Paleoenvironmental Reconstruction of Quaternary Saltville, Virginia, using Ostracode Autecology

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by

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ABSTRACT

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The Saltville valley in southwestern Virginia is home to Quaternary localities containing paleontological and archaeological remains. Historically the valley has been mined for salt and the small lakes, ponds and springs along the valley floor have a brackish signature. A preliminary report on the site's ostracode fauna suggested that the site's water was not always saline. This study analyzed modern and Quaternary ostracodes to understand the valley's hydrologic and chemical evolution. Sediments contained primarily freshwater species, including the environmentally sensitive *Candona crogmaniana*. The presence of *Pelocypris tuberculatum* and a new *Fabaeformiscandona* species throughout a vertical section spanning the latest Pleistocene and Holocene suggests that ephemeral pools were being fed by freshwater springs throughout the latest Quaternary. Climate ranges, estimated through species autecology and MOTR, reveal that the site's mean annual temperature was between 0 - 19.1℃. Ostracode salinity tolerances suggest that the site was fresh during the sampled record.

DEDICATION

To Carson, for whom I always try to inspire.

ACKNOWLEDGEMENTS

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CHAPTER 1

INTRODUCTION AND BACKGROUND

The Saltville valley of Virginia is home to one of the eastern United States' premier salt and gypsum deposits (Kent 1955; Cooper 1966; McDonald 1984). Since the 1750's, the valley has been a site of economically important mining deposits and a well-preserved Quaternary fossil record. Fossils of Pleistocene megafauna drew the attention of paleontologists and enthusiasts from all around, including Thomas Jefferson (1787). Despite its paleontological importance, the main scientific interest at Saltville has been its megafaunal assemblages (Ray et al. 1967; McDonald and Bartlett 1983; Schubert and Wallace 2009) and potential archaeological remains (McDonald 2000; Adavasio and Pedler 2017), while other aspects of its paleoecological record remain understudied. Aside from limited work on Quaternary pollen (Ray et al. 1967; Delcourt and Delcourt 1986) and herpetofaunal remains (Holman and McDonald 1986), the microfossils of Saltville are largely unreported.

Despite their abundance in valley sediments, all published research on ostracodes from Saltville can be summarized in a single sentence:

> "Preliminary data on the Ostracoda, furnished by I.G. Sohn of the U.S. Geological Survey, suggest that local bog conditions at the Saltville site may not have been saline all the time." (Ray et al. 1967: 613)

A preliminary interpretation of the site was that the saline environment attracted large herbivores (Ray et al. 1967). Although this was suggested several decades ago, the paleoenvironmental implications of Sohn's preliminary study have not been explored further. McDonald (1984) briefly mentions an in-progress project at the University of Tennessee focused on Saltville's ostracodes, but the study does not seem to have been completed or published. The current study examines new sediment samples and ostracode fossils from Saltville to reconstruct paleoenvironmental conditions and test Sohn's conclusions about the hydrochemical history of the site.

Geologic Context

Saltville is located within Smyth and Washington Counties in southwestern Virginia, in the southern Appalachian Mountains at 520m elevation. The mean annual temperature (MAT) and mean annual precipitation (MAP) from 1929 to 2019 was reported at 12.3℃ and 1163.8 mm/year, respectively (National Weather Service 2020). During the winter shallow areas of valley-bottom ponds may freeze (Jurney and Orvedal 1948). Ogle (1981) compares the mean temperatures of Saltville to those of northern coastal regions, although the temperature varies considerably throughout the year (Jurney and Orvedal 1948).

Inundated paleontological localities in the Saltville valley belong to a portion of the Holston River watershed currently dominated by marshlands and several interconnected ponds (including SV-5/7 and SV-10) (Jurney and Orvedal 1948; Ogle 1981). The ponds receive groundwater discharges from a series of point sources such as nearby Palmer Spring and widespread seepage from soil leaching and brine wells throughout the wellfield area (Ogle 1981).

The valley occurs along a section of the Greendale Syncline with bedrock consisting mostly of the Mississippian Maccrady Formation (Cooper 1966; McDonald 2000), the primary source of the salt and other mined minerals around the area (Cooper 1966).

Quaternary-aged alluvial and colluvial deposits overlie the Maccrady Formation, and are the source of previously reported fossils (Ray et al. 1967; McDonald and Bartlett 1983; McDonald 2000; Schubert and Wallace 2009), as well as the ostracodes described in this study. Directly overlying the Maccrady is a gravel layer of varying thickness (15-30cm), which consists of rounded, pebble and cobble-sized clasts with intermittent boulders and redeposited Quaternary macrofossils (Ray et al. 1967; McDonald and Bartlett 1983; McDonald 2000). Some researchers suggest the evidence of clast abrasion and rounding indicate deposition in a fluvial environment (McDonald and Bartlett 1983; McDonald 2000; Silverstein 2017). McDonald and Barlett (1983) refer to this hydrological system as the ancient “Saltville River”, which was thought to be a moderate sized stream that occupied the valley during the last glacial maximum (LGM).

The thickest Quaternary sediments in the valley are composed of humic clay and silt that unconformably overlie the gravel (McDonald and Bartlett 1983; McDonald 2000). Originally considered a homogenous mud in which the gravel clasts and animals sank (Ray et al. 1967), these sediments were later considered to be lacustrine (i.e. Lake Totten), a result of stream piracy and diminished flow during the late Pleistocene (McDonald and Bartlett 1983; McDonald 2000). McDonald (1985, 2000) summarized the Quaternary stratigraphy and radiocarbon ages (see Table 1 and Figure 1) of the Saltville valley as follows:

Historic Surface (H1): recent soil and sediment; varies in thickness and humic composition.

Holocene Lentic Clay (H2): gray to medium gray lentic clay; dark humus present throughout.

Transitional Paleosol (W1)*; *11,130 - 12,830 cal BP: Younger Dryas deposit containing soil, peat and mud; dark brown and organic-rich.

Wisconsin Lentic Clay (W2); 14,530 - 17,500 cal BP: Oldest Dryas lentic clay; organic matter is sparse; reddish oxidation occurs in upper and middle portions when exposed.

Wisconsin Alluvium (W3); 16,610 - 18,360 cal BP: Oldest Dryas lotic sediment; silty-sand lens with occasional gravel; reduced organics; likely remnant of 'Saltville River' and associated colluvium.

Wisconsin Colluvium (W4); >18,360 cal BP: Last Glacial Maximum, angular gravel with upper clasts often abraded in place. Interpreted by McDonald (2000) and McDonald and Bartlett (1983) as an alluvial deposit from the ancient 'Saltville River'.

Bedrock (P1): Mississippian Maccrady Formation which is composed primarily of shales. Varies in thickness and weathering throughout the valley.

This summary was based on multiple seasons of interdisciplinary fieldwork in the western part of the valley (McDonald and Bartlett 1983; McDonald 1985, 2000). Although it adequately characterizes the geological setting of McDonald's SV-1 and SV-2 localities, it does not take into account the geological context of more recent excavations in the central part of the valley. Further geological research is needed to refine the Quaternary landscape evolution in the Saltville valley. Although this hydrologic reconstruction may apply to the stratigraphic record in some parts of the valley (McDonald 1985, 2000), it remains untested in others, including the focus of this study, subsite SV-5/7.

All samples and sedimentary descriptions for this study were collected at subsite SV-5/7. According to Dr. Blaine Schubert, this locality was originally two separate test units (SV-5 and SV-7) opened by Dr. Ralph Eshelman. After excavation to the gravel, SV-5 was backfilled and SV-7 was left open and became a small pond. Dr. Schubert relocated these test areas, excavated and expanded SV-5, once connected with SV-7, the larger, combined test area was referred to as SV-5/7 (Schubert, personal communication).

Table 1: Calibrated radiocarbon ages of fossils and sediment for valley depositional units (McDonald 2000).

Lab Number	Element	Geologic Unit	^{14}C yrs BP	Calibrated age range (2σ)
N/A	Bulk mud	W1	9,930 ± 190	11,130-11,970
Beta-5056	Bulk paleosol	W1	10,050 ± 110	11,250-12,000
Beta-5055	Bulk peat	W1	10,690 ± 130	12,160-12,830
A-2985	Wood	W2-P1 Boundary	13,130 ± 330	14,530-16,760
SI-641	Proboscidean tusk	W2	13,460 ± 420	14,960-17,500
Beta-65209	Wood	W3	13,950 ± 70	16,610-17,180
Beta-5701	Wood twigs	W3	14,480 ± 300	16,780-18,360
Beta-117541	Bone	W3	14,510 ± 80	17,460-17,920

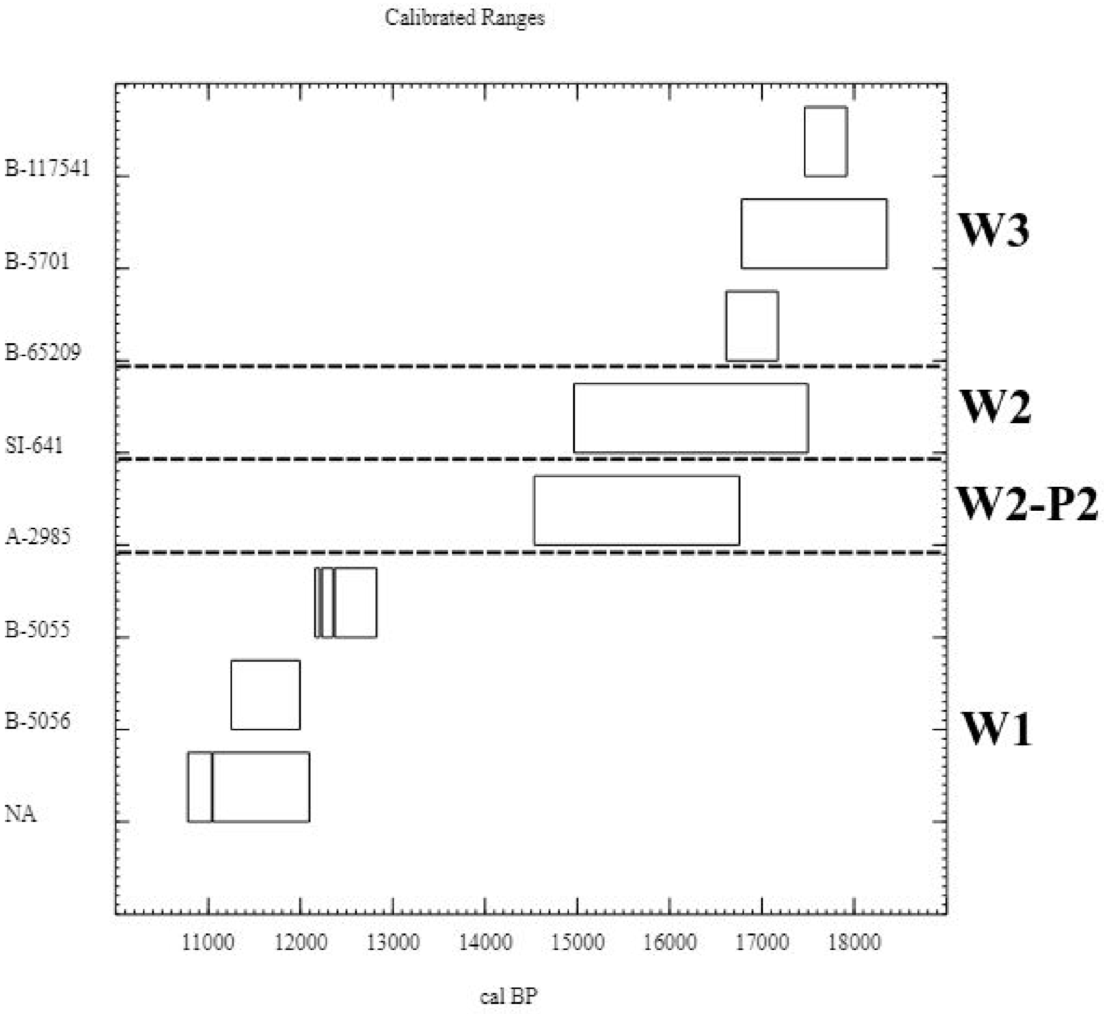

Figure 1: Saltville radiocarbon age ranges (2σ). Calibrated in CALIB 7.1 (Stuvier et al. 2020), using intcal13 (Reimers et al. 2013). Each box represents a range of possible ages for the sample. Some samples have multiple ranges as a result of multiple intercepts of the intcal13 calibration.

Paleoenvironmental Interpretations of Saltville

Quaternary Fauna - The faunal composition of late Pleistocene Saltville is dominated by herbivorous megafauna including *Megalonyx jeffersonii*, *Mammuthus primigenius*, *Mammut americanum*, *Rangifer tarandus*, *Bison* sp., *Bootherium* sp., and *Equus* sp. (Ray et al. 1967; McDonald and Bartlett 1983). Remains with bite marks indicate that large carnivorans were scavenging on *Mammuthus* in the area and remains of *Arctodus simus* have also been recovered, the most likely source of the bite marks (Schubert and Wallace 2009). Few microfossils have been collected from the locality; those that have include herpetofaunal specimens which have been described as thermophilic turtles, anurans, snakes and lizards (Holman and McDonald 1986). However, it is not known if these taxa were contemporary with Quaternary the megafauna.

Quaternary Vegetation - Pollen records have been published on two separate occasions and some plant macrofossils have been recovered but not published (Curry and Schubert, personal communication). Ray et al. (1967) report pollen recovered from sediment contained in a *Bootherium* cranium. This sample was dominated by pollen from *Pinus* spp. (pine) and *Picea* spp. (spruce), and non-arboreal families Cyperaceae (sedges) and Poaceae (grasses) (Ray et al. 1967). Delcourt and Delcourt (1986) reported on the arboreal pollen assemblages, and found the site was dominated by the same boreal conifers.

Stable Isotope Ecology - Stable isotopes of local herbivores have been used to better understand trophic and feeding behaviors (France et al. 2007; Simpson 2019). France et al. (2007) sampled nitrogen and carbon isotopes from bone collagen and found that Saltville herbivores had an exclusive C3 diet. Simpson (2019) confirmed the C3 diet of *Equus* and *Bootherium* using stable isotopes in serially sampled tooth enamel. Stable oxygen isotopes also indicated warmer conditions than were expected based on palynological analyses (Simpson 2019).

Hydrologic Reconstruction - It has been suggested that the Saltville Valley's hydrology changed from a lotic to lentic system during the late Pleistocene (McDonald and Bartlett 1983; McDonald 1985, 2000). The gravel layer was interpreted to be alluvium from a medium-sized stream which persisted until 16,600 years ago. (McDonald and Bartlett 1984; McDonald 2000). It was suggested that Lake Totten was formed around 12,800 years ago, after stream piracy, increased sedimentation, and prevalent flooding events which caused the valley to be inundated and the river to transition to a lacustrine system (McDonald 1985, 2000). Ray et al. (1967) suggested that the lacustrine and marsh-like environment of the valley was periodically frozen due to its freshwater state (based on ostracode faunas by Sohn, unpublished). The possible presence of discontinuous permafrost in the region during the late Pleistocene would have supported the notion that lakes and wetlands may have periodically frozen (French and Millar 2010).

Ecological Reconstructions - Ray et al. (1967) suggest that the Saltville area was dominated by spruce parklands, with open, sedge and grass abundant wetlands in the valley-bottoms. McDonald and Bartlett (1983) described the landscape as open and dominated by herbaceous vegetation. Delcourt and Delcourt (1986) interpret the landscape as a boreal woodland with interspersed marshes on the basis of palynological information. France et al. (2007) and Simpson (2019) through the use of stable isotopes to interpret herbivore diet, suggest the valley was a relatively open woodland dominated by C3 vegetation. The Quaternary climate of the region has been interpreted as mesic with little variation in seasonal temperature (Delcourt and Delcourt 1986; Russell et al. 2009; Simpson 2019).

Ostracoda Used in Paleontological Reconstruction

Ostracodes belong to a class of microcrustaceans with a bivalved carapace, composed of low-Mg calcite. Valves may be preserved in most aquatic deposits (Delorme 1969). High reproductive rates and resilient carapaces make ostracode valves one of the most common features in the microfossil record. The class is highly diverse with members occupying almost every aquatic habitat on the planet (Smith and Delorme 2009; Smith et al. 2015). This study reviews previous work on the order Podocopida, the only group found in continental (i.e. freshwater) environments. Ostracodes are typically benthic, with both swimming and non-swimming species occupying the littoral zone, potentially living amongst macrophytes or interstitially (i.e. within the sediment); many lacustrine species reside in the upper 1-3 cm of sediment in the limnetic zone (Mesquita-Joanes et al. 2012).

Ostracodes have been used in numerous studies as biological indicators (bioindicator) to aid in paleoecological reconstructions. Ostracodes are sensitive to seasonal variability of host water (Delorme 1969; Curry 1999). Populations and communities will rapidly respond to environmental changes (Delorme 1969; De Deckker and Forester 1988; Smith and Delorme 2009; Mesquita-Joanes et al. 2012). The tolerances of each species are unique and limited by a range of variables that include water chemistry, hydrology, and climate. Autecological chemical factors include the concentration of dissolved solids (i.e. salinity), composition of dissolved solids, average annual temperature, and pH (Delorme 1969; De Decker and Forester 1988; Holmes 1992; Smith 1993; Forester et al. 1994; Curry 1999; Mesquita-Joanes et al. 2012; Ruiz et al. 2013). Physical hydrologic factors such as turnover, water depth, and flow velocity similarly play a role in ostracode autecology (Delorme 1969; Mesquita-Joanes et al. 2012; Ruiz et al. 2013; Guo et al. 2016).

The autecology has been quantitatively and qualitatively recorded for most modern species in North America and Europe by recording aquatic and ambient climatic data alongside species presence (Delorme 1969; Smith 1993; Curry 1999; Forester et al. 2005; Horne 2007;

Curry et al 2012). Ostracode species may be assigned an environmental tolerance index (ETI) value based on their conditional ranges compared to the overall ranges of sampled sites (Sohn 1951; Delorme 1969; Curry 1999; Horne 2007). Low ETIs that are reflective of stenotopic species with narrow ranges and have specific habitat requirements, whereas large values are interpreted as eurytopic species that can tolerate many environments and conditions (e.g. cosmopolitan). For example, the cosmopolitan species *Cypridopsis vidua* has a high ETI (0.95) in regards to mean annual temperature (MAT) compared to that of *Candona crogmaniana* (0.29) which resides only in regions with warmer water temperatures (Curry et al. 2012). Using data sets such as the North American Combined Ostracode Database (NACODe), ETI's can be calculated using the following equation: $ETI = range\ of\ x_{species}/range\ of\ x_{data\ set}$.

Given that the ETI and autecology of these species have not changed since the latest Quaternary, ostracode assemblages can be used to reconstruct their paleo-hydroenvironment (Delorme 1969; Forester 1986; De Deckker and Forester 1988; Holmes 1992). Fossil assemblages of ostracodes are generally considered to be partial representatives of the whole community (i.e. thanatocoenosis or taphocoenosis). Using modern ecosystems and ETI's as references, interpretations of Quaternary aquatic environments through time can be made from a stratigraphic succession of species abundances (Smith 1997; Curry and Baker 2000; Curry and Delorme 2003; Zarikian et al. 2005; Curry et al. 2016).

Ostracode valves are formed using the free carbon and trace elements in the water column and in turn reflect the isotopic signature of their environment (Holmes and Chivas 2002; Smith and Delorme 2009; Mesquita-Joanes et al. 2012). Stable isotope analyses are common in many paleoenvironmental reconstructions utilizing ostracodes. The most commonly used isotope is δ^{18}O which can reflect changes in annual precipitation, humidity, water temperature, hydrology, and evaporation rates (Forester et al. 1994; Curry et al. 1997; Curry and Baker 2000; Curry and Filippelli 2003; Alvarez Zarikian et al. 2005; Frenzel and Boomer 2005; Curry et al. 2016). Since ostracodes valves are composed of low-Mg calcite, δ^{13}C can be used to understand sediment and water interactions, atmospheric carbon dioxide exchange, photosynthetic activity, detrital activity, and bacterial processes (Curry et al. 1997, Devriendt et al. 2017). Ratios of trace elements such as ^{87}Sr/^{86}Sr ratios (Frenzel and Boomer 2005), Sr/Ca (Frenzel and Boomer 2005; Curry et al. 2016), and Mg/Ca (De Decker and Forester 1988; Frenzel and Boomer 2005) are often used in combination with other isotopes to detail shifts in temperature, salinity, and water source. Combined with other climate proxies such as pollen, gastropods, and plant macrofossils, ostracode information can be a powerful tool used to examine and reconstruct landscape evolution, including local changes in hydrology and climate (Curry 2003).

Ostracodes in the Southeast United States

Continental Pleistocene records of ostracodes from the southeast United States are sparse compared to elsewhere in the country. In the southeastern U.S. faunal lists of modern habitats have been tabulated in South Carolina (Ferguson 1951), North Carolina (Furtos 1936), and Florida (Furtos 1936; Keyser 1976). Fossil assemblage and paleoecological studies have been limited to Florida (Teeter 1980; Zarikian et al. 2005). These sites contained many species related to those collected in this study but ultimately do not reflect the same depositional history or species present at Saltville, particularly the studies in Florida which have a large estuarine influence (Furtos 1936; Keyser 1976; Teeter 1980; Zarikian et al 2005). Sampling of more water bodies in the Southeast may reveal hypogean communities similar to Saltville and may offer a better understanding of the region’s climate and hydrological evolution.

CHAPTER 2

METHODOLOGY

Water Chemistry Sampling

Prior to sampling fossil and modern ostracodes, water chemistry analyses were conducted by the ETSU Environmental Health Sciences Laboratory (Evanshen 2019). Water samples were collected from pit SV-10, which is currently inundated and connected to one of the large ponds in the Well Fields portion of the valley. Subsite SV-5/7 was sampled in two locations: at a saline spring in the northeastern part of the excavation, and at a freshwater seep in the pit wall. Conductivity, salinity, pH, total dissolved solids (TDS), sulfate and cation concentrations were analyzed at each site following the Standard Methods for the Examination of Water and Wastewater, 22nd edition (2012) guidelines (Table 2).

Table 2: Water chemistry data from Evanshen (2019).

	Salt Spring (SV-5/7)	**Seep (SV-5/7)**	**SV-10**
Conductivity (µS/cm)	16,300	2,053	11,700
Salinity (ppt)	9.54	1.05	6.67
TDS (mg/L)	8,063	1,025	5,850
Sulfates (mg/L)	2,746	1,201	1,270
Fe^{2+} Cation (µg/L)	2,792	4,374	299
pH	7.12	7.35	7.79

Sediment Descriptions

All samples examined in this study were collected from a single, 1.10m vertical section in SV-5/7. The stratigraphy present in this profile is similar to the sequence reported by McDonald (1984, 2000) in the eastern part of the valley. Mechanical removal of overburden at SV-5/7 has truncated the uppermost units, likely removing most Holocene sediments. The following sediment descriptions of SV-5/7 were taken from this exposed vertical section.

Disturbed Slump Unit **(DS) ─** The uppermost portion of the vertical section is a slump. The thickness of this unit can be >1 m around SV-5/7, but only ~15 cm of this unit was present in the sampled profile. The unit is clay with a high composition of humic and modern plant material. Valves and shells are numerous and it is likely that some are subfossils or modern.

Oxidized Clay Unit **(OC) ─** Unconformably underlying the Disturbed Slump Unit is a unit of highly oxidized clay with very few plant macrofossils. The unit has an average thickness of 20 cm where sampled. Very few, highly deteriorated microfossils are found in this unit.

Silty Clay Unit **(SC) ─** A transitional unit composed of silty clay and some humic material. This is the thickest unit in both sampled sections with an average thickness of 50 cm. No oxidation is apparent. Plant material, gastropod and ostracode carapaces are few, but relatively well-preserved.

Silty Sand Unit **(SI) ─** Underlying the Silty Clay Unit is an abrupt transition to the thinnest unit in the section, with an average thickness of 10cm. This unit is composed of silty-sand with very little organic material. Ostracodes are abundant and well-preserved. *Mammuthus* and *Arctodus* remains found at the juncture between the corresponding unit and the underlying gravel in SV-10, have radiocarbon ages of 15,501 and 17,884 cal BP, respectively (Schubert and Wallace 2009).

Gravel Unit **(GR) ─** The lowermost unit in the vertical section consists of an unconsolidated, unsorted conglomerate made up of variable-sized clasts of carbonate and chert in a silty matrix. The silty matrix is texturally similar to that of the overlying SI unit. Only 5 cm of sediment was removed for sampling although the unit has been reported to vary in thickness up to 15 cm. The similarity to the Silt Unit combined with the many fossils found lying atop this unit may suggest that the Silt Unit and Gravel Unit share a common provenance. Both fossil ostracode valves and intact modern ostracodes are present in the unit. Living individuals may have been introduced by daily inundation of SV-5/7 thus contaminating the sample, or represent a population living interstitially within the Gravel Unit.

Fossil Sample Collection

The SV-5/7 subsite was drained of water early in the summer of 2019 to allow for an annual excavation of the site. Two vertical sections (2019-1 and 2019-2) separated by 7 meters along the north wall of the excavation area were exposed to allow for collection of sediment samples for microfossil and grain size analyses (Figure 3). Both sections were sampled but due to a screening error all results in this study were based on samples from section 2019-1. A sample was removed at every 5 cm interval (following Smith 1997) for a total of 22 samples (total depth of 1.10 m). Samples were bagged and kept cool to retain moisture.

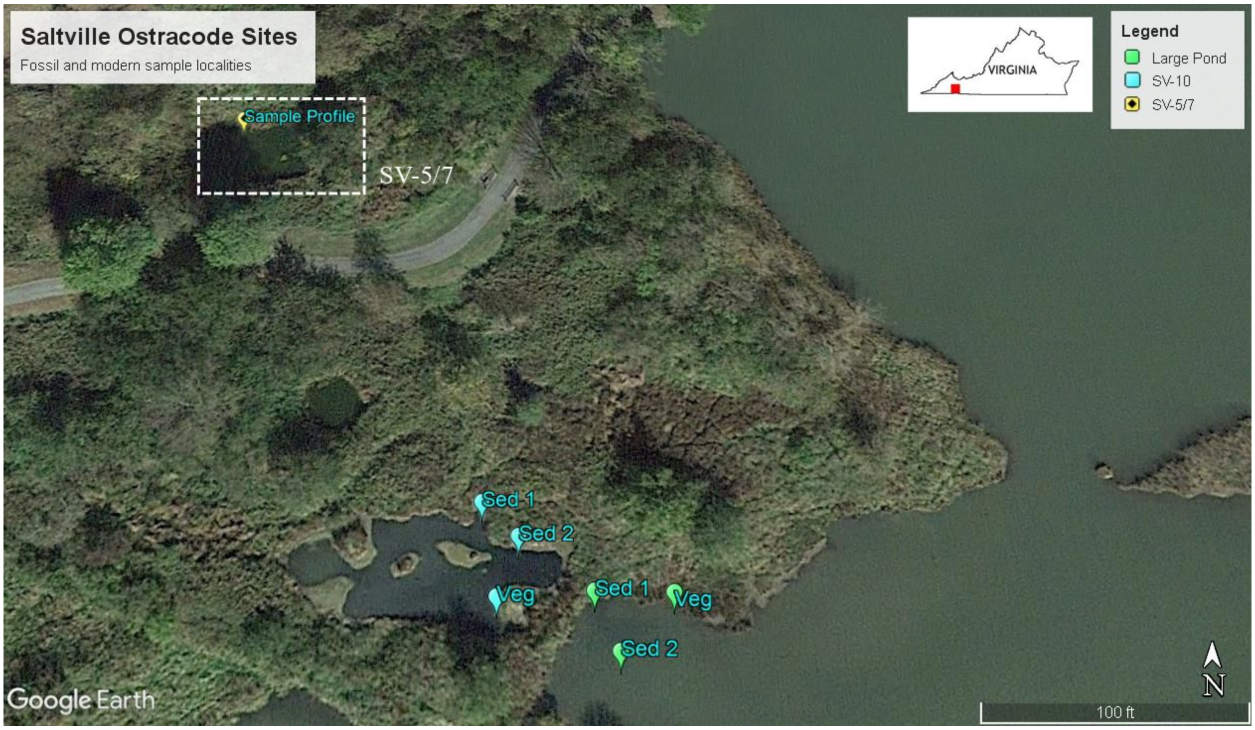

Figure 2: Sample collection sites and relative location of Saltville, VA. Modified from Google Earth satellite imagery (2015).

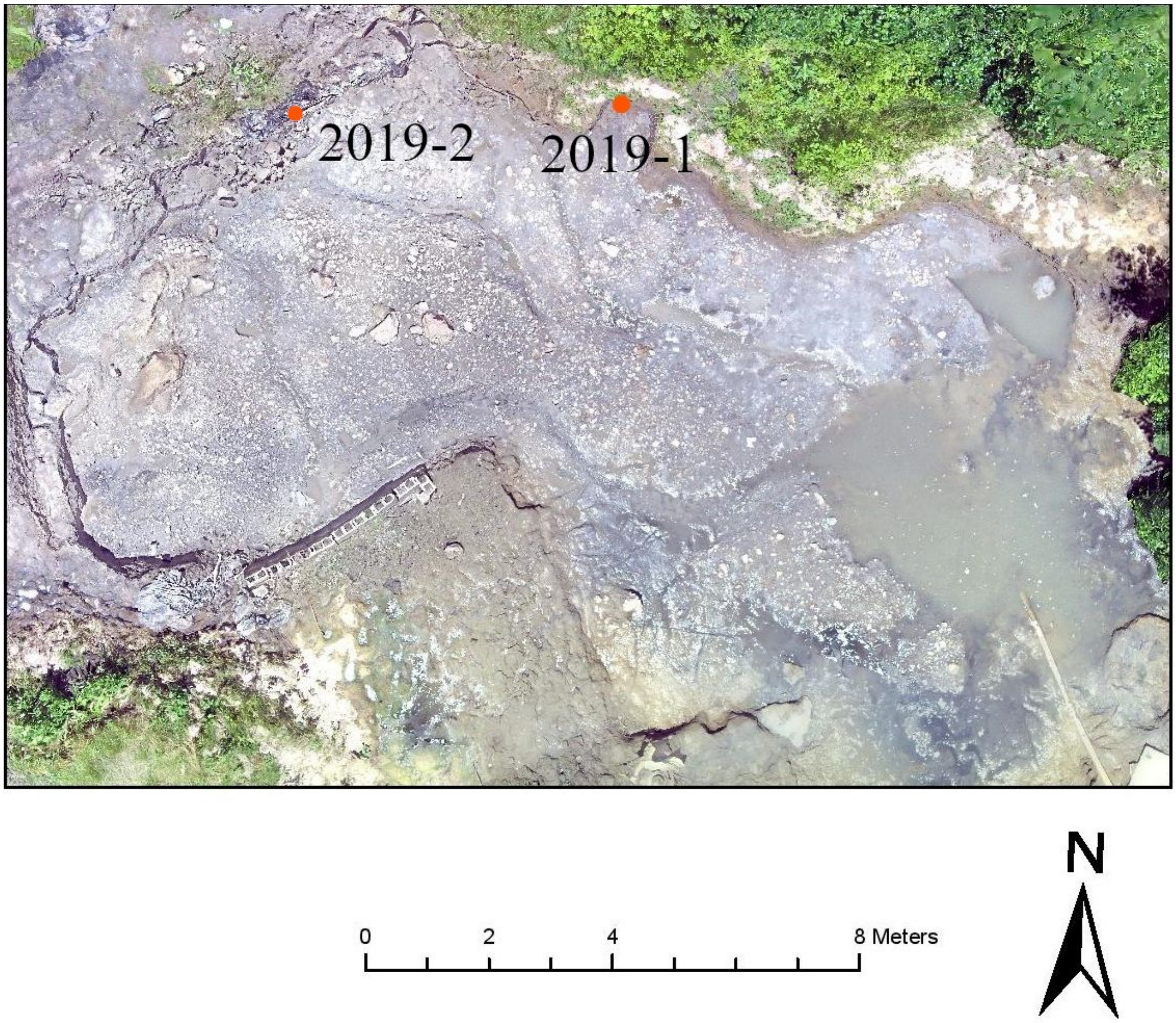

Figure 3: Aerial image of SV-5/7. Red points mark the location of the vertical profiles used in this study. Drone imagery taken by Nathan Shreve.

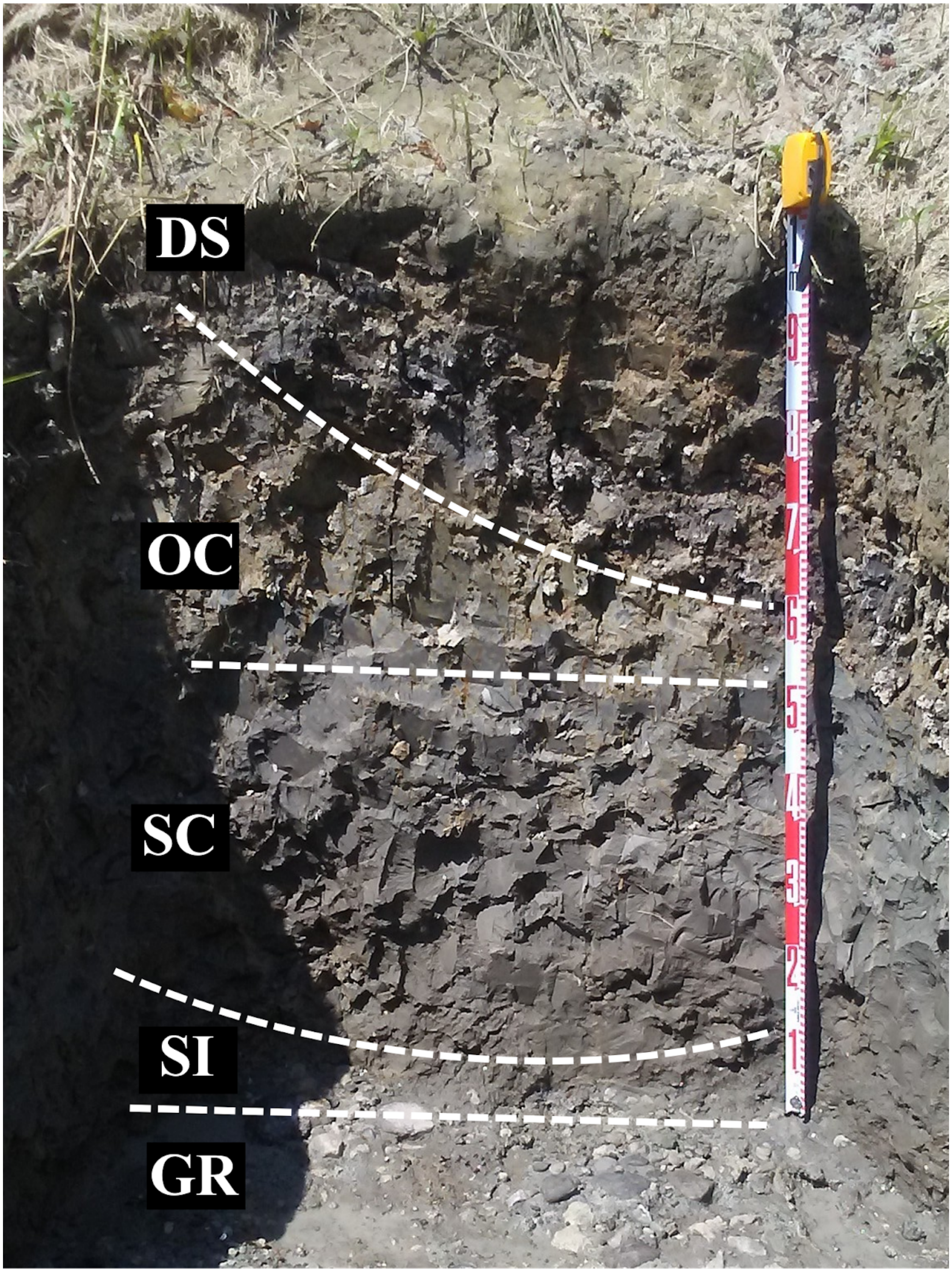

Figure 4: Stratigraphic profile 2019-1 sampled at SV-5/7. Scale 1m. Unit descriptions can be found in the *Sediment Descriptions* section.

Modern Sample Collection

For comparison to sampled fossil assemblages, living or recently deceased ostracodes were collected from neighboring subsite, SV-10, and an adjacent pond (i.e Large Pond locality). Two sediment samples were collected from each locality using an Ekman dredge, at littoral (ca. 0.55 m below water surface) and sublittoral (ca. 1.00 m below water surface) locations (see Figure 2; Delorme 1967; Smith and Delorme 2009). Macrophytes and associated sediment were removed from each site as a third sample (Curry and Filippelli 2010). Samples were placed in containers and kept in a refrigerator to retain moisture.

Sample Processing

Processing samples from the vertical sections followed a procedure developed by Brandon Curry (pers. comm.), modified from Danielpol et al. (2002). A 200g subsample was removed from each sample, with remaining sediment stored for future use. Subsamples were placed into 800 mL beakers and mixed with a tablespoon of sodium bicarbonate and roughly 400 mL of boiling tap water, allowing for the sediment to disaggregate upon cooling (Danielpol et al. 2002; Curry and Delorme 2003). After a day, each sample was washed through a series of geological sieves under a gentle shower (Danielpol et al. 2002). A terminal sieve with 150 µm openings (i.e. Tyler #100) was used to capture all complete adult ostracode valves and many juveniles. Residue was sprayed into petri dishes and allowed to dry in a fume hood. Sieves were cleaned and all remaining residue was removed to prevent contamination. All carapaces and valves, including juveniles, were collected and placed in water for a day to remove most of the sediment or organic matter prior to being mounted to micropaleontological slides using a 00 brush and dilute gum tragacanth as an archival adhesive (Danielpol et al 2002).

For modern samples, a 300g subsample was removed to account for vegetation and water captured along with the sediment. The subsample was then immediately screened using an identical sieve series as the fossil sediment under the same cold, gentle shower. The remaining residue was then placed into petri dishes and immediately picked through to capture living ostracodes, although only valves and recently deceased individuals were found. The residue was then dried in a fume hood and then all remaining valves and carapaces were picked and mounted on micropaleontological slides for identification.

Each sediment sample is to be curated on a unique micropaleontology slide in the ETSU Museum of Natural History (ETMNH) collection at the Gray Fossil Site & Museum in Gray, Tennessee. Each slide will be assigned a catalogue number with additional numbers corresponding to the numbered grid spaces containing mounted specimens. The holotype and paratypes of *Fabaeformiscandona* n. sp. will be stored on a separate slide, each with an individual collection number.

Ostracode Identification and Analysis

Identifications of adult valves and anatomical terminology (Figures 5 and 6) follow descriptions from sources such as the Delorme series (1970a,b,c,d), Lister (1975), Meisch (2000), and Smith and Delorme (2010); other specific identifications are cited in Systematic Paleontology. Species and sex were determined on the basis of adult valve shape, size, gonad traces, and other distinguishing features such as ornamentation. Juveniles were identified to instar stage (e.g. A-1, A-2, A-3) based on valve size, and to family or subfamily based on shape (Moore and Teichert 1969; Meisch 2000; Smith and Delorme 2009).

Each valve and fragment that was complete enough to provide a species identification was counted as a single valve and each complete carapace as two valves. Abundance is given as valves per gram and species diversity as a percentage of the total valves.

Species limitations, ETI's and preferred environments were assigned through specific literature references as well as databases, NACODe (Curry et al. 2012) and NEOTOMA (Williams, Grimms et al. 2008). See Species Autecology in the Systematic Paleontology section for specific sources.

Developed by Horne (2007), the Mutual Ostracode Temperature Range (MOTR) is a method of estimating past air temperatures through the use of ostracode climatic tolerances. MOTR has been used to find potential MAT and annual extremes for past assemblages. The temperature range is then estimated by the presence of certain species of ostracodes and set by the fauna's temperature tolerances, which have been recorded at modern ostracode locations. Generally, the range is determined by the highest minimum temperature and lowest maximum temperature which have been recorded amongst the fauna, emphasizing the most environmentally sensitive species. Horne (2007) suggests that this method should also produce reliable values for water chemistry and precipitation.

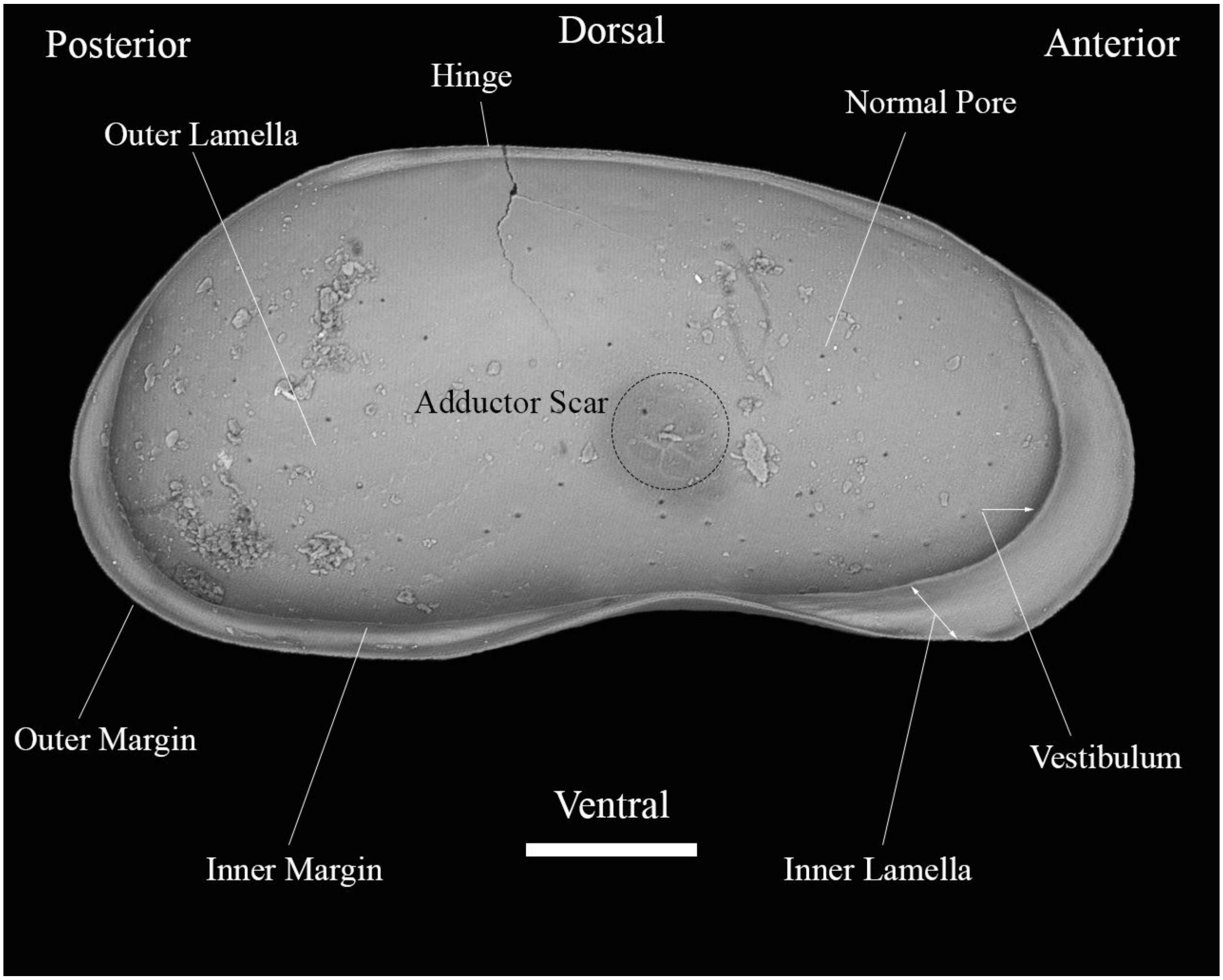

Figure 5: Example of internal shell morphology of an adult male, *Fabaeformiscandona* n. sp. left valve (LV) with labeled structures. Scale bar = 200μm

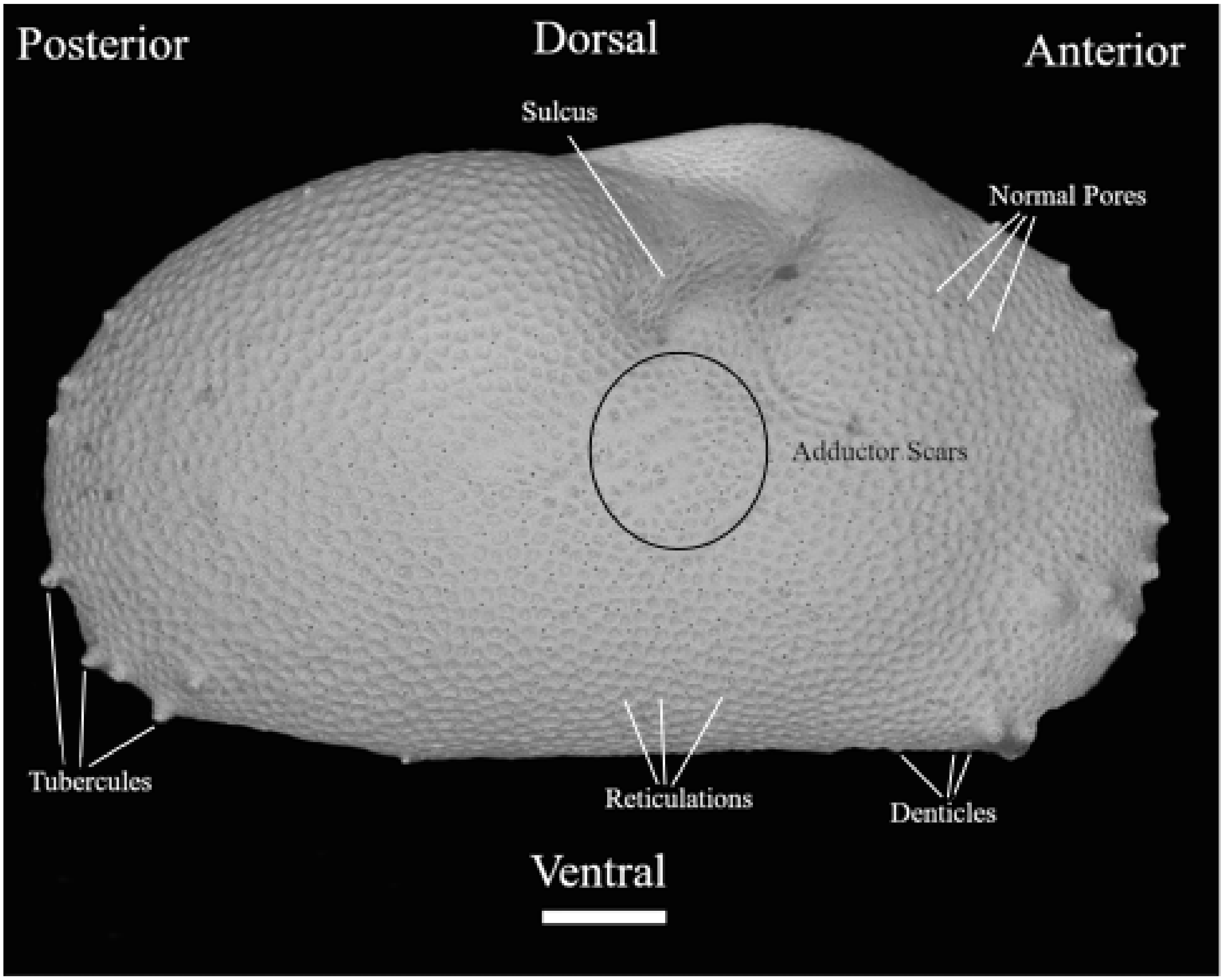

Figure 6: Example of external morphology of adult *Pelocypris tuberculatum* right valve (RV) with labeled structures, ornamentation and orientation. Note: a sulcus refers to a dorsolateral groove, e.g. this individual has two sulci and the posterior sulcus is identified. Scale bar = 200μm

CHAPTER 3

SYSTEMATIC PALEONTOLOGY

Class **Ostracoda** Latreille 1802

Order **Podocopida** Sars 1866

Suborder **Podocopina** Sars 1866

Infraorder **Darwinulocopina** Sohn 1988

Superfamily **Darwinuloidea** Brady and Norman 1889

Family **Darwinulidae** Brady and Norman 1889

Genus ***Darwinula*** Brady and Robertson 1885

Diagnosis — Elongated and ovate in lateral view with greatest height posterior of midline. Dorsal margin broadly arched and ventral margin weakly concave. Anterior margin is pointed and posterior margin is blunt. The right valve slightly overlaps the left valve ventrally. Adductor muscle scars are in a rosette pattern anterior of midline. Parthenogenetic genus; no sexual dimorphism. (Lister 1975; Meisch 2000)

Darwinula stevensoni (Brady and Robertson 1870)

Description — Adductor scars form rosette pattern, anterior of midline. Elongated ovate valves with greatest height posteriorly in lateral view. Dorsal margin is broadly convex, ventral margin is weakly concave to straight. Anterior end is strongly pointed; posterior end is broadly rounded. Valves are smooth with normal pores present throughout the valve. Thin inner lamellae with no medial expansion.

Dimensions — Measurements from Delorme (1970d)

Female RV: 0.79 (L) x 0.30 (H) mm

Female LV: 0.76 (L) x 0.33 (H) mm

Occurrences — Two left valves and one full carapace were found in the modern Large Pond sample. Total = 4 modern

Autecology — Cosmopolitan; found in most types of nonmarine habitats, including ponds, slow streams, and lakes (Meisch 2000; Smith and Delorme 2010).

Infraorder **Cypridocopina** Jones, 1901

Superfamily **Cypridoidea** Baird 1845

Family **Candonidae** Kaufmann, 1900

Subfamily **Candoninae** Kaufmann 1900

Genus ***Candona*** s. str. Baird 1845

Diagnosis — Generally reniform or subtriangular in lateral view with greatest height two-thirds the length of the valve, posteriorly. Posterodorsal margin is usually steeper and more pointed than anterodorsal margin. Elliptical in dorsal view with greatest width near midline. Adductor scars are usually located centrally with five scars located closely in radial pattern with an elongate scar located dorsally. Valves are generally smooth with few normal pores. Sexual dimorphism is usually pronounced. It is necessary to note that many species in *Candona* have been reassigned to *Fabaeformiscandona* due to a difference in mandibular palp morphology, but nonetheless the two genera share a very similar (if not identical) valve morphology. (Lister 1975; Smith and Delorme 2010)

Candona crogmaniana Turner 1894

Figure 7

Description — Subquadratic valves with greatest height posterior to midline in lateral view. Dorsal edge is strongly convex with a steep posterodorsal edge in females; ventral margin is moderately concave. Anterior end is broadly rounded; posterior end is strongly pointed in females and narrowly rounded in males. Valves are smooth with few normal pores throughout. Wide anterior inner lamella. (Figure 7)

Dimensions — Measurement as *Candona cf. C. crogmaniana* from Delorme (1970c)

Male LV: 1.58 (L) x 0.79 (H) mm

Occurrences — Present in DS unit and then absent for the remainder of the samples; absent in modern. Total = 14 fossil

Autecology — Commonly found in temporary ponds as well as springs and lakes; often located in warmer regions of North America. (Figure 8; Lister 1975; Smith and Delorme 2010)

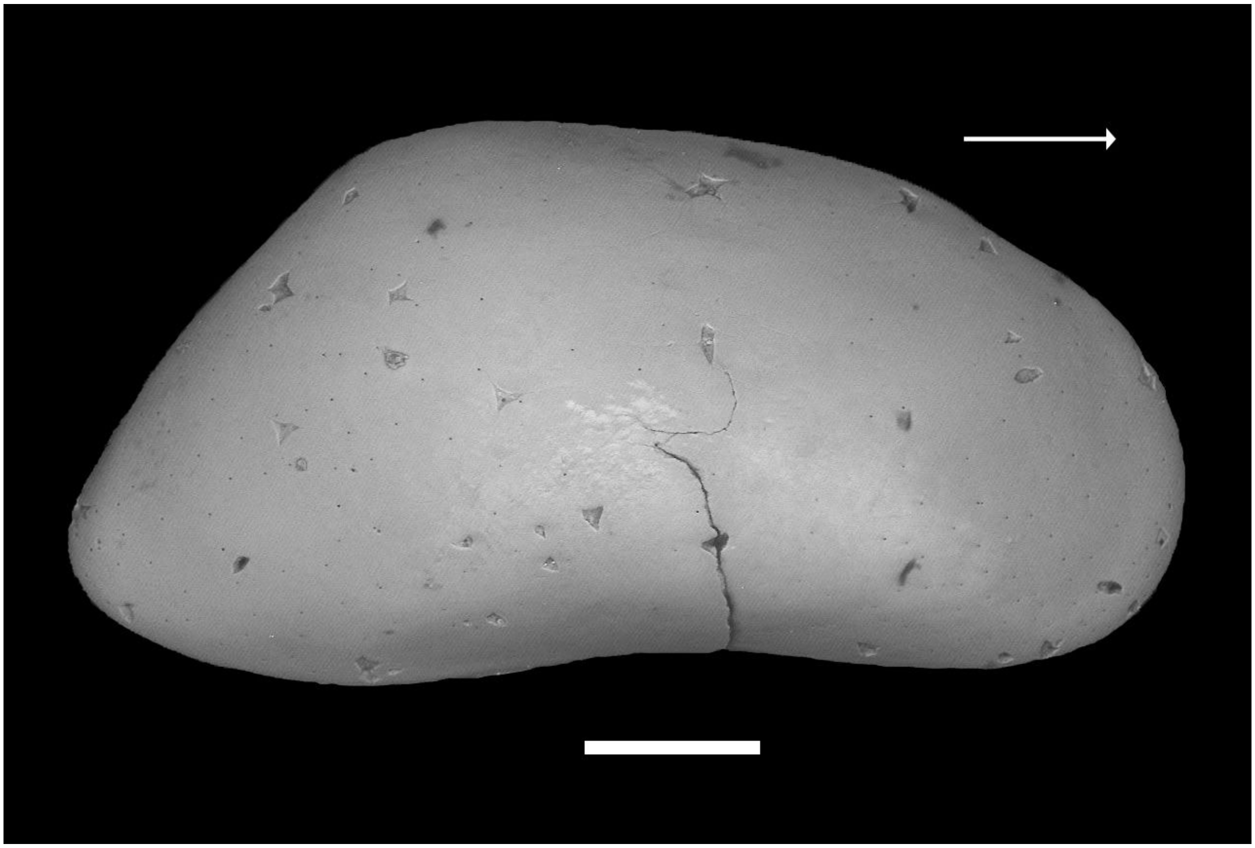

Figure 7: *Candona crogmaniana*. Female right valve, lateral external view, scale bar = 200 µm.

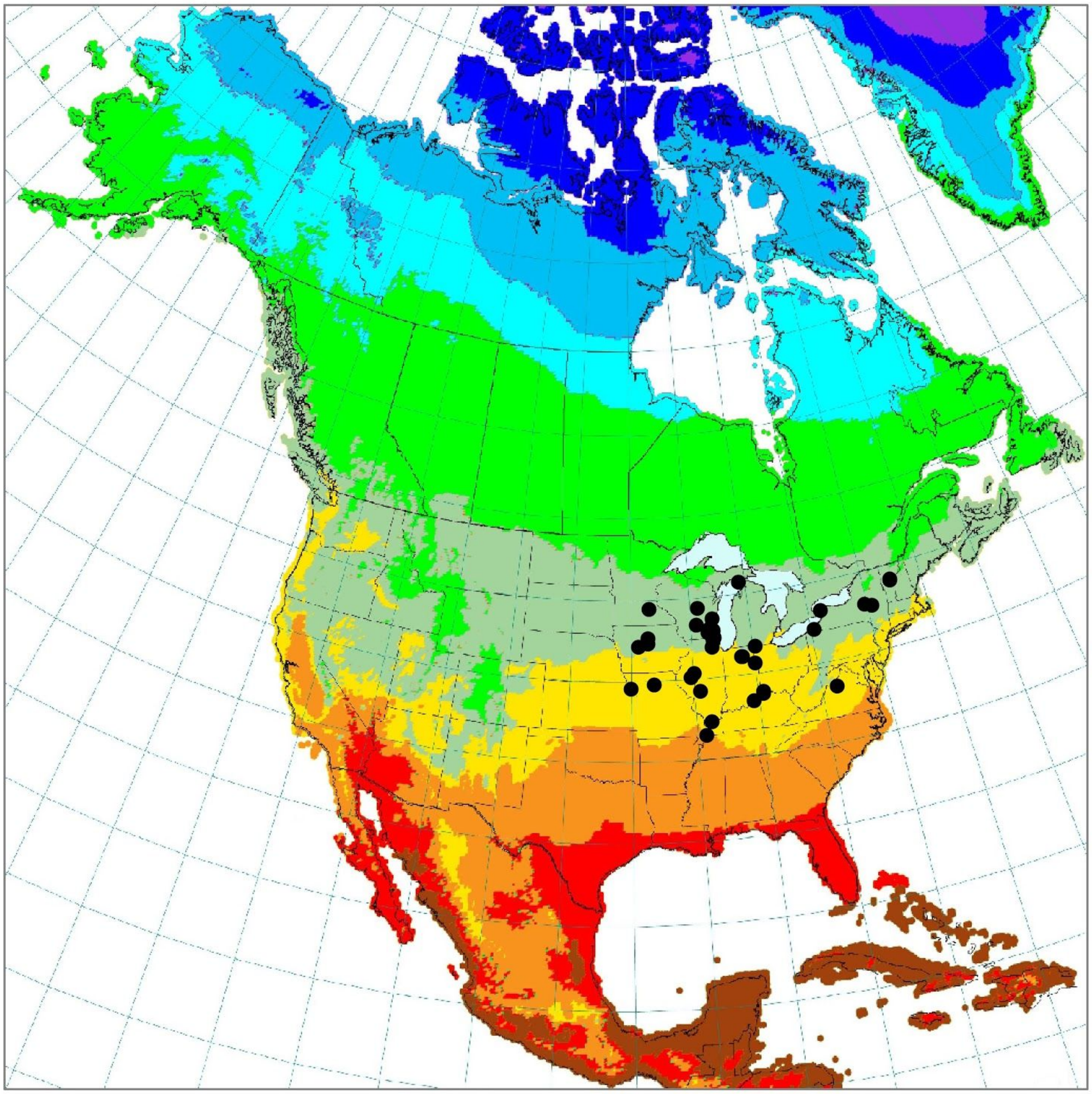

Figure 8: NACODe sites with *Candona crogmaniana*. The 50th most common ostracode in North America (Curry et al. 2012)

Genus ***Fabaeformiscandona*** Krstić 1972

Diagnosis — Aside from the number of setae on the mandibular palp, the differences in morphology between *Fabaeformiscandona* and *Candona* are negligible, especially in valve morphology. Without soft body material this species could belong to either genus.

***Fabaeformiscandona* n. sp.**

Figures 9 and 10

Taxonomic Diagnosis — This taxon was originally likened to *Candona ohioensis* but due to its smaller size and the unique shape of the female's posterior left valve, this new species likely belongs to the genus *Fabaeformiscandona* and the *F. fabaeformis* species-group due to its similarity in valve morphology. The primary distinguishing feature of this species, in regards to female valves, from the rest of the genus is its very broad and non-arching dorsal margin. The overall shape of the valve is much more narrow and less sloping than other members of the genus (e.g. *F. acuminata*, *F. fabaeformis*, *F. holtzkampfi*, *F. wegelini*). The squared posterior end is seen in other members of the genus but lacks any posterior projections as seen in *F. caudata* and *F. rawsoni* (Meisch 2000; Smith and Delorme 2009). In dorsal view, the left valve has a posterior overlapping hinge point much like many other members of the *F. fabaeformis* species-group but lacks a posterior flange like the similarly shaped *F. holtzkampfi*. The posterior inner lamellae of the valves are generally wider than the anterior; the ventral portion of the inner lamellae is similar in thickness to *F. subacuta* but lacks any medial projection (Escruva et al. 2012). The valves of males are much less distinguishable but can be separated from other species based on the weakly arched dorsal margin; the greatest height of the valve is much further posterior than other males of the genus (Meisch 2000; Smith and Delorme 2009).

Description — Valves are generally narrow overall with little change in height in lateral view; greatest height, although not easily discernible, is far posterior from midline. Left valve is greater in size and overlaps right valve; a projection is seen in female carapaces on the posterodorsal portion of the left hinge. Dorsal margin is weakly convex to near linear, but gradually dips on the posterior end of the female right valve. Ventral margin is weakly concave; left valve of the male has a ventrally pointed projection on the anterior-most portion of the venter. Anterior end is broadly rounded and generally non-diagnostic. The posterior end is broadly rounded to weakly pointed in males. Left valve of females gently dips dorsally to a strongly squared end; right valve has a more sloped margin and pointed end but generally squared. Normal pores are few and no exterior ornamentation is present. Inner lamellae are thick and wide, especially on the ventral margin of the posterior lamella.

Dimensions — All measurements taken by B. Brandon Curry and recorded as averages.

Female RV: 1.06 (L) x 0.46 (H) mm

Female LV: 1.06 (L) x 0.46 (H) mm

Male RV: 1.18 (L) x 0.58 (H) mm

Male LV: 1.24 (L) x 0.59 (H) mm

A-1 RV: 0.64 (L) x 0.28 (H) mm

A-1 LV: 0.65 (L) x 0.28 (H) mm

Occurrences — Valves and full carapaces are found within each unit and relatively large numbers in the SC and SI units, suggesting that this species has been endemic to the area during the entire depositional period; a male and a female valve were found in a modern sample with no associated soft tissue. Total = 452 fossil, 2 modern

Autecology — The majority of *Fabaeformiscandona* and *Candona* prefers shallow waters, especially temporary and permanent pools, swamps, and littoral zones of lakes. Some species have been found in deeper, lotic and some hypogean habitats, but are generally the exception (Meisch 2000).

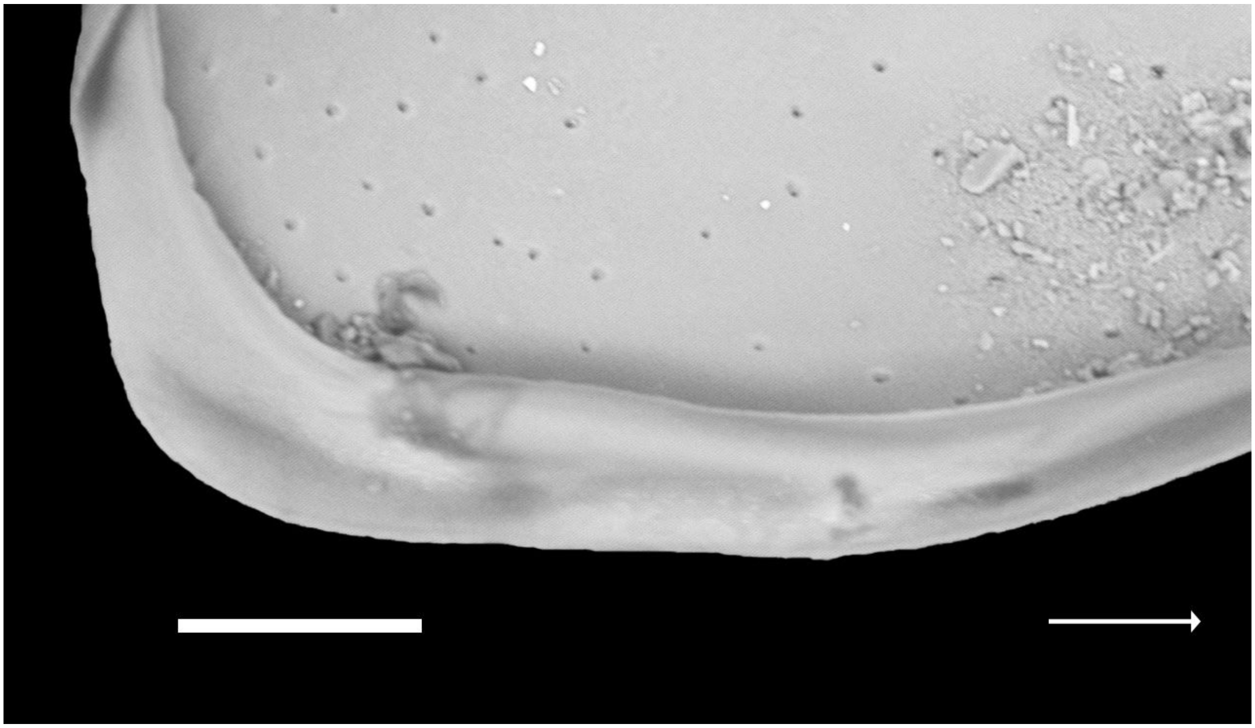

Figure 9: Detail of posteroventral inner lamella of female left valve of *Fabaeformiscandona* n. sp. Note lack of dorsal projection, as seen in *F. subacuta* (Escrivà et al. 2012). Scale = 100µm

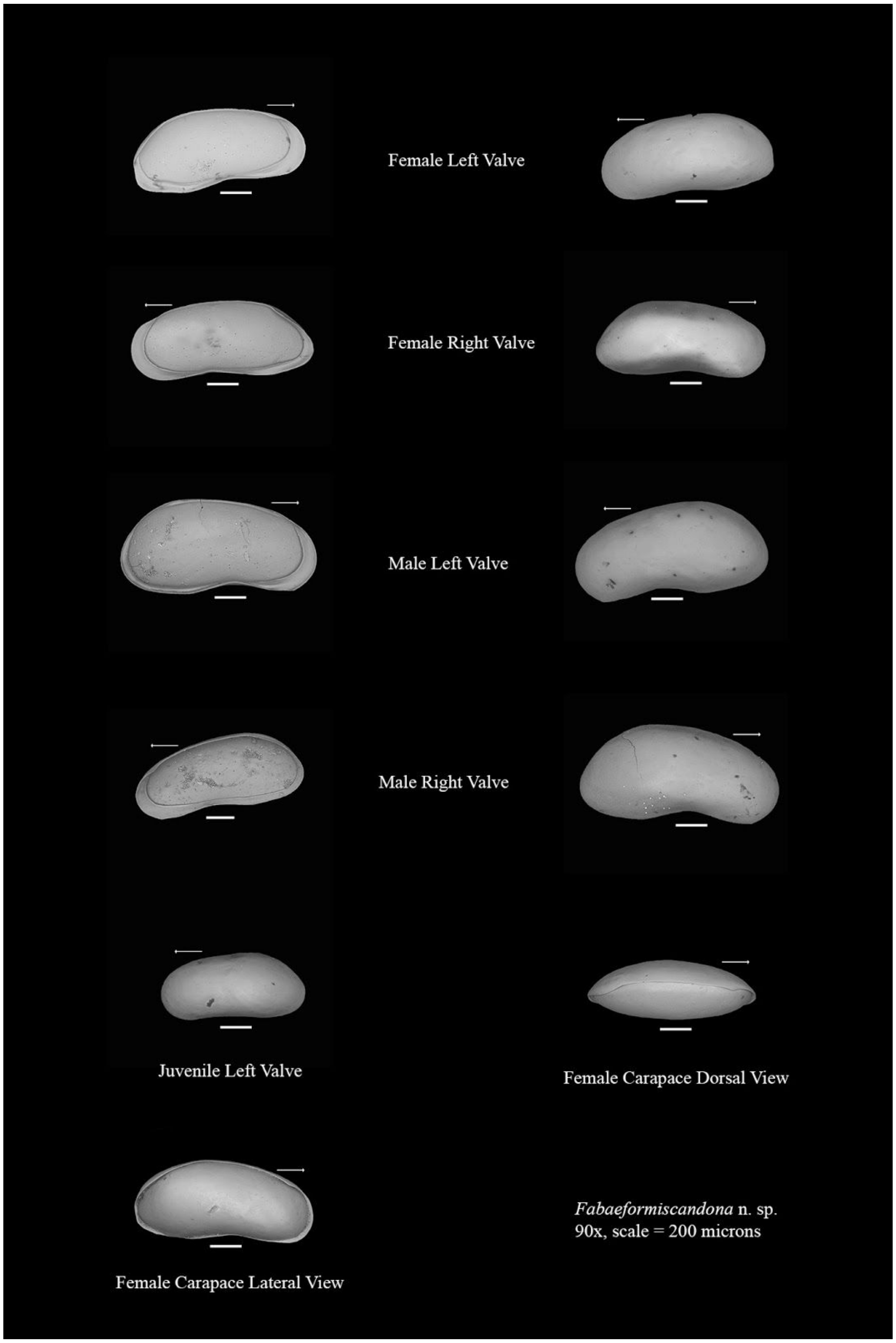

Figure 10: *Fabaeformiscandona* n. sp. diversity. All images at the same scale. Note: The image of the male right valve in concave-up orientation was taken while the valve was askew and will be corrected for future publications.

Subfamily **Cyclocypridinae** Kaufmann, 1900

Genus ***Physocypria*** Vávra 1897

Diagnosis — Valves are semicircular in lateral view with greatest height medially. Carapace is elliptical in the dorsal view. Dorsal margin is broadly arched and ventral margin is weakly concave. Inner lamellae are thin and narrow. Valves are usually smooth or moderately punctate (i.e. containing studs and dimples) with few normal pores. Denticles are present on the anterior of the right valve. Adductor muscle scars are typically centrally located with a column of four anterior scars and a column of two posterior scars. (Lister 1975; Smith and Delorme 2009)

Physocypria pustulosa Sharpe 1897

Figure 11

Description — Semicircular or ovate valves with greatest height at or directly posterior to midline, in lateral view. Left valve largely overlaps right valve dorsally and anteriorly. Dorsal edge is broadly convex; ventral margin is weakly concave on the right valve and weakly convex to straight on left valve. Anterior end is broadly rounded but less so than the posterior end. Valves are smooth with few normal pores; small denticles are present on anterior end of the right valve. (Figure 11)

Dimensions — Measurements from Delorme (1970b)

RV: 0.59 (L) x 0.41 (H) mm

LV: 0.64 (L) x 0.48 (H) mm

Occurrences — Uncommon in the majority of the column, found in SC and SI units; absent in modern. Total = 14 fossil

Autecology — Cosmopolitan; shallow water habitats; often found residing among subaquatic plants. (Figure 12; Smith and Delorme 2009)

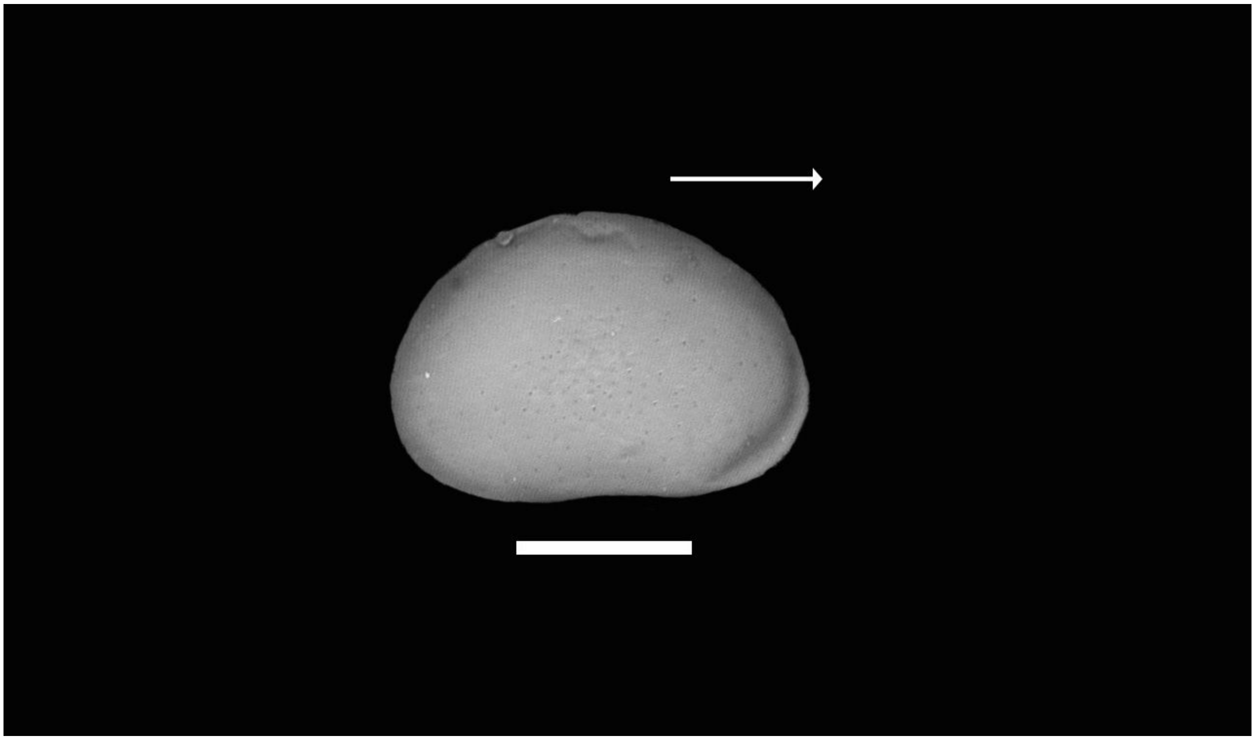

Figure 11: *Physocypria pustulosa*. Right valve, lateral external view, scale bar = 200 µm. Denticles not visible in this image.

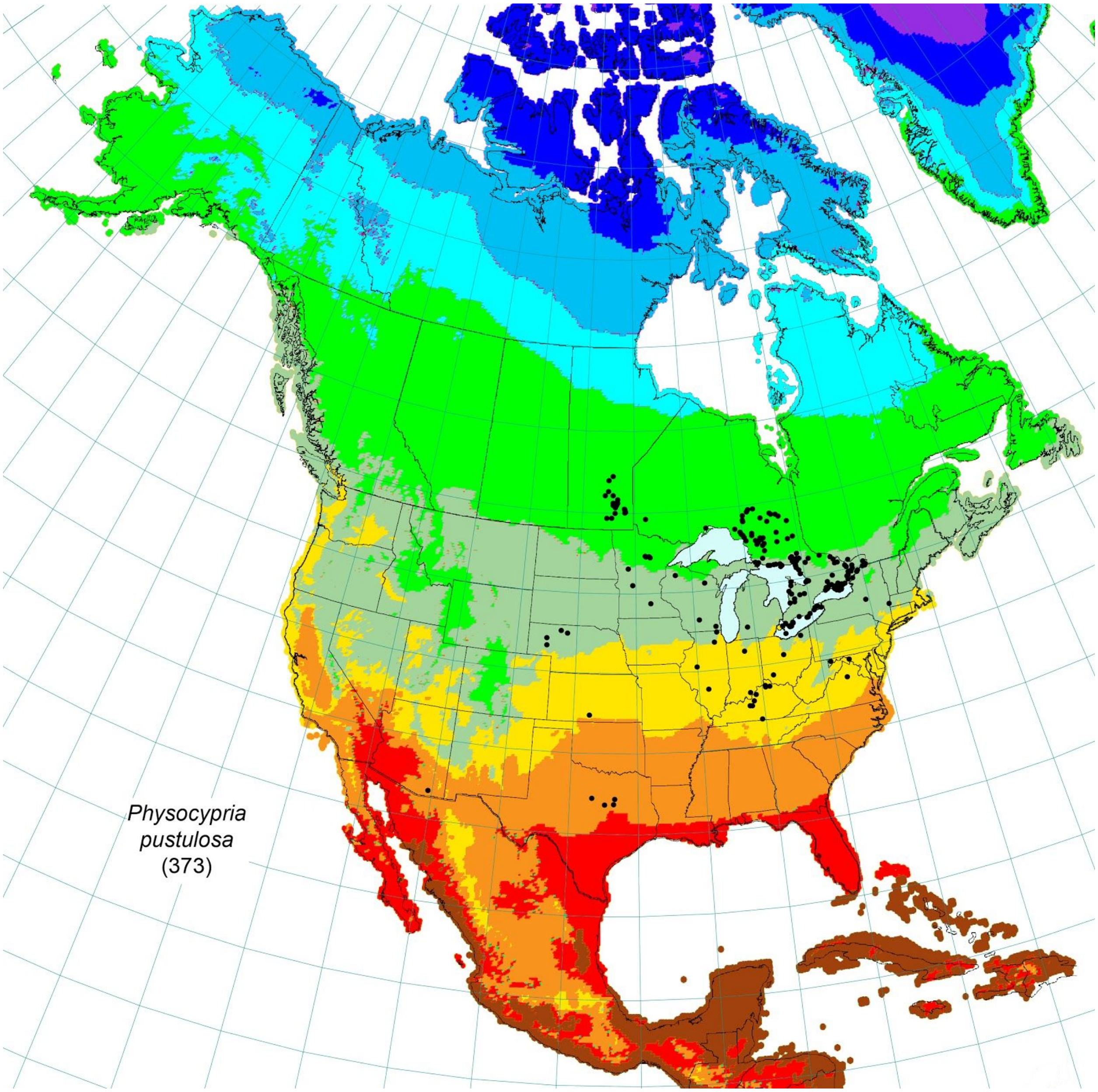

Figure 12: NACODe sites with *Physocypria pustulosa*. The 12th most common ostracode in North America (Curry et al. 2012)

Family **Cyprididae** Baird, 1845

Subfamily **Cypridopsinae** Kaufmann, 1900

Genus ***Cypridopsis*** Brady 1867

Diagnosis — Valve shape variable in side view, generally subovate to subreniform. Carapace is subovate in dorsal view, inflated medially. Left valve is longer than and overlaps the right valve. Inner lamellae typically wide, especially in anterior. Valves are smooth or punctate with many normal pores. Central muscle scars are located centrally with a column of four scars decreasing in size ventrally and two scars posterior. Parthenogenetic genus; no sexual dimorphism. (Delorme 1970b; Lister 1975)

Cypridopsis vidua (O.F. Müller 1776)

Figure 13

Description — Subreniform to subtriangular valves, in lateral view with greatest height medially. Dorsal margin is pointed at apex; ventral margin is straight to weakly concave. Anterior and posterior ends are similar with rounded and blunt. Carapace is ovate in dorsal view, widest medially. Carapace has pitted texture with numerous normal pores. (Figure 13)

Dimensions — Measurements from Delorme (1970b)

RV: 0.86 (L) x 0.56 (H) mm

LV: 0.86 (L) x 0.56 (H) mm

Occurrences — Very common in the DS unit, then uncommon in lower units, eventually disappearing in the OC unit and appearing briefly in the SI unit. Modern specimens are common in the Large Pond samples and few in SV-10. Juveniles are as common as adults but not included in total. Total = 295 fossil, 34 modern

Autecology — Cosmopolitan; swimming species; found in a wide variety of aquatic habitats and variable saline states; sensitive to low-O waters; most common ostracode in North America (Figure 14; Delorme 1970b; Lister 1975; Meisch 2000).

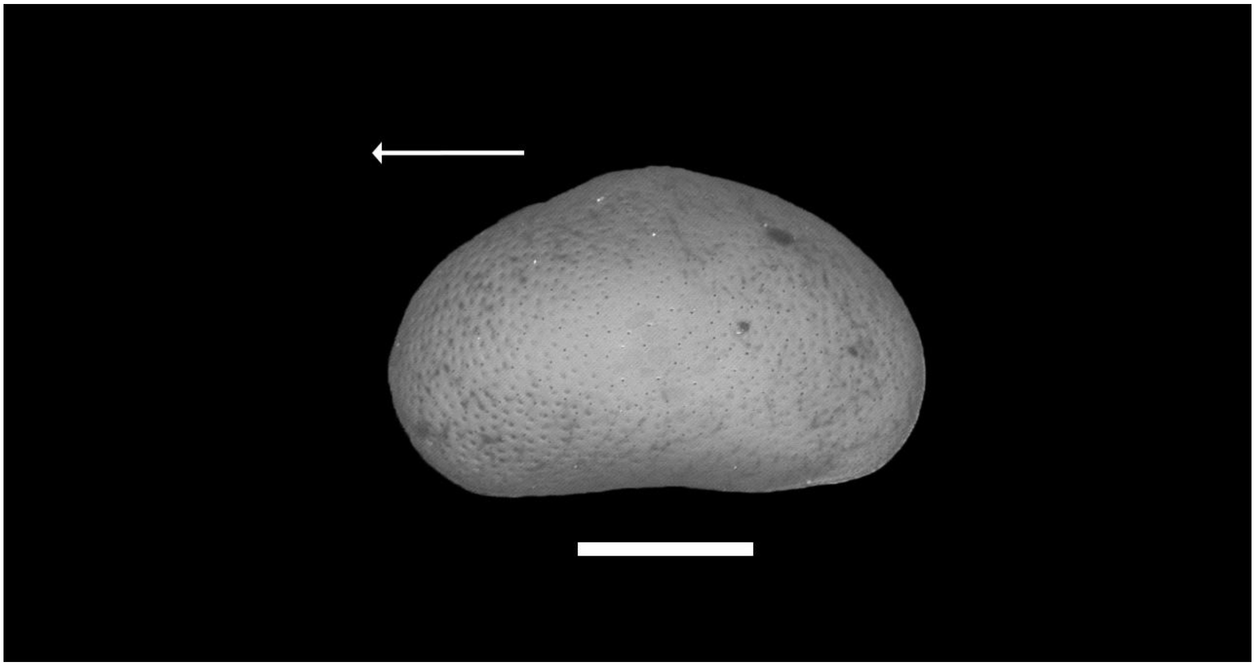

Figure 13: *Cypridopsis vidua*. Left valve, lateral external view, scale bar = 200 µm.

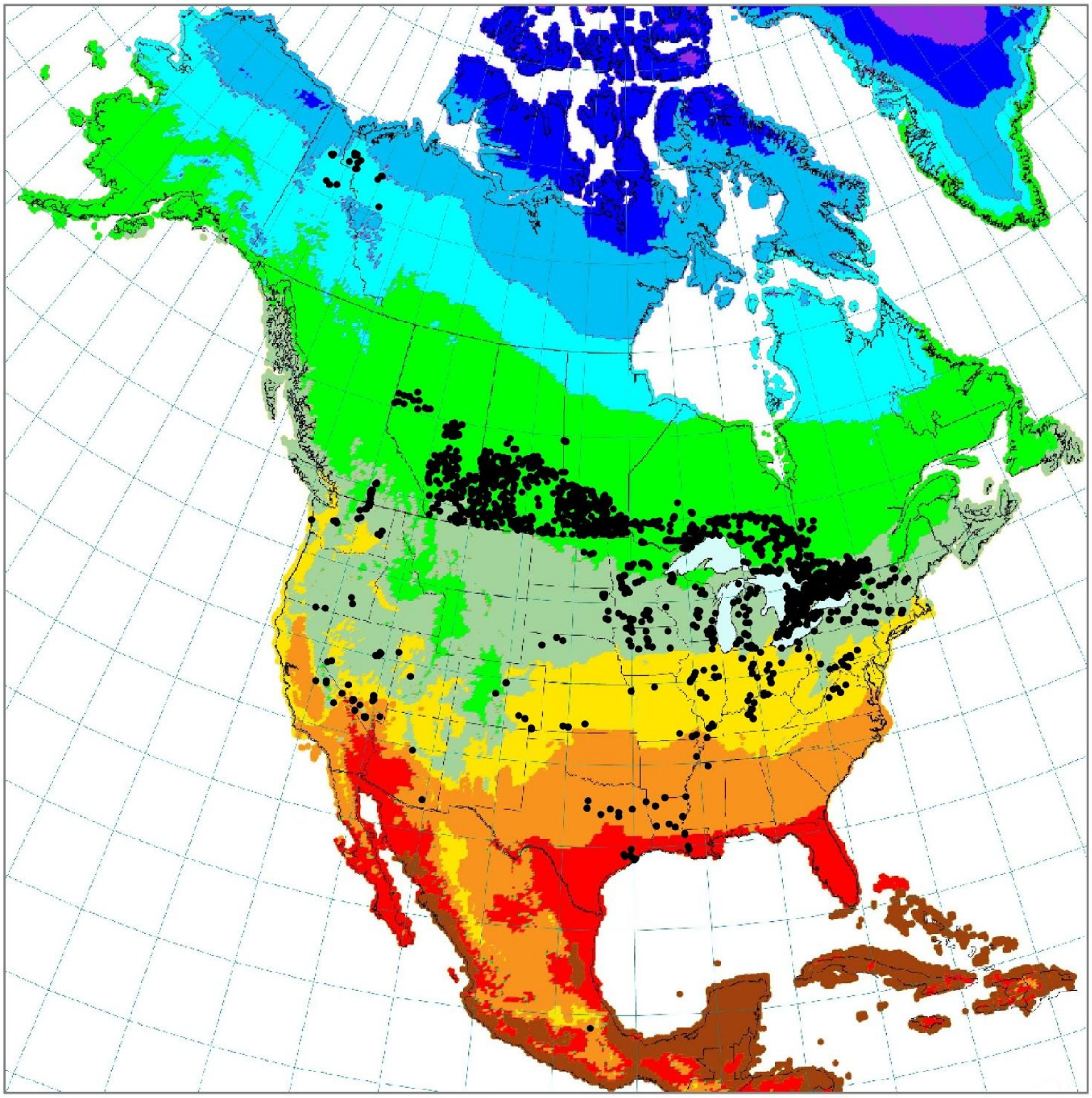

Figure 14: NACODe sites containing *Cypridopsis vidua*. The most common ostracode in North America (Curry et al. 2012).

Genus ***Potamocypris*** Brady 1870

Diagnosis — Crescent shaped valves in lateral view with greatest height anterior of midline. Left and right valves are asymmetrical and generally extend past each other. Carapace is laterally compressed in elliptical shape. Inner lamellae are variable among species but are typically wider anteriorly. Adductor scars are elongated and orientated diagonally. Sexual dimorphism is negligible, despite males being present in some populations (Lister 1975; Meisch 2000).

Potamocypris smaragdina (Vávra 1891)

Figure 15

Description — Crescent shaped valves in lateral view, that generally have large overlap of corresponding valves; greatest height is posterior of midline. Dorsal margin is broadly rounded; ventral margin is strongly concave. Anterior end is orientated ventrally and is narrowly pointed; posterior end is broadly rounded and less ventrally orientated. (Figure 15)

Dimensions — Measurements from Delorme (1970b)

RV: 0.68 (L) x 0.41 (H)

LV: 0.71 (L) x 0.40 (H)

Occurrences — Rare throughout vertical section, some adult valves are found in SC and SI units; absent in modern. Total = 7 fossil

Autecology — Found in littoral zones of permanent waters, particularly lakes, ponds and slow streams (Meisch, 2000). Can possibly reside in temporary waters due to desiccation resistant eggs, but mostly unreported from temporary sites (Figure 16; Meisch 2000).

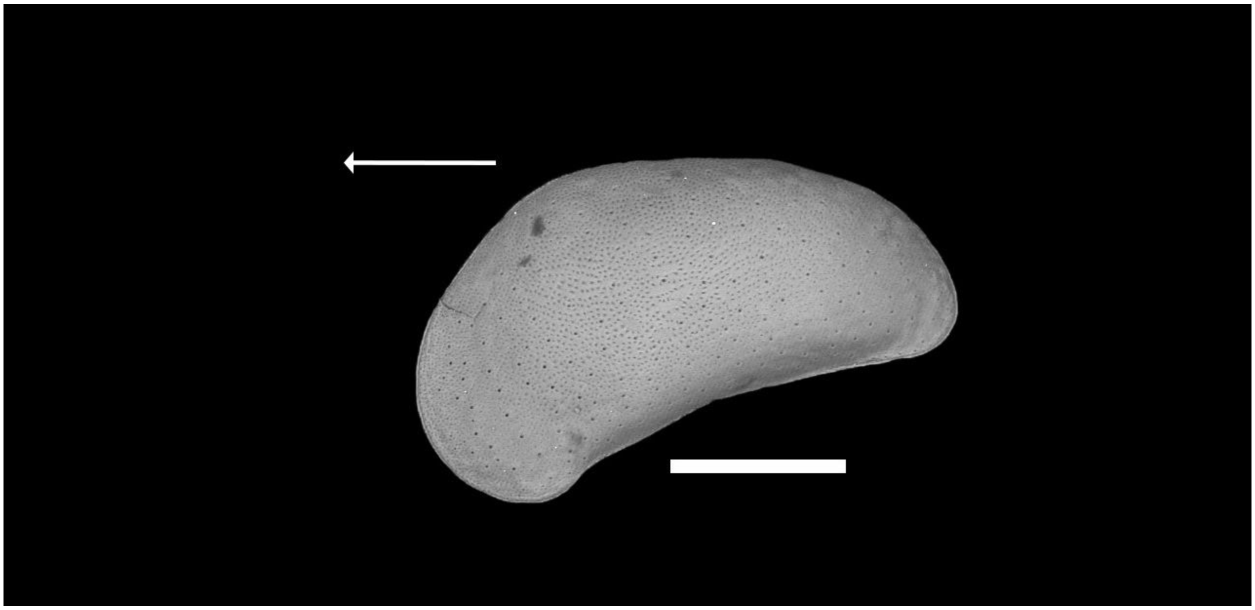

Figure 15: *Potamocypris smaragdina*. Right valve, lateral external view, scale bar = 200 µm.

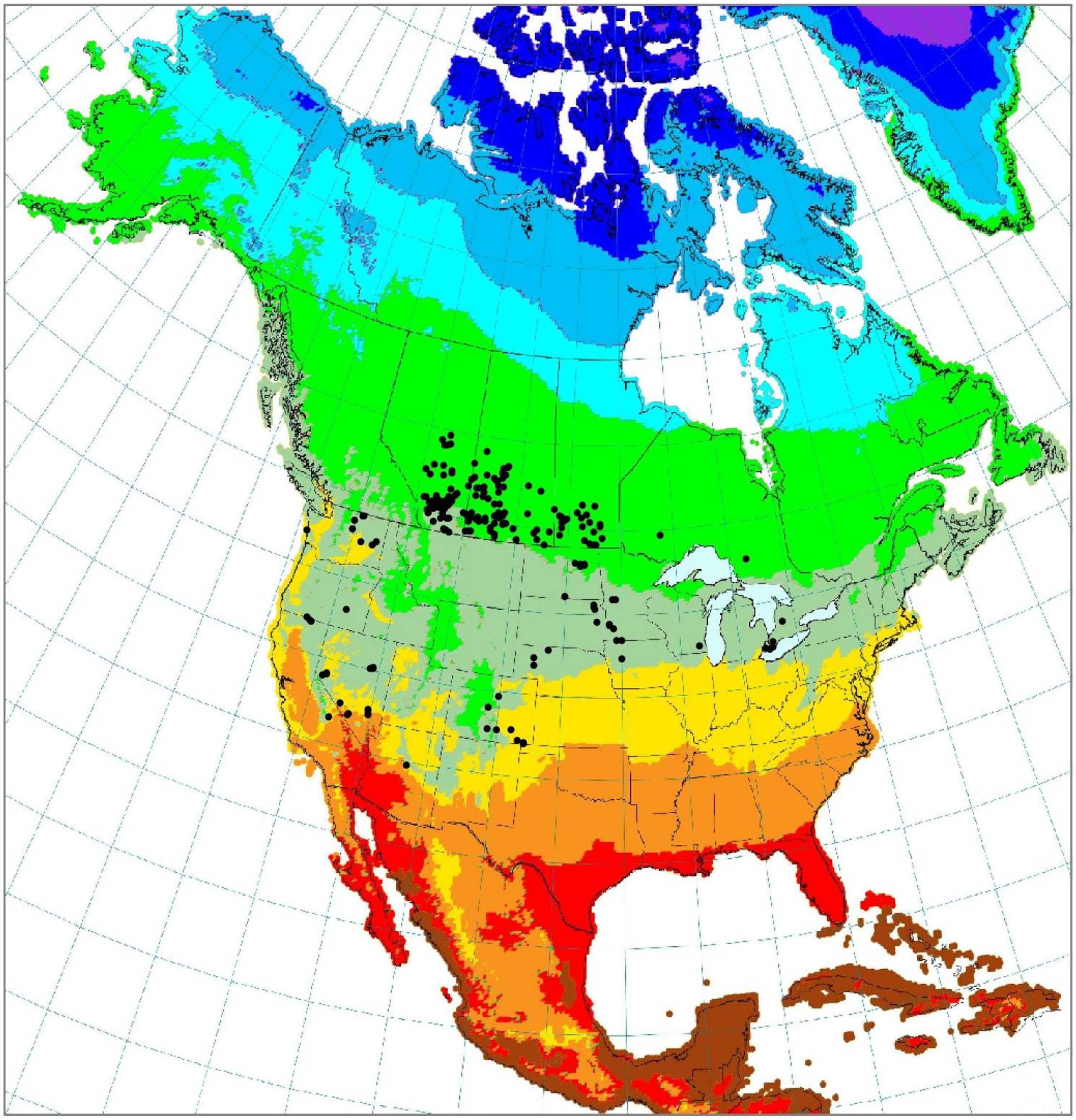

Figure 16: NACODe sites containing *Potamocypris smaragdina*. The 16th most common ostracode in North America (Curry et al. 2012)

Subfamily **Cyprinotinae** Bronshtein 1947

Genus ***Heterocypris*** Claus 1892

Diagnosis ― Valves are subovate and stout in lateral view with greatest height medially. Right valve is generally smaller and is overlapped by the left valve ventrally. Right valve lacks a dorsal hump, characterized by *Cyprinotus*. Denticles present along posteroventral edge of right valve (Meisch 2000; Smith and Delorme 2009)

Heterocypris incongruens (Ramdohr 1808)

Description — Ovate valves in lateral view with greatest height at or slightly anterior to midline. Dorsal margin is broadly convex; ventral margin is straight. Anterior end is rounded and blunt; posterior end is broadly pointed. Anterior inner lamella is wide. Valve is smooth with few normal pores.

Dimensions — Measurements as *Cyprinotus incongruens* from Delorme (1970a)

Female RV: 1.02 (L) x 0.63 (H) mm

Female LV: 1.04 (L) x 0.64 (H) mm

Occurrences — Six were found in the modern SV-10 pond and five in the Large Pond; absent in vertical column. Total = 13 modern

Autecology — Often found in shallow temporary pools; tolerant of moderate saline and low oxygen-content waters (e.g. eutrophic); generally prefers clay dominant substrates with few macrophytes (Meisch 2000).

Family **Ilyocyprididae** Kaufmann 1900

Subfamily **Ilyocypridinae** Kaufmann 1900

Genus ***Ilyocypris*** Brady and Norman 1889

Diagnosis — Valves with two sulci and subrectangular in lateral view with greatest height anteriorly. Valves are punctate and occasionally have marginal projections (i.e. alae).

Central muscle scars are located within posterior sulcus, comprising a column of four scars and one anterior scar. Sexual dimorphism is minimal (Lister 1975; Meisch 2000).

Ilyocypris gibba (Ramdohr 1808)

Figure 17

Description — Subrectangular valves in lateral view with two sulci. Valves are deeply punctate and have small tubercles on lateral edges. Dorsal margin is straight; ventral margin concaves between sulci but otherwise, is straight. Carapace is subovate in a dorsal view with greatest width near the posterior end. No projections seen in dorsal view. (Figure 17)

Remarks — The small tubercules are diagnostic in this case as the genus is highly variable and often shows morphological overlap between species (Mazzini et al. 2014). The tubercules are a diagnostic feature between *I. gibba*, which may or not have tubercles, and *I. bradyi*, which never features tubercules (Delorme 1970d; Mazzini et al. 2014).

Dimensions — Measurements from Delorme (1970d)

Female RV: 0.86 (L) x 0.48 (H) mm

Female LV: 0.79 (L) x 0.46 (H) mm

Occurrences — Only few valves found in DS and SC units; single valve found in SV-10 pond.

Total = 8 fossil, 1 modern

Autecology — Typically found in small, shallow permanent bodies of water, usually with clay or fine sediment substrates. In Europe, occasionally found in slightly saline waters as well as temporary ponds, springs and creeks (Figure 18; Meisch 2000). In Illinois and elsewhere in North America, this species is common in rivers and streams (Curry 1999; Smith and Delorme 2009).

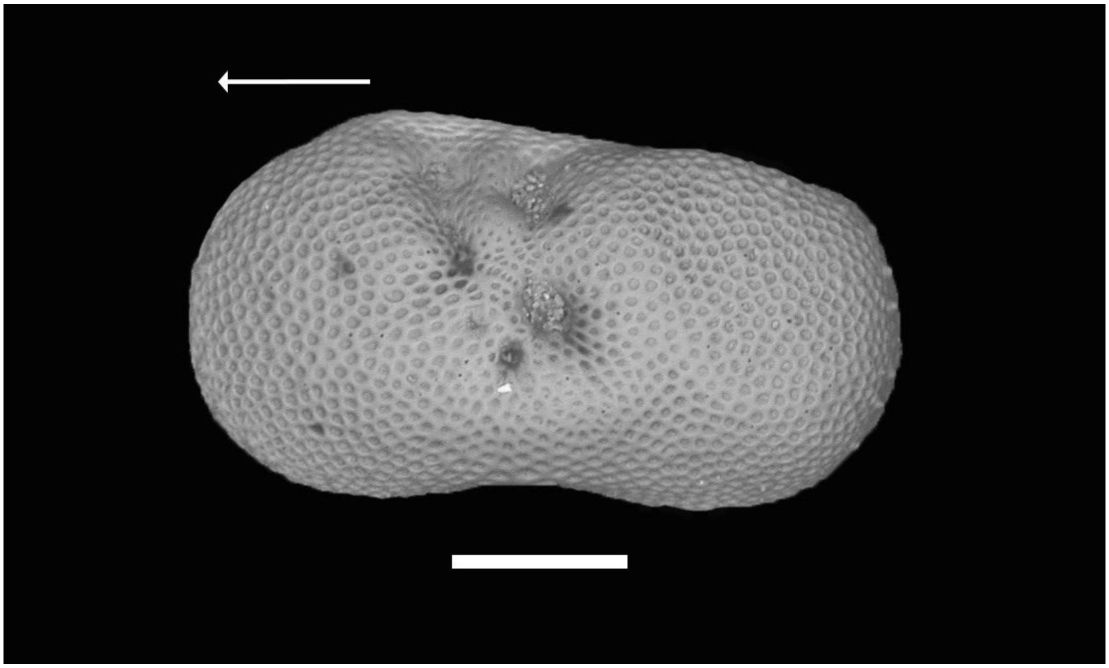

Figure 17: *Ilyocypris gibba*. Left valve, lateral external view, 90x, scale bar = 200 µm.

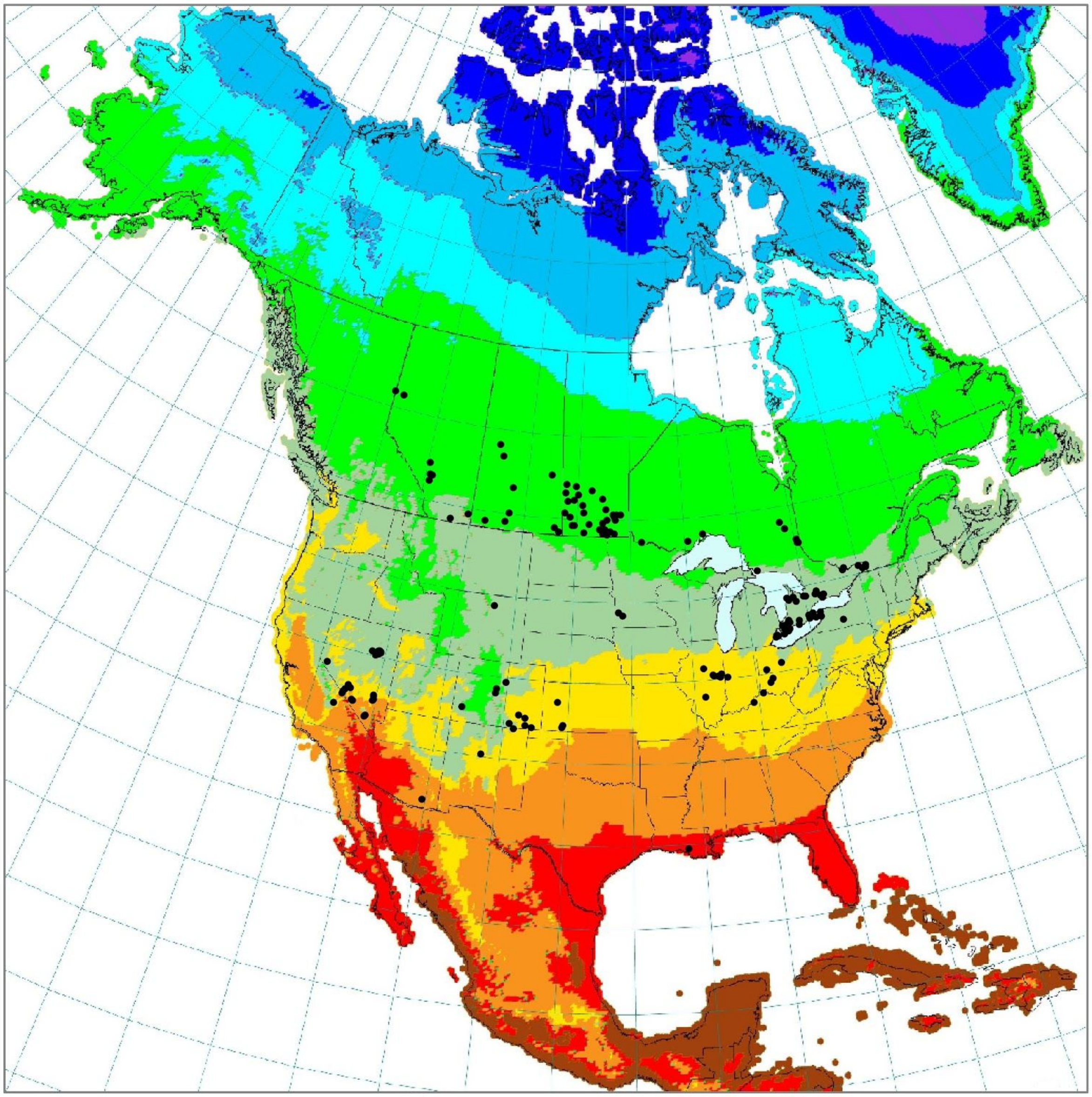

Figure 18: NACODe sites containing *Ilyocypris gibba*. The 15th most common ostracode in North America (Curry et al. 2012)

Genus ***Pelocypris*** Klie 1939

Diagnosis —Valves with two sulci and subquadrate valves in lateral view with greatest height anteriorly. Valves are punctate with large tubercles or denticles present; few normal pores. Central adductor scar consists of four scars orientated in a column and one located posteriorly. Similar to *Ilyocypris* but differentiated by large size and pincer in living individuals (Lister 1975).

Pelocypris tuberculatum (Ferguson 1967)

Figure 19

Description — Subrectangular valves in lateral view with two shallow sulci. Valves are pitted and produce large tubercles at the anterior and posterior ends. Dorsal margin is straight with a defined notch at the midpoint; ventral margin is straight and gently slopes posteriorly. Although this species and *I. gibba* share similar ornaments and textures, *P. tuberculatum* is much larger (including juveniles), has much more pronounced tubercules and the carapace is less inflated. (Figure 19)

Dimensions — Measurement from Lister (1975)

RV: 1.93 (L) x 1.12 (H) mm

Occurrences — Uncommon throughout the majority of the column and relatively common in some samples; absent in modern samples. Total = 26 fossil

Autecology — Found in shallow marshlands (e.g. playas) and ponds typical in locations with strong continental climates (Wise 1961; Ferguson Jr. 1967). Found to reside in pools connected to fast flowing streams and vernal pools fed by groundwater (Brandon Curry and Alison Smith, personal communications). No environmental data yet exists for this species.

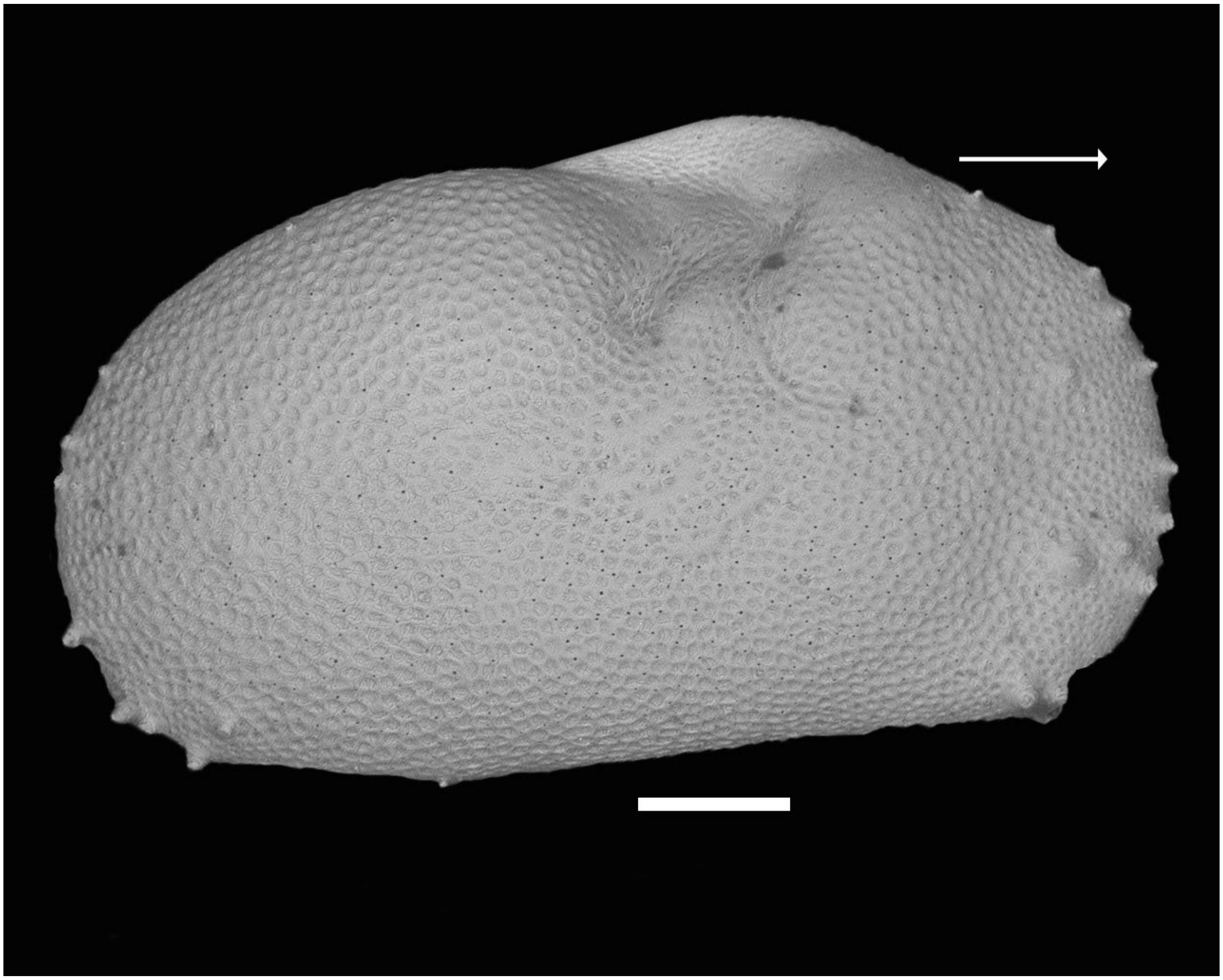

Figure 19: *Pelocypris tuberculatum*. Right valve, lateral external view, scale bar = 200 µm.

CHAPTER 4

RESULTS

Ostracode valves were found in 23 of the 24 sediment samples and 22 of those contained adult valves that could be identified and analyzed. A total of 1,963 valves (869 adults and 1,094 juvenile) were collected and identified. The new species was the most abundant taxon found, with numerous valves and carapaces recovered from modern and fossil samples. Total adult valves per sample are detailed in Table 3, number of adult valves per gram of sediment is detailed in Table 4, and number of juvenile instars are detailed in Table 5.

Table 3: Number of valves per species in each sample. FABA, *Fabaeformiscandona* n.sp.; CYPV, *Cypridopsis vidua*; PTUB, *Pelocypris tuberculatum*; CCRO, *Candona crogmaniana*; PHPU, *Physocypria pustulosa*; ILIG, *Ilyocypris gibba*; HINC, *Heterocypris incongruens*; POTS, *Potamocypris smaragdina*; DARS, *Darwinula stevensoni*.

Depth (m)	FABA	CYPV	PTUB	CCRO	PHPU	ILIG	HINC	POTS	DARS	Total
Large Pond	2	26	0	0	0	0	6	0	4	38
SV-10	0	8	0	0	0	1	7	0	0	16
C-01/0.05	3	133	0	3	0	0	0	0	0	139
C-02/0.10	0	117	0	8	0	7	0	0	0	132
C-03/0.15	5	6	1	3	0	0	0	0	0	15
C-04/0.20	6	5	2	0	0	0	0	0	0	13
C-05/0.25	4	0	1	0	0	0	0	0	0	5
C-06/0.30	0	0	0	0	0	0	0	0	0	0
C-07/0.35	1	1	0	0	0	0	0	0	0	2
C-08/0.40	0	0	0	0	0	0	0	0	0	0
C-09/0.45	3	0	0	0	1	0	0	0	0	4
C-10/0.50	2	1	0	0	0	0	0	0	0	3
C-11/0.55	11	0	0	0	0	0	0	1	0	12
C-12/0.60	16	3	0	0	0	0	0	0	0	19
C-13/0.65	5	1	0	0	0	0	0	0	0	6
C-14/0.70	3	2	0	0	0	0	0	0	0	5

C-15/0.75	19	0	5	0	0	0	0	0	0	24
C-16/0.80	34	2	2	0	1	1	0	1	0	41
C-17/0.85	70	0	2	0	5	0	0	0	0	77
C-18/0.90	38	0	1	0	1	0	0	0	0	40
C-19/0.95	58	11	2	0	1	0	0	2	0	74
C-20/1.00	73	9	4	0	1	0	0	1	0	88
C-21/1.05	95	0	6	0	4	0	0	2	0	106
C-22/1.10	6	4	0	0	0	0	0	0	0	10

Table 4: Species abundances based on valves per gram in each sample. Table only includes adult valves.

Sample	***%FABA***	***%CYPV***	***%PTUB***	***%CCRO***	***%PHPU***	***%ILIG***	***%HINC***	***%POTS***	***%DARS***	**Valves/g**
Modern Pond	6.4	67.7	0	0	0	0	1.6	0	9.7	-
Modern SV 10	0	36.3	0	0	0	9.1	54.5	0	0	-
C-01/0.05	2.2	95.7	0	2.2	0	0	0	0	0	0.69
C-02/0.10	0	88.6	0	6.1	0	5.3	0	0	0	0.66
C-03/0.15	33.3	40.0	6.67	20.0	0	0	0	0	0	0.07
C-04/0.20	46.2	38.5	15.4	0	0	0	0	0	0	0.06
C-05/0.25	80.0	0	20.0	0	0	0	0	0	0	0.02
C-06/0.30	0	0	0	0	0	0	0	0	0	0
C-07/0.35	50.0	50.0	0	0	0	0	0	0	0	0.01
C-08/0.40	0	0	0	0	0	0	0	0	0	0
C-09/0.45	75.0	0	0	0	25.0	0	0	0	0	0.02
C-10/0.50	66.7	33.3	0	0	0	0	0	0	0	0.01
C-11/0.55	91.7	0	0	0	0	0	0	8.3	0	0.06
C-12/0.60	84.2	15.8	0	0	0	0	0	0	0	0.09
C-13/0.65	83.3	16.7	0	0	0	0	0	0	0	0.03
C-14/0.70	75.0	25.0	0	0	0	0	0	0	0	0.02
C-15/0.75	79.2	0	20.8	0	0	0	0	0	0	0.12
C-16/0.80	82.9	4.9	4.9	0	2.4	2.4	0	2.4	0	0.2
C-17/0.85	90.9	0	2.7	0	4.1	0	0	0	0	0.38
C-18/0.90	95.0	0	2.5	0	2.5	0	0	0	0	0.2
C-19/0.95	78.4	14.9	2.7	0	1.4	0	0	2.7	0	0.37
C-20/1.00	82.9	10.2	4.5	0	1.1	0	0	1.1	0	0.44

C-21/1.05	89.6	0	5.7	0	3.8	0	0	1.9	0	0.53
C-22/1.10	60.6	40.0	0	0	0	0	0	0	0	0.05

Table 5: Juvenile and instar abundance in each sample. Due to lack of distinguishing morphology on juvenile valves, identifications were taken only to family level. Instar stages were based on relative carapace size to known adults (Smith and Marten 2000).

Sample and Depth	Candonid A-1	Candonid A-2	Candonid A-3	Cyprid A-1	Cyprid A-2	Total
Modern Pond	0	0	0	7	2	9
Modern SV 10	2	0	0	0	0	2
C-01/0.05	27	74	2	27	5	135
C-02/0.10	32	40	1	25	2	100
C-03/0.15	8	26	0	0	0	34
C-04/0.20	8	24	0	0	0	32
C-05/0.25	0	33	4	1	0	38
C-06/0.30	0	17	0	3	0	20
C-07/0.35	9	1	0	1	0	2
C-08/0.40	0	0	0	0	0	0
C-09/0.45	17	27	1	0	0	45
C-10/0.50	0	11	6	0	0	17
C-11/0.55	10	43	0	0	0	53
C-12/0.60	11	31	5	0	0	47
C-13/0.65	2	13	1	0	0	16
C-14/0.70	4	28	2	0	0	34
C-15/0.75	26	24	0	0	0	50
C-16/0.80	32	49	3	0	0	84
C-17/0.85	52	48	0	1	0	101
C-18/0.90	37	33	0	2	0	72
C-19/0.95	32	40	1	0	0	73
C-20/1.00	31	38	1	0	0	70
C-21/1.05	33	15	2	0	0	50
C-22/1.10	1	9	0	0	0	10

Climate and water chemistry estimates were created using MOTR methodology (Figure 20). Five species were available with environmental data for paleoenvironmental estimates due to the lack of data for *Fabaeformiscandona* n. sp. and *Pelocypris tuberculatum*. Tolerance data for the five species was taken from NACODe (Curry et al. 2012) and used to estimate ranges for MAT, mean January and July temperatures, and total dissolved solids (Table 6). Estimates for the DS unit were made distinct due to the presence of *Candona crogmaniana*; which, due to its low ETI values *C. crogmaniana*'s environmental tolerances defined each MOTR range (Table 7).

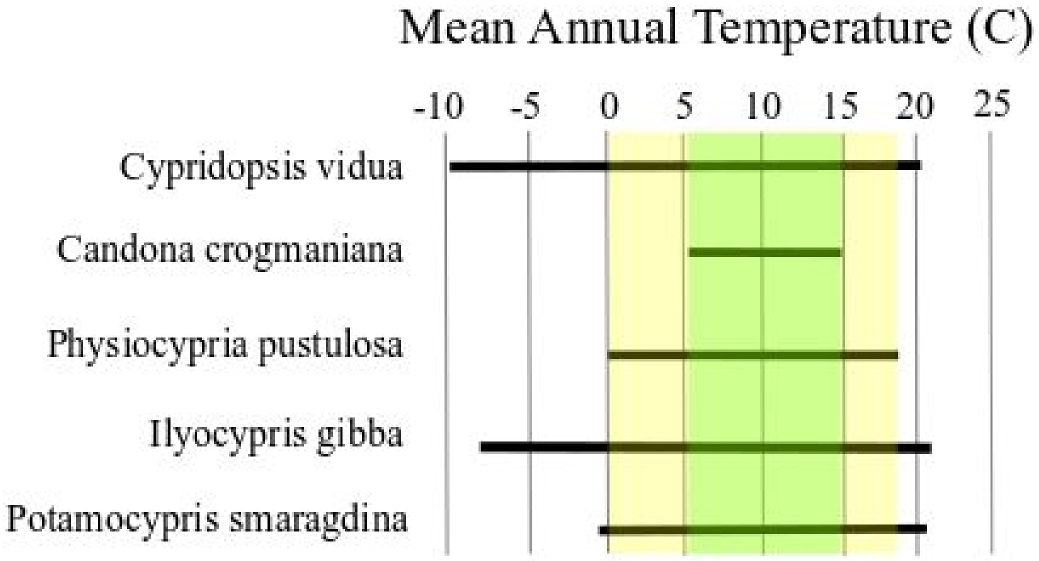

Figure 20: Temperature ranges calculated through MOTR. Green box represents range restricted by *Candona crogmaniana* and yellow box represents range without *C. crogmaniana*, which is restricted by *Physiocypria pustulosa*.

Table 6: Environmental tolerances of species found in this study. Minimum and maximum ranges recorded from NACODe. Note that *Pelocypris tuberculatum* does not have available data.

Taxon	TDS Range	pH Range	MAT (C)	Jan Ave. (C)	Jul Ave. (C)	MAP (mm/yr)
CYPV	10.63 - 10506.5	5.2 - 12	-9.9 - 20.6	-32.9 - 12.3	12.3 - 33.5	71 - 1935
CCRO	56.58 - 512.85	6.3 - 9.8	5.4 - 14.9	-11.9 - 1.9	18.8 - 26.6	740 - 1242
PHPU	24.9 - 1206.8	5.9 - 9.8	0 - 19.1	-23.1 - 8.3	14.4 - 29.6	303 - 1313
ILIG	52.1 - 1798.3	7 - 9.7	-0.3 - 9.1	-31.2 - 12.3	13.5 - 29.1	330 - 1068
POTS	12.79 - 43461	6.72 - 11	-0.3 - 16.1	-23.5 - 12.3	14.1 - 29.7	110 - 2035
PELT	N/A	N/A	N/A	N/A	N/A	N/A

DARS	7.93 - 4026	5.8 - 9.99	-1.3 - 20.6	-24.3 - 12.3	13.1 - 33.5	111 - 1570
HINC	72.7 - 17890	6.68 - 10	1.4 - 14.6	-14.2 - 0.4	13.5 - 25.3	162 - 983

Table 7: Climate and chemical ranges calculated by MOTR constraints. *Candona crogmaniana* (CCRO) is ultimately the most conditionally sensitive species and its own tolerance ranges define the estimated ranges of the site. Additional ranges that excluded *C. crogmaniana* were calculated for samples that did not contain the species.

MOTR Averages	**TDS**	**Annual (℃)**	**January**	**July**	**MAP (mm/year)**
CCRO Included	56.58 - 512.85	5.4 - 14.9	-11.9 - 1.9	18.8 - 26.6	740 - 1242
CCRO Excluded	42.1 - 1206.8	0 - 19.1	-23.1 - 29.1	14.4 - 29.1	303 - 1313

Biozone Descriptions

Five biozones have been identified throughout the stratigraphic sample, including two fossil thanatocoenosis (time-mixed death assemblage), two taphocoenosis (time-specific death assemblage) and one modern biocoenosis (life assemblage), based on shifts in diversity and abundance, which reflect the changes in sediment to some degree (Figure 21).

***Biozone 1 - modern biocoenosis*:** This biozone was collected from connected ponds, SV-10 and the Large Pond (see Figure 2.1 for collection locations), to sample living or recently deceased ostracodes. The community is dominated by the cosmopolitan and common *Cypridopsis vidua* (ETI for log TDS = 0.62) while the somewhat salt tolerant *Heterocypris incongruens* (0.47) signifies a moderately saline system. Given that the ostracodes were collected *in situ* the biozone may represent complete diversity of the ostracode community (i.e. biocoenosis) despite the relatively low diversity.

***Biozone 2 - Holocene thanatocoenosis* (0.05 - 0.15 m):** The uppermost biozone of the column represents a community dominated by *Cypridopsis vidua* with few *Candona crogmaniana* and *Ilyocypris gibba*. *Cypridopsis vidua* and *I. gibba* (0.45) are tolerant of moderate levels of salinity, but the presence of *C. crogmaniana* (0.21) suggests that the water was still very fresh during deposition. This section is restricted to the DS unit and of Holocene age. A large number of juvenile carapaces still contained soft bodies and represent a fauna from modern sediments currently found in the pond at SV-5/7.

***Biozone 3 - transitional taphocoenosis* (0.15 - 0.40 m):** This biozone spans the OC unit and possibly the beginning of the SC unit and shows an abrupt decrease in diversity and abundance. Four taxa are nearly equal in abundance in this biozone although only a total of 74 valves were reported. Most valves are fragmented or corroded, suggesting that most of the organic and ostracode material have been chemically or physically eroded. The reduced quantity and diversity of the ostracode fauna in this biozone may be the result of changes in water chemistry and/or hydrology.

***Biozone 4 - transitional taphocoenosis* (0.40 - 0.70 m):** The midsection of the column and the upper portion of the SC unit has a reduced amount of ostracodes and plant material relative to Biozone 5. Of the few ostracode species found in the biozone, *Fabaeformiscandona* n. sp. is dominant in all samples with only a few valves found of the other species.

***Biozone 5 - high diversity thanatocoenosis* (0.70 - 1.05 m):** The lowermost section of column contained the highest diversity and abundance of ostracodes in the section. *Fabaeformiscandona* n. sp. is prevalent and most common in this biozone, although many other species, especially

Pelocypris tuberculatum, are also common. The abundance of valves increases towards the base of the column which may be a result of differential settling or a change in accumulation rate, as this is also the area with the highest concentration of plant macrofossil material. Overall the sediment from this biozone is a transition of humic clay to silt, which represents the SC and SI units.

***Gravel* (1.05-1.10 m):** The gravel unit also contained ostracode valves and carapaces, but could be allochthonous, and therefore was not given a biozone status. While most of the valves were of *Fabaeformniscandona* n. sp. and were in similar condition to those in Biozone 5, it could be predicted that some specimens from Biozone 5 have been transported to the gravel layer. Juvenile carapaces containing soft body parts were also collected and could represent a recently hatched population living interstitially or within groundwater; although it is still possible that these samples were contaminated by individuals currently living in SV-5/7.

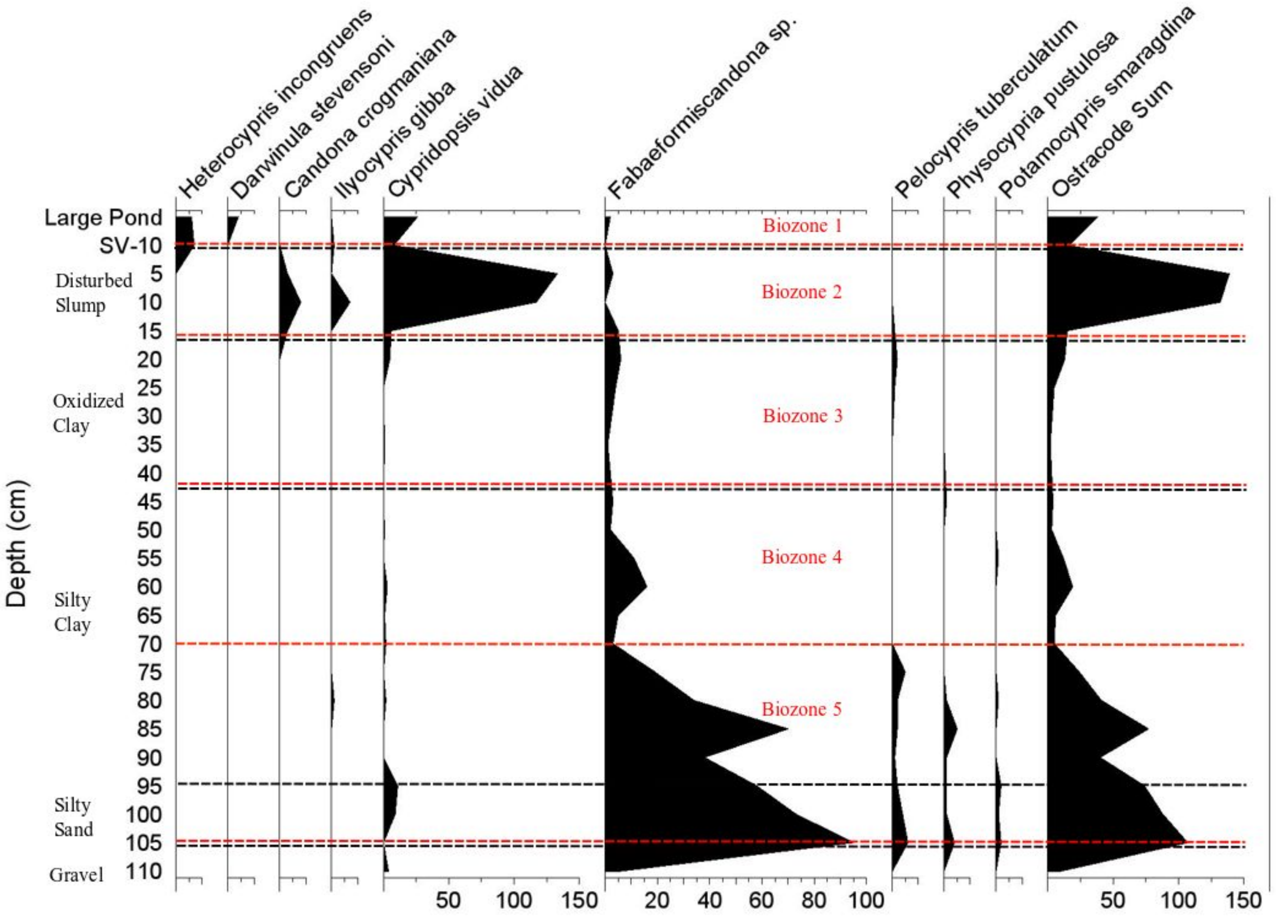

Figure 21: Species abundance in each sample with biozones (red dashed lines) and sedimentary units (black dashed lines).

CHAPTER 5

DISCUSSION

The ostracode fauna from SV-5/7 offers new insights into the overall hydropaleoecology of the site. The samples examined in this study showed very little diversity, but nonetheless contain a prolific and possibly new stygobitic species as well as the rare *Pelocypris tuberculatum*. Based on the diversity of taxa it can be projected that the Saltville valley during the Pleistocene hosted a series of shallow, seasonal lakes which were being fed by nearby springs whose hydrologic input became reduced into the Holocene (Figure 5.1).

Hydrology

The majority of the site's depositional history can be summarized as originally a lotic environment transitioning into a lentic environment. The fauna in Biozones 4 and 5 are interpreted as a community residing in shallow, interconnected pools fed by a spring in the GR unit. A transitional period can be seen in Biozone 4 and 3 which have a reduction of faunal abundance likely due to a shift in chemical conditions or hydrology. An introduction of new taxa and abundance in Biozone 2 reflects the effects of a reduction of groundwater input and an accumulation of a low energy hydrologic regime of pools and ponds similar to the current hydrology.

A major element in this paleoenvironmental interpretation is the presence of *P. tuberculatum*, which has only a few recorded field observations and no published autoecological data. However Wise (1961), Ferguson Jr., (1967) and a personal communication with Alison Smith (2020) indicate that the species prefers shallow, spring-fed ponds such as playa lakes and vernal pools. Its occurrences have been associated with long, warm summers, monsoonal springs and cold, dry winters, typical of a continental climate (Curry and Baker 2000). These lakes are often fed by aquifers or streams. The decreasing abundance of *P. tuberculatum* and *Fabaeformiscandona* n. sp. through time signals a gradual disappearance of a groundwater dominant system in exchange for a lentic environment primarily sourced by surface runoff and precipitation.

Aside from the new species, the other taxa found in Biozones 3 and 2 are generally lentic species with a few common cosmopolitan species, especially *Cypridopsis vidua*. Despite the lentic signature no truly lacustrine species are found; therefore, the Saltville valley was likely not a large lake environment (i.e. Lake Totten) as suggested by McDonald (1984, 2000), but rather a wetland area with ponds interconnected by springs and seeps, similar to present hydrology. A broader sample of the valley's ostracodes may indicate greater diversity of hydrologic environments and therefore, a more variable paleohydrologic evolution than can be seen in the fauna at SV-5/7.

The presence of the endemic *Fabaeformiscandona* in the Gravel Unit, if autochthonous, is supported by the idea that the area is being fed groundwater through springs and seeps. The new *Fabaeformiscandona* is likely a stygobitic species residing in surrounding groundwater, similar to the genus *Cavernocypris*, and occasionally makes its appearance to the surface sediments through a spring to feed or mate. Given the hypothesized stygobitic nature, the presence of the species throughout the entire column suggests that the groundwater springs have been a consistent source of input throughout deposition and mostly unaffected by the shift from a lotic to lentic environment.

Salinity

The results of this study do not support the saline conditions suggested by Ray et al. (1967). This study's findings agree with Sohn's interpretation that the site had not always been saline (Ray et al. 1967). No species in the sampled section are halophilic, although some species, such as *Cypridopsis vidua*, can tolerate brackish conditions. When this species is found in saline environments it is typically associated with halophilic species such as *Sarsicypridopsis aculeata* and *Fabaeformiscandona rawsoni*. Although there is no environmental data associated with the new species and *P. tuberculatum*, isotopic analyses of valves, water sampling of nearby springs, and recorded environmental data may reveal new insights to the Quaternary water chemistry of the valley. Despite this discrepancy, the youngest sampled unit is Holocene in age (Disturbed Slump/Biozone 2) and shows a freshwater signature based on the presence of *Candona crogmaniana*, a species limited to freshwater environments in the United States.

The brackish-tolerant taxa found in the Biozone 1 are not found together in any other biozone and represent a recent change in salinity, likely a result of mining. Mining in the Maccrady Formation began in the 1840's (Kent 1955; Ogle 1981) and the introduction of multiple wells and draining has caused an influx of saline water, thus increasing the overall salinity as seen today. The overall average tolerances of all species in this study would suggest that throughout the late Pleistocene and Holocene, the composition has remained relatively fresh and modern saline conditions are the result of hydrological changes induced by historic mining.

Climate

Temperature is important to reconstructing the paleoenvironment of Saltville and can be estimated based on the presence of species in this study. *Candona crogmaniana* is a highly sensitive, low ETI species with a narrow MAT range, trending toward warmer temperatures (5.4-14.9 ℃, Table 6, Figure 20). Occurrence of *C. crogmaniana* in Biozone 2 (Figure 21) suggests climate was relatively warm year round.

In the lower units that do not contain *C. crogmaniana*, the range of temperatures calculated by MOTR are much wider and can be as low as 0℃ and as high as 19.1℃ (MAT) with a possible range of 52.1℃ between January and July averages. This range is supported by the presence of *P. tuberculatum* which promotes the idea that the Saltville valley underwent high seasonality with potentially long summers and cold, dry winters (Wise 1961; Ferguson Jr. 1967; Curry and Baker 2000). The idea that temperatures may have fluctuated seasonally with potentially highly variable, seasonal temperatures coincides with the palynological evidence which points towards a spruce parkland with grasses and shrubs dominating a boreal landscape (Ray et al. 1967; Delcourt and Delcourt 1986, Bonan and Shugar 1989). Although some taxa have been found at negative temperature, the lower bounds for MAT in the Pleistocene, as set by MOTR, are at 0℃ with a majority of the taxa residing in warmer climates. Based on these estimates, the area may have experienced some occasional freezing during winter but not prolonged freezing. The paleoenvironment of Saltville likely has no modern analogue but may be similar to the modern spruce community seen in the Black Hills of South Dakota (National

Weather Service 2020) or the boreal woodlands of late-glacial central Kentucky (Wilkins et al. 2017).

Groundwater and Gravel

The gravel unit (GR) is the focus of an ongoing conversation regarding the early hydrology of the site. Previous studies have proposed that the clast-supported gravel is the remains of a riverine system (McDonald and Bartlett 1983; McDonald 2000), but ongoing analyses of the sediment are testing this hypothesis. The absence of autochthonous, lotic ostracodes in this unit may indicate that the gravel is a colluvium and is not alluvium. The presence of juvenile candonids with soft tissue, possibly belonging to *Fabaeformiscandona* n. sp., in the Gravel unit may indicate that groundwater is flowing from within the layer itself and a population may still reside within the sediment.

New Species

The dominant taxon throughout the fossil units is a new species of *Fabaeformiscandona.* Two valves were recovered from modern samples, but lacked soft body tissue, which would provide added taxonomic certainty. Due to the changing hydrologic environment of the site, this taxon must have relied on a consistent hydrologic factor throughout the site's depositional history (Bright 2009). It is thought that this taxon may be stygobitic or interstitial, residing in subterranean aquifers within or beneath the gravel, a consistent input into the valley's hydrology. If stygobitic in habit, the species may reproduce seasonally when the water level is close to the surface, which may explain the occurrence of living juvenile candonids within the gravel samples.

Currently the spring that feeds through the gravel is saline and although this may not have always been the case, it would suggest that this species may be tolerant to saline waters. Following this study more samples should be collected to confirm its extant status and to perform isotopic analyses to further understand its habits. Hypogean environments are stenotopic in water temperature and chemistry, meaning that temperatures are nearly reflective of ambient mean annual temperatures and mostly invariable spring water conditions (Forester 1991). These factors will predict monotonic δ^{18}O values in stygobitic ostracode valves. Until living specimens are collected or biogeochemical profiles are generated from these units, this new species of *Fabaeformiscandona*'s autecology will remain speculative.

Table 8: Summary of findings and interpretations. Biozone 3 and Gravel are left blank due to lack of sufficient species information.

Age	**Biozone**	**Taxa**	**Unit**	**Hydrology**	**Salinity (mg/L)**	**MAT (℃)**	**Precipitation (mm/yr)**
Holocene	Biozone 1	CYPV, HERC, DARS,ILIG	Modern Sediment	Standing ponds	1025-8063	12.6	1183
	Biozone 2	CYPV, FABA, CCRO, ILIG	Disturbed Slump (DS)	Standing ponds	56.6-512.8	5.4-14.9	740-1242
Pleistocene	Biozone 3	FABA, CYPV, PELT	Oxidized Clay (OC)	Transitional period	-	-	-
	Biozone 4	FABA, CYPV, PHPU, POTS	Silty Clay (SC)	Flow-reduced spring	35.9-1206.8	0-19.1	303-1313
	Biozone 5	FABA, CYPV, PELT, POTS, ILIG, PHPU	Silty Clay (SC), Silty Sand (SI)	Spring-fed, vernal pools	42.1-1206.8	0-19.1	303-1313
	Gravel	FABA, CYPV	Gravel (GR)	Spring-fed colluvium	-	-	-

CHAPTER 6

CONCLUSIONS

The Saltville valley of Virginia has a long, fossiliferous history, rich with Pleistocene megafauna. Previous studies proposed that the valley hosted a moderate river during the last glacial maximum that became a lake when flow became dammed (McDonald 1985). It has also been proposed that the high salinity of the site may have attracted the megafauna (Ray et al. 1967). Work on fossil ostracodes by I.G. Sohn was mentioned briefly in one of the initial studies of the site, but was never published or replicated. On the basis of ostracode autecology, Sohn predicted that the aquatic environment of Saltville had not always been highly saline. The current study resampled the Saltville locality for ostracode fossils and tested Sohn's predictions.

Sediment samples were collected from a vertical column in excavation site SV-5/7, which was sampled at regular intervals to track ostracode faunal changes. Five biozones were defined that correspond with stratigraphic boundaries. The fauna found in these samples are primarily found in freshwater environments, particularly shallow springs and pools. The only saline tolerant taxa were found in modern samples. This suggests that the saline signature of the site is modern and likely a by-product of the mining in the area.

Changes in ostracode fauna, particularly the new species and *Pelocypris tuberculatum*, suggest that the Saltville valley did change from a lotic to lentic system. The presence of a newly described species found throughout all samples indicates a consistent habitat throughout the shift in hydrology, likely an aquifer and associated springs. This would suggest that as the two taxa decrease through time so does the overall input of groundwater into the valley.

Late Pleistocene climate in the valley was estimated using the MOTR method. These estimates give a range of mean annual temperature higher than previous predictions based on palynological evidence (Ray et al. 1967; Delcourt and Delcourt 1986). Together, the ostracode and the pollen records indicate that the valley was a non-analogous spruce ecosystem warmer than a typical 'boreal' habitat, where freezing of open water was rare.

The diversity of ostracodes at the site is relatively low, and dominated by a new species of *Fabaeformiscandona*. This new species is unique among its genus for its narrow carapace, near-linear dorsum, and squared posterior. Living juvenile individuals and adult valves in the gravel layer would suggest this species may be residing in the Saltville valley or the Southeast's hypogean environments. Overall, the paleohydrological history of the site is, in a sense, defined by this new and unique ostracode.

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