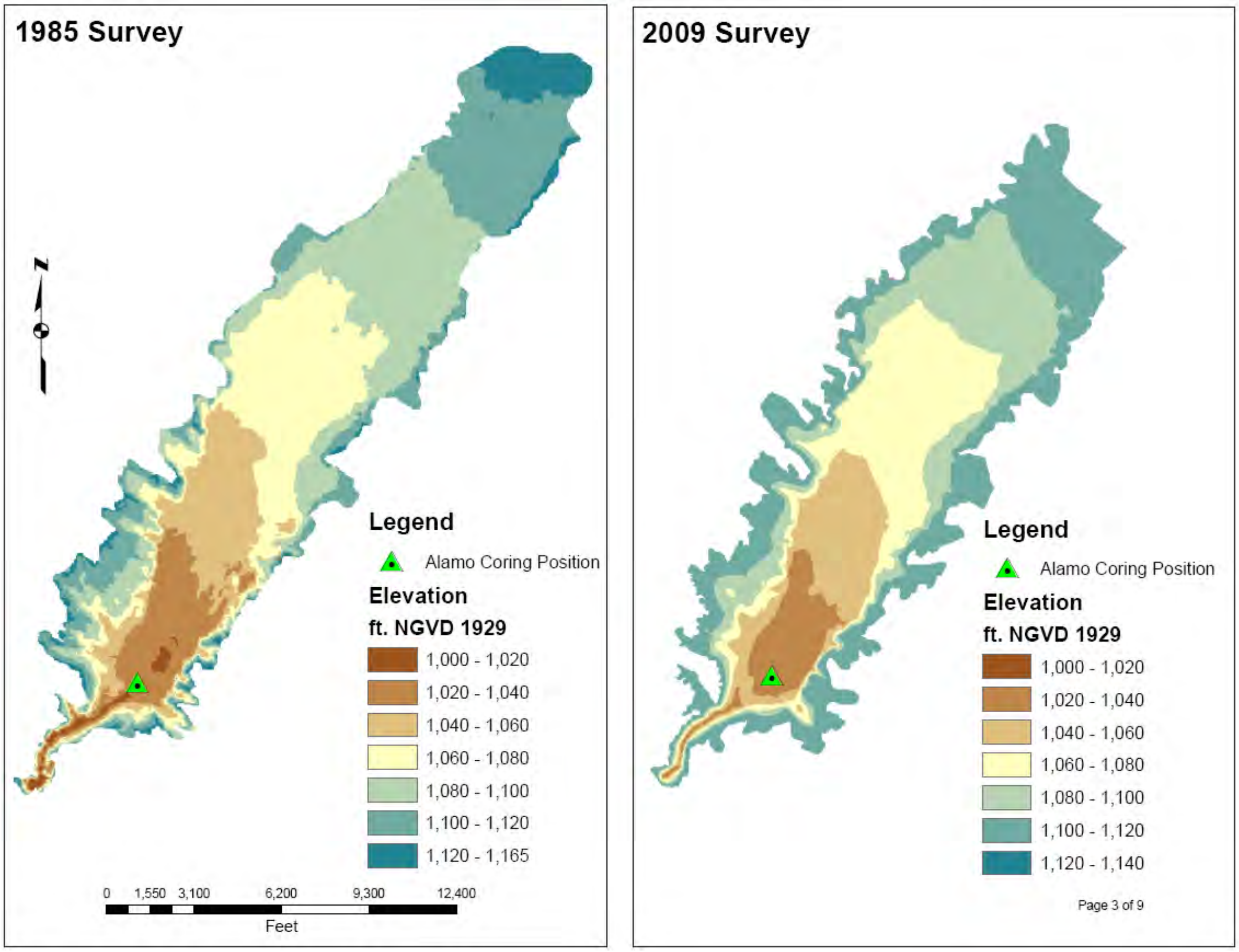


Figure 29. Comparison of 1985 (left) and current (right) bathymetric survey results.

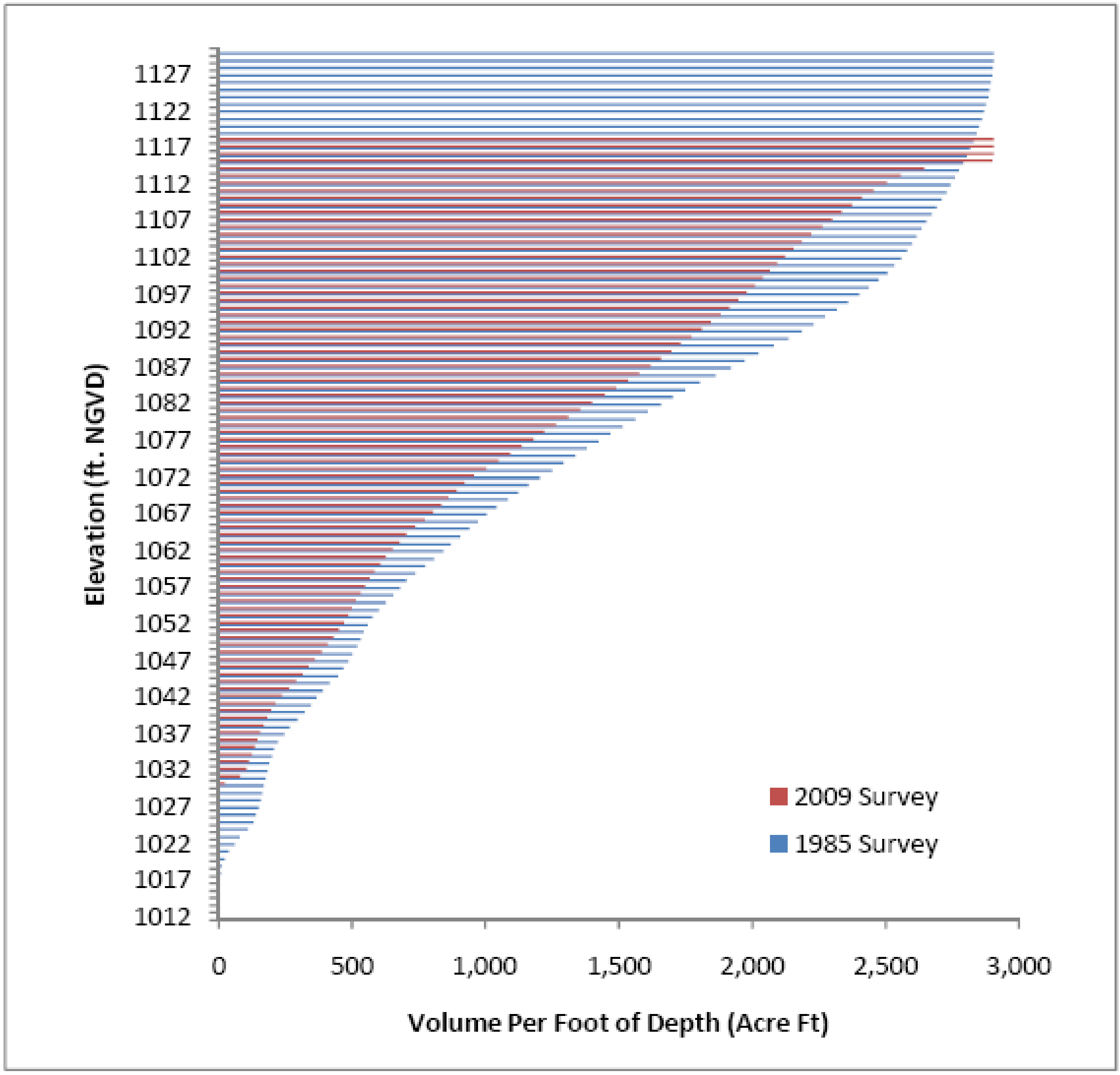


Figure 30. Comparison of elevation vs storage results for the two bathymetric surveys.

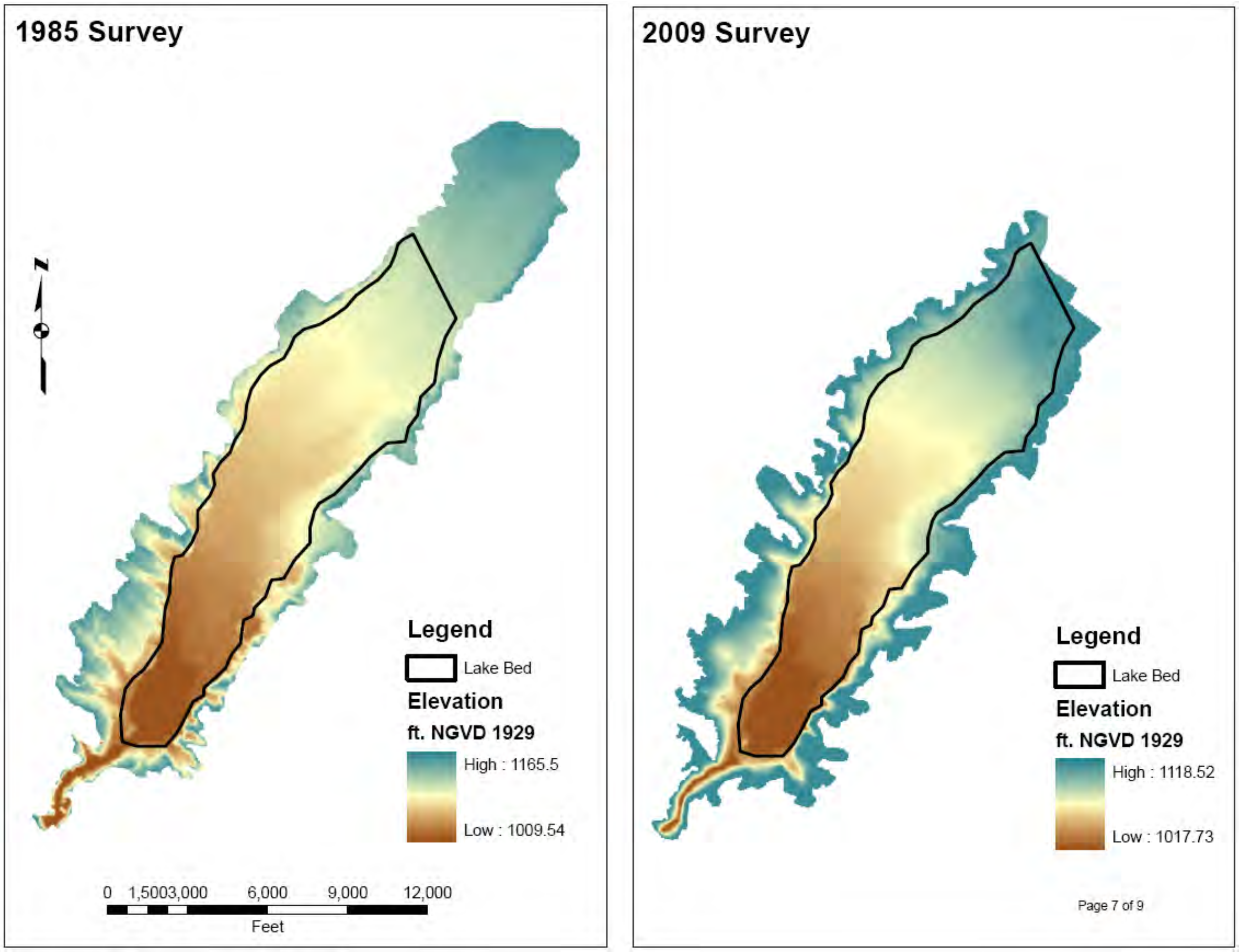


Figure 31. Comparison of lake bed area overlayed on 1985 and 2009 survey DEMs.

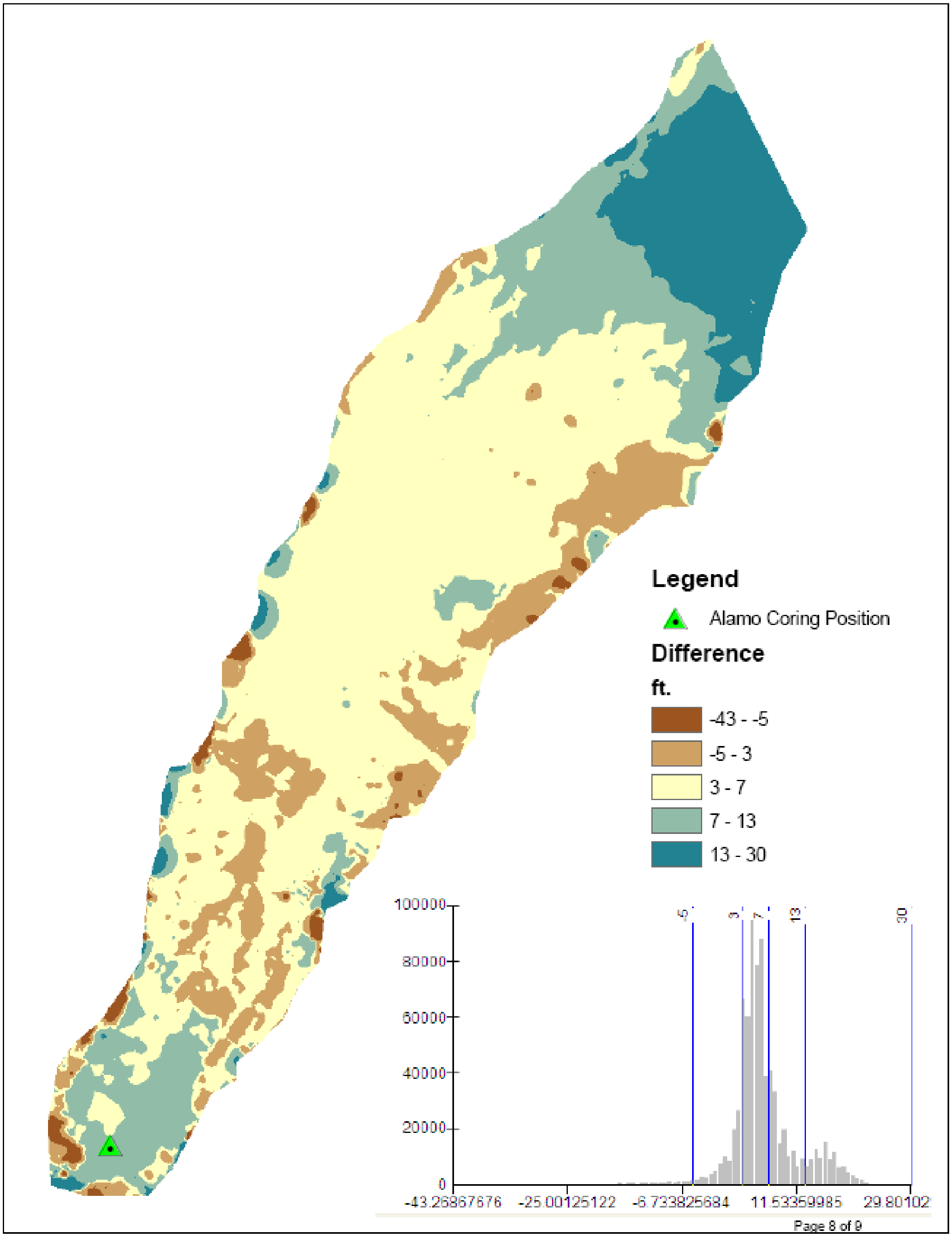


Figure 32. Difference in elevation between 1985 and 2009 in the lake bed region of Alamo Lake.

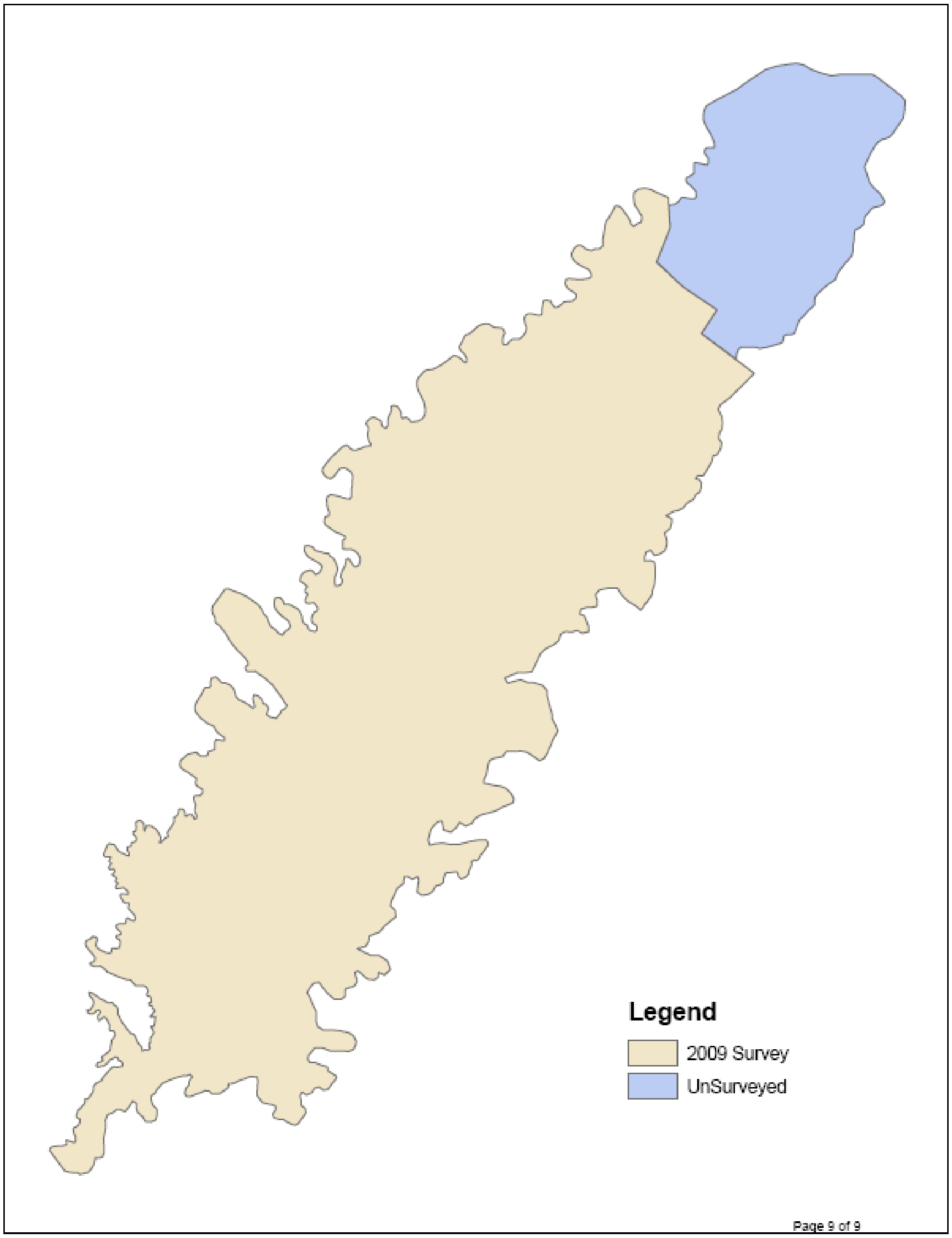


Figure 33. Area of Alamo Lake un-surveyed in current mapping.

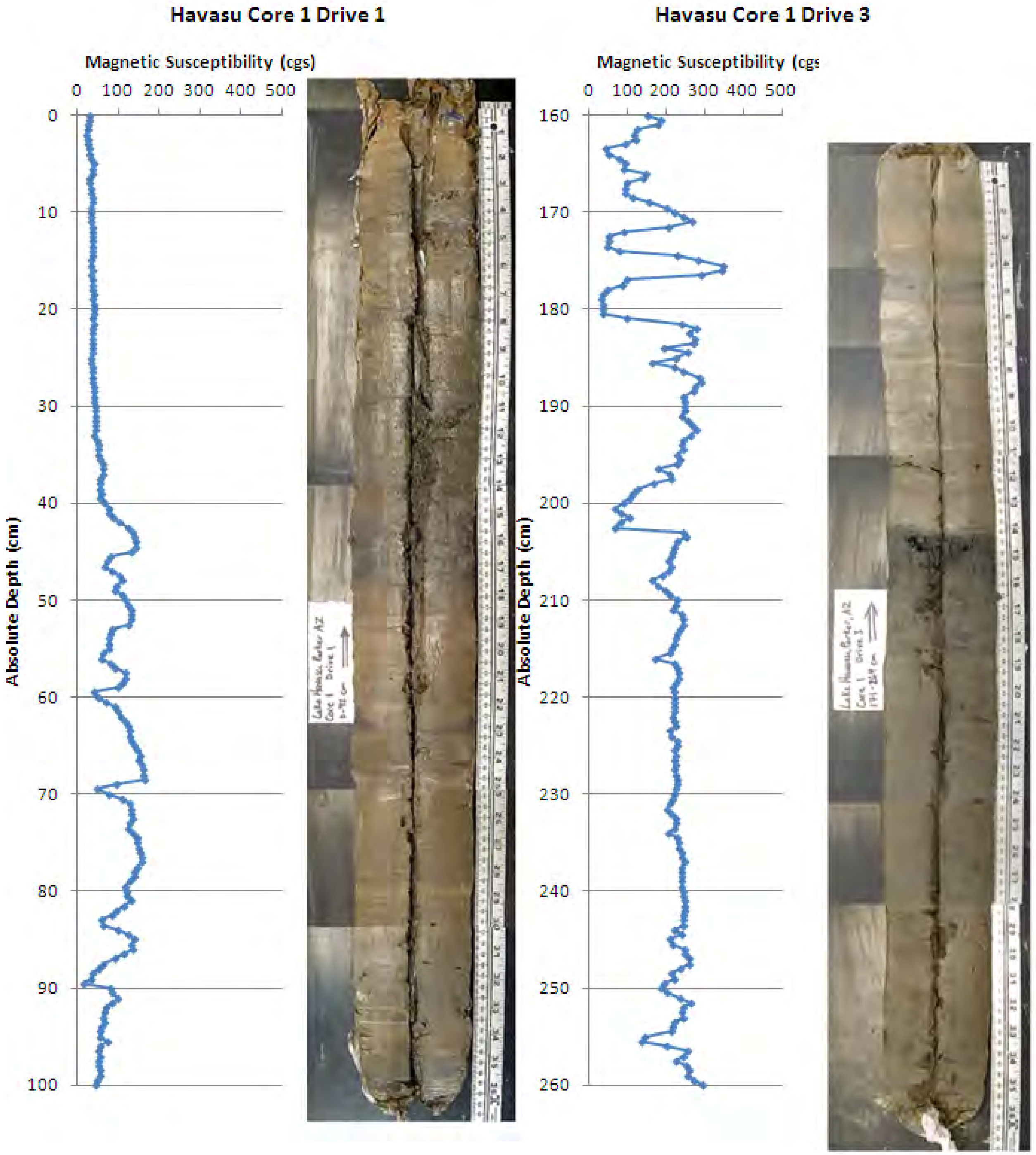


Figure 34. Magnetic susceptibility and photo images of Lake Havasu Cores C1D1 and C1D3.

Table 1. Quality Assurance Data for Metals Analysis.

SRM	Analyte	Units	n	Mean	Stdev	RSD	Certified
USGS SoNE-1	Cu	ug/g	7	24.88	3.20	12.9%	24
	Zn	ug/g	7	86.15	3.75	4.3%	87
	As	ug/g	7	12.59	0.41	3.3%	12.6
	Cd	ug/g	7	0.47	0.06	12.0%	0.48
	Pb	ug/g	7	25.09	2.12	8.5%	25.6
USGS AGV-2	Cu	ug/g	7	52.21	3.20	6.1%	53
	Zn	ug/g	7	86.37	3.75	4.3%	86
	Pb	ug/g	7	13.64	2.12	15.5%	13
MESS-3	Hg	ng/g	4	88.91	2.28	2.6%	91

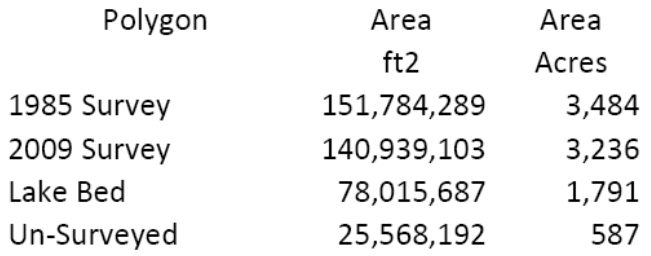
Table 2. Summary of Cores Collected.

Site	Latitude	Longitude	Length of Core (cm)
Alamo Core 2	N 34^o 14’ 34.5”	113^o 35’ 15.4”	414
Alamo Core 3	N 34^o 16’ 04.6”	113^o 34’ 18.9”	165
Alamo Core 4	N 34^o 16’ 48.2”	113^o 33’ 39.2”	96
Alamo Short Core 1	N 34^o 14’ 34.5”	113^o 35’ 15.4”	50
Alamo Short Core 2	N 34^o 16’ 04.6”	113^o 34’ 18.9”	80
Alamo Short Core 3	N 34^o 16’ 48.2”	113^o 33’ 39.2”	45
Alamo Short Core 4	N 34^o 17’ 13.3”	113^o 33’ 17.3”	35
Alamo Short Core 5	N 34^o 17’ 56.8”	113^o 33’ 07.2”	30
Havasu Core 1	N 34^o 18’ 15.8”	113^o 07’ 52.2”	406
Havasu Core 2	N 34^o 18’ 13.6”	113^o 07’ 01.7”	371
Havasu Core 3	N 34^o 17’ 56.2”	113^o 06’ 18.8”	170
Havasu Short Core 1	N 34^o 18’ 15.8”	113^o 07’ 52.2”	55
Havasu Short Core 2	N 34^o 18’ 13.6”	113^o 07’ 01.7”	65
Havasu Short Core 3	N 34^o 17’ 56.2”	113^o 06’ 18.8”	30
Havasu Short Core 4	N 34^o 18’ 03.7”	113^o 06’ 40.8”	55
Havasu Short Core 5	N 34^o 18’ 02.5”	113^o 07’ 51.5”	65

Table 3. Sedimentation Rates Based on Core Chronometry.

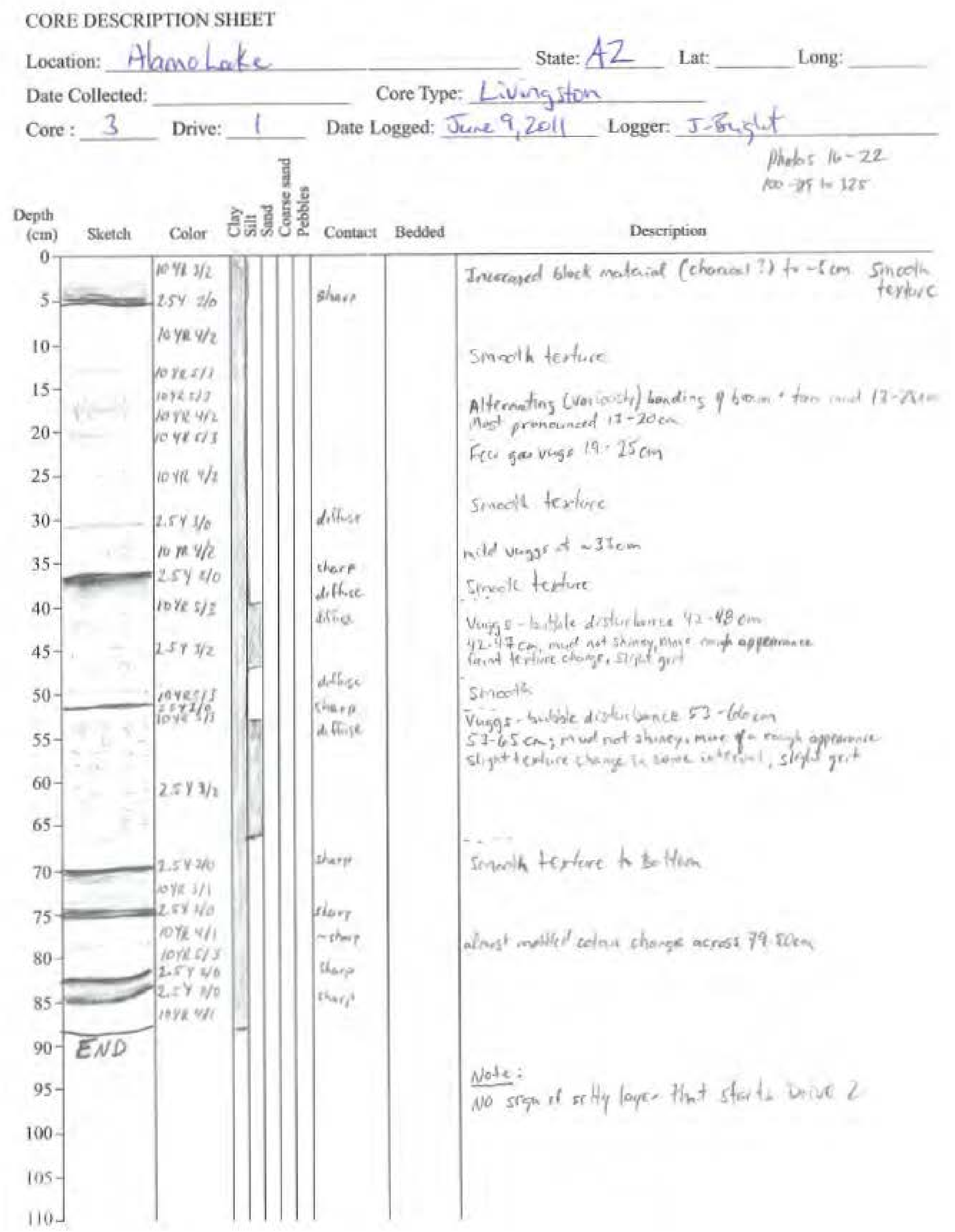
Core	**Position (cm)**	**Year**	**Δ(length) (cm)**	**Δ(time) (cm)**	**Sedimentation Rate (cm/yr)**
Havasu Core 1	0	2011			
	98	1963	98	48	2.04
	150	1954	52	9	5.78
	406	1938	256	16	16.00
	Average		406	73	5.56
Havasu Core 2	0	2011			
	37	1963	37	48	0.77
	125	1954	88	9	9.78
	371	1938	246	16	15.38
	Average		371	73	5.08
Havasu Core 3	0	2011			
	120	1954	120	57	2.11
Alamo Core 2	0	2004			
	414	1968	414	36	11.50
Alamo Core 3	0	2011			
	165	1968	165	43	3.84
Alamo Core 4	0	2011			
	96	1968	96	43	2.23

Table 4. Areal extent of bathymetric surveys conducted in 1985 and 2009.



Polygon	Area ft2	Area Acres
1985 Survey	151,784,289	3,484
2009 Survey	140,939,103	3,236
Lake Bed	78,015,687	1,791
Un-Surveyed	25,568,192	587

Appendix A. Lithologic Descriptions of Cores



CORE DESCRIPTION SHEET

Location: Alamo Lake State: AZ Lat: Long:

Date Collected: Core Type: Livingston

Core : 3 Drive: 1 Date Logged: June 9, 2011 Logger: J-Bright

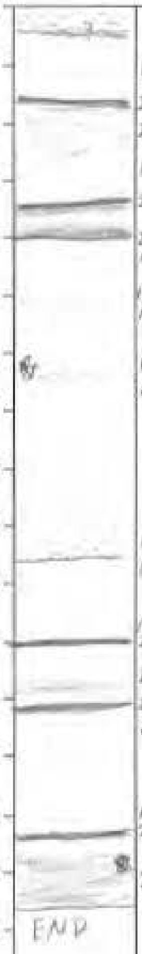
Photos 16-22
100-35 to 125

Depth (cm)	Sketch	Color	Contact	Bedded	Description
0		10YR 3/2			Increased black material (charcoal?) to ~5cm Smooth texture
5		2.5Y 2/0	sharp		
10		10YR 4/2			Smooth texture
		10YR 5/1			
15		10YR 5/3			Alternating (variously) banding of brown + tan mud 17-21cm Most pronounced 17-20cm
		10YR 4/2			
20		10YR 5/3			Few gas vugs 19-25cm
25		10YR 4/2			Smooth texture
30		2.5Y 3/0	diffuse		
		10YR 4/2			mild vuggs at ~33cm
35		2.5Y 2/0	sharp		Smooth texture
			diffuse		
40		10YR 5/2	diffuse		Vuggs - bubble disturbance 42-48 cm 42-47cm, mud not shiney, more rough appearance faint texture change, slight grit
45		2.5Y 3/2			
			diffuse		Smooth
50		10YR 5/3 2.5Y 2/0 10YR 5/3	sharp diffuse		Vuggs - bubble disturbance 53-66cm 53-65cm; mud not shiney, more of a rough appearance slight texture change in same interval, slight grit
55					
60		2.5Y 3/2			
65					
70		2.5Y 2/0	sharp		Smooth texture to bottom
		10YR 3/1			
75		2.5Y 2/0	sharp		
		10YR 4/1	~sharp		
80		10YR 5/3			almost mottled colour change across 79-80cm
		2.5Y 4/0	sharp		
85		2.5Y 3/0	sharp		
		10YR 4/1			
90	END				
95					Note: No sign of silty layer that starts Drive 2
100					
105					
110					

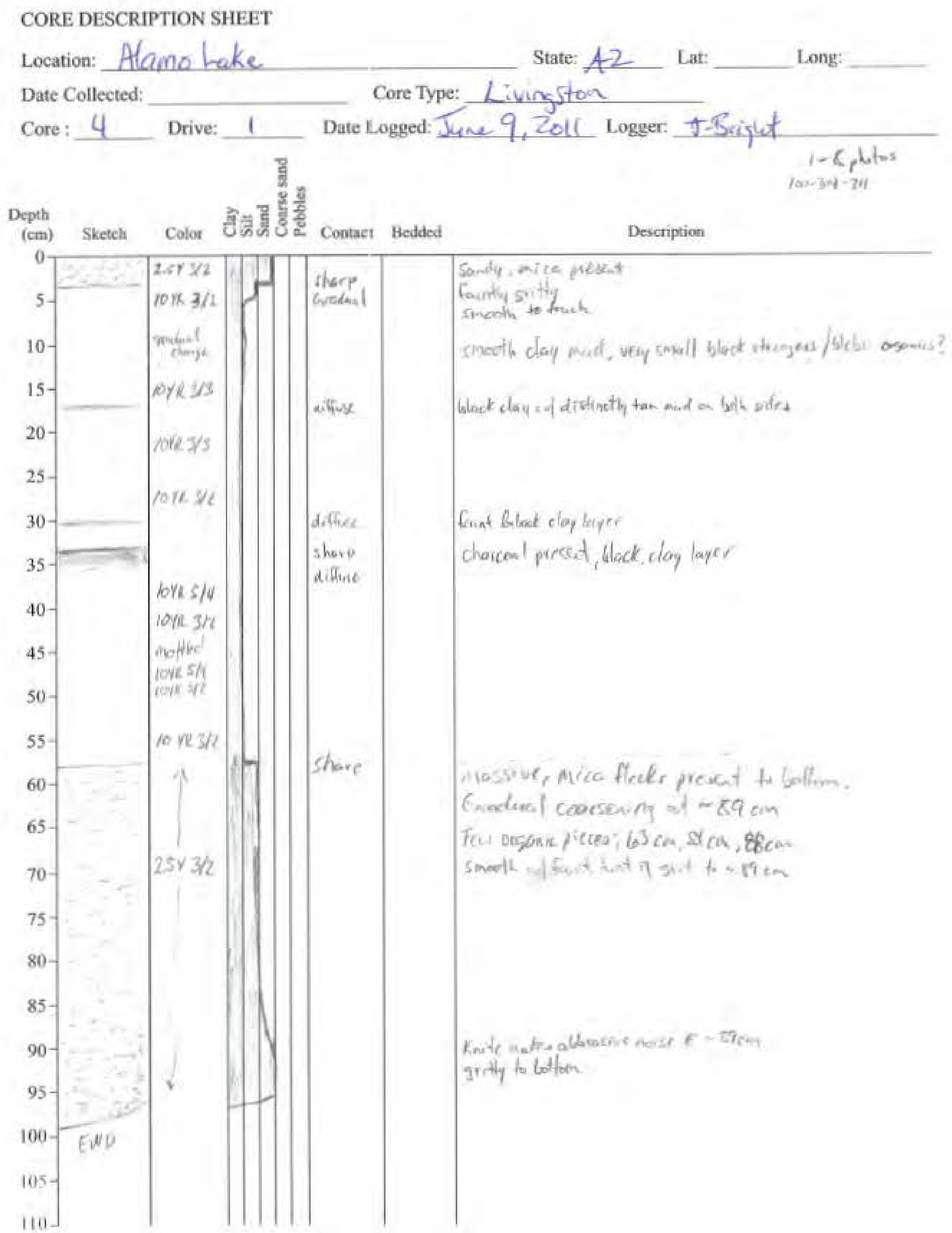
CORE DESCRIPTION SHEET

Location: Alamo Lake, State: AZ Lat: Long:
Date Collected: Core Type: Livingston
Core : 3 Drive: 2 Date Logged: June 9, 2011 Logger: J-Wright

Photos 9-15
100-312 to 318



Depth (cm)	Color	Clay	Silt	Sand	Coarse sand	Pebbles	Contact	Bedded	Description
0									Top is disturbed, Possibly a silty layer to ~2cm. Faint grit Mud is smooth below 2cm
5	10YR 4/2							weakly	faintly alternating colour bands (tan + brownish green)
10	2.5Y 2/0 2.5Y 7/0						sharp		Smooth mud. Black diffusing away below horizon at 8cm. Gone by 13cm.
15	10YR 4/2 2.5Y 2/0								smooth mud
20	2.5Y 2/0 10YR 5/3 ↓								
25	10YR 4/2 10YR 5/3 ↓						diffuse		Colour change @ 25cm Smooth mud
30	10YR 4/2 10YR 5/3 ↓						diffuse		organics (?) @ 31cm, color change
35									
40									
45	10YR 3/1 10YR 5/3						sharp		smooth mud transitions to a rougher mud @ 41cm still smooth texture, very small [illegible] ? smooth, glossy mud at 48cm. Color change @ 48cm [illegible]
50								weakly	
55	10YR 5.5/3 2.5Y 2/0 2.5Y 4/0						sharp diffuse		smooth, glossy. Possible gradual lightening in colour to 55cm
60	2.5Y 2/0 10YR 5/3 ↓						sharp		smooth glossy mud. Darkening of color from ~62 to ~72
65									
70	10YR 3/1 2.5Y 2/0						sharp		
75	2.5Y 2/0 to 3/0						diffuse		organics (?) at 73.5cm
80									
85									
90									
95									
100									
105									
110									



CORE DESCRIPTION SHEET

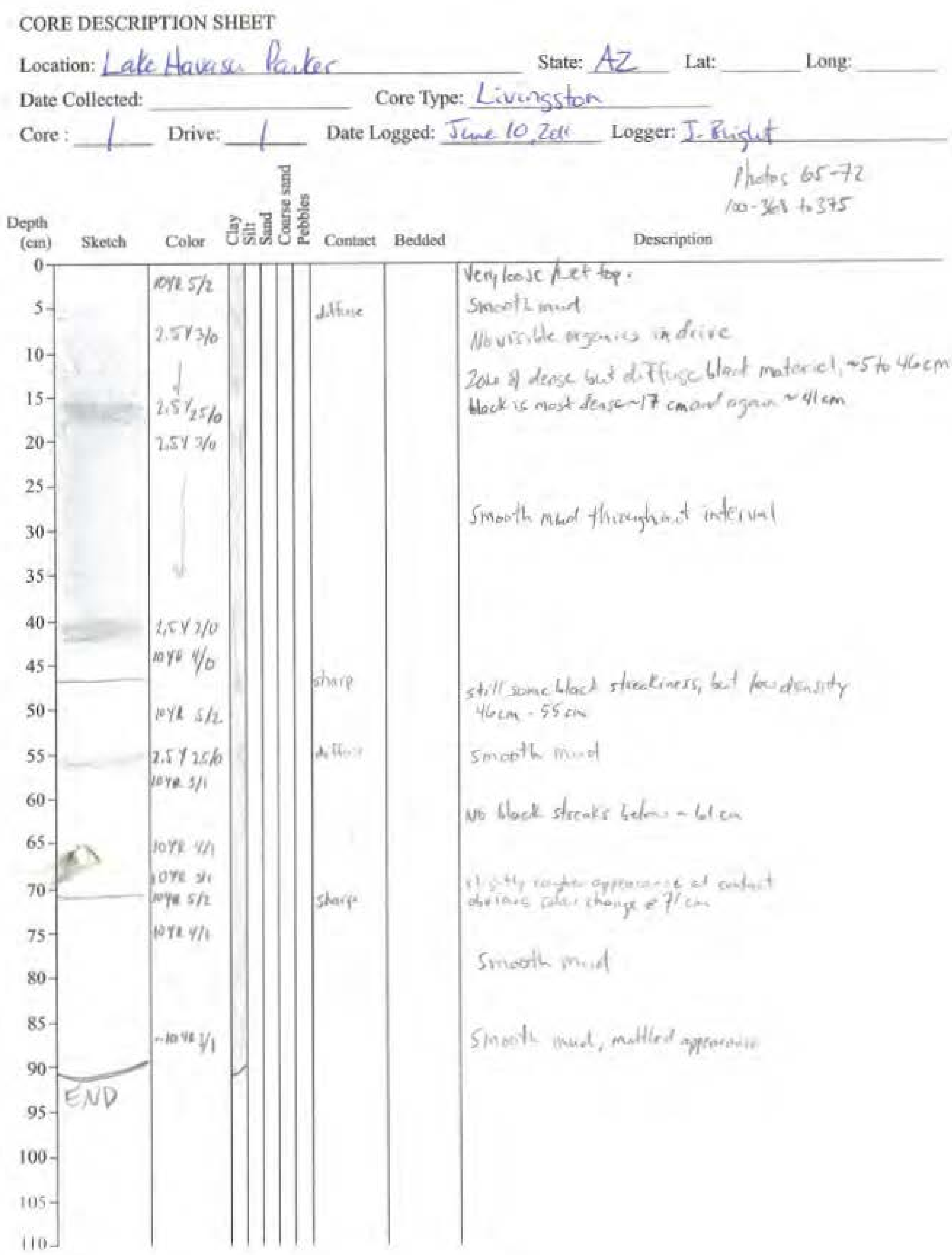
Location: Alamo Lake State: AZ Lat: Long:

Date Collected: Core Type: Livingston

Core : 4 Drive: 1 Date Logged: June 9, 2011 Logger: J-Bright

1-6 photos
100-314-211

Depth (cm)	Sketch	Color	Clay	Silt	Sand	Coarse sand	Pebbles	Contact	Bedded	Description
0		2.5Y 3/2						sharp		Sandy, mica present
5		10YR 3/1						Gradual		Faintly gritty Smooth to touch
10		gradual change								smooth clay mud, very small black stringers/blebs organics?
15		10YR 3/3						diffuse		black clay w/ distinctly tan mud on both sides
20		10YR 3/3								
25		10YR 3/2								
30								diffuse		Faint black clay layer
35								sharp diffuse		charcoal present, black, clay layer
40		10YR 5/4 10YR 3/2								
45		mottled 10YR 5/4								
50		10YR 3/2								
55		10 YR 3/1								
60								sharp		massive, mica flecks present to bottom. Gradual coarsening at ~89 cm Few organic pieces; 63 cm, 81 cm, 88cm Smooth w/ faint hint of silt to ~89 cm
65										
70		2.5Y 3/2								
75										
80										
85										
90										Knife makes abrasive noise @ ~89cm gritty to bottom
95										
100	END									
105										
110										



CORE DESCRIPTION SHEET

Location: Lake Havasu Parker State: AZ Lat: ______ Long: ______

Date Collected: ______ Core Type: Livingston

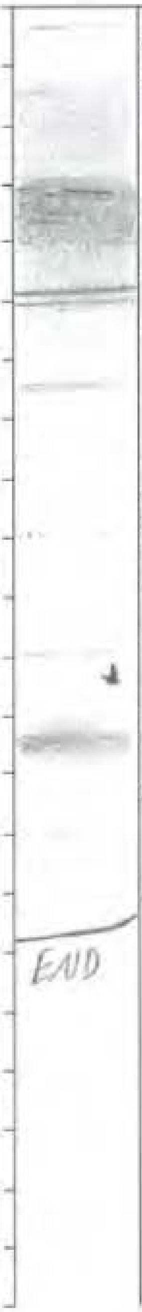
Core : 1 Drive: 1 Date Logged: June 10, 2011 Logger: J. Bright

Photos 65-72
100-368 to 375

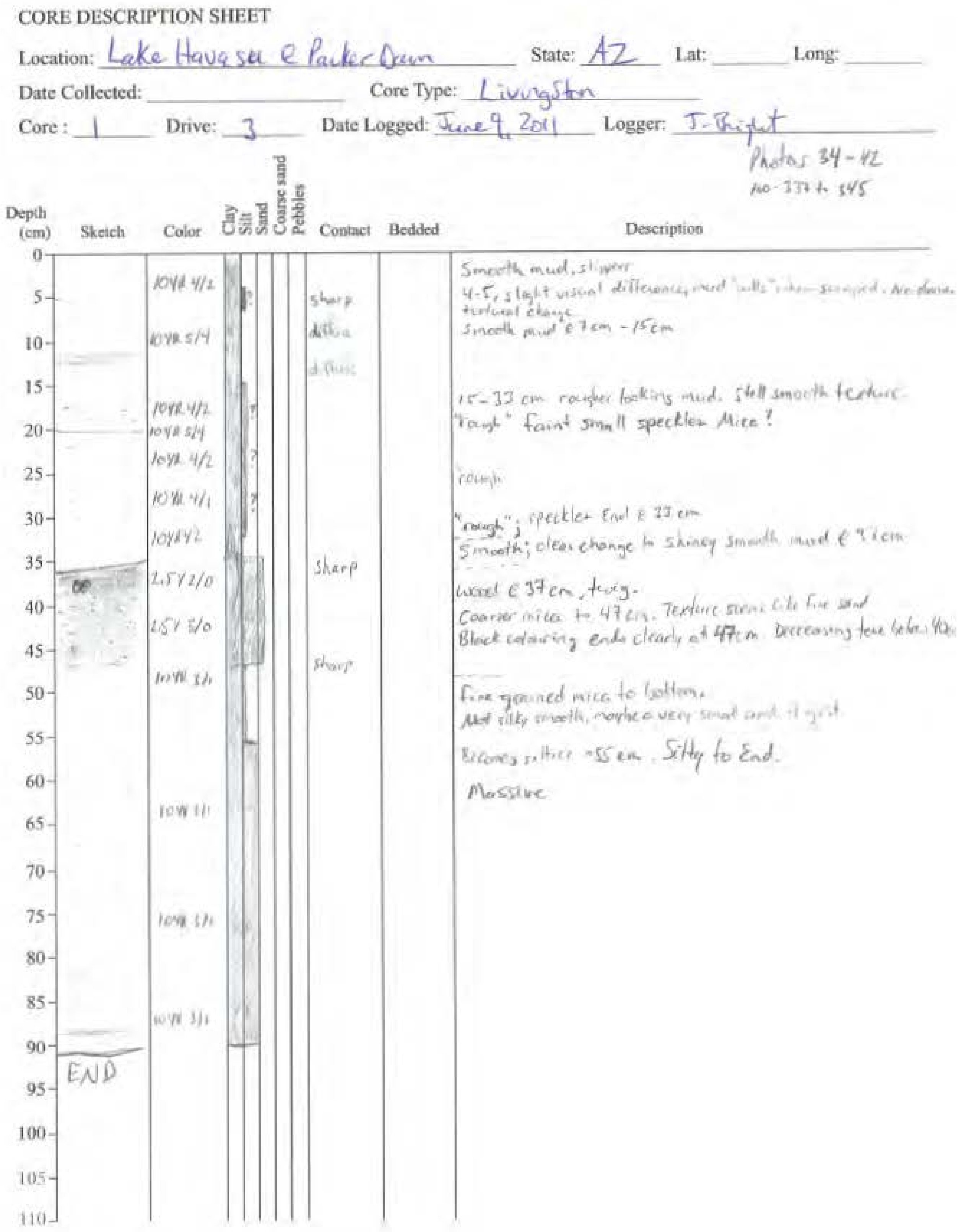
Depth (cm)	Sketch	Color	Clay	Silt	Sand	Course sand	Pebbles	Contact	Bedded	Description
0		10YR 5/2								Very loose wet top.
5								diffuse		Smooth mud
10		2.5Y 3/0								No visible organics in drive Zone of dense but diffuse black material, ~5 to 46cm
15		2.5Y 2.5/0								black is most dense ~17 cm and again ~41 cm
20		2.5Y 3/0								
25										
30										Smooth mud throughout interval
35										
40		2.5Y 3/0								
45		10YR 4/0						sharp		still some black streakiness, but low density 46cm - 55cm
50		10YR 5/2								
55		2.5Y 2.5/0 10YR 3/1						diffuse		smooth mud
60										No black streaks below ~61 cm
65		10YR 4/1								
70		10YR 3/1 10YR 5/2						sharp		slightly rougher appearance at contact obvious color change @ 71 cm
75		10YR 4/1								
80										Smooth mud
85		~10YR 3/1								Smooth mud, mottled appearance
90										
95	END									
100										
105										
110										

CORE DESCRIPTION SHEET

Location: Lake Havasu, Parker State: AZ Lat: ______ Long: ______
Date Collected: ______ Core Type: Livingston
Core : 1 Drive: 2 Date Logged: June 10, 2011 Logger: J. Bright
Photos 57 to 64
100-360 to 367



Depth (cm)	Color	Clay	Silt	Sand	Course sand	Pebbles	Contact	Bedded	Description
0	10YR 4/2								Smooth mud
5	2.5YR 5/0								diffuse black zone most intense ~17cm.
10	2.5YR 4/0						diffuse		Smooth mud
15	2.5YR 2/0								
20	2.5YR 3/0						sharp		Smooth mud
25	2.5YR 4/0						diffuse ↓		
30	10YR 4/1						diffuse		Smooth mud
35	10YR 5/1						irregular		
40	10YR 4/2 10YR 4/1						diffuse sharp		slight increase in roughness at 45cm. More dark specks.
45	10YR 4/2 10YR 4/1								Smooth mud
50	2.5YR 2/2						diffuse		slight increase in dark specks @ 54cm
55	↑ 2.5YR 4/0								organics @ 57cm
60	2.5YR 2/0						diffuse mottled		Smooth mud
65	10YR 5/1								Banded, not clearly laminated. Darker bands might have rougher appearance
70							sharp		
75	10YR 5/4						irregular		smooth mud
80									
85									
90									
95									
100									
105									
110									



CORE DESCRIPTION SHEET

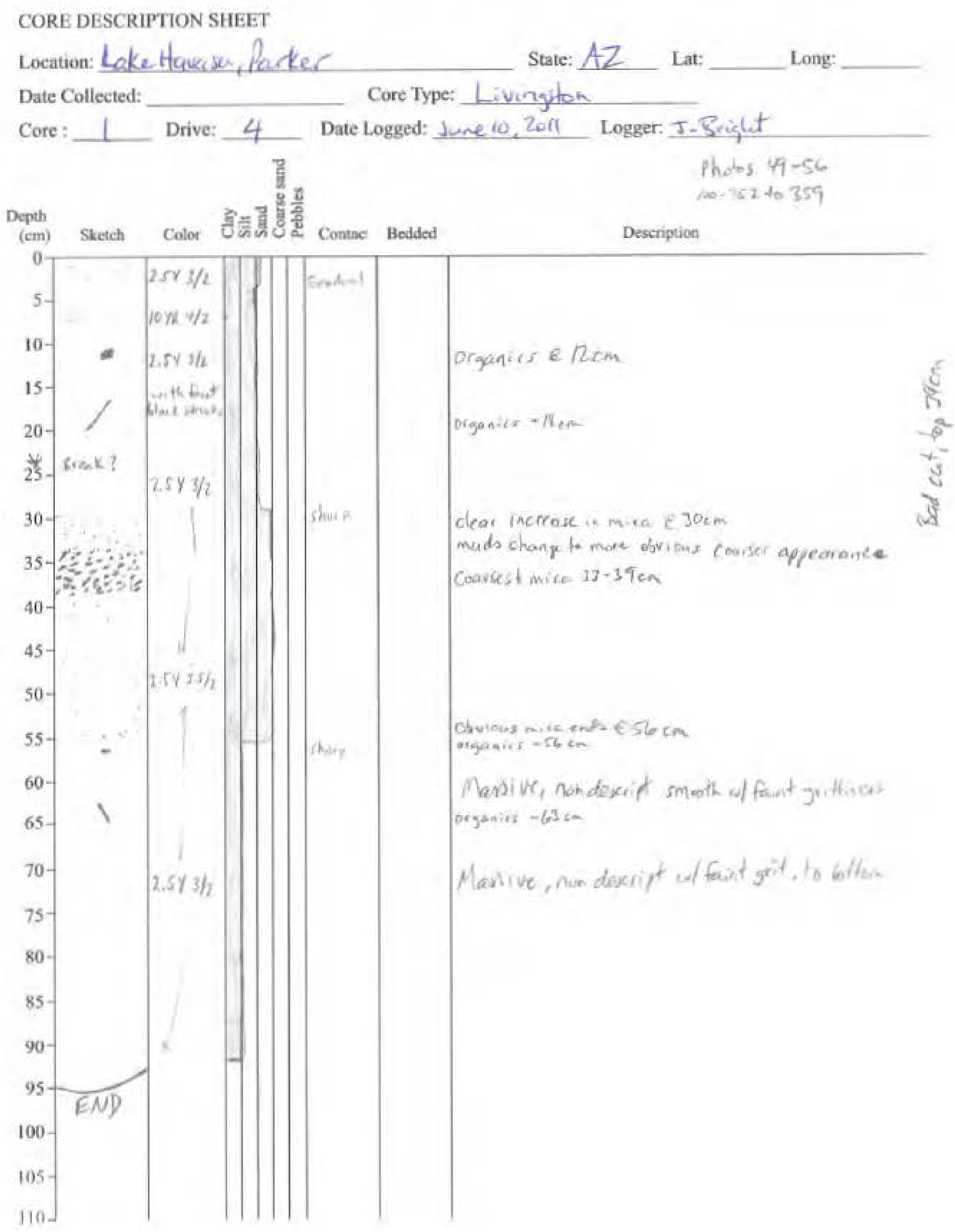
Location: Lake Havasu @ Parker Dam State: AZ Lat: Long:

Date Collected: Core Type: Livingston

Core : 1 Drive: 3 Date Logged: June 9, 2011 Logger: J. Bright

Photos 34-42
No-337 to 345

Depth (cm)	Color	Contact	Description
0			Smooth mud, slippery
5	10YR 4/2	sharp	4-5, slight visual difference, mud "sells" when scraped. No discernable textural change
10	10YR 5/4	diffuse	Smooth mud @ 7cm - 15cm
15		diffuse	
20	10YR 4/2 10YR 5/4		15-33 cm rougher looking mud. Still smooth texture "rough" faint small speckles Mica?
25	10YR 4/2		rough
30	10YR 4/1 10YR 4/2		"rough"; speckles End @ 33 cm
35		Sharp	Smooth; clear change to shiney smooth mud @ 34 cm
40	2.5Y 2/0		Wood @ 37cm, twig.
45	2.5Y 3/0	sharp	Coarser mica to 47 cm. Texture seems like fine sand Black colouring ends clearly at 47cm. Decreasing tone below 40cm
50	10YR 3/1		Fine grained mica to bottom. ~~Not~~ silky smooth, maybe a very small amount of grit
55			Becomes siltier ~55 cm. Silty to End.
60			Massive
65	10YR 3/1		
75	10YR 3/1		
85	10YR 3/1		
90			



CORE DESCRIPTION SHEET

Location: Lake Havasu, Parker State: AZ Lat: Long:

Date Collected: Core Type: Livingston

Core: 1 Drive: 4 Date Logged: June 10, 2011 Logger: J. Bright

Photos 49-56
100-352 to 359

Color:
- 2.5Y 3/2
- 10YR 4/2
- 2.5Y 3/2 with faint black streaks
- 2.5Y 3/2
- 2.5Y 2.5/2
- 2.5Y 3/2

Contact:
- Gradual
- sharp
- sharp

Description:

Organics @ 12cm

organics ~18cm

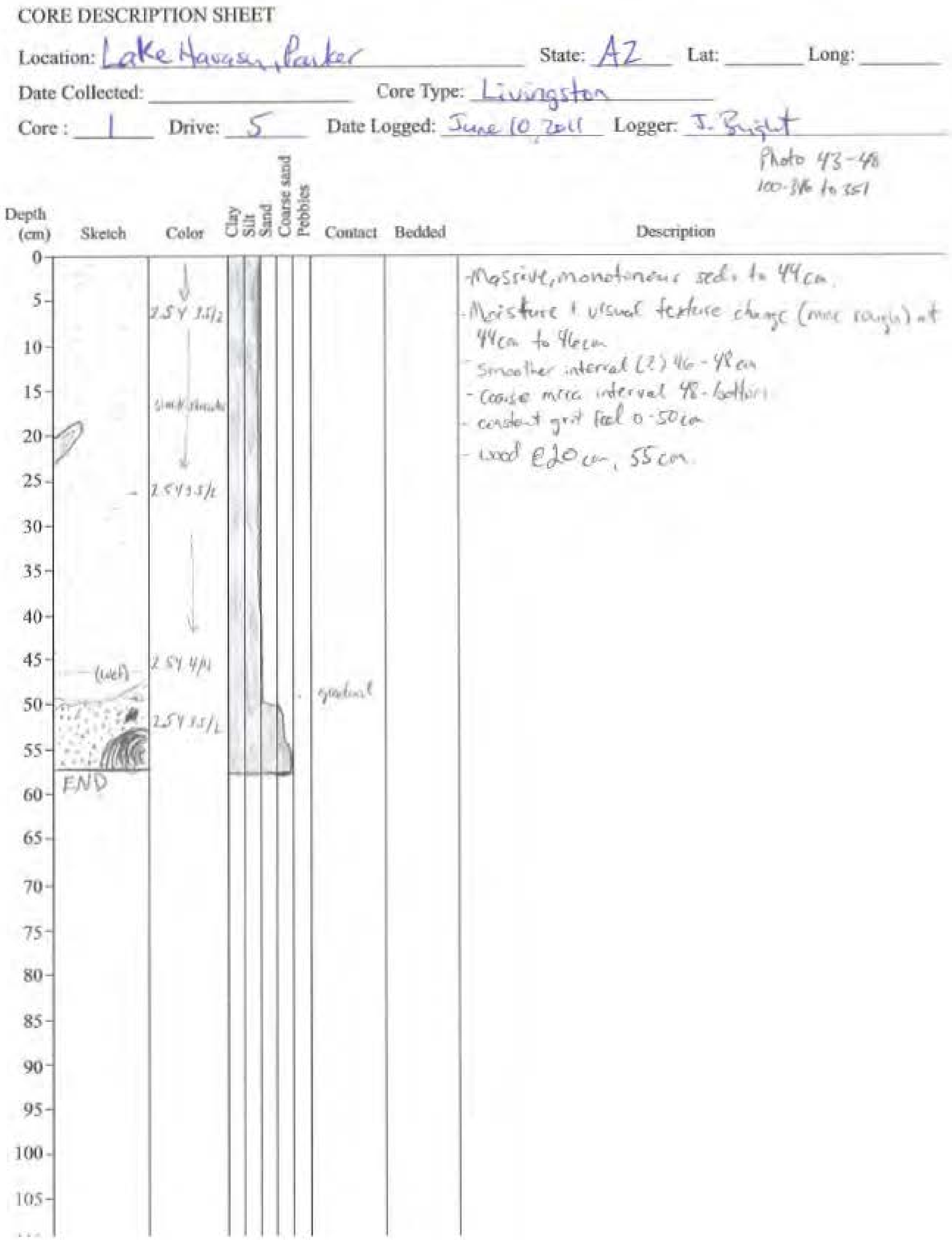
clear increase in mica @ 30cm
muds change to more obvious coarser appearance
Coarsest mica 33-39cm

Obvious mica ends @ 56 cm
organics ~56 cm

Massive, nondescript smooth w/ faint grittiness
organics ~63 cm

Massive, non descript w/ faint grit, to bottom

Bad cut, top 74cm



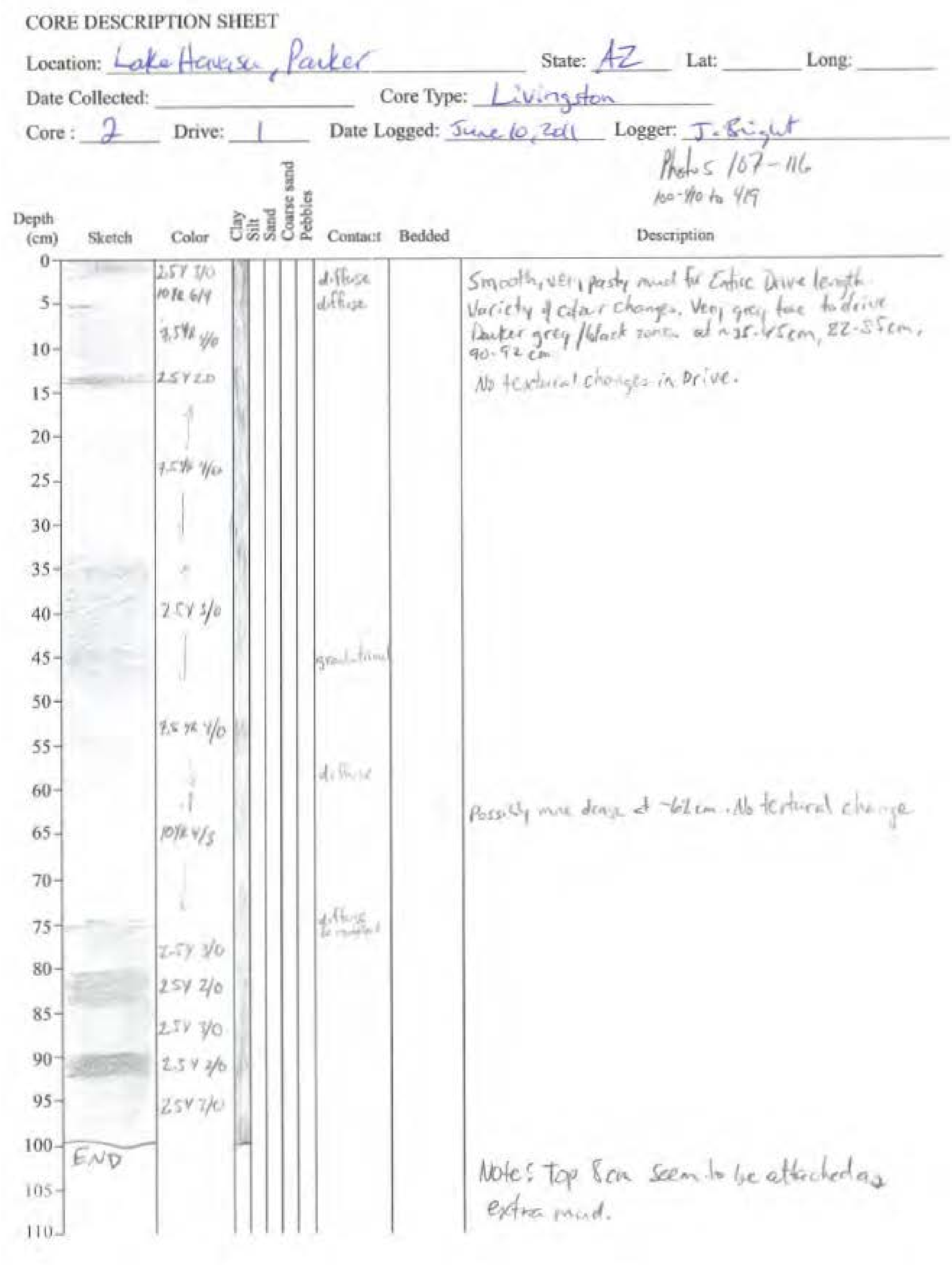
CORE DESCRIPTION SHEET

Location: Lake Havasu, Parker
State: AZ
Lat: ______
Long: ______
Date Collected: ______
Core Type: Livingston
Core: 1
Drive: 5
Date Logged: June 10 2011
Logger: J. Bright

Photo 43-48
100-346 to 351

Description

- Massive, monotonous sed. to 44cm.
- Moisture & visual texture change (more rough) at 44cm to 46cm
- Smoother interval (?) 46-48cm
- Coarse mica interval 48-bottom
- constant grit feel 0-50cm
- wood @20cm, 55cm.



CORE DESCRIPTION SHEET

Location: Lake Havasu, Parker State: AZ Lat: Long:

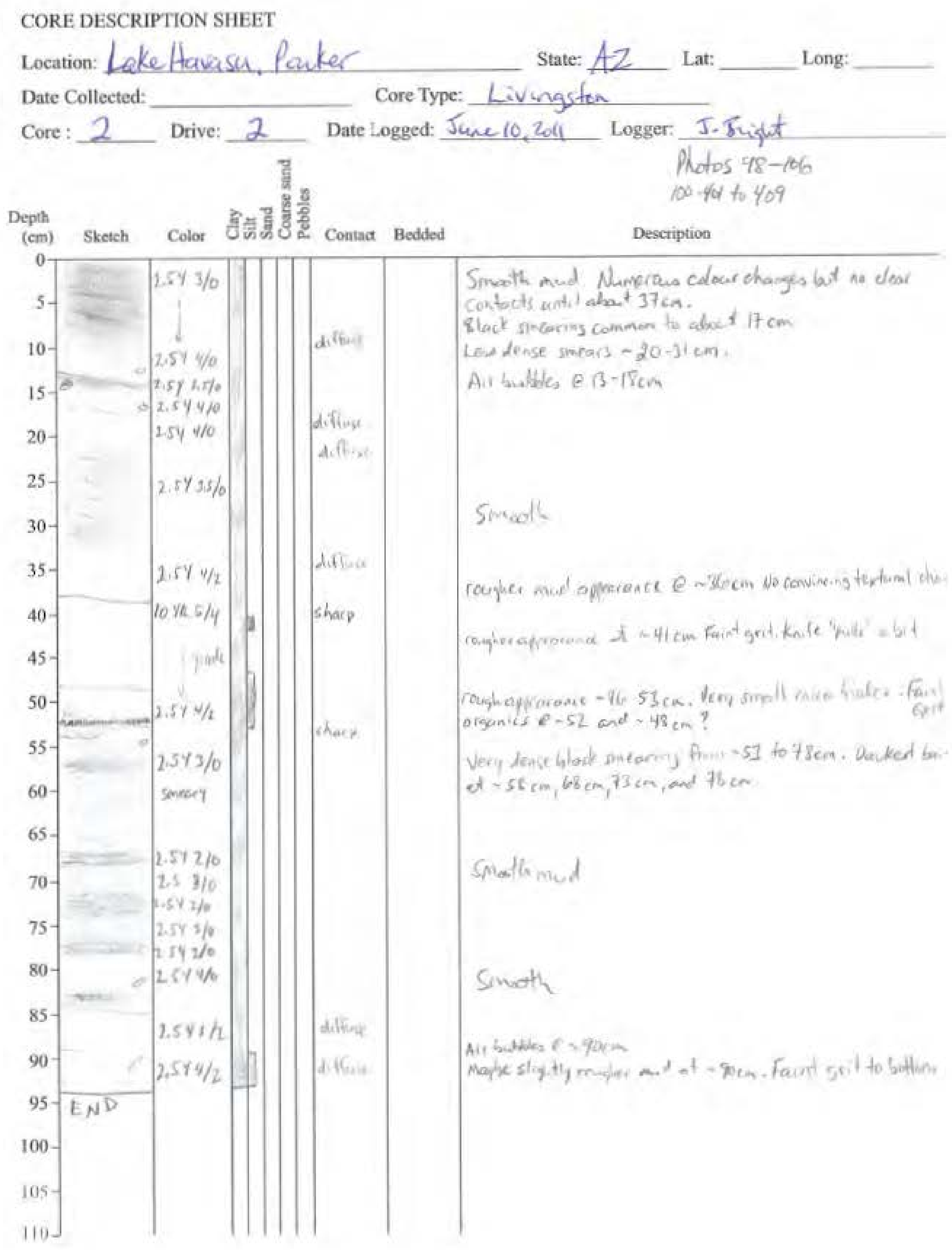
Date Collected: Core Type: Livingston

Core : 2 Drive: 1 Date Logged: June 10, 2011 Logger: J. Bright

Photos 107-116

100-110 to 419

Depth (cm)	Sketch	Color	Clay	Silt	Sand	Coarse sand	Pebbles	Contact	Bedded	Description
0		2.5Y 3/0						diffuse		Smooth, very pasty mud for Entire Drive length. Variety of color changes. Very grey tone to drive Darker grey/black zones at ~35-45cm, 82-85cm, 90-92 cm
5		10YR 6/4						diffuse		
10		7.5YR 4/0								
15		2.5Y 2/0								No textural changes in Drive.
20										
25		7.5YR 4/0								
30										
35										
40		2.5Y 5/0								
45								gradational		
50										
55		7.5YR 4/0								
60								diffuse		Possibly more dense at ~62cm. No textural change
65		10YR 4/3								
70										
75								diffuse to gradational		
80		2.5Y 3/0 2.5Y 2/0								
85		2.5Y 3/0								
90		2.5Y 2/0								
95		2.5Y 7/0								
100	END									
105										Note: top 8cm seem to be attached as extra mud.
110										



CORE DESCRIPTION SHEET

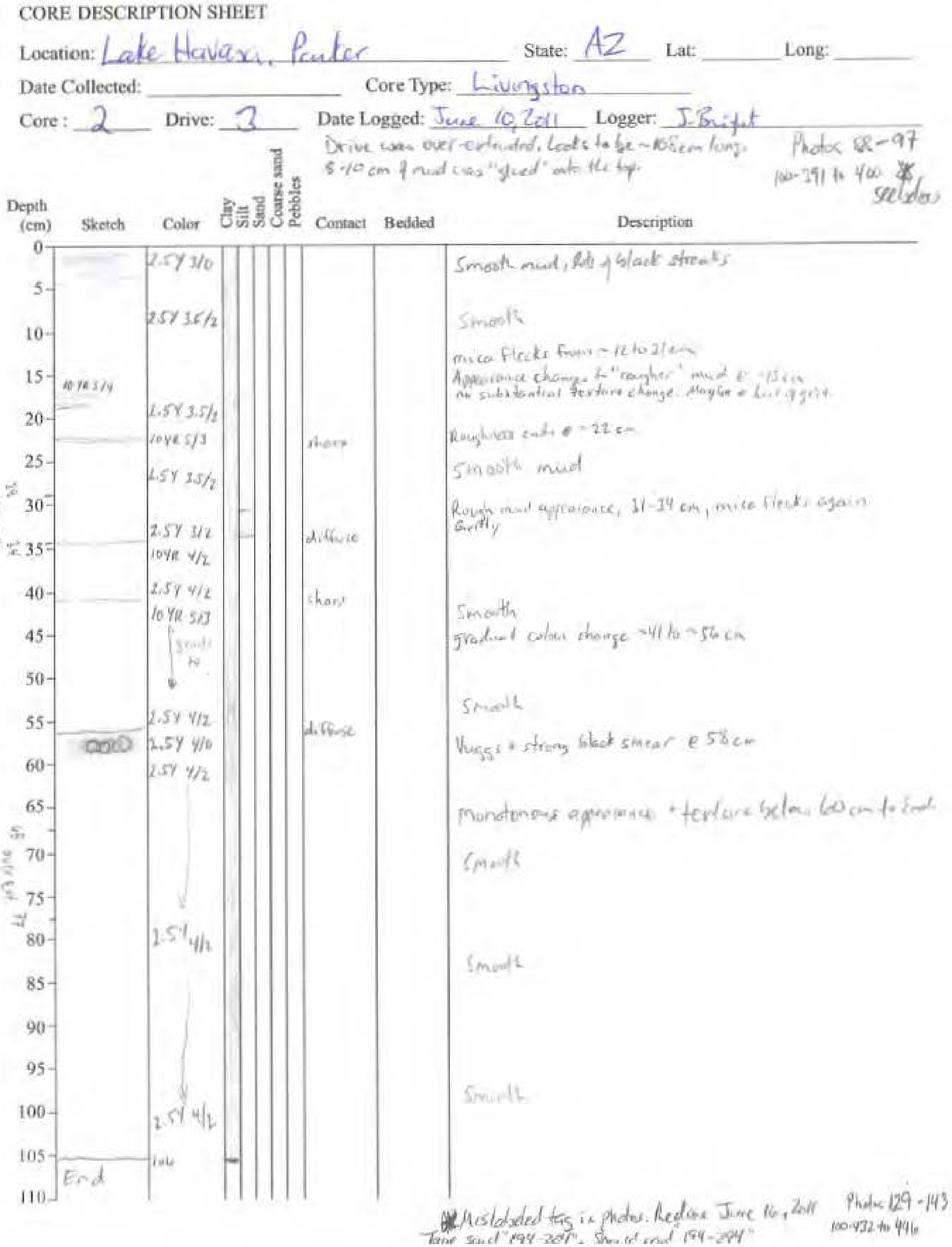
Location: Lake Havasu, Parker State: AZ Lat: ______ Long: ______

Date Collected: ______ Core Type: Livingston

Core: 2 Drive: 2 Date Logged: June 10, 2011 Logger: J. Bright

Photos 98–106
100-401 to 409

Depth (cm)	Sketch	Color	Clay	Silt	Sand	Coarse sand	Pebbles	Contact	Bedded	Description
0		2.5Y 3/0								Smooth mud. Numerous colour changes but no clear contacts until about 37cm.
5										Black smearing common to about 17 cm
10		2.5Y 4/0						diffuse		Less dense smears ~20-31 cm. Air bubbles @ 13-15cm
15		2.5Y 2.5/0 2.5Y 4/0								
20		2.5Y 4/0						diffuse diffuse		
25		2.5Y 3.5/0								
30										Smooth
35		2.5Y 4/2						diffuse		rougher mud appearance @ ~36cm No convincing textural cha
40		10YR 5/4						sharp		rougher appearance at ~41cm Faint grit. Knife 'pulls' a bit
45		pale								
50		2.5Y 4/2								rough appearance ~46-53cm. Very small mica flakes. Faint grit organics @ ~52 and ~48 cm?
55		2.5Y 3/0						sharp		Very dense black smearing from ~53 to 78cm. Darker ban- at ~58 cm, 68 cm, 73 cm, and 76 cm
60		smeary								
65										
70		2.5Y 2/0 2.5 3/0 2.5Y 2/0								Smooth mud
75		2.5Y 3/0 2.5Y 2/0								
80		2.5Y 4/0								Smooth
85		2.5Y 3/2						diffuse		
90		2.5Y 4/2						diffuse		Air bubbles @ ~90cm Maybe slightly rougher mud at ~90cm. Faint grit to bottom
95	END									
100										
105										
110										



CORE DESCRIPTION SHEET

Location: Lake Havasu, Parker State: AZ Lat: ______ Long: ______

Date Collected: ______ Core Type: Livingston

Core : 2 Drive: 3 Date Logged: June 10, 2011 Logger: J. Bright

Drive was over-extended. Looks to be ~105 cm long. 5-10 cm of mud was "glued" onto the top.

Photos 88-97
100-391 to 400 *
see below

Depth (cm)	Sketch	Color	Clay	Silt	Sand	Coarse sand	Pebbles	Contact	Bedded	Description
0		2.5Y 3/0								Smooth mud, lots of black streaks
5		2.5Y 3.5/2								Smooth
10										mica flecks from ~12 to 21 cm
15	10YR 5/4									Appearance change to "rougher" mud @ ~13 cm no substantial texture change. Maybe a bit of grit.
20		2.5Y 3.5/2 10YR 5/3						sharp		Roughness ends @ ~22 cm
25		2.5Y 3.5/2								Smooth mud
30										Rough mud appearance, 31-34 cm, mica flecks again Gritty
35		2.5Y 3/2 10YR 4/2						diffuse		
40		2.5Y 4/2 10YR 5/3						sharp		Smooth gradual colour change ~41 to ~56 cm
45		gradual to								
50										Smooth
55		2.5Y 4/2 2.5Y 4/0						diffuse		Vuggs + strong black smear @ 58 cm
60		2.5Y 4/2								
65										Monotonous appearance + texture below 60 cm to End.
70										Smooth
75										
80		2.5Y 4/2								Smooth
85										
90										
95										Smooth
100		2.5Y 4/2								
105	End	106								
110										

38 Drv ext. 34

58 drive ext. 77

* Mislabeled tag in photos. Redone June 16, 2011
Tags said "194-201". Should read 194-204"

Photos 129-143
100-432 to 446

CORE DESCRIPTION SHEET

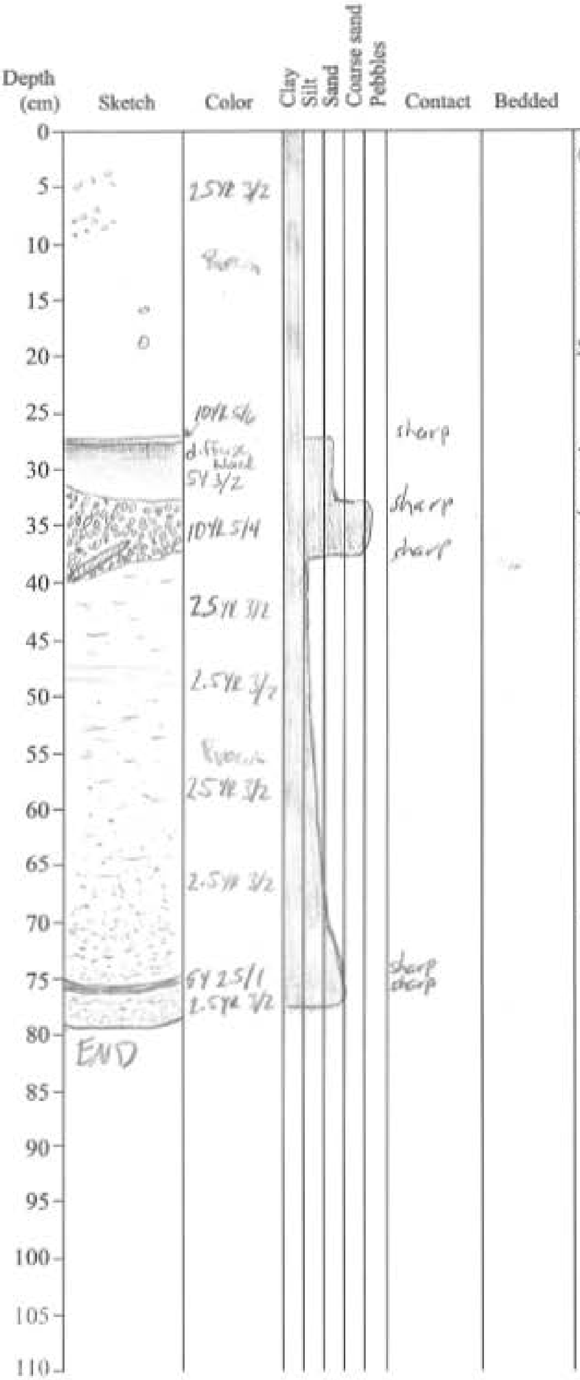
Location: Lake Havasu, Parker State: AZ Lat: ______ Long: ______

Date Collected: ______ Core Type: Livingston

Core : 2 Drive: 4 Date Logged: June 16, 2011 Logger: J. Bright

Photos 117 – 127
100-420 to 430

Photo 128
100-421
= 2M single



Description

Core broken @ ~57 cm, ~28 cm at weak cohesion through coarse interval @ ~35 cm

gas pockets ~5, 8-10 cm

Smooth pasty mud to 28 cm

gas pockets ~16, 19 cm

texture coarsens abruptly at 28 cm
mica flecks visible

texture coarsens even more, abruptly at ~37 cm

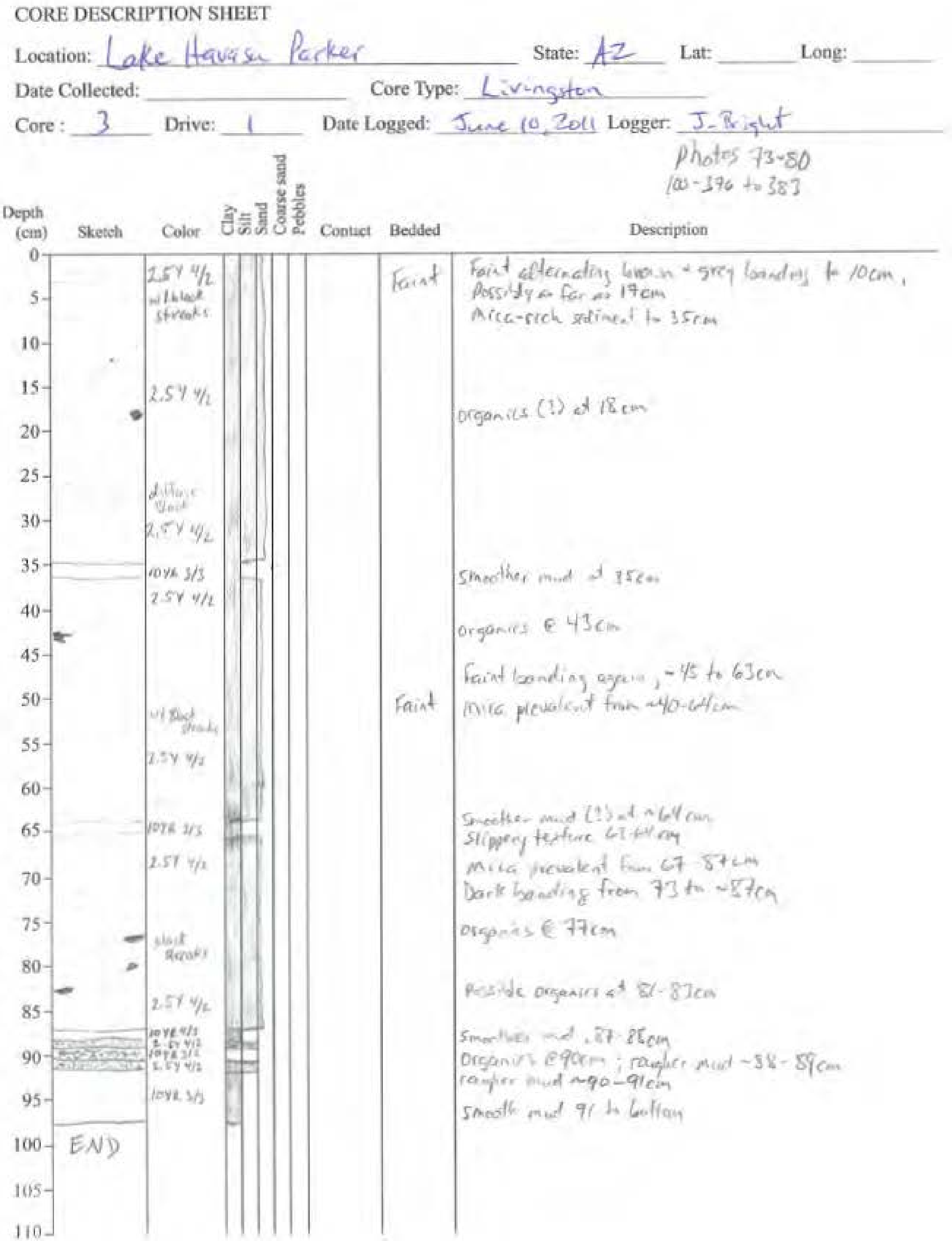
texture fines abruptly at 38-39 cm
mica flecks visible

Gritty, massive below 39 cm

slight colour changes ~47-50 cm. No obvious textural changes

coarseness increases gradually towards ~70 cm

coarse mica flecks obvious at ~72 cm



CORE DESCRIPTION SHEET

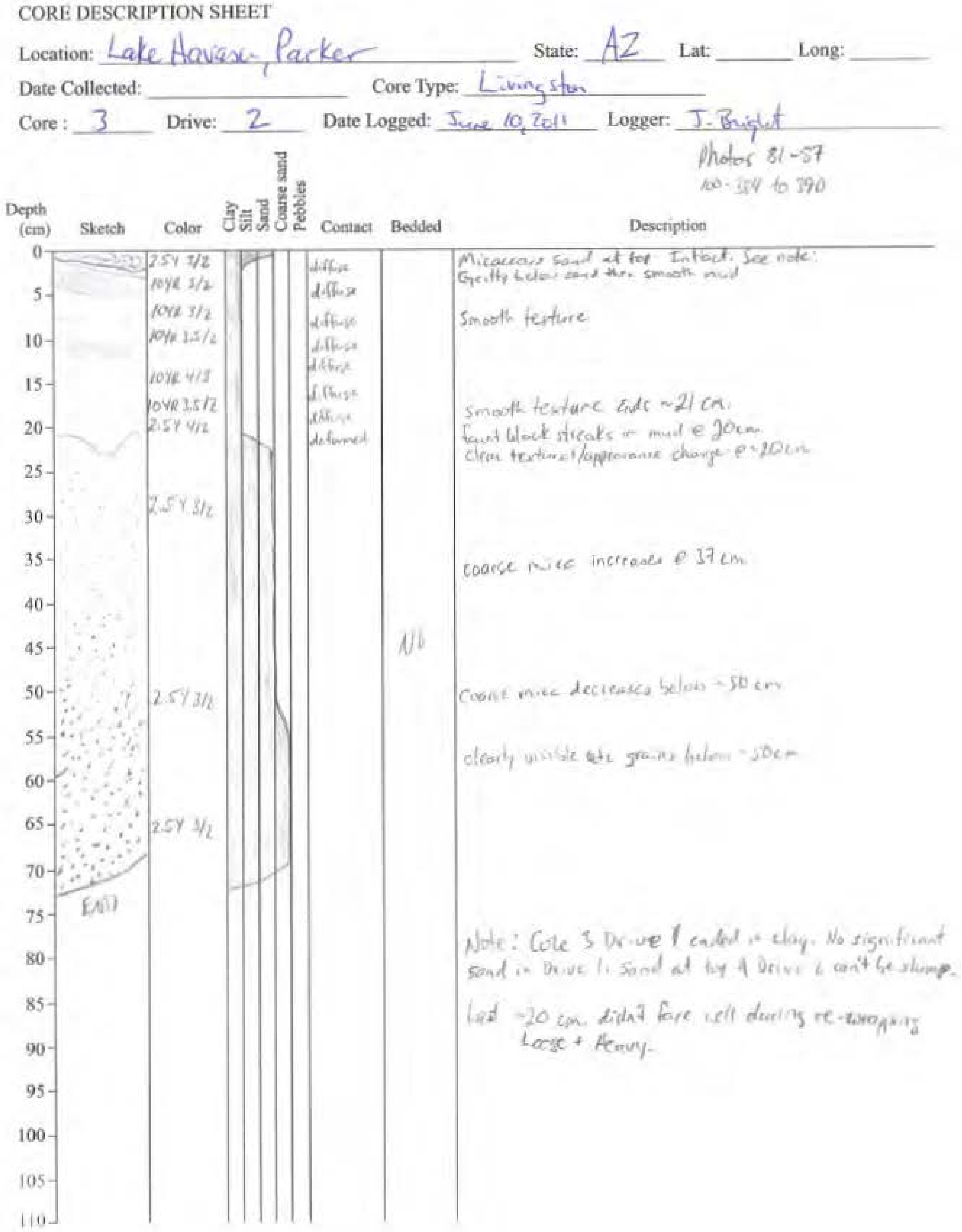
Location: Lake Havasu Parker State: AZ Lat: Long:

Date Collected: Core Type: Livingston

Core : 3 Drive: 1 Date Logged: June 10, 2011 Logger: J. Bright

Photos 73-80
100-376 to 383

Depth (cm)	Sketch	Color	Clay	Silt	Sand	Coarse sand	Pebbles	Contact	Bedded	Description
0		2.5Y 4/2 w/ black streaks							Faint	Faint alternating brown + grey banding to 10cm, Possibly as far as 17cm Mica-rich sediment to 35cm
5										
10										
15		2.5Y 4/2								organics (?) at 18cm
20										
25		diffuse black								
30		2.5Y 4/2								
35		10YR 3/3 2.5Y 4/2								Smoother mud at 35cm
40										organics @ 43cm
45										faint banding again, ~45 to 63cm
50		w/ black streaks							Faint	Mica prevalent from ~40-64cm
55		2.5Y 4/2								
60										
65		10YR 3/3								Smoother mud (?) at ~64 cm Slippery texture 63-64 cm
70		2.5Y 4/2								Mica prevalent from 67-87cm Dark banding from 73 to ~87cm
75		black streaks								organics @ 77cm
80										Possible organics at 81-87cm
85		2.5Y 4/2								
90		10YR 4/3 2.5Y 4/2 10YR 3/2 2.5Y 4/2								Smoother mud 87-88cm Organics @90cm ; rougher mud ~88-89cm rougher mud ~90-91cm
95		10YR 3/3								Smooth mud 91 to bottom
100	END									
105										
110										



CORE DESCRIPTION SHEET

Location: Lake Havasu, Parker State: AZ Lat: ______ Long: ______

Date Collected: ______ Core Type: Livingston

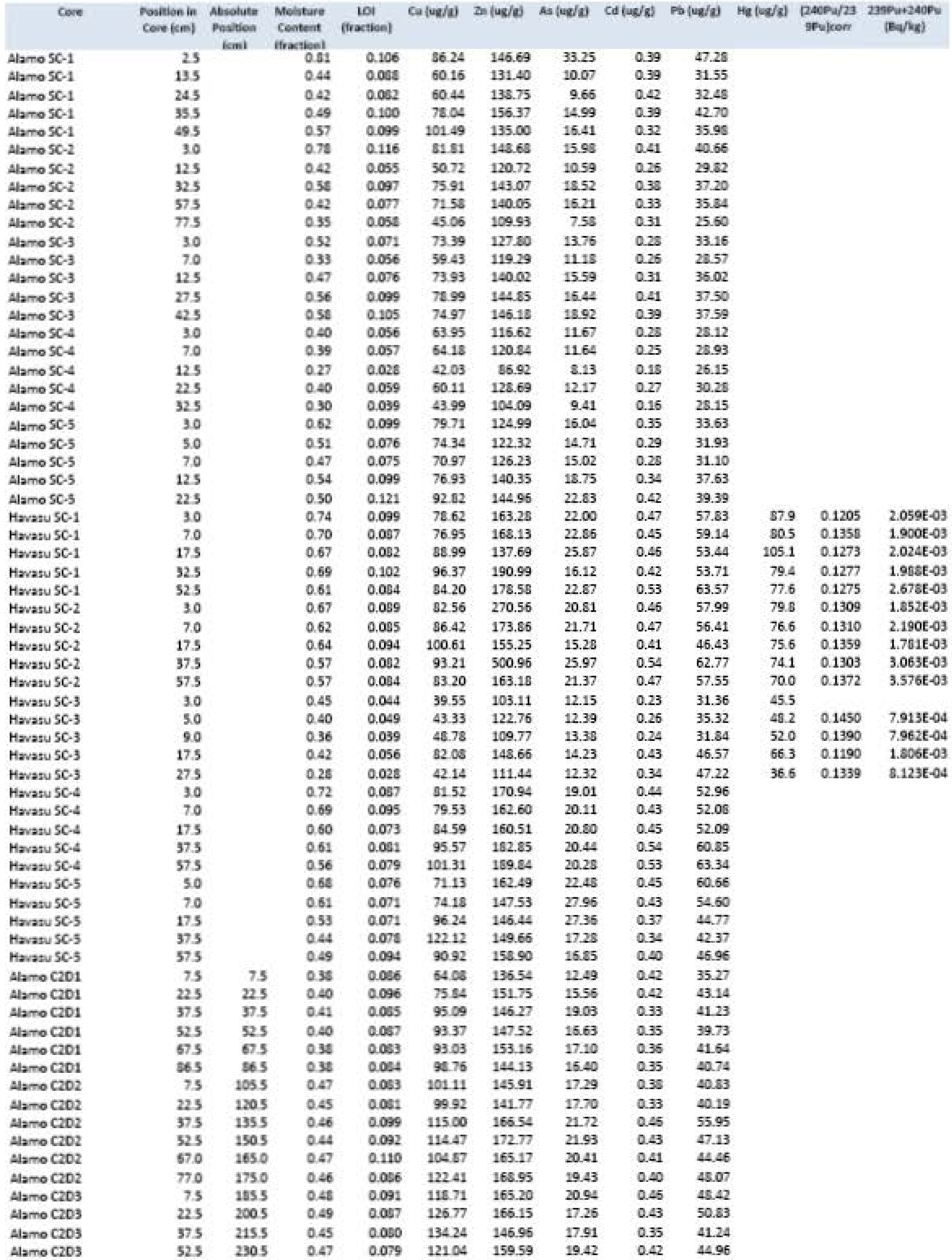
Core: 3 Drive: 2 Date Logged: June 10, 2011 Logger: J. Bright

Photos 81-57

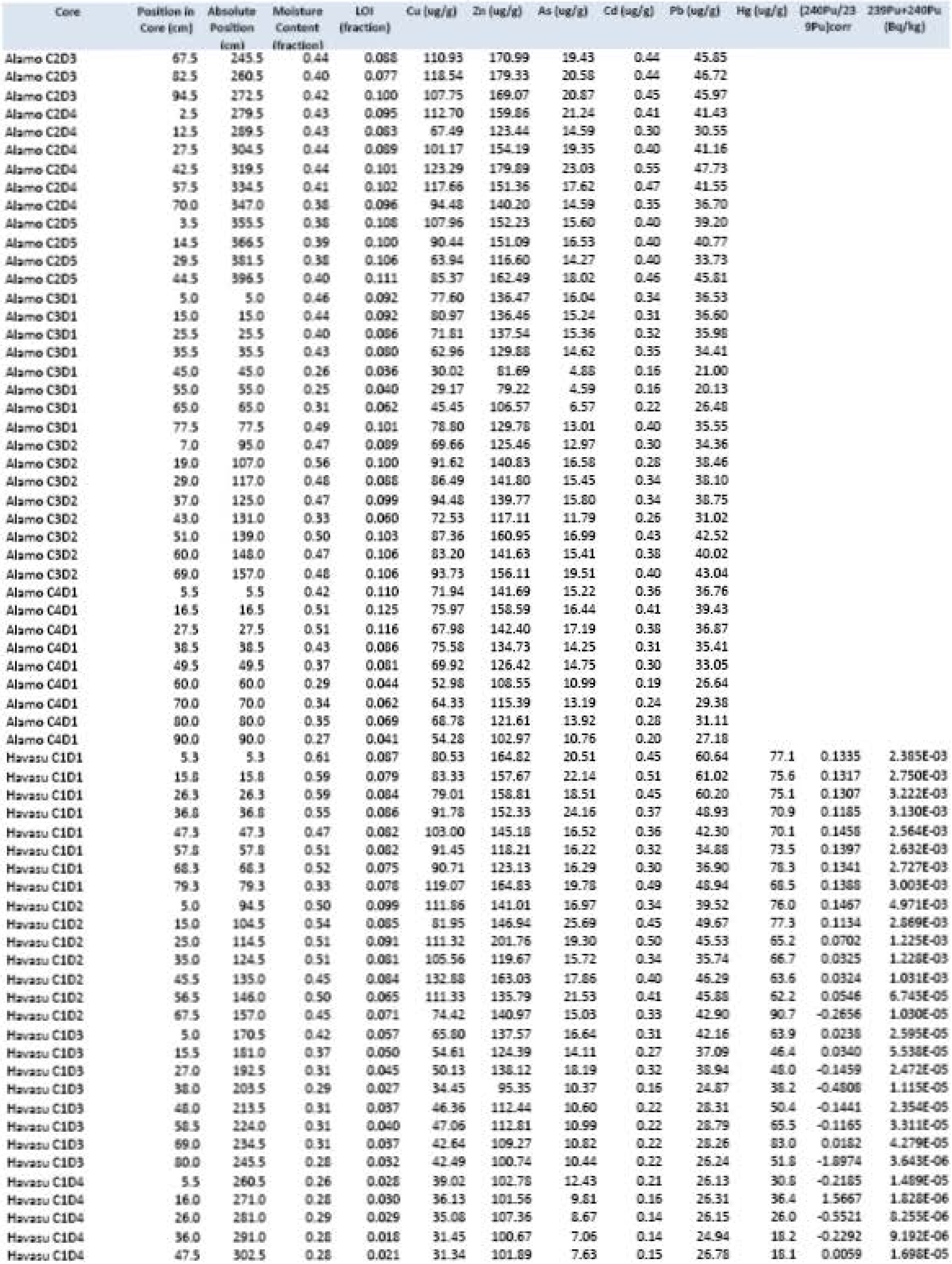
100-384 to 390

Depth (cm)	Sketch	Color	Clay	Silt	Sand	Coarse sand	Pebbles	Contact	Bedded	Description
0		2.5Y 3/2						diffuse		Micaceous sand at top. Intact. See note: Gritty below sand then smooth mud
5		10YR 3/2 10YR 3/2						diffuse diffuse		Smooth texture
10		10YR 3.5/2						diffuse diffuse		
15		10YR 4/3 10YR 3.5/2						diffuse diffuse		smooth texture ends ~21 cm.
20		2.5Y 4/2						deformed		faint black streaks in mud @ 20cm. Clear textural/appearance change @ ~20cm
25										
30		2.5Y 3/2								
35										coarse mica increases @ 37 cm
40										
45									NB	
50		2.5Y 3/2								Coarse mica decreases below ~50 cm
55										clearly visible qtz grains below ~50cm
60										
65		2.5Y 3/2								
70										
75	END									
80										Note: Core 3 Drive 1 ended in clay. No significant sand in Drive 1. Sand at top of Drive 2 can't be slump.
85										Last ~20 cm didn't fare well during re-wrapping. Loose + Heavy.
90										
95										
100										
105										
110										

Appendix B. Listing of Physical and Chemical Data



Core	Position in Core (cm)	Absolute Position (cm)	Moisture Content (fraction)	LOI (fraction)	Cu (ug/g)	Zn (ug/g)	As (ug/g)	Cd (ug/g)	Pb (ug/g)	Hg (ug/g)	(240Pu/239Pu)corr	239Pu+240Pu (Bq/kg)
Alamo SC-1	2.5		0.81	0.106	86.24	146.69	33.25	0.39	47.28			
Alamo SC-1	13.5		0.44	0.088	60.16	131.40	10.07	0.39	31.55			
Alamo SC-1	24.5		0.42	0.082	60.44	138.75	9.66	0.42	32.48			
Alamo SC-1	35.5		0.49	0.100	78.04	156.37	14.99	0.39	42.70			
Alamo SC-1	49.5		0.57	0.099	101.49	135.00	16.41	0.32	35.98			
Alamo SC-2	3.0		0.78	0.116	81.81	148.68	15.98	0.41	40.66			
Alamo SC-2	12.5		0.42	0.055	50.72	120.72	10.59	0.26	29.82			
Alamo SC-2	32.5		0.58	0.097	75.91	143.07	18.52	0.38	37.20			
Alamo SC-2	57.5		0.42	0.077	71.58	140.05	16.21	0.33	35.84			
Alamo SC-2	77.5		0.35	0.058	45.06	109.93	7.58	0.31	25.60			
Alamo SC-3	3.0		0.52	0.071	73.39	127.80	13.76	0.28	33.16			
Alamo SC-3	7.0		0.33	0.056	59.43	119.29	11.18	0.26	28.57			
Alamo SC-3	12.5		0.47	0.076	73.93	140.02	15.59	0.31	36.02			
Alamo SC-3	27.5		0.56	0.099	78.99	144.85	16.44	0.41	37.50			
Alamo SC-3	42.5		0.58	0.105	74.97	146.18	18.92	0.39	37.59			
Alamo SC-4	3.0		0.40	0.056	63.95	116.62	11.67	0.28	28.12			
Alamo SC-4	7.0		0.39	0.057	64.18	120.84	11.64	0.25	28.93			
Alamo SC-4	12.5		0.27	0.028	42.03	86.92	8.13	0.18	26.15			
Alamo SC-4	22.5		0.40	0.059	60.11	128.69	12.17	0.27	30.28			
Alamo SC-4	32.5		0.30	0.039	43.99	104.09	9.41	0.16	28.15			
Alamo SC-5	3.0		0.62	0.099	79.71	124.99	16.04	0.35	33.63			
Alamo SC-5	5.0		0.51	0.076	74.34	122.32	14.71	0.29	31.93			
Alamo SC-5	7.0		0.47	0.075	70.97	126.23	15.02	0.28	31.10			
Alamo SC-5	12.5		0.54	0.099	76.93	140.35	18.75	0.34	37.63			
Alamo SC-5	22.5		0.50	0.121	92.82	144.96	22.83	0.42	39.39			
Havasu SC-1	3.0		0.74	0.099	78.62	163.28	22.00	0.47	57.83	87.9	0.1205	2.059E-03
Havasu SC-1	7.0		0.70	0.087	76.95	168.13	22.86	0.45	59.14	80.5	0.1358	1.900E-03
Havasu SC-1	17.5		0.67	0.082	88.99	137.69	25.87	0.46	53.44	105.1	0.1273	2.024E-03
Havasu SC-1	32.5		0.69	0.102	96.37	190.99	16.12	0.42	53.71	79.4	0.1277	1.988E-03
Havasu SC-1	52.5		0.61	0.084	84.20	178.58	22.87	0.53	63.57	77.6	0.1275	2.678E-03
Havasu SC-2	3.0		0.67	0.089	82.56	270.56	20.81	0.46	57.99	79.8	0.1309	1.852E-03
Havasu SC-2	7.0		0.62	0.085	86.42	173.86	21.71	0.47	56.41	76.6	0.1310	2.190E-03
Havasu SC-2	17.5		0.64	0.094	100.61	155.25	15.28	0.41	46.43	75.6	0.1359	1.781E-03
Havasu SC-2	37.5		0.57	0.082	93.21	500.96	25.97	0.54	62.77	74.1	0.1303	3.063E-03
Havasu SC-2	57.5		0.57	0.084	83.20	163.18	21.37	0.47	57.55	70.0	0.1372	3.576E-03
Havasu SC-3	3.0		0.45	0.044	39.55	103.11	12.15	0.23	31.36	45.5		
Havasu SC-3	5.0		0.40	0.049	43.33	122.76	12.39	0.26	35.32	48.2	0.1450	7.913E-04
Havasu SC-3	9.0		0.36	0.039	48.78	109.77	13.38	0.24	31.84	52.0	0.1390	7.962E-04
Havasu SC-3	17.5		0.42	0.056	82.08	148.66	14.23	0.43	46.57	66.3	0.1190	1.806E-03
Havasu SC-3	27.5		0.28	0.028	42.14	111.44	12.32	0.34	47.22	36.6	0.1339	8.123E-04
Havasu SC-4	3.0		0.72	0.087	81.52	170.94	19.01	0.44	52.96			
Havasu SC-4	7.0		0.69	0.095	79.53	162.60	20.11	0.43	52.08			
Havasu SC-4	17.5		0.60	0.073	84.59	160.51	20.80	0.45	52.09			
Havasu SC-4	37.5		0.61	0.081	95.57	182.85	20.44	0.54	60.85			
Havasu SC-4	57.5		0.56	0.079	101.31	189.84	20.28	0.53	63.34			
Havasu SC-5	5.0		0.68	0.076	71.13	162.49	22.48	0.45	60.66			
Havasu SC-5	7.0		0.61	0.071	74.18	147.53	27.96	0.43	54.60			
Havasu SC-5	17.5		0.53	0.071	96.24	146.44	27.36	0.37	44.77			
Havasu SC-5	37.5		0.44	0.078	122.12	149.66	17.28	0.34	42.37			
Havasu SC-5	57.5		0.49	0.094	90.92	158.90	16.85	0.40	46.96			
Alamo C2D1	7.5	7.5	0.38	0.086	64.08	136.54	12.49	0.42	35.27			
Alamo C2D1	22.5	22.5	0.40	0.096	75.84	151.75	15.56	0.42	43.14			
Alamo C2D1	37.5	37.5	0.41	0.085	95.09	146.27	19.03	0.33	41.23			
Alamo C2D1	52.5	52.5	0.40	0.087	93.37	147.52	16.63	0.35	39.73			
Alamo C2D1	67.5	67.5	0.38	0.083	93.03	153.16	17.10	0.36	41.64			
Alamo C2D1	86.5	86.5	0.38	0.084	98.76	144.13	16.40	0.35	40.74			
Alamo C2D2	7.5	105.5	0.47	0.083	101.11	145.91	17.29	0.38	40.83			
Alamo C2D2	22.5	120.5	0.45	0.081	99.92	141.77	17.70	0.33	40.19			
Alamo C2D2	37.5	135.5	0.46	0.099	115.00	166.54	21.72	0.46	55.95			
Alamo C2D2	52.5	150.5	0.44	0.092	114.47	172.77	21.93	0.43	47.13			
Alamo C2D2	67.0	165.0	0.47	0.110	104.87	165.17	20.41	0.41	44.46			
Alamo C2D2	77.0	175.0	0.46	0.086	122.41	168.95	19.43	0.40	48.07			
Alamo C2D3	7.5	185.5	0.48	0.091	118.71	165.20	20.94	0.46	48.42			
Alamo C2D3	22.5	200.5	0.49	0.087	126.77	166.15	17.26	0.43	50.83			
Alamo C2D3	37.5	215.5	0.45	0.080	134.24	146.96	17.91	0.35	41.24			
Alamo C2D3	52.5	230.5	0.47	0.079	121.04	159.59	19.42	0.42	44.96			



Core	Position in Core (cm)	Absolute Position (cm)	Moisture Content (fraction)	LOI (fraction)	Cu (ug/g)	Zn (ug/g)	As (ug/g)	Cd (ug/g)	Pb (ug/g)	Hg (ug/g)	(240Pu/239Pu)corr	239Pu+240Pu (Bq/kg)
Alamo C2D3	67.5	245.5	0.44	0.088	110.93	170.99	19.43	0.44	45.85			
Alamo C2D3	82.5	260.5	0.40	0.077	118.54	179.33	20.58	0.44	46.72			
Alamo C2D3	94.5	272.5	0.42	0.100	107.75	169.07	20.87	0.45	45.97			
Alamo C2D4	2.5	279.5	0.43	0.095	112.70	159.86	21.24	0.41	41.43			
Alamo C2D4	12.5	289.5	0.43	0.083	67.49	123.44	14.59	0.30	30.55			
Alamo C2D4	27.5	304.5	0.44	0.089	101.17	154.19	19.35	0.40	41.16			
Alamo C2D4	42.5	319.5	0.44	0.101	123.29	179.89	23.03	0.55	47.73			
Alamo C2D4	57.5	334.5	0.41	0.102	117.66	151.36	17.62	0.47	41.55			
Alamo C2D4	70.0	347.0	0.38	0.096	94.48	140.20	14.59	0.35	36.70			
Alamo C2D5	3.5	355.5	0.38	0.108	107.96	152.23	15.60	0.40	39.20			
Alamo C2D5	14.5	366.5	0.39	0.100	90.44	151.09	16.53	0.40	40.77			
Alamo C2D5	29.5	381.5	0.38	0.106	63.94	116.60	14.27	0.40	33.73			
Alamo C2D5	44.5	396.5	0.40	0.111	85.37	162.49	18.02	0.46	45.81			
Alamo C3D1	5.0	5.0	0.46	0.092	77.60	136.47	16.04	0.34	36.53			
Alamo C3D1	15.0	15.0	0.44	0.092	80.97	136.46	15.24	0.31	36.60			
Alamo C3D1	25.5	25.5	0.40	0.086	71.81	137.54	15.36	0.32	35.98			
Alamo C3D1	35.5	35.5	0.43	0.080	62.96	129.88	14.62	0.35	34.41			
Alamo C3D1	45.0	45.0	0.26	0.036	30.02	81.69	4.88	0.16	21.00			
Alamo C3D1	55.0	55.0	0.25	0.040	29.17	79.22	4.59	0.16	20.13			
Alamo C3D1	65.0	65.0	0.31	0.062	45.45	106.57	6.57	0.22	26.48			
Alamo C3D1	77.5	77.5	0.49	0.101	78.80	129.78	13.01	0.40	35.55			
Alamo C3D2	7.0	95.0	0.47	0.089	69.66	125.46	12.97	0.30	34.36			
Alamo C3D2	19.0	107.0	0.56	0.100	91.62	140.83	16.58	0.28	38.46			
Alamo C3D2	29.0	117.0	0.48	0.088	86.49	141.80	15.45	0.34	38.10			
Alamo C3D2	37.0	125.0	0.47	0.099	94.48	139.77	15.80	0.34	38.75			
Alamo C3D2	43.0	131.0	0.33	0.060	72.53	117.11	11.79	0.26	31.02			
Alamo C3D2	51.0	139.0	0.50	0.103	87.36	160.95	16.99	0.43	42.52			
Alamo C3D2	60.0	148.0	0.47	0.106	83.20	141.63	15.41	0.38	40.02			
Alamo C3D2	69.0	157.0	0.48	0.106	93.73	156.11	19.51	0.40	43.04			
Alamo C4D1	5.5	5.5	0.42	0.110	71.94	141.69	15.22	0.36	36.76			
Alamo C4D1	16.5	16.5	0.51	0.125	75.97	158.59	16.44	0.41	39.43			
Alamo C4D1	27.5	27.5	0.51	0.116	67.98	142.40	17.19	0.38	36.87			
Alamo C4D1	38.5	38.5	0.43	0.086	75.58	134.73	14.25	0.31	35.41			
Alamo C4D1	49.5	49.5	0.37	0.081	69.92	126.42	14.75	0.30	33.05			
Alamo C4D1	60.0	60.0	0.29	0.044	52.98	108.55	10.99	0.19	26.64			
Alamo C4D1	70.0	70.0	0.34	0.062	64.33	115.39	13.19	0.24	29.38			
Alamo C4D1	80.0	80.0	0.35	0.069	68.78	121.61	13.92	0.28	31.11			
Alamo C4D1	90.0	90.0	0.27	0.041	54.28	102.97	10.76	0.20	27.18			
Havasu C1D1	5.3	5.3	0.61	0.087	80.53	164.82	20.51	0.45	60.64	77.1	0.1335	2.385E-03
Havasu C1D1	15.8	15.8	0.59	0.079	83.33	157.67	22.14	0.51	61.02	75.6	0.1317	2.750E-03
Havasu C1D1	26.3	26.3	0.59	0.084	79.01	158.81	18.51	0.45	60.20	75.1	0.1307	3.222E-03
Havasu C1D1	36.8	36.8	0.55	0.086	91.78	152.33	24.16	0.37	48.93	70.9	0.1185	3.130E-03
Havasu C1D1	47.3	47.3	0.47	0.082	103.00	145.18	16.52	0.36	42.30	70.1	0.1458	2.564E-03
Havasu C1D1	57.8	57.8	0.51	0.082	91.45	118.21	16.22	0.32	34.88	73.5	0.1397	2.632E-03
Havasu C1D1	68.3	68.3	0.52	0.075	90.71	123.13	16.29	0.30	36.90	78.3	0.1341	2.727E-03
Havasu C1D1	79.3	79.3	0.33	0.078	119.07	164.83	19.78	0.49	48.94	68.5	0.1388	3.003E-03
Havasu C1D2	5.0	94.5	0.50	0.099	111.86	141.01	16.97	0.34	39.52	76.0	0.1467	4.971E-03
Havasu C1D2	15.0	104.5	0.54	0.085	81.95	146.94	25.69	0.45	49.67	77.3	0.1134	2.869E-03
Havasu C1D2	25.0	114.5	0.51	0.091	111.32	201.76	19.30	0.50	45.53	65.2	0.0702	1.225E-03
Havasu C1D2	35.0	124.5	0.51	0.081	105.56	119.67	15.72	0.34	35.74	66.7	0.0325	1.228E-03
Havasu C1D2	45.5	135.0	0.45	0.084	132.88	163.03	17.86	0.40	46.29	63.6	0.0324	1.031E-03
Havasu C1D2	56.5	146.0	0.50	0.065	111.33	135.79	21.53	0.41	45.88	62.2	0.0546	6.745E-05
Havasu C1D2	67.5	157.0	0.45	0.071	74.42	140.97	15.03	0.33	42.90	90.7	-0.2656	1.030E-05
Havasu C1D3	5.0	170.5	0.42	0.057	65.80	137.57	16.64	0.31	42.16	63.9	0.0238	2.595E-05
Havasu C1D3	15.5	181.0	0.37	0.050	54.61	124.39	14.11	0.27	37.09	46.4	0.0340	5.538E-05
Havasu C1D3	27.0	192.5	0.31	0.045	50.13	138.12	18.19	0.32	38.94	48.0	-0.1459	2.472E-05
Havasu C1D3	38.0	203.5	0.29	0.027	34.45	95.35	10.37	0.16	24.87	38.2	-0.4808	1.115E-05
Havasu C1D3	48.0	213.5	0.31	0.037	46.36	112.44	10.60	0.22	28.31	50.4	-0.1441	2.354E-05
Havasu C1D3	58.5	224.0	0.31	0.040	47.06	112.81	10.99	0.22	28.79	65.5	-0.1165	3.311E-05
Havasu C1D3	69.0	234.5	0.31	0.037	42.64	109.27	10.82	0.22	28.26	83.0	0.0182	4.279E-05
Havasu C1D3	80.0	245.5	0.28	0.032	42.49	100.74	10.44	0.22	26.24	51.8	-1.8974	3.643E-06
Havasu C1D4	5.5	260.5	0.26	0.028	39.02	102.78	12.43	0.21	26.13	30.8	-0.2185	1.489E-05
Havasu C1D4	16.0	271.0	0.28	0.030	36.13	101.56	9.81	0.16	26.31	36.4	1.5667	1.828E-06
Havasu C1D4	26.0	281.0	0.29	0.029	35.08	107.36	8.67	0.14	26.15	26.0	-0.5521	8.255E-06
Havasu C1D4	36.0	291.0	0.28	0.018	31.45	100.67	7.06	0.14	24.94	18.2	-0.2292	9.192E-06
Havasu C1D4	47.5	302.5	0.28	0.021	31.34	101.89	7.63	0.15	26.78	18.1	0.0059	1.698E-05

Core	Position in Core (cm)	Absolute Position (cm)	Moisture Content (fraction)	LOI (fraction)	Cu (ug/g)	Zn (ug/g)	As (ug/g)	Cd (ug/g)	Pb (ug/g)	Hg (ug/g)	(240Pu/239Pu)corr	239Pu+240Pu (Bq/kg)
Havasu C1D4	58.5	313.5	0.31	0.036	47.34	107.23	10.87	0.20	27.32	54.0	0.0865	2.113E-05
Havasu C1D4	67.5	322.5	0.31	0.039	48.49	104.49	11.11	0.18	27.47	60.0	0.1280	1.281E-05
Havasu C1D4	76.5	331.5	0.31	0.037	47.19	106.27	11.20	0.21	27.94	50.8	-0.0773	7.879E-05
Havasu C1D4	86.0	341.0	0.30	0.037	44.54	106.84	10.55	0.19	28.06	47.5	0.0230	5.908E-05
Havasu C1D5	5.0	354.5	0.29	0.036	43.47	95.61	9.98	0.22	25.92	41.3	0.0678	4.267E-05
Havasu C1D5	15.0	364.5	0.29	0.037	43.27	103.89	10.36	0.20	28.20	49.6	-0.0094	3.097E-05
Havasu C1D5	25.0	374.5	0.31	0.039	45.40	107.20	10.99	0.22	29.13	52.0	0.0501	5.246E-05
Havasu C1D5	35.5	385.0	0.34	0.046	50.80	112.89	12.73	0.26	30.13	63.2	-0.3418	1.753E-05
Havasu C1D5	44.5	394.0	0.26	0.033	35.07	105.02	9.10	0.17	28.30	28.2	-0.3373	1.534E-05
Havasu C1D5	51.5	401.0	0.22	0.020	21.58	73.48	8.38	0.11	28.14	17.9	0.2999	-2.356E-06
Havasu C2D1	5.3	5.3	0.56	0.055	92.94	163.22	22.48	0.56	55.68		0.1198	3.317E-03
Havasu C2D1	15.8	15.8	0.57	0.062	100.27	168.16	20.24	0.52	58.46		0.1415	3.027E-03
Havasu C2D1	26.3	26.3	0.58	0.063	92.17	177.02	21.10	0.51	61.57		0.1394	3.280E-03
Havasu C2D1	36.8	36.8	0.55	0.059	89.48	161.71	21.38	0.46	53.81		0.0613	3.151E-02
Havasu C2D1	47.3	47.3	0.47	0.056	101.38	145.37	16.72	0.37	42.23		0.1353	2.660E-03
Havasu C2D1	57.8	57.8	0.43	0.050	90.61	137.45	15.15	0.30	39.92		0.1452	2.332E-03
Havasu C2D1	68.3	68.3	0.53	0.060	133.01	158.61	20.19	0.45	48.25		0.1469	4.807E-03
Havasu C2D1	78.8	78.8	0.55	0.060	94.40	171.83	22.66	0.46	55.57		0.1238	4.498E-03
Havasu C2D1	89.0	89.0	0.53	0.072	84.83	160.62	19.37	0.45	49.42		0.1162	2.814E-03
Havasu C2D2	5.0	104.0	0.57	0.072	85.34	157.36	20.92	0.44	50.41		0.1136	2.973E-03
Havasu C2D2	15.0	114.0	0.51	0.071	81.63	141.54	17.13	0.43	43.00		0.0991	2.663E-03
Havasu C2D2	25.0	124.0	0.52	0.063	115.93	184.93	18.16	0.43	44.92		0.0532	5.810E-04
Havasu C2D2	35.0	134.0	0.47	0.055	97.95	143.57	15.61	0.33	40.38		0.0325	9.380E-04
Havasu C2D2	45.0	144.0	0.41	0.056	130.51	204.87	18.85	0.39	43.98		0.0378	1.521E-03
Havasu C2D2	55.0	154.0	0.53	0.059	199.60	153.87	19.03	0.41	44.69		0.0371	1.934E-04
Havasu C2D2	65.0	164.0	0.57	0.063	387.05	152.41	24.80	0.36	47.10		0.0379	6.750E-05
Havasu C2D2	75.0	174.0	0.50	0.065	112.76	175.81	19.25	0.42	50.05		0.0951	5.261E-05
Havasu C2D2	84.5	183.5	0.37	0.039	59.77	121.88	13.00	0.24	35.12		0.2736	2.202E-05
Havasu C2D3	5.0	195.0	0.37	0.045	105.10	135.40	16.45	0.28	37.86		0.1239	7.077E-05
Havasu C2D3	15.0	205.0	0.33	0.033	54.89	119.70	14.13	0.24	33.44		0.2410	1.155E-05
Havasu C2D3	24.0	214.0	0.35	0.043	56.25	123.48	14.91	0.25	35.29		0.1948	4.560E-05
Havasu C2D3	33.0	223.0	0.33	0.036	54.06	118.22	13.70	0.26	33.32		0.1767	3.382E-05
Havasu C2D3	42.5	232.5	0.55	0.059	73.99	145.39	20.45	0.32	48.37		0.1090	2.228E-05
Havasu C2D3	52.0	242.0	0.38	0.039	64.79	139.17	18.17	0.29	41.75		0.0327	1.354E-04
Havasu C2D3	62.0	252.0	0.29	0.033	48.00	116.71	11.27	0.21	29.47		0.8892	1.623E-05
Havasu C2D3	72.0	262.0	0.32	0.041	53.13	130.27	12.53	0.23	33.43		-0.0206	4.069E-05
Havasu C2D3	82.5	272.5	0.31	0.043	56.00	131.48	14.81	0.22	34.06		0.0534	1.034E-04
Havasu C2D3	93.3	283.3	0.30	0.032	49.76	139.69	18.58	0.35	40.69		14.6294	6.400E-06
Havasu C2D4	4.5	297.5	0.29	0.025	48.59	124.10	13.77	0.24	32.61		0.1119	2.585E-05
Havasu C2D4	13.5	306.5	0.28	0.030	48.71	140.11	17.50	0.33	40.00		-0.0495	2.195E-05
Havasu C2D4	22.3	315.3	0.35	0.037	70.49	203.25	35.14	0.56	65.25		0.0521	4.312E-05
Havasu C2D4	28.8	321.8	0.23	0.010	28.76	89.80	11.95	0.17	27.34		0.0157	3.429E-05
Havasu C2D4	34.5	327.5	0.13	0.007	24.20	73.73	10.55	0.14	44.05		-0.7515	2.465E-06
Havasu C2D4	43.0	336.0	0.33	0.024	50.42	108.99	10.84	0.23	28.44		0.0333	4.973E-05
Havasu C2D4	53.0	346.0	0.34	0.030	50.83	132.83	11.32	0.24	29.11		0.2121	2.012E-05
Havasu C2D4	63.3	356.3	0.33	0.027	50.26	113.34	11.33	0.25	29.00		0.0523	3.395E-05
Havasu C2D4	72.3	365.3	0.29	0.030	35.18	106.68	8.40	0.16	26.63		0.1737	1.329E-05
Havasu C3D1	5.5	5.5	0.23	0.009	31.63	96.22	6.44	0.12	26.87		0.1019	1.874E-04
Havasu C3D1	16.5	16.5	0.26	0.018	39.81	96.01	8.23	0.14	25.51		0.1397	3.458E-04
Havasu C3D1	27.3	27.3	0.27	0.027	48.25	103.46	9.79	0.17	27.53		0.1507	6.771E-04
Havasu C3D1	33.8	33.8	0.34	0.038	81.71	129.91	14.46	0.28	35.73		0.1392	1.689E-03
Havasu C3D1	39.5	39.5	0.26	0.020	44.97	95.78	9.08	0.18	25.87		0.1343	5.607E-04
Havasu C3D1	48.5	48.5	0.27	0.032	57.85	104.92	10.51	0.45	27.84		0.1479	7.608E-04
Havasu C3D1	56.3	56.3	0.26	0.022	47.55	97.82	9.04	0.19	25.29		0.1217	4.811E-04
Havasu C3D1	61.3	61.3	0.29	0.026	59.65	108.39	11.54	0.22	29.58		0.1403	1.238E-03
Havasu C3D1	67.5	67.5	0.26	0.019	56.67	114.68	9.57	0.32	28.43		0.1398	6.220E-04
Havasu C3D1	77.3	77.3	0.27	0.027	54.58	105.02	10.01	0.19	27.54		0.1148	6.494E-04
Havasu C3D1	87.3	87.3	0.37	0.040	107.48	139.36	15.32	0.32	38.32		0.1382	2.405E-03
Havasu C3D2	5.0	102.0	0.37	0.038	61.58	122.57	14.40	0.29	33.57		0.1156	2.211E-03
Havasu C3D2	15.5	112.5	0.34	0.035	70.99	131.95	14.15	0.31	36.09		0.0779	1.108E-03
Havasu C3D2	26.0	123.0	0.24	0.009	28.86	94.16	9.06	0.15	24.55		-0.3141	7.797E-06
Havasu C3D2	36.0	133.0	0.25	0.009	20.93	68.40	5.55	0.10	19.44		-0.1302	1.297E-05
Havasu C3D2	46.0	143.0	0.24	0.011	25.98	96.86	5.92	0.08	23.58		-0.4090	9.084E-06
Havasu C3D2	56.0	153.0	0.18	0.005	10.07	36.88	3.74	0.05	21.09		0.4791	1.617E-05
Havasu C3D2	66.5	163.5	0.21	0.009	13.34	52.48	4.12	0.08	23.45		-0.7320	6.161E-06