475

Changing Sedimentation Rates during the Last Three Centuries at Lake Elsinore, Riverside County, California

Final Report
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Table of Contents

1. Purpose of Study.......... 4
2. Summary of Results.......... 5
3. Study Site.......... 5
4. Field Work and Core Recovery.......... 6
5. Laboratory Methods.......... 7
   - 5.1 Percent Water Content.......... 8
   - 5.2 Pollen Analysis.......... 8
   - 5.3 Sediment Chemistry.......... 9
   - 5.4 Lead-210 (^{210}Pb) and Cesium-137 (^{137}Cs) Analysis.......... 9
   - 5.5 Radiocarbon Dating.......... 10
   - 5.6 Magnetic Susceptibility.......... 11
   - 5.7 Grain Size Analysis.......... 11
   - 5.8 Percent Total Organic Matter.......... 11
   - 5.9 Percent Total Carbonate.......... 11
6. Results.......... 12
   - 6.1 Percent Water Content.......... 12
   - 6.2 Pollen Analysis.......... 13
     - 6.2.1 Zone 2.......... 13
     - 6.2.2 Zone 1.......... 13
   - 6.3 Sediment Chemistry.......... 15
   - 6.4 Cesium-137 (^{137}Cs) Dating.......... 17
   - 6.5 Radiocarbon Dating.......... 17
   - 6.6 Magnetic Susceptibility.......... 18
   - 6.7 Percent Total Organic Matter.......... 18
   - 6.8 Percent Total Carbonate.......... 18
7. Discussion.......... 18
   - 7.1 Developing Core Chronology.......... 18
     - 7.1.1 Using Percent Water Content to Correlate Cores.......... 19
     - 7.1.2 Pollen Age Control.......... 19
     - 7.1.3 Sediment Chemistry.......... 21
     - 7.1.4 Cesium-137 (^{137}Cs) Dating.......... 21
     - 7.1.5 Radiocarbon Dating.......... 21
   - 7.2 Sedimentation Rates.......... 23

7.2.1 Lake Elsinore.. 23
7.2.2 Lake Elsinore v Railroad Canyon Reservoir................................. 24
7.2.3 Impact of Sediment Compaction on Sedimentation Rates............... 25
7.2.4 Incomplete Recovery in LESS02-11 and its Potential Effect on 25
Reconstructed Sedimentation Rates... 25
8. Summary.. 29
9. References.. 30
10. Appendices.. 34

List of Figures

Figure 1. Study site map with core locations.. 4
Figure 2. Percent water content for cores LE-01 and LESS02-11.................. 12
Figure 3. Pollen data for cores LE-01 and LESS02-11................................ 14
Figure 4. Lead data for core LE-01... 15
Figure 5. Trace element data for LE-01... 16
Figure 6. Cesium-137 data for core LESS02-11.. 17
Figure 7. Chronological markers in the LE-01 and LESS02-11..................... 22
Figure 8. LE-01 Age-depth curve with sedimentation rates.......................... 27
Figure 9. LESS02-11 Age-depth curve with sedimentation rates.................... 28

List of Tables

Table 1. Core Information.. 7
Table 2. Radiocarbon Dates 18
Table 3. Sedimentation Rates.. 23

1. Purpose of the Study

The purpose of this study was to determine recent sedimentation rates in Lake Elsinore by stratigraphic analyses of sediment cores (Figure 1). An important question was whether or not twentieth century erosion in the Lake Elsinore watershed had resulted in sedimentation rates in the lake that were significantly higher than "natural" or pre-19th Century levels. A related question was whether or not recent sedimentation in Lake Elsinore was significantly different from that registered by the United States Geological Survey (USGS) for Railroad Canyon Reservoir (i.e. Canyon Lake) (USGS, 1998). Railroad Canyon Reservoir was built on the San Jacinto River upstream from Lake Elsinore in 1927 (Mann, 1951).

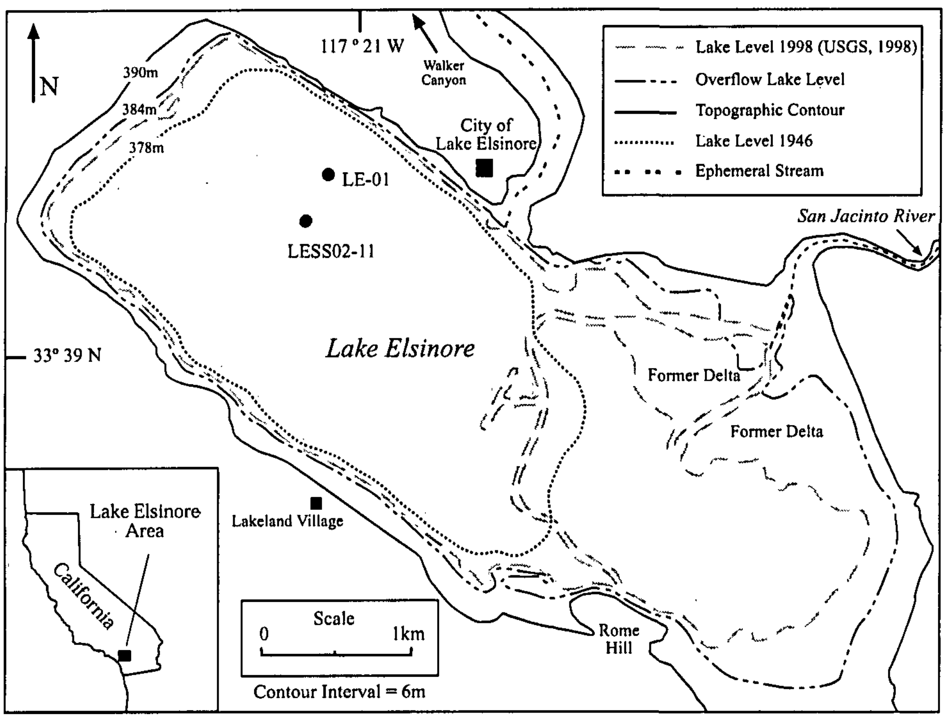

Figure 1. Map of the study area showing core recovery locations at Lake Elsinore, Riverside County, California.

If sedimentation rates in Lake Elsinore are much less than Canyon Lake, then Lake Elsinore should be de-listed for sediment impairment (Contract Statement to UC Berkeley, 2002). Whether or not this is the case, however, requires the examination of sedimentation rates in Lake Elsinore before the construction of Canyon Lake. In this study we compare pre-20th century and 20th century sedimentation rates in Lake Elsinore over the last 270 years. This comparison will provide a better basis for lake management. We note, however, that longer sediment cores will be required to fully understand the lake's "natural" variability over long periods of changing boundary conditions (i.e., climate and tectonics). Consequently, our results should be considered preliminary.

2. Summary of Results

The main conclusions of this study are:

1. Twentieth century sedimentation rates for Lake Elsinore ranged from 10.1 mm/yr to 15.3 mm/yr. The average rate of 13.5mm/yr is roughly half the reported Canyon Lake sedimentation rate of 24 mm/yr for the period 1927-1998 (USGS, 1998).
2. Sedimentation rate estimates for the 18th and 19th centuries are less certain than those for the 20th century because of the limited number of chronological markers. Sedimentation rates for the period 1730 to 1910 ranged from 2.8mm to 5.0mm/yr. The average rate of 3.6 mm/yr is ~3x less than the twentieth century rate.
3. The construction of the Canyon Lake Reservoir has considerably reduced the input of sediment into Lake Elsinore. Even so, the average twentieth century sedimentation rate is still 3x greater than the 18th and 19th century rates.

3. Study Site

Lake Elsinore is located in down faulted-graben along the Elsinore fault, 120 km south-east of Los Angeles (Figure 1). It is the largest natural lake in the southern California Coast Ranges. Total sediment thickness underlying Lake Elsinore is estimated to be more than 600 m, possibly 1000 m (Mann, 1956; Pacific Groundwater Digest, 1979; Damiata and Lee, 1986; Hull, 1991). Lake Elsinore has a relatively small drainage basin (<1240 km^2) through which the San Jacinto River flows (seasonally) and terminates within the lake's basin (USGS, 1998). A small reservoir north of Lake Elsinore (Canyon Lake) was built in 1927 in an attempt to regulate Lake Elsinore's lake level and supply water for surrounding agriculture (Mann, 1947). The capacity of Canyon Lake Reservoir is small compared to the total capacity of Lake Elsinore (~12%) and thus it has proven rather ineffective in controlling lake level change (Mann, 1947). Lake Elsinore overflows to the northwest through Walker Canyon very rarely. This happened only 3 times in the 20th century and 20 times since 1769 (Lynch, 1931; USGS,1998). Each overflow event was very short-lived (<several weeks) demonstrating that Lake Elsinore is essentially a closed-basin lake system (Lynch, 1931; USGS, 1998). Conversely, Lake Elsinore dried completely on only 4 occasions since A.D. 1769 (Lynch, 1931, USGS, 1998). During one low stand, the lake was described by locals as "nothing more than a marshy patch of tules" (Mann, 1947).

When Lake Elsinore is its overflow elevation of 384 meters it is about 8.8 km long and about 2.9 km wide, and has a maximum surface area of 2,509 hectares. The average area of the lake since 1916 has been about 1,538 hectares (California Division of Water Resources, 1953). At present, the lake is quite shallow, with a maximum depth of only 6 m. It has been as deep as 13 m, based on historical records (Mann, 1951). Possible wind induced mixing may occur during excessively windy seasons (Mann. 1947). Sediment from the lake bottom exhibits a strong odor of hydrogen sulfide (H_2S) suggesting an oxygen deficiency in the hypolimnion (Mann, 1951; Anderson, 2001). Annual water loss to evaporation from the lake's surface is >1 m; consequently, water residence time in Lake Elsinore is very short (< 5 years?), and likely much shorter during drought periods (<1 year) (Mann, 1947; USGS, 1998). According to Mann (1947) a strong grain size gradient exists from the littoral zone (shore environment) to the profundal zone (basin environment). The same author attributes the grain size gradient to wave action winnowing of the littoral sediments in combination with sediment transport processes that limit the transportation of larger grains into the deeper part of the lake.

4. Fieldwork and Core Recovery

In September 2001, Liam Reidy and a group of students from the University of California, Berkeley, Geography Department, recovered a 113 cm sediment core (LE-01) from the deepest basin in Lake Elsinore (Table 1, Figure 1). A hand operated Livingston piston corer was used to extract the core. In June 2002, Liam Reidy (UCB), Steve Lund (USC), Matthew Kirby (CSUF), and Chris Poulsen (USC now at the University of Michigan) from the Department of Earth Sciences at the University of Southern California (USC) and Cal-State Fullerton (CSUF) Department of Geological Sciences recovered an additional core (LESS02-11) using a heavy duty Livingston corer (Figure 1). Core LESS02-11 has a total length of 180 cm (Table 1). Recovery of longer cores was not possible due to occurrence of dense clay layers at depth. Cores were encased in plastic core liners and/or plastic wrap with aluminum foil and transported to the UCB Pollen Laboratory, the USC Paleomagnetism Laboratory, and the CSUF Paleoclimatology Laboratory for sub-sampling and analysis.

Table 1. Core Information.

Core I.D.	Latitude	Longitude	Water Depth	Total Length
LE-01	33°40′.100 N	117°20′.200 W	6.00 m	113 cm
LESS02-11	33°39′.723 N	117°21′.299 W	5.50 m	180 cm

Several short cores were also taken in shallow water near the shoreline. However, sedimentation rates in these cores proved to be very low. We therefore concentrated our efforts on the two cores taken in the deep water basin, where sedimentation rates can safely be assumed to be maximum estimates for the lake as a whole.

5. Laboratory Methods

The determination of sedimentation rates depends on accurate core chronologies. Several dating methods were used in an effort to establish Lake Elsinore sedimentation rates including: pollen analysis, sediment chemistry, lead-210 (^{210}Pb), cesium-137 (^{137}Cs), and accelerator mass spectrometry radiocarbon dating (AMS ^{14}C). In addition the cores were analyzed for organic content, water content, magnetic susceptibility and grain size variation as a means of cross correlation.

5.1 Percent Water Content.

Determination of percent water content is a quick and easy way to document changes in sediment lithology and to cross-correlate cores from the same region of a lake basin. Percent water content is particularly useful in lakes like Lake Elsinore that are susceptible to periodic desiccation. Periods of drying will desiccate the sediment and substantially change its water content relative to sediment that is deposited in sub-aqueous conditions.

Water content was determined as follows: Three to five cm^3 of wet sediment was placed into a pre-weighed beaker. The wet sediment weight was measured. The sediment was then dried at 60°C for 24 hours. The dry sediment was re-weighed to determine the percent weight water loss to evaporation (i.e., percent water content). Percent water content was determined for core LE-01 at various intervals ranging from 2.5 to 5.0 cm. Percent water content was determined for LESS02-11 at 1.0 cm intervals.

5.2 Pollen Analysis.

Pollen analysis provides information about the history of vegetation change including the introduction of exotic species. In California the first appearance of exotic species in sediment cores is a well-tested method for use in determining recent sedimentation rates (Mudie and Byrne, 1980). Cores LE-01 and LESS02-11 were analyzed for fossil pollen at regular intervals (5, 10 or 15 cm). Standard pollen extraction and preparation procedures were followed (Faegri and Iversen, 1975). Two tablets each containing approximately 13,911 *Lycopodium* spores were added to each sample as a control (Stockmarr, 1971). Samples were then processed with the following treatments: hydrochloric acid (10 per cent), potassium hydroxide (10 per cent), hydrofluoric acid (48 per cent), isopropanol wash, nitric acid (70 per cent), glacial acetic acid wash, and acetolysis (9 parts acetic anhydride and 1 part concentrated sulfuric acid). The residues from the chemical digestion were stained with safranin, dehydrated with tertiary butyl alcohol, suspended in silicone oil, and mounted on microscope slides.

Pollen counts were made on a Zeiss transmitted light microscope at 400x magnification. Pollen grains were identified with the aid of the University of California Museum of Paleontology (UCMP) Pollen Reference Collection and published keys (McAndrews et al., 1973; Kapp et al, 2000). Some grains could not be identified and were labeled "unknown". Damaged, torn or crumpled grains that were unidentifiable were counted as "indeterminate". A minimum of 400 pollen grains and fern spore types were counted for each of the twenty 20 samples analyzed. Terrestrial pollen percentages were calculated from the sum of terrestrial pollen and fern spores. Aquatic pollen percentages were calculated using the total sum of aquatic pollen. Pollen diagrams were constructed using Calpalyn (Bauer et al., 1991).

5.3 Sediment Chemistry.

Twenty four samples from Core LE-01 were analyzed with a Phillips PW 2400 X-Ray Fluorescence (XRF) scanner in the Department of Earth and Planetary Science at UC Berkeley to determine bulk elemental composition. XRF analysis determines the elemental composition of the inorganic component of the sediments and therefore provides information about the history of land use in a lake's drainage basin. Samples were prepared by combustion at 550°C for one hour to remove water and organic material. Three grams of inorganic sediment per sample were ground to a powder, treated with a bonding agent, and compressed into pellets prior to XRF analysis.

5.4 Lead-210 (^{210}Pb) and Cesium-137 (^{137}Cs) Analyses

LESS02-11 was analyzed for both ^{210}Pb and ^{137}Cs, which were measured using gamma spectroscopy (D. Hammond, personal comm.). Samples were ground and placed in a polyethylene tube (1 cm OD x 4.5 cm high) and inserted into the well of an intrinsic germanium gamma detector (EG&G Ortec). Samples were counted for 1-3 days to determine the activity of the Pb-210 and Cs-137 isotopes. ^{210}Pb produced a peak of 46 keV and Cs-137 produced a peak of 662 keV. Ra-226 was also counted to determine the supported level of ^{210}Pb. It produced a peak of 186 keV. The counting efficiency for each peak was determined with standards obtained from the EPA and configured in a similar geometry. Backgrounds for each peak were determined from the count rates of envelopes on both sides of each peak. Uncertainties are based on the counts observed in each peak and its background channels.

Lead-210 activity in samples from LE-01 were analyzed by alpha spectrometry. Twelve samples were analyzed in order to define the levels of unsupported ^{210}Pb in the sediments following standard methods (Appleby and Oldfield, 1978). A known quantity of Polonium-209 (^{209}Po) spike was added to one gram of dry sediment and leached in 8 N HNO_3 for four hours at 90°C. After the leach, the sample was centrifuged and the undigested sediment discarded. The leachate was then evaporated to the point of dryness. The precipitated residue was then dissolved in hydrochloric acid (0.5 N). Ascorbic acid was added to the sample in order to complex the iron. A silver planchette was plated for at least four hours over a magnetic spinner at 50°C. Lead-210 activity was detected via its granddaughter isotope ^{210}Po. Disintegrations per second were measured with an Ortec multichannel alpha-counter and a multichannel analyzer. Unsupported levels of ^{210}Pb activity were determined by subtracting the supported or background level.

Lead-210 analysis is a classic dating technique for young (<200 years) sediments (Krishnaswami et al., 1971; Anderson et al., 1987; Chillrud et al., 1999). Lead-210 is rapidly deposited into sedimentary environments, such as lakes, via atmospheric fallout facilitated by precipitation. Unfortunately in Southern California, the deposition of ^{210}Pb in measurable quantities is limited by the infrequent precipitation and the prevailing wind direction. As a result, the ^{210}Pb analyses on LE-01 and LESS02-11 did not provide useful information regarding sediment chronology. Another radioisotope that can be used to date recent sediments is ^{137}Cs. Cesium-137 is not a naturally occurring isotope but was produced in significant quantities in the 1950's and 1960's during atmospheric testing of nuclear weapons (Robbins and Edgington, 1975). The first appearance of ^{137}Cs in sediments is generally dated at 1953, whereas its peak abundance is dated at 1963, or the apex of nuclear weapons testing (Chillrud et al., 1999). Cesium-137 data from core LESS02-11 provided useful results.

5.5 Radiocarbon Dating

Two sediment samples from core LESS02-11 were sent to BETA Analytic, Inc. for accelerator mass spectrometry (AMS) radiocarbon dating. Using standard techniques, BETA Analytic, Inc. determines the radiocarbon age on the total organic carbon fraction of the sediment.

5.6 Magnetic Susceptibility

Core LE-01 was scanned at 1 cm intervals to measure magnetic susceptibility. Samples from LESS02-11a and b were extracted at 0.5 cm intervals and placed in pre-weighed 10 cc plastic cubes. Magnetic susceptibility was measured twice on each sample with the y-axis rotated once per analysis. All samples were analyzed using a Bartington MS2 Magnetic Susceptibility instrument. All magnetic susceptibility measurements were determined immediately (i.e., same day) after the core was split and described to avoid possible magnetic mineral diagenesis with exposure to air. Following the measurement of magnetic susceptibility, the samples were re-weighed to obtain total sediment weight. The average magnetic susceptibility value for each sample was then divided by the sample weight to account for mass differences. Measurements were made to the 0.1 decimal place and reported as mass magnetic susceptibility (CHI = c) in SI units (x10-7 m3kg-1).

5.7 Grain Size Analysis

Grain size measurements were attempted using additional magnetic susceptibility measurements that are sensitive to changes in grain size. Grain size analyses using this technique were not successful due to the extremely low ambient magnetic susceptibility of the lake sediments. As a result, there are no grain size data to report.

5.8 Percent Total Organic Matter

Total organic matter was determined using the loss on ignition method (Dean, 1974). Samples were extracted from cores LESS02-8 and LESS02-10 at 1.0 cm intervals. All samples were dried at room temperature prior to grinding with a mortar and pestle. Ground samples were placed in a drying oven at 105°C for 24 hours to remove excess moisture. Dried samples were transferred to pre-weighed crucibles, weighed to obtain dry sediment weight, and heated to 550°C in an Isotempâ muffle oven for two hours. After two hours the samples were re-weighed to obtain the percentage total organic matter from total weight loss.

5.9 Percent Total Carbonate

Total carbonate was determined also using the loss on ignition method (Dean, 1974; REF). Samples were extracted from cores LESS02-8 and LESS02-10 at 1.0 cm intervals.

Following the 550°C analysis and weighing, crucibles were re-heated to 950°C for two hours. After two hours the samples were re-weighed and percentage total carbonate was calculated.

6. Results

6.1 Percent Water Content

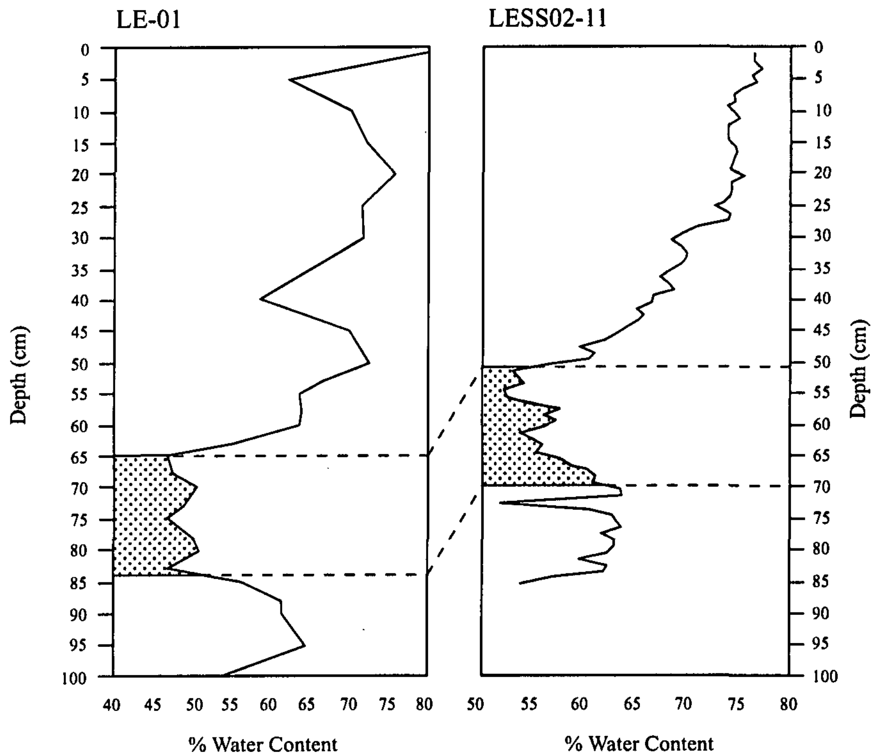

Figure 2. Percent total water content for core LE-01 and LESS02-11. Vadose desiccation zone shown by shaded area

Figure 2 shows the percent water content for cores LE-01 and LESS02-11. As expected, the percent water content values are highest near the core tops where the compaction of sediment is minimal, thus reducing the migration of water from the sediment pore spaces. The percent water content in core LE-01 ranges from ~83% to ~47%. A notable low water content interval occurs between 65 and 84 cm in core LE-01 (Figure 2). The percent water content in core LESS02-11 ranges from ~76% to ~52%. A notable low water content interval occurs between 84 and 65 cm in LE-01 and 65-52 in core LESS02-

11. In section 7.1.1, we use the low water content interval in cores LE-01 and LESS02-11 to cross-correlate the core stratigraphies.

6.2 Pollen Analysis

Pollen analysis has provided a record of vegetation change in the watershed during the last 270 years. A total of forty different pollen and spore types were identified in the samples analyzed (Appendix 1). The changing frequencies of the more important taxa are shown in Figure 3. Pollen concentrations are shown in grains per cm^3. For purposes of discussion two pollen zones are recognized. Zone 2 *(170-151 cm)* is defined by the absence of non-native pollen types (Figure 3). High relative percentages of Asteraceae (~30%) and *Pinus* (~10%), and low percentages of *Quercus* and Poaceae characterize this zone. Pollen concentrations are also low (~30,000 grains per cm^3). Zone 1 *(150-0 cm)* is characterized by the first appearance of non-native pollen types and increases in tree pollen percentages. The pollen frequencies change dramatically in this zone. The first non-native type to appear is *Erodium cicutarium* at 150 cm. We assign a date of 1800 ±20 to this level. *Erodium* is present in all samples examined above 150 cm. It reaches a peak of 4% of the non-aquatic pollen sum at 100 cm, but declines to <1% at top of the core. Asteraceae declines from a high of >30% of the non-aquatic pollen sum at 150 cm to less than <4% at the top of the record. *Quercus* increases from <5% in zone 2 to >15% at the top of zone 1. *Pinus* declines from a high of ~14% in zone 2 to ~4% at the 60 cm level. Above 50 cm it increases again, reaching ~9% at the top of the record. Non-native *Eucalyptus* pollen was first encountered at 110 cm which we assume to represent 1910 ±10. Percentages of *Eucalyptus* are low between 110 cm and 70 cm. Above 60 cm *Eucalyptus* increases to ~5% of the pollen sum. *Juglans* is present throughout the record at <1% but increases in abundance towards the top of the core. *Fraxinus* is not present until 100 cm and increases to ~5% of the pollen sum at the top of the core. Amaranthaceae pollen is low (~5%) throughout most of zone 1 but spikes to >30% at 60 cm. Rhamnaceae and Rosaceae remain ~17% of the non-aquatic pollen sum throughout the core. Pollen concentration rates increase during zone 1 to ~75,000 grains per cm^3.

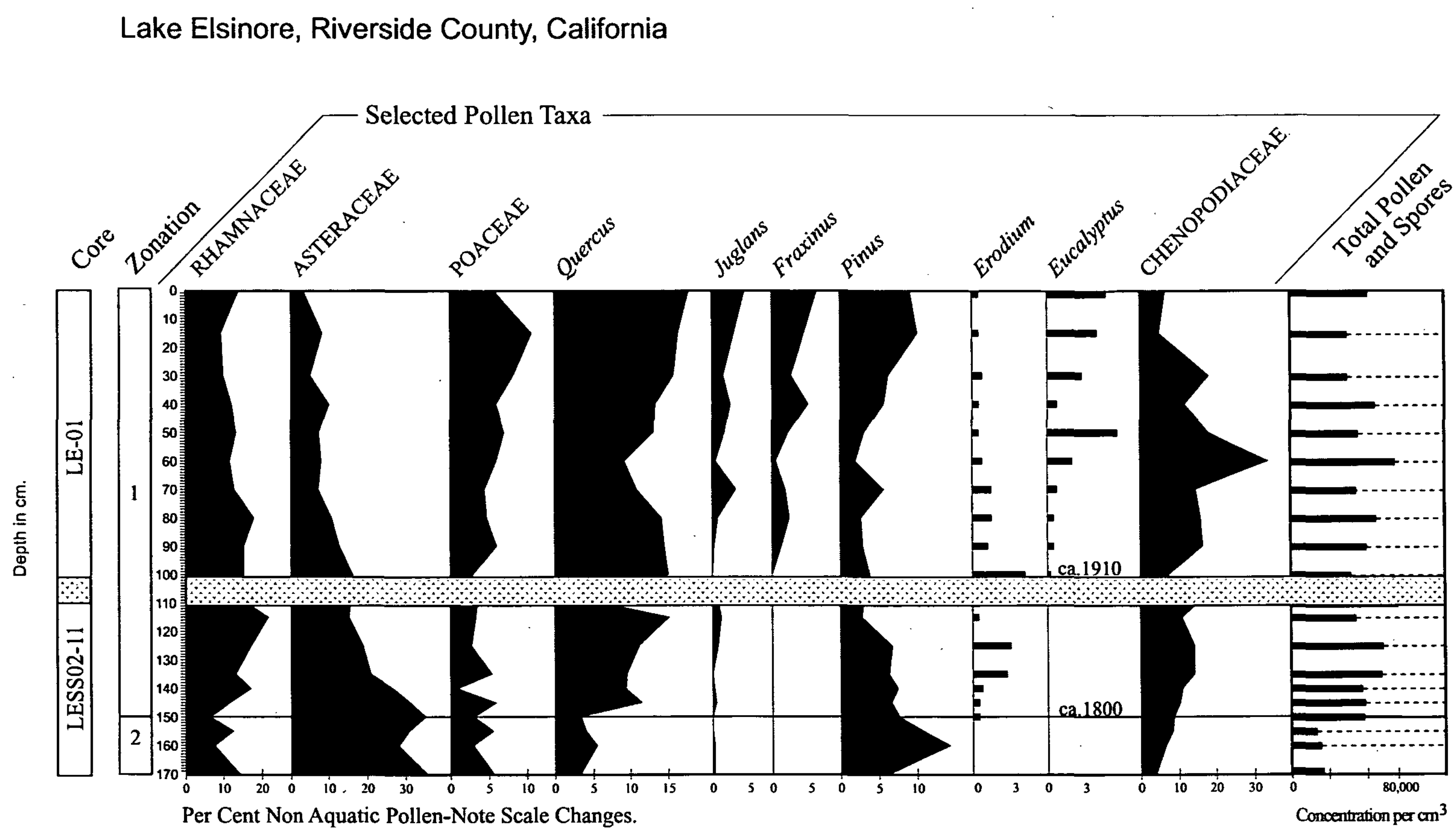

Figure 3. Pollen diagram showing pollen frequencies for core LE-01 and the lower section of LESS02-11.

6.3 Sediment Chemistry

A total of 36 elements were measured by X-Ray Fluorescence (XRF) (Appendix 2). The results for lead (Pb) showed the most variation during the recent past and provide a chronological marker for the near surface sediments (Figure 4). Lead concentrations vary from 14-50 ppm (parts per million) in LE-01. Lead levels peak to 50 ppm at 40 cm and we assume this represents the heavy use of leaded gas in the area in the mid-1970's. Above this level, lead concentrations gradually decline to 36 ppm in the surface sample. Chromium, zinc, copper, vanadium, and sulfate concentrations also increase towards the top of the core. The increases can possibly be attributed to recent development in the Lake Elsinore area.

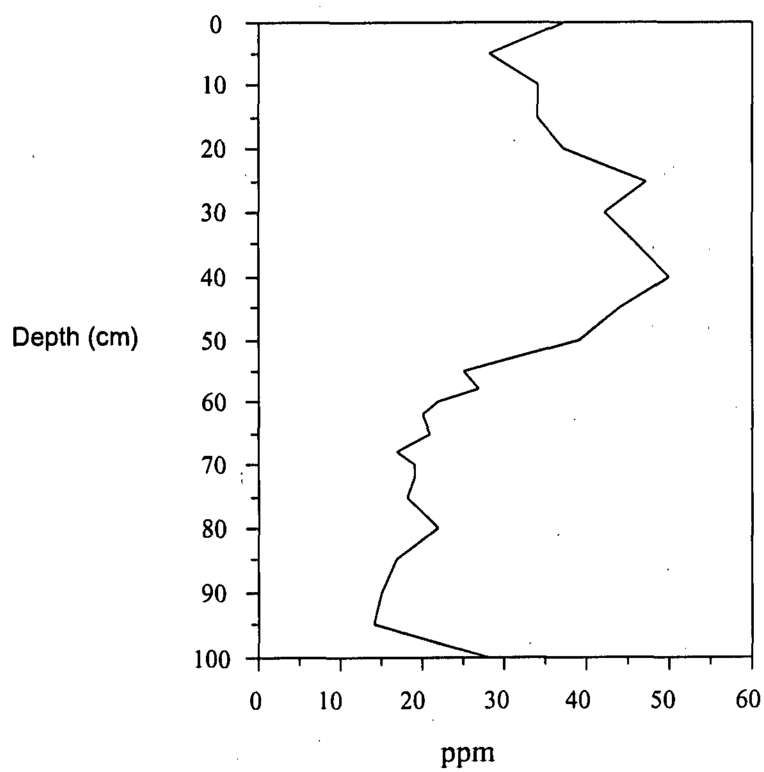

Figure 4. Lead concentration in LE-01.

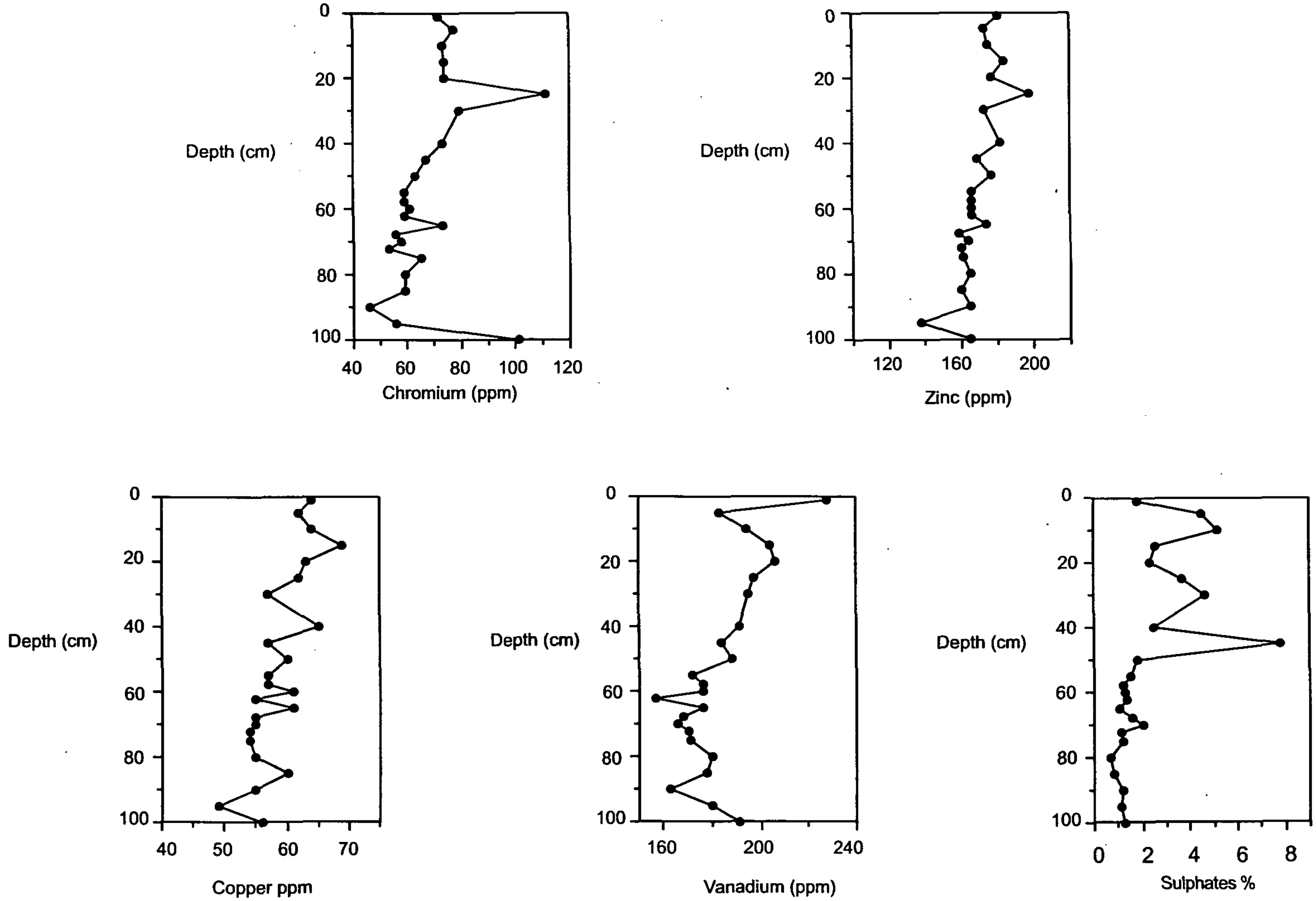

Figure 5. Concentrations of chromium, zinc, vanadium, copper and sulfates in LE-01.

6.4 Cesium-137 (^{137}Cs) Dating

The first occurrence of ^{137}Cs in core LESS02-11 is at 60 cm (Figure 6). Chillrud et al. (1999) date the first occurrence of ^{137}Cs in lake sediments at 1953. However, samples below 60 cm were not analyzed for ^{137}Cs and we can not therefore assign a date to the first appearance of ^{137}Cs in core LESS02-111. The 46 cm peak in ^{137}Cs, however, is interpreted to represent 1963 the peak year of nuclear testing (Chillrud et al., 1999). We discuss below (section 7.1), how the ^{137}Cs can be used for dating in conjunction with the pollen data. We assign a date of 1963 to the 46 cm depth in core LESS02-11 (Figure 6).

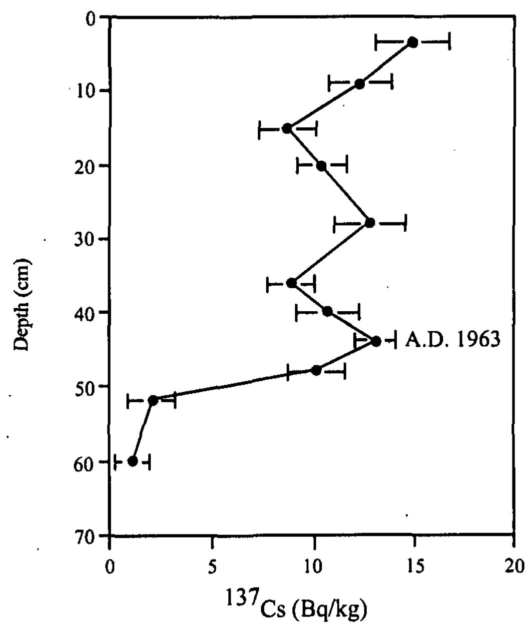

Figure 5. Cesium-137 profile for core LESS02-11.

6.5 Radiocarbon Dating

Surface sediments from LESS02-11, dated by the AMS ^{14}C method, produced a "modern" or post 1950 age (Table 2). The second AMS ^{14}C date from 145cm in LESS02-11 produced an age range of 810±40 BP (Table 2). For reasons discussed in section 7.1, we argue that this older date represents reworked material and is therefore not used in the age model.

6.6 Magnetic Susceptibility

Magnetic susceptibility measurements did not provide useful information to help correlate the cores recovered as part of this investigation. The CHI data results are presented in Appendix 4 for both LESS02-11 and LE-01.

6.7 Percent Total Organic Matter

Results for percent total organic matter are presented in Appendix 5. The results did not provide useful information to help determine sedimentation rates.

6.8 Percent Total Carbonate

Total carbonate did not provide useful information to help determine sedimentation rates. The results are presented in Appendix 6.

Table 2. Radiocarbon Dates for core LESS02-11.

Sample I.D.	Core Depth (cm)	Conventional Radiocarbon Age	Calibrated Age* (cal. yrs. B.P.)	2-Sigma Calibrated Age (cal, yrs. B.P.)	$^{13}C/^{12}C$
BETA-171203	LESS02-11 (core top)	103.5± percent modern carbon	NA	NA	-22.8
BETA-171204	LESS02-11 (145 cm)	810±40 BP	715 cal yrs. B.P.	745 to 685 cal yrs. B.P.	-23.7

*Stuiver et al., 1998

7. Discussion

7.1. Developing Core Chronology

We have constructed a core chronology for Lake Elsinore using the following lines of evidence: non-native pollen types, changes in elemental lead concentrations, ^{137}Cs activity, and radiocarbon dating. Analyses of grain size, magnetic susceptibility, percent total organic and total carbonate did not provide useful information to help develop core chronology and are therefore not included in the age model determination.

7.1.1 Using Percent Water Content to Create a Composite Core: Due to the difficulty in obtaining cores longer than 1.80 meters, neither LE-01 nor LESS02-11 spans the past 270 years in its entirety (Figure 7. Core LE-01 only includes the upper 113 cm of sediment. Whereas, core LESS02-11 includes 180 cm of sediment, but over two separate drives. As a result, core LESS02-11 is missing sediment from 85 to 110 cm depth. To better assess how the sediment from the two cores cross-correlate, we used percent water content data as a quick and easy method of cross-correlation. Percent water content is a reasonable basis for comparison because both cores LE-01 and LESS02-11 were taken from the same deep basin in Lake Elsinore, certainly within several 100 meters of one another. As expected, both cores contain similar lithologies characterized by grey to black clay. Also both cores have a stiff, crumbly clay layer; for example, between 65 and 84 cm in core LE-01 and between 50 and 70 cm in core LESS02-11. The percent water content data clearly demarcates this layer (Figure 2). In both cores, the percent water content is low across the sediment interval (Figure 2). We use the similarity in percent water content between cores LE-01 and LESS02-11, specifically the low water content interval, as the basis for cross-correlating the core stratigraphies. In terms of sediment facies (i.e., depositional environment) interpretation, the stiff, crumbly, low water content clay interval is interpreted as a vadose desiccation zone formed during the 1950's and early 1960's lake level lowstand at Lake Elsinore. Although it is possible to cross-correlate both cores based on stratigraphic markers we develop sedimentation rates for each core independently.

7.1.2 Pollen Age Control: Many plant species not indigenous to California have been introduced into the Lake Elsinore during the period of European settlement, and in some cases their pollen can be readily identified. These non-native pollen types are therefore useful chronological markers, especially if the history of introduction is well known. Two important non-native pollen types in the Elsinore cores are *Erodium cicutarium* and *Eucalyptus*. *Erodium cicutarium* and *Eucalyptus* pollen have been used to indicate European settlement horizons in sediment cores from coastal California (Mudie and Byrne, 1980; Cole and Liu, 1994; Mensing and Byrne, 1998; Cole and Wahl, 2000; Reidy, 2001).

The first appearance of *Erodium* at 150 cm probably reflects the arrival of the Spanish in the Lake Elsinore area during the second half of the 18th Century (1769-1800)(Mensing and Byrne, 1998). The closest mission to Lake Elsinore, Mission San Juan Capistrano, was established in 1776. It is located 32 km to the southwest of the lake. However, there was little contact between the coastal Spanish settlements and the Elsinore area during the early European period (Bowman, 1947), and the La Laguna land grant was made as late as 1844 (Donley et al, 1979). We therefore assign a date of 1800±20 yr for the first appearance of *Erodium* in the Lake Elsinore cores (Figure 3).

The introduction of *Eucalyptus* into California is well documented (Weir, 1957). It was first introduced in 1853 and by the 1870's was widely planted around the state, especially in urban areas. The City of Lake Elsinore was established in 1884 and it is likely that *Eucalyptus* was first planted locally at this time. In the 1880's Lake Elsinore was home to just two families, 300-400 cattle, and hundreds of sheep (Anonymous, 1884). However, *Eucalyptus* flowers are insect pollinated, and large volumes of wind dispersed pollen are therefore not produced. Thus, *Eucalyptus* trees must be close to a given core site for *Eucalyptus* pollen to appear in the pollen record. The sediment cores used for this study are located approximately 1.5km west of the city. *Eucalyptus* is first present at a depth of 110 cm in core LESS02-11 (Figure 3).

The first appearance of *Eucalyptus* pollen in the lake sediments is probably the result of extensive tree plantings undertaken by the *Eucalyptus* syndicate locally during the first decade of the twentieth century (Holmes, 1912). By 1912, 500 acres in the vicinity of Elsinore had been planted with *Eucalyptus* (Holmes, 1912). Ornamental plantings of *Eucalyptus* on private property around the lake during this time would also have been an important source of pollen. We therefore assign a date of 1910±10 yr for the first appearance of *Eucalyptus* (Figure 3). The large increase in Amaranthaceae pollen at 60 cm also provides a chronological marker (Figure 3). It seems likely that weedy members of the Amaranthaceae family (including *Atriplex* spp. and *Chenopodium* spp.) became more important when the lake dried out in late 1950's and early 1960's. *Atriplex* and *Chenopodium* probably expanded on the former lake bottom when water levels were low. We therefore assign a date of 1960±2 yr for the peak in Amaranthaceae in core LE-01 (Figure 3). Increases in *Quercus, Pinus, Fraxinus* and *Juglans* pollen towards the top of the core suggest vegetation change during the historic period. The increase in *Quercus* is probably associated with a reduction in fire frequencies in the Lake Elsinore area during the past 200 years. Mensing (1993) also noted an increase in *Quercus* in southern California during the historic period. The drop in Asteraceae (most likely *Baccharis pilularis*) and coeval increase in Poaceae is probably due to grazing impacts around the lake in historic time. Woody shrubs were probably cleared to encourage grasses for grazing cattle and sheep. The increase in *Fraxinus*, *Juglans*, and *Pinus* towards the top of the record is most likely the result of tree plantings and orchards around the lake during the twentieth century.

7.1.3 Sediment Chemistry: The vertical profile of lead concentrations (Figure 4) indicates changes in lead deposition in the lake during the twentieth century. In southern California the use of leaded gasoline began in the early 1900's, increased from the 1940's and peaked during the mid-1970's (Chow et al, 1973). Lead gradually declines towards the top of the core. This trend correlates to the history of development at Lake Elsinore and the use of leaded gasoline until it was phased out beginning in the mid-1970's. The lead profile is in general agreement with results of Callender and Van Metre (1997) and Callender and Rice (2000) who found decreasing lead concentrations in late 20th century lake and reservoir sediments. We assign a date of 1975±5 for the peak in lead for in LE-01 (Figure 4). Zinc, copper, vanadium, chromium, and sulphates increase slightly toward the top of the core (Figure 5) and provide evidence of industrial development in the Lake Elsinore area during the second half of the twentieth century.

7.1.4 Cesium-137 Dating: The ^{137}Cs data show a peak between 46 and 42 cm (Figure 6). Seen in the context of the pollen data, the "best" depth location for the peak in ^{137}Cs is at 46 cm (Figure 6).

7.1.5 Radiocarbon Dating: The surface sediment radiocarbon age in core LESS02-11 is dated as "modern", which suggests that there is no old carbon effect in the lake basin at present (Table 2). The old carbon effect is caused by the presence of weathered and eroded sediment from geologically old, carbon-rich rocks. The influx of old carbon greatly exaggerates the real age of the sediment rendering the radiocarbon data useless. The lack of an old carbon effect is important because it implies that radiocarbon dating can be used to date sediments from Lake Elsinore without obfuscation due to old carbon effects.

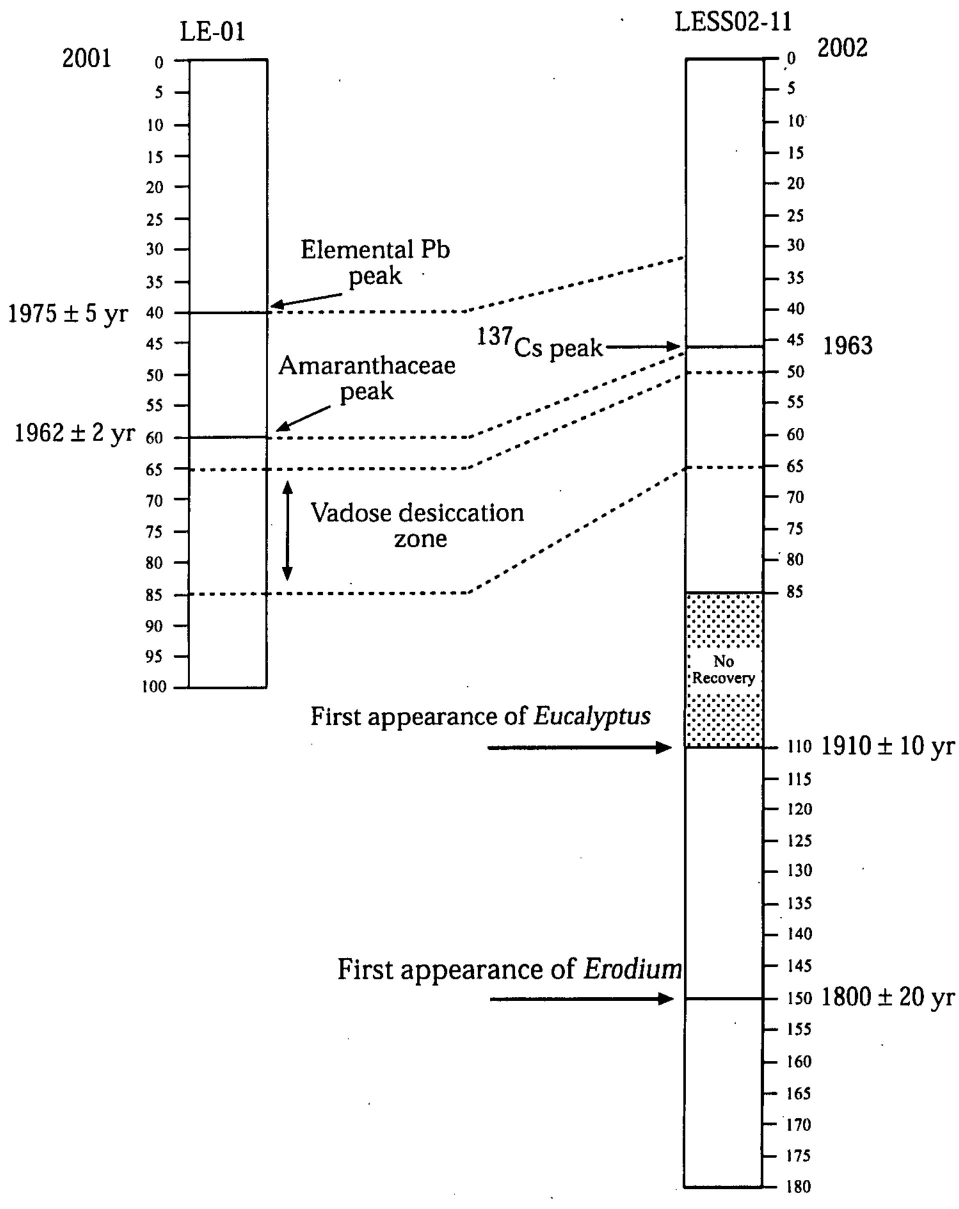

Figure 7. Chronological markers for LE-01 and LESS02-11. Dashed lines indicate probable depth equivalents between the two cores based on water content (see Fig. 2).

The sediment from which the second AMS ^{14}C date was determined is a crumbly, low water content clay in comparison to the proceeding and succeeding sediment intervals (Table 2). As previously noted, this crumbly, low water content clay is interpreted as an indicator of a vadose desiccation zone formed during low lake levels. Because the ^{14}C date comes from a sediment interval coeval to a lake level low stand, we consider this date to be too old, possibly because of reworked carbon from littoral sediments. This interpretation is supported by pollen, which indicates the first appearance of *Erodium* at 150 cm in core LESS02-11 (Figure 3). Unlike sediment that is primarily derived from erosion, the pollen is likely derived via eolian processes and thus it is less likely to have been reworked from the littoral zone during a low lake level stand. Therefore, the ^{14}C date at 145 cm is not used in our age model.

7.2 Sedimentation Rates

7.21 Lake Elsinore: Two cores (LE-01 and LESS02-11) were analyzed to help determine the recent sedimentation rate(s) at Lake Elsinore. Both cores were recovered from the same deep basin in the lake and therefore probably represent maximum sedimentation rates for the lake. Maximum sedimentation rates indicated are 11.7 mm/yr in LESS02-11 and 15.3 mm/yr in LE-01 for the period ca. 1963-2001 (Figures 8 and 9).

Table 3. Lake Elsinore Sedimentation Rates.

Time Period	Average (mm/yr)	Range (mm/yr)
Pre-20th Century	3.6	2.8 to 5.0
20th Century	12.7	10.1 to 15.3

The LE-01 sedimentation rate represents the maximum for the lake during the 20th Century. Three chronological markers, including the surface age, were used to calculate linear sedimentation rates in LE-01 from ca. 1962 to 2001 (Figure 8). The peak in Amaranthaceae at 1962 ±2 yr (60 cm), the peak in elemental Pb at 1975 ±5 (40 cm) and the surface date 2001 (0 cm). The average sedimentation rate for the upper 60 cm of the core is 15.3 mm/yr. The base of core LE-01 probably represents 1920-30 based on the presence of *Eucalyptus* pollen at the base of the core.

Four chronological markers including the surface age, were used to calculate linear sedimentation rates in LESS02-11 (Figure 9). The estimated basal date of 1730 is based on linear extrapolation of the sedimentation rate to the base of core LESS02-11 (175 cm) (Figure 9). The range of pre-20th century sedimentation rates in LESS02-11 is based on two age estimates: the first appearance of *Erodium* at 1800±20 (150 cm) and of *Eucalyptus* at 1910±10 (110 cm). The minimum sedimentation rate for the period 1780-1920 is 2.8 mm/yr. The maximum rate for the period 1820-1900 is 5.0 mm/yr. The average sedimentation rate for the period 1800 1910 is 3.6 mm/yr (Figure 9). The peak in ^{137}Cs activity at 46 cm is dated to 1963. The indicated range in sedimentation rates between 1910±10 and 1963 is 10.1 to 14.8 mm/yr (Figure 9). The sedimentation rate between the peak in ^{137}Cs and the top of LESS02-11 is 11.7 mm/yr. The average sedimentation rate for both cores during the twentieth century is 13.7 mm/yr.

In summary, the average pre-twentieth century sedimentation rate of 3.6 mm/yr is over three and a half times lower than the average twentieth century sedimentation rate of 13.6 mm/yr. The most reasonable explanation for this difference is 20th century urbanization, which has dramatically increased the percent of impervious cover in the Lake Elsinore drainage basin. As a result, the rate of direct sediment run-off into the lake basin has increased. Higher sedimentation rates in response to urbanization and other human activities are well documented in lakes from all regions of the urbanized world (e.g., Hilfinger et al., 2001).

7.2.2 Lake Elsinore versus Railroad Canyon Reservoir: The Unites States Geological Survey determined that the sedimentation rate in Canyon Lake reservoir was 24 mm/yr during the twentieth century (USGS, 1998). The mean sedimentation rate for Lake Elsinore during the 20th Century was 13.6 mm/yr (12 mm/yr for LESS02-11; and 15.3 mm/yr for LE-01). The mean Canyon Lake sedimentation rate is almost as twice as high as the Lake Elsinore 20th century sedimentation rate. Higher sedimentation rates are expected in Canyon Lake for two major reasons: 1) Canyon Lake acts as a sediment trap for the San Jacinto River upstream of Lake Elsinore during flow; and 2) development around Canyon Lake has also increased sediment deposition.

7.2.3 Impact of Compaction on Sedimentation Rates: Linear sedimentation rates can vary depending upon the degree of compaction, which in near surface sediments is largely due to variations in water content or sediment type, e.g., peat or clay. The cores upon which this study is based show little variation in sediment type but water content does increase towards the surface (Figure 2). In both cores, the water content in the top 5 cm is about 75 percent whereas in the lower 35 cm, values range between 45-65 percent. The average difference of 20 percent water content effects the sedimentation rates accordingly. However, this difference is insignificant when compared with the difference between the average 20th century sedimentation rate and the pre-20th century rate as shown in Table 3. Ideally, a more precise measure of sediment accumulation rate would use mass accumulation rates per unit area per unit time. In this report we use linear sedimentation rates to enable comparisons with the previous study by the USGS.

7.2.3 Incomplete Recovery in Core LESS02-11 and its Potential Effect on Reconstructed Sedimentation Rates: As we noted in section 4, there was a gap of 25 centimeters between the two cores sections recovered at core site LESS02-11. This reflects the fact that in the first core section only 85 centimeters were recovered after a 1 meter push, and the second push started at a depth of 110 centimeters below the sediment water interface. The sedimentation rates reported above were calculated using the assumption that the missing 25 centimeters represents a real gap. It is, however, possible that the gap is an artifact of the coring operation itself. For example, coring in compact sediments often causes the coring device to penetrate at an angle away from the vertical. If this did happen the gap may be less than the 25 centimeters indicated. Several of the pollen curves shown in Figure 3 suggest that there might be even a slight (5-10 cm) overlap between the lower and upper sections of LESS02-11. If this was the case, it would mean that the *Erodium* and *Eucalyptus* marker horizons shown in Figure 8 would have to be shifted up by ca., 32 centimeters. This would not change the pre-Twentieth Century sedimentation rate estimates but it would reduce the estimates for the period 1900 to 1996 by 50 percent, i.e., from between 10.1 and 14.8

mm/yr, as indicated in Figure 8, to between 5.1 and 7.3 mm/yr. The overall average for the 20th century would be ca., 8 mm/yr. The uncertainty regarding the twentieth century sedimentation rates will only be resolved by further coring.

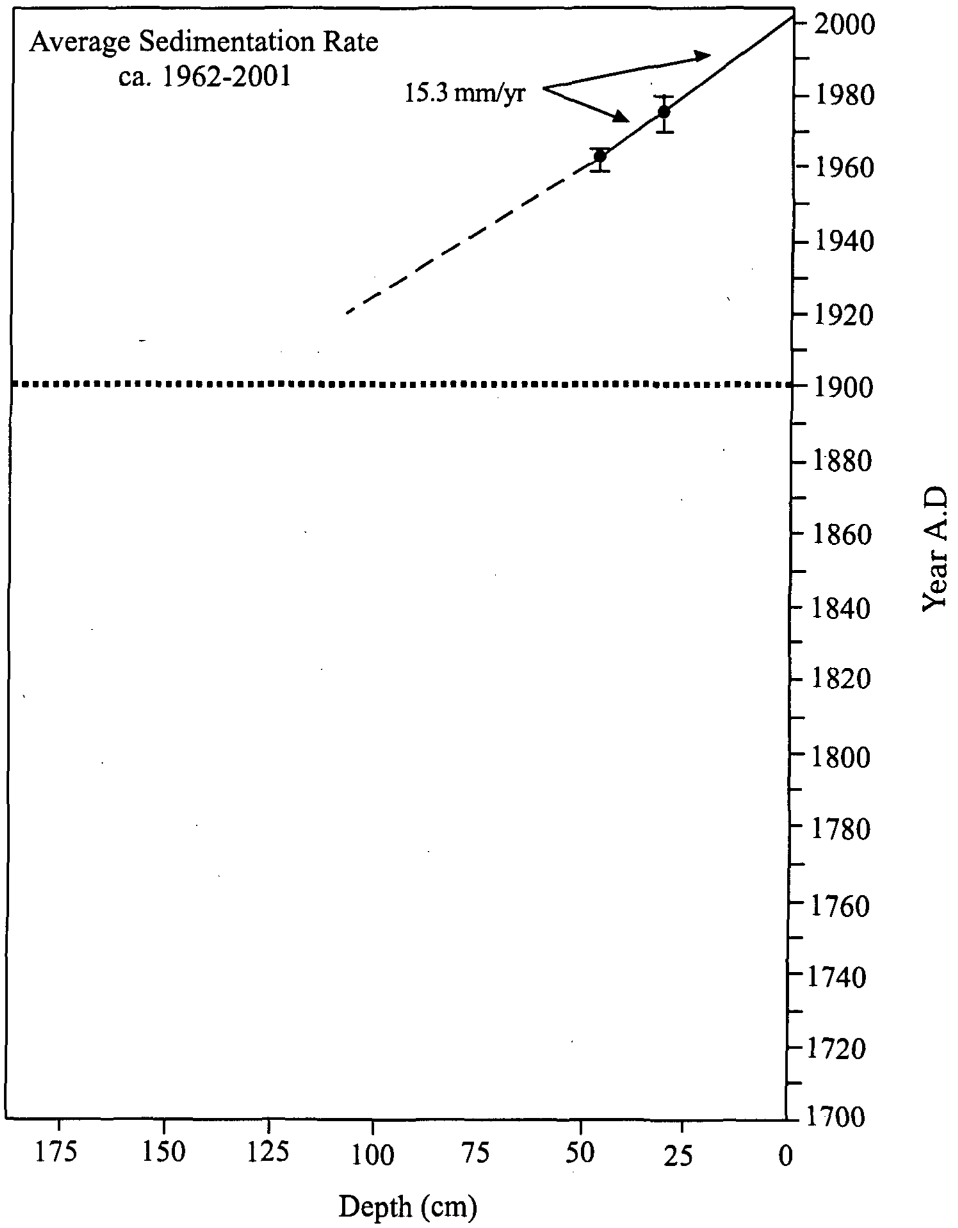

Figure 8. Age Depth Curve with sedimentation rates for core LE-01. Dashed line is the linear age-depth extrapolation to the core bottom. If the extrapolation is correct the bottom of the core dates to apprximately 1920.

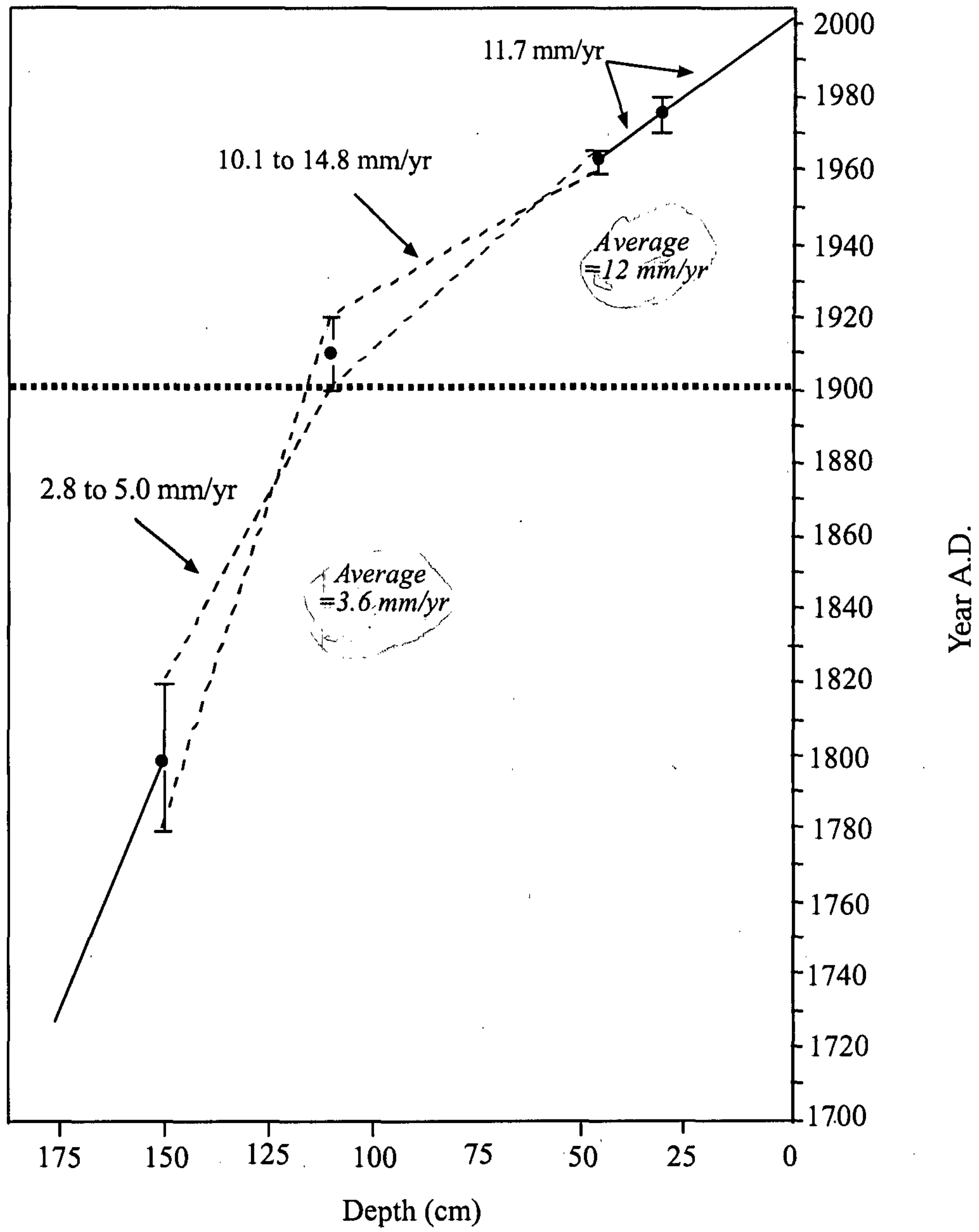

Figure 9. Age Depth Curve with sedimentation rates for core LESS02-11. Solid line is the linear age-depth extrapolation to core bottom. The bottom of the core is approximately 1730. Note the difference in sedimentation rates between the pre-20th century and the 20th century period.

8. Summary

1. Twentieth century sedimentation rates at Lake Elsinore range from 10.1 mm/yr to 15.3 mm/yr the average of which (12.7 mm/yr) is roughly half the average rate of 24 mm/yr at Canyon Lake during approximately the same time period.

2. The estimated Lake Elsinore sedimentation rates for the period ~ 1730 to 1910 range from 2.8 to 5.0 mm/yr, the average of which is 3.6 mm/yr i.e. ~3x less than the twentieth century average.

3. The average twentieth century sedimentation rate (12.7 mm/yr) significantly exceeds sedimentation rates during both the 18th and 19th centuries. In other words, the construction of Canyon Lake has slowed but not eliminated the impact of humans (i.e., urbanization) on the rate of sediment infilling of Lake Elsinore.

4. Sedimentation rates determined from the cores analyzed in this study can be assumed to be closest maximum values insofar as the cores were taken from the deepest part of the lake, to where sediment focusing is likely to have taken place.

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Appendix 1. Lake Elsinore Pollen Data (1 of 3).

	0cm	15cm	30cm	40cm	50cm	60cm	70cm
Pinus	37	41	25	23	13	8	23
TCT	9	8	8	3	9	3	7
Quercus	72	66	63	54	54	37	44
Alnus	8	5	2	2	1	1	-
Lithocarpus	-	-	1	-	-	-	-
Acer	-	-	-	-	1	-	-
Eucalyptus	19	16	11	3	23	8	3
Fraxinus	24	17	10	19	9	2	7
Juglans	18	12	6	10	7	2	13
Pseudostuga	-	-	1	-	1	1	-
Rhamnaceae	57	38	40	49	55	47	52
Rosaceae	-	-	-	-	-	-	-
Salix	12	6	18	7	11	-	6
Erodium cicutarium	1	2	3	2	2	3	6
Asteraceae L S	1	6	5	15	9	2	7
Asteraceae H S	14	34	21	41	31	33	30
Ambrosia	13	18	16	14	13	7	10
Artemisia	8	13	18	12	14	1	12
Liguliflorae	-	-	1	1	2	-	-
Caryophyllaceae	2	1	2	1	-	-	-
Leguminosae	-	1	-	-	--	-	-
Onagraceae	-	1	-	-	-	-	-
Salvia spp.	12	8	6	-	8	2	4
Eriogonum	5	5	4	10	6	9	9
Rumex spp.	-	-	-	2	-	-	-
Polemoniaceae	-	-	-	-	-	-	-
Poaceae	23	43	33	24	29	24	18
Amaranthaceae	27	27	20	73	47	75	135
Typha latifolia	1	1	-	1	-	-	-
Typha/Sparganium	-	-	-	-	-	5	2
Cyperaceae	5	5	19	12	19	5	26
Potamogeton	-	-	-	-	-	-	-
Trilete Spores	-	-	1	-	-	-	-
Monolete Spores	1	1	2	3	-	-	-
Umbelliferae	1	1	-	-	-	-	-
Toxicodendron diversiloba	-	-	-	1	-	-	-
Plantago lanceolata	-	-	-	1	-	-	-
Ranunculaceae	1	1	-	-	-	-	-
Indeterminate	26	26	20	14	44	32	49
Unknown	1	1	-	2	1	-	-
Total Pollen and Spores	405	405	403	402	403	415	402

Appendix 1. Lake Elsinore Pollen Data (2 of 3).

	80cm	90cm	100cm	110cm	115cm	125cm	135cm
Pinus	11	12	16	12	12	27	26
TCT	4	2	10	-	4	3	4
Quercus	57	60	62	27	64	45	39
Alnus	-	1	2	1	5	-	1
Lithocarpus	-	-	2	-	-	-	-
Acer	-	-	-	5	5	5	7
Eucalyptus	2	2	1	1	-	-	-
Fraxinus	9	5	-	-	-	-	-
Juglans	3	1	-	3	5	3	-
Pseudostuga	-	1	-	-	-	-	-
Rhamnaceae	72	63	63	64	92	69	54
Rosaceae	-	-	2	-	-	-	-
Salix	5	8	9	3	27	3	6
Erodium cicutarium	6	5	17	2	2	12	11
Asteraceae L S	9	12	17	-	-	-	-
Asteraceae H S	44	53	67	62	65	76	86
Ambrosia	13	5	23	4	12	11	8
Artemisia	22	17	21	7	12	18	5
Liguliflorae	1	1	-	-	-	2	-
Caryophyllaceae	-	-	-	-	-	-	2
Leguminosae	-	-	-	-	-	-	-
Onagraceae	1	1	-	-	-	-	-
Salvia spp.	1	-	1	-	1	2	-
Eriogonum	10	7	10	2	3	4	9
Rumex spp.	-	-	-	-	-	-	-
Polemoniaceae	-	-	-	2	1	1	1
Poaceae	19	25	12	14	14	11	22
Amaranthaceae	59	64	68	60	46	57	58
Typha latifolia	-	-	-	-	-	9	-
Typha/Sparganium	-	-	-	7	3	-	4
Cyperaceae	32	16	11	51	14	13	19
Potamogeton	-	5	-	-	-	-	-
Trilete Spores	1	1	1	3	4	2	10
Monolete Spores	2	1	-	2	1	3	7
Umbelliferae	-	-	-	-	-	-	-
Toxicodendron diversiloba	-	-	-	-	-	-	-
Plantago lanceolata	-	-	-	-	-	-	-
Ranunculaceae	-	-	-	-	-	-	-
Indeterminate	58	31	51	54	34	34	34
Unknown	-	-	1	19	-	-	-
Total Pollen and Spores	403	407	412	405	426	410	413

Appendix 1. Lake Elsinore Pollen Data (3 of 3).

	140cm	145cm	150cm	155cm	160cm	170cm
Pinus	30	27	32	43	57	25
TCT	1	2	1	1	1	-
Quercus	38	47	14	16	22	13
Alnus	1	-	-	1	-	1
Lithocarpus	-	-	-	-	-	-
Acer	2	4	2	4	5	5
Eucalyptus	-	-	-	-	-	-
Fraxinus	-	-	-	-	-	-
Juglans	1	2	-	-	1	1
Pseudostuga	-	-	-	-	-	-
Rhamnaceae	69	48	28	50	31	56
Rosaceae	-	-	-	-	-	-
Salix	4	2	1	-	3	-
Erodium cicutarium	3	2	2	-	-	-
Asteraceae L S	-	-	-	-	-	-
Asteraceae H S	108	128	147	123	113	140
Ambrosia	5	1	-	-	6	-
Artemisia	3	3	2	6	4	2
Liguliflorae	1	1	1	1	-	-
Caryophyllaceae	-	-	-	-	1	-
Leguminosae	-	-	-	1	-	-
Onagraceae	-	1	1	-	-	1
Salvia spp.	-	-	-	-	-	2
Eriogonum	3	2	2	1	2	2
Rumex spp.	-	-	-	-	-	-
Polemoniaceae	-	1	2	1	2	2
Poaceae	4	24	13	22	12	22
Amaranthaceae	44	42	36	33	26	15
Typha latifolia	-	-	1	-	5	-
Typha/Sparganium	3	6	1	7	-	8
Cyperaceae	27	27	25	24	34	38
Potamogeton	-	-	-	-	-	-
Trilete Spores	10	6	8	9	12	10
Monolete Spores	6	4	-	5	13	2
Umbelliferae	-	-	-	-	-	-
Toxicodendron diversiloba	-	-	-	-	-	-
Plantago lanceolata	-	-	-	-	-	-
Ranunculaceae	-	-	-	-	-	-
Indeterminate	43	34	99	55	56	55
Unknown	-	-	-	-	-	-
Total Pollen and Spores	406	414	418	404	405	400

Appendix 2. LE-01 XRF Data (1 of 4)

Element	Na2O	MgO	Al2O3	SiO2	P2O5	SO3	Cl	K2O	CaO
Sample	(%)	(%)	(%)	(%)	(%)	(%)	(ppm)	(%)	(%)
LE1	1.3	5.2	18	50.8	0.32	1.79	2841	2.44	9.74
LE5	1.3	5.2	15.8	45.8	0.26	4.51	1744	2.55	10.32
LE10	1.3	4.3	15.2	43.7	0.27	5.15	2177	2.37	10.83
LE15	1.4	4.9	18.6	51.9	0.28	2.55	3000	2.45	8.17
LE20	1.5	5.2	17.8	49.1	0.28	2.31	3273	2.49	10.26
LE25	1.5	4.8	16.1	46.1	0.3	3.66	3228	2.46	10.81
LE30	1.5	4.6	15.5	45.1	0.29	4.63	3505	2.46	10.97
LE40	1.8	5.1	17.2	49.4	0.32	2.5	4284	2.5	10.62
LE45	1.3	3.8	13.5	39.4	0.26	7.8	3450	2.34	12.14
LE50	2	5.6	17.9	51.4	0.28	1.78	4187	2.74	8.67
LE55	2.1	5.9	17.7	51.2	0.27	1.52	4238	2.83	8.9
LE58	2.2	5.7	17.2	49.9	0.26	1.22	3630	2.79	8.45
LE60	2.3	6.1	17.9	51.7	0.26	1.29	3943	2.84	8.37
LE62	2.3	6	18.5	52.7	0.26	1.33	3136	2.78	7.13
LE65	2.3	5.9	18.1	52.9	0.25	1.07	2767	2.84	7.38
LE68	2.2	6.3	17.1	50.3	0.27	1.59	2815	2.87	8.54
LE70	2.2	6.1	17	50	0.25	2.04	3600	2.87	8.63
LE72	2.4	6.6	17.5	51.4	0.26	1.13	3381	2.88	8.67
LE75	2.5	6.5	17.7	51.1	0.26	1.19	4159	2.85	8.22
LE80	2.7	6.4	18.3	53.7	0.25	0.7	4247	2.96	6.28
LE85	3.1	5.9	18	52.5	0.28	0.85	7578	2.82	7.47
LE90	3.6	5.8	18.8	53.2	0.25	1.17	11539	2.74	5.39
LE95	8.9	6.7	15	45.5	0.26	1.1	47270	2.43	11.07
LE100	3	5.6	16.4	49	0.3	1.31	10342	2.65	10.85

Appendix 2. LE-01 XRF Data (2 of 4).

Element	TiO2	V	Cr	MnO	Fe2O3	Co	Ni	Cu	Zn
Sample	(%)	(ppm)	(ppm)	(%)	(%)	(ppm)	(ppm)	(ppm)	(ppm)
LE1	0.94	238	72	0.14	10.4	30	36	59	181
LE5	0.94	193	77	0.14	10.23	37	35	57	173
LE10	0.93	204	73	0.14	10.24	111	31	59	175
LE15	0.97	214	74	0.13	10.67	22	36	64	184
LE20	0.97	216	74	0.15	10.55	33	34	58	177
LE25	0.95	207	111	0.14	10.18	28	47	57	198
LE30	0.94	205	79	0.14	10.15	30	33	52	173
LE40	0.95	201	73	0.14	10.15	22	34	60	182
LE45	0.93	194	67	0.14	10.17	26	33	52	169
LE50	0.98	198	63	0.15	10.33	17	33	55	177
LE55	0.96	182	59	0.14	10.18	15	32	52	166
LE58	0.94	186	59	0.14	10.03	40	32	52	166
LE60	0.96	186	61	0.15	10.11	19	30	56	166
LE62	0.95	167	59	0.14	10.29	22	30	50	166
LE65	0.95	186	73	0.14	10.08	34	35	56	174
LE68	0.95	178	56	0.15	10.05	24	30	50	159
LE70	0.95	176	58	0.15	10.29	16	31	50	164
LE72	0.95	180	53	0.15	10.12	21	31	49	160
LE75	0.94	181	65	0.15	10.29	14	33	49	161
LE80	0.94	190	59	0.14	10.37	20	32	50	165
LE85	0.92	188	59	0.13	10.09	15	32	55	160
LE90	0.92	173	46	0.13	10.49	16	31	50	165
LE95	0.8	190	56	0.14	9.03	15	29	44	138
LE100	0.88	201	101	0.13	9.61	28	44	51	165

Appendix 2. LE-01 XRF Data (3 of 4).

Element	Ga	Ge	As	Rb	Sr	Y	Zr	Nb	Mo
Sample	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)
LE1	22	2	17	111	410	35	63	12	9
LE5	24	1	18	110	457	34	62	12	11
LE10	21	2	14	106	403	34	67	11	9
LE15	24	1	22	119	361	39	70	12	12
LE20	24	1	14	114	474	39	68	13	14
LE25	22	2	18	108	430	34	70	11	15
LE30	22	1	19	110	449	35	70	12	13
LE40	23	1	13	113	466	38	75	12	10
LE45	21	1	13	107	441	34	70	12	10
LE50	24	1	14	120	440	36	64	12	9
LE55	24	1	11	117	468	34	53	12	9
LE58	24	1	16	115	456	33	53	12	11
LE60	24	2	14	118	459	34	58	13	11
LE62	26	2	11	114	400	33	52	13	13
LE65	25	1	14	119	428	35	69	13	10
LE68	23	1	9	114	461	32	55	12	11
LE70	25	2	19	117	469	34	52	12	12
LE72	24	1	17	115	498	33	55	12	10
LE75	24	1	10	114	458	32	47	12	8
LE80	26	1	12	120	378	32	53	13	7
LE85	25	1	15	116	376	32	55	12	8
LE90	26	1	23	118	308	31	40	12	27
LE95	22	1	20	102	625	30	45	11	53
LE100	24	1	13	108	498	32	59	11	17

Appendix 2. LE-01 XRF Data (4 of 4).

Element	Ba	La	Ce	Pr	Nd	Sm	Pb	Th	U
Sample	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)
LE1	810	50	91	14	51	7	36	16	2
LE5	845	46	92	13	44	8	28	17	1
LE10	793	42	86	14	34	8	34	16	1
LE15	807	46	83	11	40	7	34	17	5
LE20	861	52	98	14	43	8	37	17	6
LE25	838	38	102	10	40	8	47	18	5
LE30	831	42	77	12	38	6	42	15	5
LE40	816	55	85	12	41	7	50	17	1
LE45	810	64	73	13	33	7	44	15	4
LE50	827	57	100	15	45	7	39	18	6
LE55	842	69	104	18	37	9	25	18	5
LE58	825	42	109	14	49	7	27	18	3
LE60	913	47	107	13	49	8	22	19	5
LE62	873	51	96	12	37	9	20	19	3
LE65	863	47	102	14	50	8	21	20	5
LE68	867	61	87	14	38	8	17	15	4
LE70	871	59	97	13	33	8	19	18	3
LE72	839	51	110	14	38	9	19	17	6
LE75	852	51	109	14	56	8	18	18	8
LE80	825	43	94	13	38	8	22	19	7
LE85	748	38	122	13	48	9	17	21	3
LE90	709	65	131	19	57	9	15	22	5
LE95	807	40	75	9	22	7	14	18	20
LE100	781	56	91	14	39	7	28	19	8

Appendix 3. LESS02-11 Percent Water (1 of 2)

Depth (cm)	Percent Water	Depth (cm)	Percent Water
1.5	76.35	44.5	64.44
2.5	76.44	45.5	63.34
3.5	77.13	46.5	62.27
4.5	76.26	47.5	59.83
5.5	76.75	48.5	61.14
6.5	75.51	49.5	60.71
7.5	74.65	50.5	56.87
8.5	74.65	51.5	53.26
9.5	73.85	52.5	53.68
10.5	74.66	53.5	54.38
11.5	74.89	54.5	52.59
12.5	73.98	55.5	52.82
13.5	73.95	56.5	54.88
14.5	73.97	57.5	57.99
15.5	74.5	58.5	56.43
16.5	74.72	59.5	57.41
17.5	74.49	60.5	56.35
18.5	74.13	61.5	54.12
19.5	74.24	62.5	55.50
20.5	75.44	63.5	56.19
21.5	74.46	64.5	55.62
22.5	74.37	65.5	57.82
23.5	74.18	66.5	59.00
24.5	73.62	67.5	60.31
25.5	72.68	68.5	61.25
26.5	74.15	69.5	61.00
27.5	73.98	70.5	63.76
28.5	71.00	71.5	63.83
29.5	69.60	72.5	52.10
30.5	68.54	73.5	60.56
31.5	69.52	74.5	62.82
32.5	70.02	75.5	63.41
33.5	69.74	76.5	63.66
34.5	69.62	77.5	61.89
35.5	68.42	78.5	63.02
36.5	67.58	79.5	63.12
37.5	68.31	80.5	62.57
38.5	68.67	81.5	59.88
39.5	66.81	82.5	62.51
40.5	66.64	83.5	62.10
41.5	65.28	84.5	57.22
42.5	65.79	85.5	54.17
43.5	65.50		

Appendix 3. LE-01 Percent Water (2 of 2)

Depth (cm)	Percent Water
0	83.70
5	62.18
10	70.19
15	72.12
20	75.73
25	71.55
30	71.70
40	58.47
45	70.00
50	72.38
53	66.67
55	63.56
58	63.87
60	63.56
63	54.92
65	46.67
68	47.58
70	50.41
73	48.82
75	47.01
78	50.00
80	50.82
83	46.83
85	56.03
88	61.34
90	61.48
95	64.29
100	53.85

Appendix 4. Magnetic Susceptibility LESS02-11 (1 of 4)

Depth	CHI	Depth	CHI	Depth	CHI
0.25	8.92	19.75	9.32	39.25	9.54
0.75	8.77	20.25	9.54	39.75	10.29
1.25	9.53	20.75	9.32	40.25	8.6
1.75	7.6	21.25	7.26	40.75	8.97
2.25	10.67	21.75	10.92	41.25	7.76
2.75	7.81	22.25	7.88	41.75	7.85
3.25	9.81	22.75	13.04	42.25	8.66
3.75	9.56	23.25	10.54	42.75	8.81
4.25	8.43	23.75	8.82	43.25	7.77
4.75	8.2	24.25	10.26	43.75	7.32
5.25	7.48	24.75	9.54	44.25	11.09
5.75	8.99	25.25	9.62	44.75	9.71
6.25	9.83	25.75	7.56	45.25	9.08
6.75	9.35	26.25	9.85	45.75	9.47
7.25	8.56	26.75	8.18	46.25	8.63
7.75	9.78	27.25	8.81	46.75	9.75
8.25	8.85	27.75	9.34	47.25	9.12
8.75	10.87	28.25	7.96	47.75	10.56
9.25	10.81	28.75	9.43	48.25	6.45
9.75	10.64	29.25	9.67	48.75	7.7
10.25	9.7	29.75	9.54	49.25	11.33
10.75	10.94	30.25	11.38	49.75	8.96
11.25	11.08	30.75	10.04	50.25	7.76
11.75	12.21	31.25	10.83	50.75	8.15
12.25	9.3	31.75	12.61	51.25	7.97
12.75	12.53	32.25	8.7	51.75	5.61
13.25	7.88	32.75	10.39	52.25	10.2
13.75	10.04	33.25	8.31	52.75	6.2
14.25	11.31	33.75	7.7	53.25	6.9
14.75	9.69	34.25	8.14	53.75	9.35
15.25	9.66	34.75	10.37	54.25	8.61
15.75	14.28	35.25	9.59	54.75	9.61
16.25	8	35.75	7.09	55.25	4.74
16.75	9	36.25	10.2	55.75	7.66
17.25	7.61	36.75	10.32	56.25	7.78
17.75	10.96	37.25	10.19	56.75	10.62
18.25	10.95	37.75	10.26	57.25	6.68
18.75	8.84	38.25	8.22	57.75	8.05
19.25	11.57	38.75	11.8	58.25	6.76

Appendix 4. Magnetic Susceptibility LESS02-11 (2 of 4)

Depth	CHI	Depth	CHI	Depth	CHI
58.75	7.93	78.25	7.83	121.75	8.34
59.25	7.88	78.75	5.7	122.25	7.93
59.75	7.13	79.25	7.3	122.75	8.73
60.25	7.22	79.75	6.98	123.25	9.39
60.75	6.86	80.25	4.74	123.75	9.6
61.25	6.71	80.75	8.68	124.25	8.57
61.75	5.72	81.25	7.44	124.75	9.86
62.25	6.4	81.75	8.45	125.25	5.02
62.75	5.86	82.25	7.81	125.75	6.52
63.25	4.17	82.75	5.92	126.25	7.93
63.75	7.42	83.25	6.95	126.75	7.31
64.25	6.94	83.75	9.56	127.25	7.06
64.75	6.65	84.25	8.82	127.75	9.02
65.25	7.92	84.75	6.47	128.25	6.5
65.75	5.4	85.25	7.27	128.75	6.71
66.25	5.5	85.75	7.35	129.25	8.69
66.75	4.38	110.25	11.22	129.75	8.84
67.25	6.37	110.75	10.8	130.25	12.72
67.75	6.45	111.25	12.57	130.75	6.7
68.25	7.32	111.75	12.6	131.25	10.79
68.75	6.34	112.25	11.2	131.75	8.25
69.25	7.73	112.75	12.24	132.25	6.73
69.75	7.03	113.25	13.6	132.75	10.9
70.25	9.55	113.75	9.6	133.25	7.45
70.75	5.44	114.25	9.31	133.75	5.7
71.25	7.35	114.75	12.15	134.25	10.43
71.75	6.61	115.25	12.1	134.75	8.86
72.25	8.3	115.75	7.08	135.25	9.56
72.75	7.8	116.25	5.52	135.75	6.2
73.25	8.78	116.75	7.21	136.25	6.01
73.75	5.64	117.25	9.26	136.75	6.35
74.25	6.56	117.75	8.1	137.25	5.89
74.75	7.15	118.25	7.36	137.75	5.52
75.25	4.1	118.75	8.9	138.25	6.09
75.75	7.36	119.25	13.92	138.75	4.4
76.25	6.11	119.75	14.46	139.25	6.86
76.75	8.55	120.25	8.82	139.75	9.06
77.25	8.98	120.75	6.03	140.25	7.58
77.75	8.97	121.25	7.03	140.75	6.8

Appendix 4. Magnetic Susceptibility LESS02-11 (3 of 4)

Depth	CHI	Depth	CHI
141.25	7.32	160.75	5.3
141.75	4.65	161.25	5.38
142.25	5.08	161.75	5.84
142.75	3.7	162.25	6.29
143.25	5.38	162.75	4.78
143.75	7.25	163.25	3.9
144.25	6.81	163.75	5.71
144.75	5.24	164.25	5.36
145.25	7.78	164.75	5.38
145.75	5.04	165.25	4.3
146.25	6.34	165.75	5.29
146.75	3.21	166.25	6.25
147.25	6.36	166.75	3.53
147.75	7.65	167.25	4.18
148.25	6.89	167.75	6.11
148.75	5.02	168.25	6.07
149.25	7.35	168.75	6.87
149.75	5.59	169.25	5.1
150.25	6.02	169.75	7.84
150.75	6.76	170.25	5.09
151.25	5.63	170.75	5.12
151.75	6.93	171.25	5.21
152.25	4.48	171.75	4.53
152.75	5.91	172.25	6.85
153.25	5.1	172.75	5.65
153.75	5.22	173.25	6.62
154.25	3.85	173.75	6.47
154.75	7.58	174.25	7.96
155.25	5.05	174.75	8.83
155.75	5.99	175.25	9.39
156.25	5.35		
156.75	4.14		
157.25	4.56		
157.75	5.26		
158.25	2.98		
158.75	3.79		
159.25	6.41		
159.75	8.41		
160.25	4.57		

Appendix 4. Magnetic Susceptibility LESS02-11 (4 of 4)

Depth	CHI	Depth	CHI	Depth	CHI
1	1	38	6	75	16
2	1	39	6	76	18
3	1	40	5	77	19
4	1	41	5	78	20
5	1	42	5	79	21
6	2	43	5	80	21
7	1	44	4	81	21
8	2	45	3	82	20
9	1	46	3	83	19
10	1	47	2	84	18
11	5	48	2	85	18
12	6	49	4	86	17
13	8	50	6	87	16
14	10	51	6	88	15
15	10	52	7	89	15
16	9	53	8	90	15
17	9	54	7	91	16
18	8	55	8	92	16
19	9	56	7	93	17
20	8	57	7	94	16
21	9	58	7	95	15
22	9	59	8	96	14
23	8	60	8	97	14
24	8	61	7	98	13
25	8	62	8	99	12
26	8	63	9	100	12
27	7	64	10	101	12
28	8	65	11	102	11
29	8	66	12	103	11
30	8	67	12	104	10
31	8	68	12	105	10
32	8	69	13	106	9
33	8	70	13	107	9
34	8	71	14	108	10
35	8	72	14	109	9
36	7	73	14	110	9
37	7	74	15		

Appendix 5. Percent Total Organic Matter LESS02-11 (1 of 2)

Depth (cm)	%Total Organic Matter	Depth (cm)	%Total Organic Matter
1.5	15.54	44.5	10.31
2.5	16.62	45.5	10.31
3.5	16.62	46.5	10.53
4.5	15.43	47.5	10.59
5.5	15.52	48.5	10.55
6.5	15.3	49.5	14.17
7.5	14.82	50.5	10.67
8.5	14.1	51.5	9.75
9.5	13.11	52.5	11.71
10.5	12.9	53.5	11.63
11.5	12.37	54.5	10.96
12.5	12.13	55.5	11.11
13.5	10.83	56.5	10.1
14.5	10.55	57.5	10.92
15.5	10.31	58.5	10.31
16.5	10.45	59.5	10.27
17.5	10.45	60.5	9.74
18.5	10.84	61.5	9.35
19.5	10.46	62.5	9.47
20.5	10.68	63.5	9.54
21.5	10.77	64.5	9.65
22.5	10.72	65.5	10.81
23.5	10.83	66.5	10.08
24.5	10.79	67.5	9.96
25.5	10.96	68.5	10.57
26.5	11.08	69.5	10.47
27.5	11.09	70.5	10.96
28.5	10.7	71.5	11.04
29.5	10.29	72.5	8.27
30.5	9.85	73.5	12.3
31.5	9.69	74.5	13
32.5	9.96	75.5	12.98
33.5	10	76.5	12.18
34.5	10.02	77.5	11.75
35.5	9.93	78.5	12.24
36.5	10.09	79.5	11.06
37.5	10.42	80.5	10.33
38.5	10.46	81.5	9.35
39.5	10.23	82.5	10.91
40.5	10.1	83.5	11.24
41.5	10.07	84.5	11.51
42.5	10.12	85.5	10.2
43.5	9.94		

Appendix 6. Percent Total Carbonate LESS02-11 (1 of 3)

Depth (cm)	% Ca Carbonate	Depth (cm)	% Ca Carbonate	Depth (cm)	% Ca Carbonate
0.25	12.75	19.25	9.92	38.25	9.13
0.75	13.77	19.75	8.99	38.75	8.64
1.25	14.18	20.25	8.23	39.25	8.86
1.75	13.78	20.75	9.46	39.75	8.91
2.25	14.73	21.25	9.73	40.25	8.83
2.75	13.69	21.75	8.56	40.75	8.56
3.25	12.43	22.25	9.12	41.25	8.78
3.75	11.69	22.75	7.52	41.75	8.86
4.25	11.75	23.25	8.07	42.25	9.04
4.75	12.27	23.75	8.14	42.75	9.43
5.25	12.78	24.25	8.13	43.25	10.32
5.75	13.89	24.75	8.48	43.75	9.63
6.25	13.09	25.25	10.7	44.25	9.56
6.75	12.49	25.75	6.65	44.75	9.36
7.25	10.54	26.25	8.89	45.25	9.66
7.75	10.06	26.75	8.29	45.75	10.52
8.25	10.55	27.25	9.37	46.25	9.59
8.75	10.97	27.75	8.51	46.75	9.74
9.25	11.08	28.25	8.03	47.25	9.28
9.75	11.55	28.75	14.54	47.75	9.49
10.25	11.88	29.25	8.79	48.25	9.25
10.75	10.27	29.75	9.35	48.75	9.31
11.25	10.85	30.25	13.11	49.25	9.36
11.75	11.29	30.75	10.08	49.75	9.57
12.25	10.2	31.25	8.42	50.25	9.28
12.75	8.51	31.75	8.92	50.75	9.4
13.25	8.52	32.25	9.01	51.25	9.41
13.75	8.26	32.75	12.42	51.75	10.16
14.25	9.18	33.25	8.67	52.25	10.27
14.75	9.43	33.75	9.4	52.75	9.95
15.25	9.65	34.25	9.13	53.25	10.28
15.75	10.56	34.75	8.5	53.75	10.69
16.25	8.62	35.25	8.81	54.25	10.67
16.75	8.47	35.75	9.13	54.75	10.6
17.25	8.59	36.25	9.19	55.25	10.61
17.75	9.15	36.75	9.1	55.75	10.61
18.25	8.81	37.25	9.32	56.25	10.32
18.75	9.39	37.75	9.31	56.75	10.4

Appendix 6. Percent Total Carbonate LESS02-11 (2 of 3)

Depth (cm)	% Ca Carbonate	Depth (cm)	% Ca Carbonate	Depth (cm)	% Ca Carbonate
57.25	10.64	76.25	16.87	119.25	12.08
57.75	10.13	76.75	17.05	119.75	11.19
58.25	10.34	77.25	16.47	120.25	10.33
58.75	10.09	77.75	16.85	120.75	10.03
59.25	10.05	78.25	16.12	121.25	9.61
59.75	9.85	78.75	14.85	121.75	8.91
60.25	10.37	79.25	15.67	122.25	7.98
60.75	10.37	79.75	14.95	122.75	8.91
61.25	10.11	80.25	15.16	123.25	11.35
61.75	10.39	80.75	12.14	123.75	13.19
62.25	9.62	81.25	10.04	124.25	15.24
62.75	10.24	81.75	6.55	124.75	17.59
63.25	10.18	82.25	7.41	125.25	18.29
63.75	9.15	82.75	7.59	125.75	18.39
64.25	10.05	83.25	10.42	126.25	17.27
64.75	10.24	83.75	10.64	126.75	17.03
65.25	9.72	84.25	10.46	127.25	16.57
65.75	8.5	84.75	10.5	127.75	16.21
66.25	10.33	85.25	9.39	128.25	15.26
66.75	10.08	85.75	10.6	128.75	15.53
67.25	10.93	110.25	8.8	129.25	14.41
67.75	10.23	110.75	8.06	129.75	14.77
68.25	9.25	111.25	8.05	130.25	15.5
68.75	10.04	111.75	7.71	130.75	16.56
69.25	9.48	112.25	7.94	131.25	18.04
69.75	9.92	112.75	8.64	131.75	20.13
70.25	10.16	113.25	9.22	132.25	20.84
70.75	9.76	113.75	9.34	132.75	21.05
71.25	9.85	114.25	9.39	133.25	20.76
71.75	10.36	114.75	8.51	133.75	19.94
72.25	10.59	115.25	8.29	134.25	18.83
72.75	9.72	115.75	9.08	134.75	18.34
73.25	7.32	116.25	10.29	135.25	20.17
73.75	8.06	116.75	11.76	135.75	19.49
74.25	15.41	117.25	13.49	136.25	20.11
74.75	13.99	117.75	14.42	136.75	20.98
75.25	16.37	118.25	13.85	137.25	21.3
75.75	15.72	118.75	13.09	137.75	19.29

Appendix 6. Percent Total Carbonate LESS02-11 (3 of 3)

Depth (cm)	% Ca Carbonate	Depth (cm)	% Ca Carbonate
138.25	20.02	157.25	14.42
138.75	20.2	157.75	16.21
139.25	20.34	158.25	16.99
139.75	20.53	158.75	17.81
140.25	20.7	159.25	17.97
140.75	20.79	159.75	18.16
141.25	20.71	160.25	18.51
141.75	23.41	160.75	18.17
142.25	23.35	161.25	17.65
142.75	23.17	161.75	17.52
143.25	22.94	162.25	15.45
143.75	22.72	162.75	14.28
144.25	19.78	163.25	13.84
144.75	19.42	163.75	13.4
145.25	19.27	164.25	12.87
145.75	19.04	164.75	14.1
146.25	18.99	165.25	13.93
146.75	18.77	165.75	13.74
147.25	18.62	166.25	13.45
147.75	18.41	166.75	13.2
148.25	18.43	167.25	12.98
148.75	18.32	167.75	12.79
149.25	18.14	168.25	12.61
149.75	18.03	168.75	12.48
150.25	17.99	169.25	12.4
150.75	17.97	169.75	12.4
151.25	17.98	170.25	12.38
151.75	18.27	170.75	12.26
152.25	18.35	171.25	11.71
152.75	18.4	171.75	11.11
153.25	17.79	172.25	10.44
153.75	16.82	172.75	10.33
154.25	15.93	173.25	12.2
154.75	14.4	173.75	14.51
155.25	12.69	174.25	16.47
155.75	12.42	174.75	18.23
156.25	12.62	175.25	20.3
156.75	13.04		