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The paleoenvironmental implications of the ostracodes and diatoms from selected samples in Pliocene and Pleistocene lacustrine sediments in the Beaver basin, Utah

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CONTENTS

Abstract

The Beaver basin, south-central Utah, (fig. 1) contains Pliocene and Pleistocene lacustrine sediments that may have served as traps for uranium being leached from nearby volcanic source rocks. An important factor in determining the potential for uranium mineralization in these sediments is the ancient water chemistry, which has been determined,in addition to other physical properties of these lakes, by examining the ostracodes and diatoms from several critical localities Our study suggests that at least four distinctive lacustrine systems and various marginal environments existed in the Beaver basin during the Pliocene through early Pleistocene. The lacustrine systems we have recognized include an early freshwater lake (of Pliocene? age), a late Pliocene saline lake, a late Pliocene and early Pleistocene slightly saline to freshwater lake, and an early Pleistocene freshwater lake-pond-stream(?)-network similar to some of the modern-day environments.

Introduction

A U.S. Geological Survey project entitled "Uranium Systems of the Marysvale Volcanic Field, West-Central Utah" is concerned with the origin and depositional behavior of uranium in various geological environments. Machette (1980a,b) has identified and mapped extensive sequences of Miocene(?), Pliocene, and Pleistocene lacustrine sediments in the Beaver basin, located in the western portion of the study area, and Steven and others (1980) indicated that these ancient lake systems may have been trapping uranium leached from the adjoining volcanic highlands of the Tushar Mountains to the east of the area portrayed in fig. 1. An understanding of ancient physical and chemical lacustrine environments is fundamental in understanding the depositional behavior of uranium in this and many other areas of the Western United States. Ostracodes and diatoms, frequently preserved in Tertiary and Quaternary lacustrine sediments, are the principal paleontologic indicators of paleolimnologic conditions, because they are sensitive to small variations in their chemical and physical lacustrine habitat.

The purpose of this report is to provide a limnological interpretation of the physical-chemical properties of the lakes in which the various lacustrine sediments in the Beaver basin were deposited. The sample localities are listed in Appendix A and the fossil contents of each sample are listed in Appendix B. Our sampling program was designed only to outline the broader characteristics of the paleolimnological history of the Beaver basin. Two critical sections (localities 2 and 6) were sampled in detail, and numerous other localities were studied to provide a general picture of the history of the late Pliocene through early Pleistocene lakes in this basin.

The results of this paleontologic study suggest that the lacustrine system in the Beaver basin has distinctive chemical and probably physical properties that allow recognition of particular lacustrine phases whose chronology is provided by volcanic ash stratigraphy (Machette, 1980a). Thus, the biologic components that typify the lacustrine phases can also be used to create a local biostratigraphy.

Acknowledgments

We thank Michael N. Machette for providing us with detailed information on the stratigraphy of the units discussed in this report. We also thank him for taking us to all the localities discussed herein and for providing figures 3 and 4.

General ostracode paleoenvironmental setting

Ostracode species that inhabit nonmarine environments are highly sensitive to the water chemistry. Particular species are known to inhabit or to tolerate certain kinds of water chemistries. Eugster and Jones (1979 and references therein), as well as Phillips and van Denburgh (1971) and van Denburgh (1975) provide general discussions about the evolution of water chemistries in closed basin lakes as measured by major cation and anion content. In closed basin systems, if the water entering is relatively fresh, the final water composition will become progressively enriched in certain cations and anions and depleted in other cations or anions. The changes from original water compositions to final water compositions appear to be well-defined pathways that are at least in part defined by the relative abundances of the Ca, Mg, and HCO_3 of the inflow water (Eugster and Jones, 1979, fig. 2). One of the pathways leads to Na-CO_3-Cl water compositional end product (Eugster and Jones, 1979, fig. 2). This end product is reached by depleting the original water chemistry of Ca, Mg, and possibly K through precipitation of various minerals and (or) uptake of these cations on clay mineral surfaces. The SO_4 is lost through mineral precipitation and (or) the metabolic activities of certain bacteria. Some unknown amount of $CaCO_3$ is precipitated out in the shell-forming process of organisms such as ostracodes.

The above process, that results in the Na-CO_3-Cl end product, may be expressed as a cation ratio of (Na+K)/(Ca+Mg) computed from either milligram per liter or milliequivalents per liter. This cation ratio would then change from one of approximate equality (freshwater) to substantial inequality (saline water) as the final composition is reached. Based upon limited modern chemical data from lakes in which the ostracode fauna is known, there appears to be a positive correlation between the occurrence of Limnocythere sappaensis and a high (Na+K)/(Ca+Mg) cation ratio. This species is the only ostracode that has been found in lakes with the cation ratio of 90 to 1,826. Thereby, a particular ostracode species tolerances seem to approximate a segment of a chemical evolutionary pathway discussed by Eugster and Jones (1979). The salinities of these lakes ranged from 3 to 41 parts per thousand (ppt) total dissolved solids. However, salinity per se does not correlate with the occurrences of L. sappaensis because several examples of high salinity are known where L. sappaensis does not occur. These latter cases all have low (Na+K)/(Ca+Mg) ratios as well as other ostracode species.

We have chemical data from one locality at which L. sappaensis occurs with other ostracode species. The (Na+K)/(Ca+Mg) ratio is 58, which is still high, but is smaller than the known examples where L. sappaensis occurs by itself. Interestingly, in this latter example the water chemistry is a Na-Cl-CO_3-SO_4 type which is similar to the step Eugster and Jones (1979, fig. 2) indicate precedes the final Na-CO_3-Cl step in the chemical pathway. Thus the ostracode fauna may well be suitable for predicting not only the chemical pathway but also the steps involved in the pathway.

No obvious relationship seems to exist between Limnocythere sappaensis and the anion compositions of the lakes in which it occurs. In all the examples where a water composition is available, the sum of the bicarbonate-carbonate plus chlorides represents 80 percent (meg/l) or more of the anions present.

We must emphasize once again that the above relationship is very tentative and is not supported by a large data base or by the proper set of test situations. Thus, although the existence of Limnocythere sappaensis as a function of particular cation ratios seems probable, it is not a definitive relationship at this time.

Paleoenvironmental implications of the ostracodes and diatoms from the various localities sampled in the Beaver basin

We took 45 ostracode and diatom samples from nine localities that M.N. Machette (oral commun., 1980) believes to be representative of the lacustrine stratigraphy, as well as of the total spectrum of paleoenvironments within this stratigraphy. The localities are numbered in accordance with Machette's (1980a,b) stratigraphy -- locality 1 represents the youngest sediments and locality 9 the oldest. The areal and stratigraphic relationships of these localities are given in figures 1 and 2, respectively. Appendix A provides specific locality information and a list of samples taken at those localities. Appendix B provides a listing of ostracodes, diatoms, and other organisms by sample. In most instances, the species composition at any one locality is sufficiently constant to permit a paleoenvironmental interpretation of the locality rather than of the samples within the locality.

Localities 2 and 6 represent the primary sites we sampled. These localities are believed to contain material that is representative of the late Pliocene through early Pleistocene lake(s) in the Beaver basin (Machette, 1980a,b). Figures 3 and 4 (Machette's Last Chance Bench ash locality and Triple ash locality, respectively) illustrate the location of sample sites relative to Machette's measured sections. The other localities (1, 3, 4, 5, 7, and 8) were not systematically sampled. These localities have sediments that are younger or older than the sediment at localities 2 and 6, or provide extra control points for localities 2 and 6 (fig. 2). Because localities 2 and 6 were the only ones that were sampled systematically and in detail, we will discuss the paleoenvironments of these two sections from bottom to top first. Then we will discuss the paleoenvironmental interpretations of the other localities in stratigraphic order, provided by Machette (1980a,b), from oldest to youngest.

Locality 6

This locality has three volcanic ashes, including the Huckleberry Ridge ash bed (Izett and Wilcox, in press) near the top of the section, that provide stratigraphic control (fig. 4). Based upon our microfossil collections, this section can be divided into two segments that have different paleoenvironmental settings. The lower segment extends from the base of the measured section (3 m below the lower ash) to a point between samples UT80RMF20 and 22, about 9 to 10 m above the middle ash. The upper segment extends from the latter point up to the base of the Huckleberry Ridge ash bed (30.3 m from the top of the lower ash) (fig. 4).

The ostracode assemblage that was found in the lower segment (fig. 4; appendix B, samples UT80RMF15-21) is dominated by Limnocythere sappaensis, but other ostracodes (L. robusta and Candona rawsoni) are also present in some samples. Based upon our preceding discussion and upon the known modern occurrences of L. sappaensis, this assemblage indicates that the water was saline and that the salinity varied. This salinity was dominated by Na and K and was depleted in Ca and Mg cations. The anion composition was largely dominated by carbonates (HCO_3 and CO_3) and by chlorides, but some sulfates may also have been common during parts of this lake's history. The salinity may well have varied. The total dissolved solids (TDS) probably varied on a broad range, possibly as much as 3 to 50 ppt, but most probably fell in the range of 3 to 20 ppt where lower values occurred when L. sappaensis occurs with other species and higher values when it occurs by itself. The pH would have been high in the range of about 8.5 to 11. The cladoceran Moina has been found in many of the same environments as L. sappaensis, and thus its presence here tends to support the chemical interpretation based upon the ostracodes.

The diatom flora is represented by specimens from two samples (13V80-1 and UT80RMF15). Anomoensis costata and Campylodiscus clypeus are the dominants and subdominants, respectively, and the other species are listed in appendix B. This assemblage typifies inland, shallow, alkaline habitats. Total dissolved solids of modern habitats in which A. costata dominates commonly range from 2 to more than 40 ppt. C. clypeus seems to be restricted to lower TDS, although there are few modern data regarding its distribution. The generally poor preservation of this flora that has undergone dissolution is often associated with alkaline environments.

The correlation of particular physical factors, such as temperature, turbidity, or permanency of the water body with particular ostracodes or diatoms, is not well established. However, the diatoms A. costata and C. clypeus and the ostracode L. sappaensis are often found in water bodies whose size ranges from small ponds to large lakes. The water bodies are usually shallow, often less than 3 m deep, and very turbid. The water body may be either permanent or temporary. L. sappaensis has a broad temperature tolerance that ranges from subfrigid to subtropical, but is most common in temperate provinces that are dominated by continental climates.

Paleoenvironments in which the above dominant ostracodes and diatoms exist typically do not support diverse biologic communities. Organisms such as copepods, blue-green algae, and ostracodes and diatoms usually form most of the biomass.

The ostracode assemblage that was found in the upper segment (fig. 4; appendix B, samples UT80RMF20-25) indicates a different chemical and probably physical paleolimnologic setting. None of these samples is dominated by L. sappaensis, and when L. sappaensis is present it is poorly preserved relative to the other ostracodes, perhaps implying that it is reworked from older sediments. The ostracode assemblage and the other organisms indicate that this environment has a much lower salinity and most probably a different or lower cation ratio than did the environment that was present during deposition of sediments in the lower segment We suspect that the salinity varies seasonally from freshwater (less than 3 ppt) to perhaps 5 to 10 ppt. Occasional higher salinity values are possible. The water chemistry was most probably dominated by Na, K, Cl (HCO_3+CO_3), and SO_4. The change in salinity and in water composition is most probably a result of dilution of the former lake, either by occasional draining and (or) reception of more water. Because this system seems to have some salinity, we suspect the latter is more reasonable. No diatoms were found in this part of the section.

The presence of *Scirpus*, *Chara*, and snails suggests that this was a relatively shallow environment with water depths of less than 3 m. This was probably a permanent environment, although the system would have undergone seasonal changes in water level and salinity. The ostracodes suggest that a temperate continental climatic regime was present, but, from the above salinity inferences, this was a wetter climate than the climate that existed during the lower segment. Because the water was fresher, the lake would have been able to support a greater variety of organisms, and hence probably contained organic material derived from emergent vegetation, green and blue-green algae, as well as a variety of faunal components.

Locality 2

This locality consists of alternating brown sand and green silts that overlie the Huckleberry Ridge ash bed and that contain an ash, informally named the Last Chance Ash bed (fig. 3). The ostracode assemblages throughout the section (appendix B UT80RMF8-14) are relatively uniform, suggesting that only one environmental setting existed. The ostracode assemblage indicates that the water was fresh (below 3 ppt) but may have varied seasonally to as much as 10 ppt. Occasional variations above this salinity range are possible, particularly for samples UT80RMF10,12 in which L. sappaensis is present. The (Na+K)/(Ca+Mg) cation ratio was probably low, in most cases below 50, but Na and perhaps K were probably the dominant cations. The dominant anions were probably HCO_3-CO_3 and Cl. Some sulfates are also present. The pH is in the range of 7.8-8.0 to 9. Goose Lake, Oregon, should represent a good salinity and water chemistry analog for this lake (Phillips and van Denburgh, 1971).

The diatom flora is present only occurs in two samples (appendix B, UT80RMF8 and 12). This flora is poorly preserved and is dominated by Anomoeneis costata, which suggests a shallow, brackish-water lake environment that is comparatively high in HCO_3-CO_3 with Na as the dominant cation. The other diatoms that were found in these assemblages suggest that the water ranged from fresh to slightly saline. A. costata is known to survive in water at relatively low salinity and, in fact, has a habitat preference similar to that of Limnocythere sappaensis.

The lake was most probably a relatively shallow (less than 3 m), low-energy, permanent body of water. The ostracodes are most commonly found in north temperate to subfrigid climatic regimes today, perhaps suggesting a colder climate than the one that dominated at locality 6.

This lake probably supported a diverse assemblage of organisms, including green and blue-green algae, perhaps subaquatic macrophytes, emergent macrophytes, and numerous faunal elements. The diversity of other organisms would be low when this lake was highly saline and greatest when it was freshwater.

Locality 9

A single sample was taken at locality 9 (UT80RMF31), and some of the oldest sediments in the basin are believed to be represented at this locality (fig. 2). The ostracodes recovered from this sediment are poorly preserved and thus cannot be accurately identified to the specific level. Because of the lack of a species identification and the probability that other ostracodes could have been present and not preserved, we believe that no paleoenvironmental interpretation is warranted in this case.

Locality 8

Locality 8 is the site of four samples (appendix B, UT80RMF29,30 and 13V80-2,3) that were collected from a small outcropping of marl. The ostracodes from samples UT80RMF29 and 30 are typical inhabitants of water bodies that have seasonal variations in salinity, usually in the range of freshwater (less than 3 ppt) to about 5 ppt. The water chemistry consists of approximately equal abundances of the major cations (Na, K, Ca, Mg) and bicarbonate and sulfate anions. The pH may have varied over a broad range, perhaps 8 to 10. These ostracodes usually live in permanent or temporary ponds or streams. The ostracodes, charophytes, and gastropods indicate that the water was shallow, less than 3 m deep, and probably less than 1 m in depth. The presence of fish bones implies the presence of a stream or stream connection. The climatic regime was probably temperate. Emergent marginal aquatic vegetation, green and blue-green algae, as well as a variety of faunal elements would comprise the biomass at this site.

The diatom assemblage in sample 13V80-2 is dominated by *Denticula elegans* and species of *Rhopalodia* and *Epithemia*. *Diatomella balifouriana* is common. The dominant species characterize the environment as a shallow, alkaline, somewhat saline pond or marsh. The total salinity probably did not exceed

3 ppt, although seasonal variations above this limit are possible. Diatomella balfouriana is usually found in very fresh, cool water of mountainous regions, in association with damp moss, springs, and similar environments. It is ecologically incompatible with the other species in this assemblage and may have been introduced into this deposit by streams that drained higher elevations.

Locality 7

Locality 7 is the site where only one sample (UT80RMF26) was collected, below an ash believed to be the Huckleberry Ridge ash bed. The ostracode assemblage is similar to the assemblage in the lower segment of locality 6 (see discussion, this report) and most probably is correlative with it. No diatoms were found in this sample.

Locality 5

Locality 5 is the site of two samples (appendix B, UT80RMF6,7) that were taken below the Huckleberry Ridge ash bed. The ostracode assemblages, as well as the other organisms present in those two samples, suggest that the same partition of environments exists at this site as did at locality 6 (see discussion, this report). Sample UT80RMF6 contains a faunal group similar to that of the lower segment, whereas UT80RMF7 corresponds to the upper segment of locality six. If these two samples do correspond to the entire section examined at locality 6, then this section is greatly reduced in thickness by erosion or sedimentary bypass.

Sample UT80RMF7 contains a diatom assemblage of poorly preserved frustules of Anomoeoneis costata, Cyclotella striata, and occasional statospores of Chaetoeras. These forms suggest that the water was somewhat brackish. No diatoms were recovered from the upper segment of locality 6, and so it is difficult to equate these two units on the available evidence.

Chaetoceras and Cyclotella striata are planktonic forms and probably indicate the presence of deeper water and (or) more open lacustrine conditions at this locality than at other localities associated with the Huckleberry Ridge ash bed.

Locality 4

Locality 4 is the site of three ostracode-bearing samples (appendix B, UT80RMF32,33,34). Sample UT80RMF32 was collected just below the Huckleberry Ridge ash bed, and UT80RMF33 was collected just above the same ash. Neither of these samples contained well-preserved ostracodes, perhaps suggesting that the assemblages are not representative of the original life assemblages. Sample UT80RMF32 contains ostracodes that suggest that it was deposited in an environment similar to the lower segment of locality 6 (see discussion, this report). Sample UT80RMF33 contains only one species that is not indicative of any one environment represented at other localities; however, it is not dissimilar to the environmental setting at locality 2 or to the upper segment at locality 6 (see discussion, this report). Interestingly, these two samples were collected from what could be the edge of the lake basin and they contain Chara sp., which is indicative of shallow water.

Sample UT80RMF34 contains an assemblage of ostracodes that suggests the presence of a freshwater (less than 3 ppt) pond or marginal lake environment. Preservation of the material was poor and suggests that the assemblage could be a biased sample. Therefore, further discussion of paleoenvironmental settings seems unwarranted.

Diatom samples 14V80-1A and B were collected at the same site as UT80RMF32. Sample 1A is from about 1.4 m below the Huckleberry Ridge ash bed and 1B is from about 1.0 m below the ash. Sample 1B is dominated by what appears to be resting cysts of the brackish-water diatom Plagiotropis. The presence of Amphora coffaeiformis(?) further suggests brackish-water conditions. Both diatoms are found in comparatively shallow water. This environment is similar to that indicated by the ostracodes in sample UT80RMF32.

Diatom sample 14V80-1A is dominated by Denticula elegans, Fragilaria brevistriata and species of Nitzschia and Cymbella. There are also a large number of diatoms species that represent moderately alkaline shallow water environments, but many others suggest completely fresh, circumneutral water. This assemblage probably is the result of a mixing of diatom assemblages from different habitats. Such a circumstance might occur near the margin of a lake where entering streams might affect the salinity and pH of shallow embayments. This sample shows a strong similarity to diatomites collected by R. E. Anderson (U.S. Geological Survey, sample R-2278-1).

The environment represented by sample 14V80-1B is clearly a different type of lacustrine environment than the one represented by 14V80-1A. These two samples are only about 40 cm apart stratigraphically and further study of the section might suggest that there is an unconformity between these deposits. The possible magnitude of such an unconformity cannot be determined because the change from the largely freshwater assemblage in sample 14V80-1A to the saline assemblage in 14V80-1B could have occurred rapidly or could represent substantial amounts of time.

Diatom sample 14V80-2 is dominated by Fragilaria brevistriata and by Nitzschia denticula. Denticula elegans is common. Many other species are present in small numbers, and collectively they suggest a shallow, alkaline water environment. The sample has a close floristic similarity to 14V80-1A and to those samples collected by R. E. Anderson. If the latter comparison is correct, it would imply that sample 14V80-2 is older than the Huckleberry Ridge ash bed and the late Pliocene saline lake phase discussed herein under localities 6 and 4.

Diatom samples 14V80-3A and B contain a diverse, well-preserved diatom flora characterized by shallow, comparatively freshwater species. Once again, they are floristically most similar to the assemblage in sample 14V80-1A that underlies the Huckleberry Ridge ash bed, suggesting that these samples are older than the ash. The diatoms in samples 14V80-3A and B, as well as in 2 and 1A, suggest the presence of an older lacustrine sequence in the Beaver basin. The presence of the distinctive Diatomella balfouriana in sample 14V80-3B indicates that this deposit might be correlative with 13V80-2 at locality 8 (see discussion, this report).

Diatom samples 14V80-4A and B were collected at the same site as UT80RMF34. They contain similar diatom floras in which Diatomella balfouriana, Denticula elegans, and Fragilaria brevistriata are either dominant, subdominant, or common. They are similar enough floristically to correlate them with 14V80-3A and B, and probably with 14V80-2 and 14V80-1A. It is not unusual to find a certain amount of variation in species composition in diatom floras of the same deposit, both vertically and horizontally A more detailed study of the diatoms in this isolated, faulted section would probably allow a precise intercorrelation between them.

The possible correlation of diatoms from 14V80-3A and B and 14V80-4A and B with 14V80-2, 14V80-1A and 13V80-2 (locality 8) would suggest that this environment might have been fairly widespread. The diatoms in these samples, as well as the ostracodes in UT80RMF34 and UT80RMF29,30 (locality 8), suggest the presence of a pond, a small lake, or marginal lacustrine settings that may have been connected by small streams. This environment was then replaced by the saline lake environment discussed under locality 6.

Locality 3

Samples UT80RMF27 and 28 contain a diverse assemblage of ostracodes, charophytes, and gastropods. The ostracode assemblage suggests that the salinity was predominantly within the freshwater range (less than 3 ppt) but probably varied seasonally. These ostracodes (appendix B, UT80RMF27,28) are frequently found in ponds or lakes in which the salinity is low in the spring and early summer (below 2 ppt), but increases to 3 to 5 ppt in the late summer to fall. Although most of the ostracode population growth takes place during the freshwater period, many individuals survive into the saline period. These ostracodes are also commonly found in the marginal lacustrine environments such as ponds and marshes that surrounding saline lakes. The total ostracode assemblage is similar to the assemblages reported for locality 2 (appendix B, UT80RMF8-14.

All the ostracodes (appendix B, UT80RMF27,28) in this assemblage, but particularly Limnocythere ceriotuberosa, imply that the water chemistry was dominated by Na, HCO_3, and Cl. K, Mg, and SO_4 may have been common also. Ca is usually depleted in the environments where these ostracodes are found. The water chemistry of Goose Lake, Oregon, (Phillips and van Denburgh, 1971) serves as an excellent modern analog for these ostracodes.

The diatoms, particularly Nitzschia granulata, typically live in the environment discussed above for the ostracodes. The diatom assemblage as a whole is perhaps more indicative of the marginal lacustrine setting noted above, particularly marshes. Possibly the diatoms indicate an environment that was peripheral to the larger lacustrine environment discussed previously under locality 2. However, the total assemblage (appendix B, UT80RMF28) more closely resembles the assemblage found at locality 8 (appendix B, 13V80-3).

Locality 1

The ostracodes (appendix B, UT80RMF2,3,4,5) form an assemblage whose environmental preference is similar to that described for locality 3. That is, the environment is predominantly freshwater (less than 3 ppt) but undergoes seasonal fluctuations in salinity. Perhaps one of the only differences is the presence of Limnocythere sappaensis which suggests that the water chemistry was richer in HCO_3 than at locality 3. However, the water chemistry was still dominated by Na-HCO_3-Cl.

The diatoms (appendix B, 12V80-1) support the interpretation for the ostracodes. Cocconeis placentula is a common epiphytic diatom often found in shallow ponds and ditches. Its presence here suggests that these deposits represent a minor and restricted lacustrine environment.

Summary

This study was based upon a set of samples that were collected to evaluate the nature of the lacustrine environments that are represented by the stratigraphically diverse sediments in the Beaver basin. Although this study was not conducted systematically enough to definitively describe each lacustrine setting and its marginal environments, we have been able to clearly outline the diversity of environments that existed in this region.

Figure 2 illustrates the general stratigraphic relationships of our samples to each other as well as their approximate spatial arrangement (see also fig. 1). Within the latter framework, we recognize what appears to be four distinctive environments with various marginal environments. The earliest settings that have adequate material for discussion are represented by locality 8, and perhaps by the secondary sites at locality 4 (4b-E). This environment is largely freshwater (less than 3 ppt) one, but one that probably varied seasonally in salinity, perhaps to as mush as 5-10 ppt. This environment seems to have been one of numerous lakes and streams rather than of a simple large lake. However, because we did not collect numerous samples from this environment, it is possible that we are only sampling the margin of a larger system.

The second environmental setting is represented by localities 5, 6, and 7; where locality 6 is the major sample site. This environment was a large saline lake that had salinities higher than 3 ppt, but probably less than 20 ppt most of the time. The water chemistry was dominated by $NaHCO_3$ but Cl also may have been common. The water should have been depleted; that is, concentrations are small relative to the dominants in Ca Mg, and SO_4. K and CO_3 may have been common. The lake probably was a large but shallow (less than 20 ft) body of water that was characterized by a moderate amount of turbidity. This lake appears to have become diluted during the interval (see discussion under locality 6, upper segment) just before the Huckleberry Ridge ash bed was deposited.

The third environment is represented by localities 2 and 3, where locality 2 is the primary locality. This lake was freshwater during most of the year, but did vary seasonally in salinity. The predominant water chemistry was a Na-HCO_3-Cl type. Ca, Mg, and SO_4 were present in reduced concentrations relative to the dominant cations and anions. This lake was of moderate size, although shallow and turbid. The lake level probably fluctuated, leaving substantial marshes, ponds, and small lakes around the margin.

The fourth environment is represented by locality 1. Once again, this was a freshwater setting, but one that varied seasonally in salinity. The water chemistry was more diversified and probably included Na, K, Mg, and perhaps Ca, in approximately equal concentrations, as well as HCO_3, Cl, and

SO_4. This environment probably consisted of small lakes, ponds, and marshes that could expand in size occasionally to form larger shallow-water lakes. Perhaps this environment represents the final phase of the lake discussed under locality 2.

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Appendix A

Sample Localities

Locality 1--Samples UT80RMF2, 3, 4, 5 and 12V80-1

Beaver, Utah, 15-minute to topographic quadrangle, T. 29 S., R. 8 W., SW1/4 SE1/4 SE1/4 sec. 23.

Samples taken from walls of a small drainage ditch that is oriented approximately east-west. Samples UT80RMF2, 3 from south wall of drainage ditch in crossbedded, sandy, ostracode coquina beds; sample 2 is about 80 cm below sample 3. Samples UT80RMF4, 5, and 12V80-1 from north wall of ditch; 4 and 5 in green clay silt beds containing gastropods and 12V80-1 from a 2.5-cm-thick diatomite. All the units in this area are extensively faulted.

Locality 2--Sample UT80RMF8-14.

Beaver, Utah, 15-minute topographic quadrangle, T. 29 S., R. 8 W., SE1/4 SW1/4 SW1/4 sec. 1.

Samples taken from a section on the WSW edge of Last Chance Bench above the Huckleberry Ridge ash bed and above and below an ash, informally named the Last Chance Bench ash. Section composed of alternating green clayey silts and brown clayey sandy silts. Sample UT80RMF8 from about 1.8 m below the Last Chance Bench ash in one of the green units; UT80RMF9 from about 0.9 m below the Last Chance Bench ash in another green unit. UT80RMF10 from a green unit about 3 m above the same ash. Sample UT80RMF11 from a green unit that has been faulted into the section. UT80RMF12 from a green unit about 10 m above the Last Chance Bench ash; UT80RMF 13 from about 12 m above the same ash in another green bed. UT80RMF14 from about 11 m above the same ash in a brown bed between samples 12 and 13.

Locality 3--Samples UT80RMF27, 28

Beaver, Utah, 15-minute topographic quadrangle, T. 28 S., R. 7 W., SW1/4 SW1/4 NW1/4 sec. 20.

Samples taken from a small outcropping of sediment on the crest of a hogback directly east of the dirt road. Sample 27 from thin sand bed and sample 28 from the green clay below the sand.

Locality 4--Samples UT80RMF32-34 and 14V80-1A, B, 2, 3A, B, and 4A, B

Minersville 15-minute topographic quadrangle, T. 30 S., R. 8 W., 250 m E., 420 m S., NW corner sec. 17.

Sample UT80RMF32 was taken from sediments about 40 cm below prominent volcanic ash (Huckleberry Ridge? ash bed). Samples 14V80-1A from about 1.4 m and 14V80-1B from about 1 m below the same ash.

Minersville 15-minute topographic quadrangle, T. 30 S., R. 8 W., 400 m E. and 510 m S., NW corner sec. 17.

Sample UT80RMF33 was taken from sediments about 1 m above prominent volcanic ash (Huckleberry Ridge? ash bed).

Minersville 15-minute topographic quadrangle, T. 30 S., R. 8 W., 800 m E., 960 m S., NW corner sec. 17.

Sample 14V80-2 from small outcrop that forms a low-relief ridge about halfway up the hillside.

Minersville 15-minute topographic quadrangle, T. 30 S., R. 8 W., 930 m E., 770 m S., NW corner sec. 17.

Samples 14V80-3A, B; A is 50 cm below B, and both are from an outcrop about 5 m below a prominent topographic saddle.

Minersville 15-minute topographic quadrangle, T. 30 S., R. 8 W., 205 m S., 550 m E., NW corner sec. 17.

Sample 14V80-4A from unit below basaltic ash; 14V80-4B from unit about 1 m above basaltic ash; UT80RMF34 from about 30-40 cm below 14V80-4B.

Locality 5--Samples UT80RMF6, 7

Adamsville 15-minute topographic quadrangle, T. 29 S., R. 9 W., SW1/4 SW1/4 SE1/4 sec. 25.

Samples taken from low-lying ridge about 500 m west of the Minersville Reservoir along an abandoned access road below a prominent exposure of the Huckleberry Ridge ash bed. Sample UT80RMF6 from a calcareous clayey silt unit and about 60 cm below the base of the ash; UT80RMF7 from a brown to tan sand unit and about 25 cm below the base of the ash.

Locality 6 Samples--UT80RMF15-25 and 13V80-1

Beaver, Utah, 15-minute topographic quadrangle, T. 28 S., R. 7 W., NW1/4 NE1/4 SW1/4 sec. 31.

Samples taken from a section on the SW edge of The Hogsback surface below the Huckleberry Ridge ash bed. This section contains two other ashes, a lower coarse-grained lapilli bed and a finer grained middle ash. Sample UT80RMF15 is about 45 cm below the lower ash, sample 13V80-1 is from about 10 cm above the lower ash. UT80RMF16 is from about 45 cm above the lower ash, UT80RMF18 is about 60 cm above the middle ash, and UT80RMF19 is about 3 m above the middle ash. UT80RMF20 and 21 are 7.2 and 7.3 m, respectively, above the middle ash. Samples UT80RMF22, 23, 24 and 25 are about 6, 4, 1.5 and 0.25 m, respectively, below the Huckleberry Ridge ash bed.

Locality 7--Sample UT80RMF26

Beaver, Utah, 15-minute topographic quadrangle, T. 28 S., R. 7 W., NW1/4 NW1/4 SW1/4 sec. 19.

Sample taken from sediments exposed in a small ravine below a prominent volcanic ash believed to be the Huckleberry Ridge ash bed.

Locality 8--Samples UT80RMF29, 30 and 13V80-2, 3

Beaver, Utah, 15-minute topographic quadrangle, T. 27 S., R. 7 W., center sec. 6 directly below the number 6 on the topographic sheet.

Samples taken from an outcropping of marly sediments exposed in a small saddle. Sample 29 is from sediments about 9 m below the saddle, and sample 80 is on the saddle.

Locality 9--Sample UT80RMF31

Beaver, Utah, 15-minute topographic quadrangle, T. 27 S., R. 7 W., NW1/4 SW1/4 SE1/4 sec. 12

Sample taken from a small outlier of conglomerate on Maple Flats about 26 m below the base of the conglomerate on the west side of the horst.

Appendix B

A list of the ostracodes, diatoms, and charophytes found in the samples collected near Beaver, Utah, (see appendix I for exact sample locality). The species of the respective organisms are listed in their order of abundance from the most common to the rarest. The designation of species by number (e.g., sp.1 sp.2) is for denoting species diversity and does not refer to other reports published or unpublished.

UT8ORMF 2

Ostracodes

Candona patzcuaro Tressler, 1954

Limnocythere ceriotuberosa Delorme, 1967

Limnocythere camera Delorme, 1967

Limnocythere sappaensis Staplin, 1963

Eucypris sp. indet.

Barren of diatoms

UT8ORMF 3

Ostracodes

Candona patzcuaro Tressler, 1954

Limnocythere ceriotuberosa Delorme, 1967

Limnocythere sappaensis Staplin, 1963

Barren of diatoms

UT80RMF 4

Ostracodes

Candona patzcuaro Tressler, 1954

Cypridopsis vidua (Muller, 1776)

Limnocythere sappaensis Staplin, 1963

Diatoms (poorly preserved fragments)

Epithemia adnata

Navicula sp.

Charaphytes

Chara sp. 1

Other organisms

gastropods

UT80RMF 5

Ostracodes

Candona patzcuaro Tressler, 1954

Limnocythere camera Delorme, 1967

Barren of diatoms

Other organisms

gastropods

UT80RMF 6

Ostracodes

Limnocythere sappaensis Staplin, 1963

Barren of diatoms

Other organisms

Moina sp. indet. ephippia (Cladoceran)

UT80RMF 7

Ostracodes

Limnocythere sappaensis Staplin, 1963

Limnocythere robusta Delorme, 1967

Eucypris sp. 1

Candona sp. indet.

Diatoms (poorly preserved fragments)

Campylodiscus clypeus

Cyclotella striata

Anomoeoneis costata

Chaetoceras sp. cf. *C. muelleri*

UT80RMF 8

Ostracodes

Limnocythere robusta Delorme, 1967

Limnocythere playtforma Delorme, 1971

Limnocythere camera Delorme, 1967

Candona sp. 1

Diatoms (poorly preserved fragments)

Rhopalodia gibba

Gomphonema sp.

Anomoeoneis costata (dominant)

Denticula elegans

UT80RMF 9

Ostracodes

Limnocythere robusta Delorme, 1967

Limnocythere playtforma Delorme, 1971

UT80RMF 10

Ostracodes

Limnocythere robusta Delorme, 1967

Limnocythere sappaensis Staplin, 1963

Limnocythere platyforma Delorme, 1971

Candona sp. indet.

Barren of diatoms

UT80RMF 11

Ostracodes

Limnocythere robusta Delorme, 1967

Candona patzcuaro Tressler, 1954

Barren of diatoms

UT80RMF 12

Ostracodes

Limnocythere robusta Delorme, 1967

Candona patzcuaro Tressler, 1954

Limnocythere ceriotuberosa Delorme, 1967

Limnocythere sappaensis Staplin, 1963

Diatoms

Anomoeoneis costata

Other organisms

Daphniid ephippia

UT80RMF 13

Ostracodes

Limnocythere robusta Delorme, 1967

Barren of diatoms

UT80RMF 14

Ostracodes

Limnocythere robusta Delorme, 1967

Limnocythere platyforma Delorme, 1971

Limnocythere ceriotuberosa Delorme, 1967

Candona sp. indet.

Barren of diatoms

UT80RMF 15

Ostracodes

Limnocythere robusta Delorme, 1967

Diatoms

Anomoeoneis costata

resting cysts(?) of *Anomoeoneis costata*

Nitzschia spp.

Chaetoceras sp. cf. *C. muelleri*

Campylodiscus clypeus

Rhopalodia gibba

UT80RMF 16

Ostracodes

Limnocythere sappaensis Staplin, 1963

Limnocythere robusta Delorme, 1967

Barren of diatoms

UT80RMF 17

Ostracodes

Limnocythere sappaensis Staplin, 1963

Limnocythere robusta Delorme, 1967

Barren of diatoms

Other organisms

Moina sp. indet. ephippia

UT80RMF 18

Ostracodes

Limnocythere sappaensis Staplin, 1963

Barren of diatoms

UT80RMF 19

Barren of ostracodes, diatoms and charaphytes

UT80RMF 20

Ostracodes

Limnocythere sappaensis Staplin, 1963

Limnocythere robusta Delorme, 1967

Candona rawsoni Tressler, 1957

Barren of diatoms

Other organisms

Moina sp. indet. ephippia

Daphniid ephippia

UT80RMF 21

Ostracodes

Limnocythere sappaensis Staplin, 1963

Limnocythere robusta Delorme, 1967

Candona sp. indet.

Other organisms

Moina sp. indet. ephippia

Daphniid ephippia

UT80RMF 22

Ostracodes

<u>Limnocythere robusta</u> Delorme, 1967

<u>Limnocythere sappaensis</u> Staplin, 1963

<u>Limnocythere ceriotuberosa</u> Delorme, 1967

<u>Candona</u> sp. indet.

Charaphytes

<u>Chara</u> sp. 2

Other organisms

<u>Moina</u> sp. indet. ephippia

Daphniid ephippia

UT80RMF 23

Ostracodes

<u>Limnocythere robusta</u> Delorme, 1967

<u>Limnocythere sappaensis</u> Staplin, 1963

<u>Candona</u> sp. indet.

UT80RMF 24

Ostracodes

<u>Limnocythere robusta</u> Delorme, 1967

Other organisms

<u>Scirpus</u> sp. indet. seeds

UT80RMF 25

Ostracodes

Candona sp. indet.

Other organisms

Scirpus sp. indet seeds

gastropod (terrestrial?)

UT80RMF 26

Ostracodes

Limnocythere robusta Delorme, 1967

Limnocythere sappaensis Staplin, 1963

UT80RMF 27

Ostracodes

Limnocythere platyforma Delorme, 1971

Candona patzcuaro Tressler, 1953

Limnocythere ceriotuberosa Delorme, 1967

Limnocythere robusta Delorme, 1967

Charophytes

Chara sp. 2

Other organisms

gastropods

UT80RMF 28

Ostracodes

Candona patzcuaro Tressler, 1953

Limnocythere playtforma Delorme, 1971

Limnocythere ceriotuberosa Delorme, 1967

Limnocythere robusta Delorme, 1967

Limnocythere camera Delorme, 1967

Diatoms: (rare but well-preserved)

Epithemia adnata

Nitzschia granulata (common)

Pinnularia sp. cf. _P._ _microstauron_

Anomoeoneis costata (common)

Navicula hungarica

Rhopalodia gibba (common)

Navicula cuspidata

Surirella ovalis

Nitzschia hybrida

Rhopalodia gibberula

Charophytes

Chara sp. 2

Chara sp. 3

Other organisms

gastropods

UT80RMF 29

Ostracodes

Candona patzcuaro Tressler, 1953

UT80RMF 30

Ostracodes

Candona patzcuaro Tressler, 1953

Ilyocypris cf. *I. bradyii* Sars, 1890

Charophytes

Chara sp. 1

Other organisms

gastropods

fish bones

UT80RMF 31

Ostracodes

Limnocythere sp. indet.

UT80RMF 32

Ostracodes

Limnocythere sappaensis Staplin, 1963

Charophytes

Chara sp. 4

UT80RMF 33

Ostracodes

Candona sp. indet.

Charophytes

Chara sp. 4

UT80RMF 34

Ostracodes

<u>Limnocythere</u> sp. indet.

<u>Cyprinotus</u> sp. 1

<u>Darwinula stephensoni</u> (Brady and Robertson, 1890)

Diatom samples that were not processed for calcareous microfossils.

12V80-1 (approx. equivalent to UT80RMF 4)

<u>Cymbella mexicana</u>

<u>Cocconeis placentula</u> (dominant)

<u>Epithemia adnata</u>

<u>Melosira italica</u>

<u>Gomphonema olivaceum</u>

<u>Cymbella</u> spp.

<u>Stauroneis anceps</u>

13V80-1 (just below UT80RMF 16)

<u>Anomoeoneis costata</u> (poor preservation)

<u>Campylodiscus clypeus</u>

13V80-2 (approx. equivalent to UT80RMF 29)

Pinnularia sp.

Rhopalocia gibba (common)

Rhopalodia gibberula (common)

Denticula elegans (dominant)

Diatomella balfouriana (common)

Nitzschia denticula

Caloneis sp. cf. *C. bacillum*

Fragilaria brevistriata

Epithemia argus

13V80-3 (approx. equivalent to UT80RMF 30)

Denticula elegans

Nitzschia granulata (dominant)

Pinnularia microstauron

Surirella ovata

Scoliopleura peisonis

Caloneis sp.

Rhopalodia gibba

Rhopalodia gibberula

Anomoeoneis costata

Amphora sp. cf. *A. proteus*

Cymbella cistula

Nitzschia frustulum?

14V80-1A (approx. equivalent to UT80RMF 32)

Anomoeoneis costata

Cymbella sp. cf. C. cistula (very common)

Achnanthes flexella

Denticula elegans (dominant)

Epithemia sp.

Fragilaria brevstriata (subdominant)

Achnanthes minutissima

Rhopalodia gibba

Pinnularia mocrostauron

Eunotia flexuosa

Epithemia argus

Melosira distans

Anomoeoneis sphaerophora

Cymbella sp. cf. C. hauckii

Nitzschia denticula

14V80-1B (approx. equivalent to UT80RMF 32)

apiculate diatom resting cysts Plagiotropis sp.

Amphora sp. cf. A. coffaeiformis

Nitzschia sp.

14V80-2

Fragilaria brevistriata (dominant)

Fragilaria sp. cf. *F. elliptica*

Rhopalodia gibba

Denticula elegans (common)

Nitzschia denticula (subdominant)

Pinnularia sp.

Cymbella minuta

Cymbella spp.

Cocconeis placentula

Eunotia sp.

Gomphonema sp.

Amphora sp.

Melosira distans

Rhopalodia gibberula

14V80-3A

Fragilaria brevistriata

Cymbella spp.

Rhopalodia gibba

Amphora sp.

Rhoicosphenia curvata

Melosira itlaica

Diploneis sp.

Caloneis sp.

Rhopalodia gibberula

Synedra sp.

Nitzschia denticula

Nitzschia spp.

14V80-3B

Rhopalodia gibba

Denticula elegans

Epithemia turgida

Melosira italica

Rhoicosphenia curvata

Eunotia sp.

Rhopalodia gibberula

Nitzschia sp.

Pinnularia sp.

Fragilaria brevistriata

Diploneis ovalis

Fragilaria virescens

*Diatomella balfouriana

14V80-4A (approx. equivalent to UT80RMF 34)

Epithemia hyndmanii

Rhopalodia gibberula

Denticula elegans (subdominant)

Melosira italica fo. _interrupta_

*_Diatomella balfouriana_ (common)

Melosira distans

Cymbella sp.

Fragilaria brevistriata (dominant)

Rhopalodia gibba

Nitzschia denticula

Epithemia adnata

Epithemia sorex

Mustogloia smithii

Pinnularia microstauron

14V80-4B (approx. equivalent to UT80RMF 34)

Epithemia hyndmanni

Denticula elegans (subdominant)

Cymbella sp.

Rhopalodia gibberula

*Diatomella balfournia (dominant)

Epithemia sorex

Fragilaria brevistriata (subdominant)

Mastogloia smithii

Nitzschia denticula

Amphora sp.

Rhopalodia gibba

Eunotia sp.

Pinnularia spp.

Mastogloia smithii

Cocconeis placentula

FIGURE 1. Schematic index map showing general region around Beaver, Utah and localities that were sampled. QTsl, lacustrine deposits (Pleistocene and Pliocene); Tsp, upper piedmont member (Pliocene); Tsmf conglomerate of Maple Flats (Pliocene); and Tsl, lower piedmont member (Pliocene and Miocene).

FIG. 1

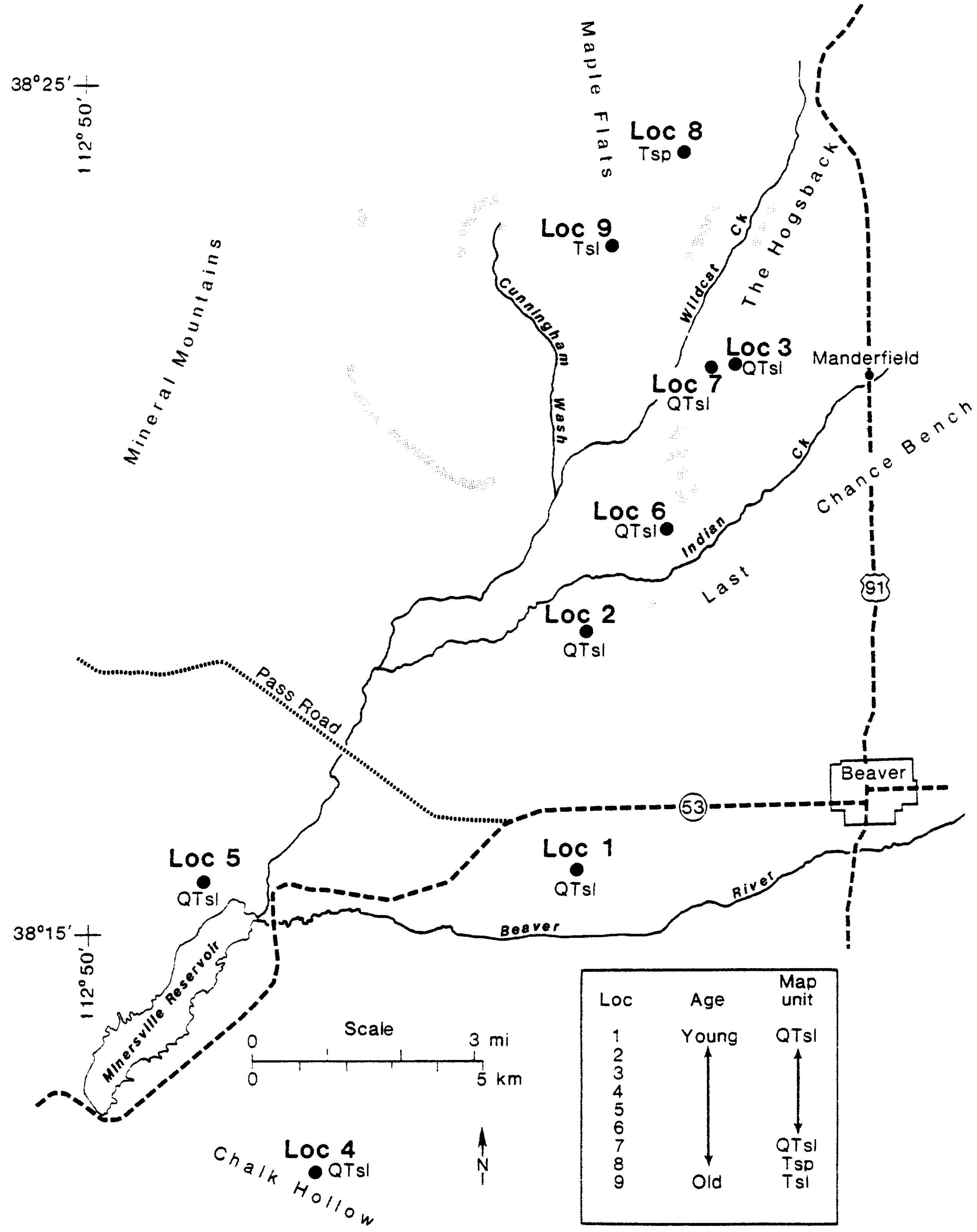
38°25'
112°50'
Maple Flats
Loc 8
Tsp
Loc 9
Tsl
Mineral Mountains
Cunningham Wash
Wildcat Ck
The Hogsback
Loc 3
QTsl
Loc 7
QTsl
Manderfield
Chance Bench
Indian Ck
Loc 6
QTsl
Last
91
Loc 2
QTsl
Pass Road
Beaver
53
Loc 5
QTsl
Loc 1
QTsl
Beaver River
38°15'
112°50'
Minersville Reservoir
Scale
0
3 mi
0
5 km
N
Loc 4
QTsl
Chalk Hollow
Loc
Age
Map unit
1
2
3
4
5
6
7
8
9
Young
Old
QTsl
QTsl
Tsp
Tsl

FIGURE 2. Schematic cross section through the Beaver basin illustrating lithologic units defined by Machette (1980 a, b) and showing approximate stratigraphic relationships of the localities that were sampled for this report. QTsl, lacustrine deposits (Pleistocene and Pliocene); Tsp, upper piedmont member (Pliocene); Tsmf, conglomerate of Maple Flats (Pliocene); and Tsl, lower piedmont member (Pliocene and Miocene).

FIG. 2

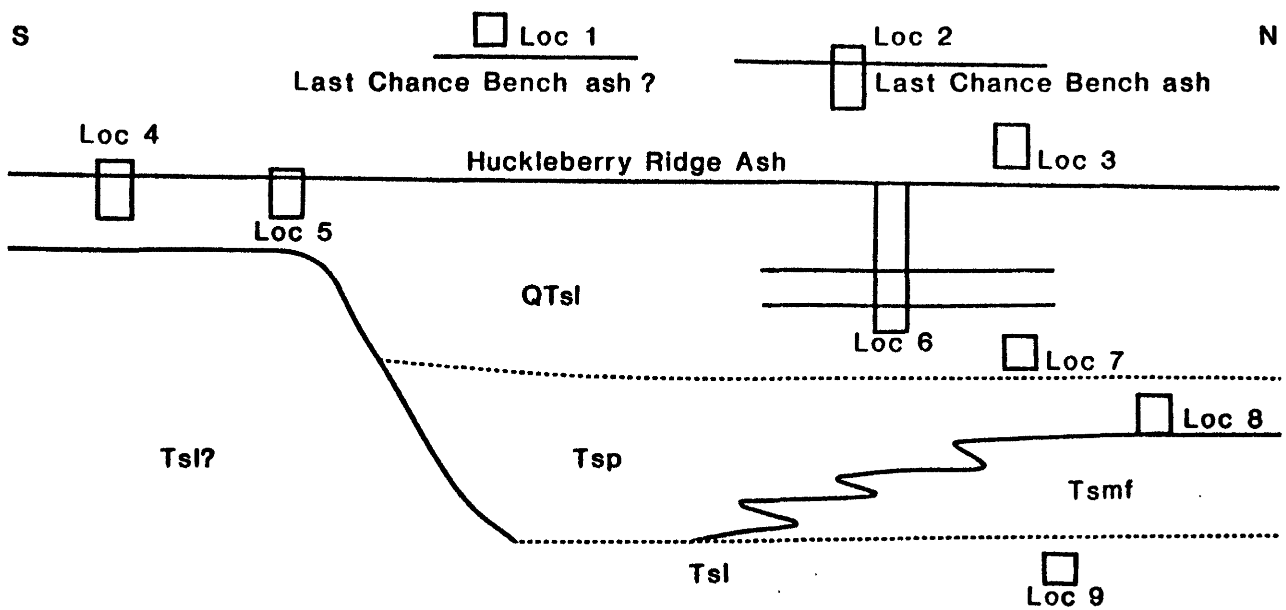
S
N
Loc 1
Last Chance Bench ash ?
Loc 2
Last Chance Bench ash
Loc 4
Huckleberry Ridge Ash
Loc 3
Loc 5
QTsl
Loc 6
Loc 7
Loc 8
Tsl?
Tsp
Tsmf
Tsl
Loc 9

FIGURE 3. Stratigraphic section at locality 2 (M. N. Machette's Last Chance Bench ash locality), Beaver basin, Utah. Sample number and position in section of our samples are shown at right. Lithologic descriptions of the numbered units are as follows:

Unit 9 Yellowish-brown sandy silt (greater than 0.8m thick)

Unit 8 Light brown and light orange-brown varigated sand

Unit 7 Very light green silty clay, calcareous (0.6m thick)

Unit 6 Light green silty clay compact (about 1.3m thick)

Unit 5 Brown, slightly oxidized sand (about 2 m thick)

Unit 4 Light green silty clay compact (about 3.5 m thick)

Unit 3 Light brown slightly oxidized sand (about 3.5 m thick)

Unit 2 Brown slightly oxidized pebbly sand (about 2m thick)

Unit 1 Green compact silty clay (greater than 2 m thick)

LAST CHANCE BENCH ash

FIG. 3

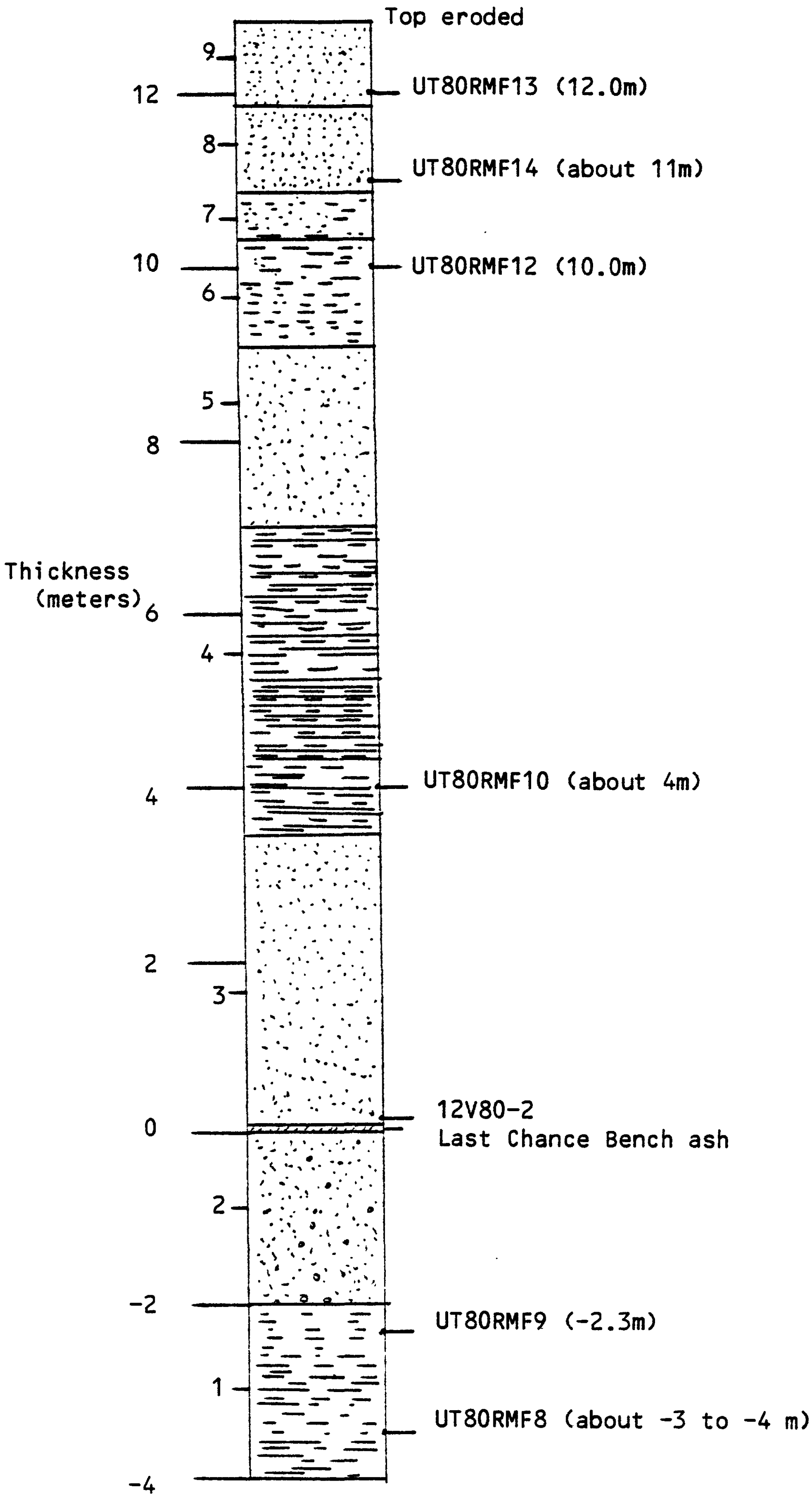

FIGURE 4. Stratigraphic section at locality 6 (M. N. Machette's Triple ash locality) Beaver basin, Utah. Sample numbers and position in section of our samples are shown at right. Lithologic descriptions of the numbered units are as follows:

Unit 24 Light gray fine to medium glassy sand, horizontal bedding at base, cross bedding, ripples.

Unit 23 Thick, homogeneous sequence of very light green silty clay to clay with rare sandy silts, oxidized.

Unit 22 Light green silty-clay, gypsum, calcareous and iron stained (1 m thick).

Unit 21 Light green silty-clay, gypsum, calcareous and silty (0.8 m thick).

Unit 20 Olive green laminated silty clay, gypsum (0.9 m thick).

Unit 19 Medium green-gray laminated clay with silt and oxidized sand layers.

Unit 18 Medium green silty-clay, dense, blocky (0.6m thick).

Unit 17 Interbedded light green-brown fine grained sand; well bedded and medium brown silty fine grained sand, slightly calcareous (1.3m thick).

Unit 16 Light green silty clay, slightly sandy, calcareous with minor gypsum, sandy at base. (2.7m thick).

Unit 15 Medium brown to gray sand to coarse sand with pebbles grading up into a medium brown to organish-brown, slightly pebbly to granular sand (1.3m).

Unit 14 Light green silty-clay with iron stained sandy layers. Upper one-half is light green compact silt to silty clay, grading up into a light green sand without gypsum (3.7 m thick).

Unit 13 Medium gray-brown coarse sand, pebbly, fines upward into a light brown fine grained sand, 4cm thick light green silty clay and light green fine grained sand.

Unit 12 Light green silty clay grading up into a light green clay with rare sand lenses and slightly gypsiferous

Unit 11 Light orange-brown to light green silty sand grading up into silty clay.

Unit 10 Light green silty clay, sand lenses and partings.

Unit 9 Orangish-brown to brown fine grained sand.

Unit 8 Very light green very silty sand.

Unit 7 White silty ash.

Unit 6 Massive light green silty clay with gypsum and light brown sand lenses.

FIG. 4 Lithologic unit descriptions continued.

Unit 5 Orange-brown fine grained sand (10cm thick).

Unit 4 Same as unit 2 (75 cm thick).

Unit 3 Coarse grained sandy obsidian lapilli ash (5cm thick).

Unit 2 Light green silty clay, gypsum and calcite (1.5m thick)

Unit 1 Light brown sand, loose (greater than 1.5 m thick).

TRIPLE ASH LOCALITY

FIG. 4