Chapter 5

Summary and Conclusions

5.1 RESULTS SUMMARY

5.1.1 Overview

This dissertation represents the first systematic study of late Pleistocene terrestrial gastropod fossils in the Driftless Area since Chamberlin and Salisbury (1885), including the northernmost full-glacial biotic assemblage in the Midwest (Kuchta et al., 2007a). Several of the gastropod taxa described represent the first records of these species in Wisconsin (e.g. *Discus shimeki, Columella columella alticola, Vertigo oughtoni*). The relationships between the fossil assemblages and stratigraphic architecture suggest that fossil assemblages should be similar throughout the region, and will help constrain the timing of important depositional episodes within the UMV. The amino acid racemization analysis demonstrates that this technique can be used to identify gastropods that did not coexist and provides a baseline from which to extend an amino acid geochronology into other fossiliferous deposits in Wisconsin and Minnesota.

The late Pleitoscene gastropod fauna from the Upper Mississippi Valley is dominated by Cordilleran-Boreal taxa, such as *Discus shimeki* and *Columella columella alticola* (Figure 5.1). This compares to the modern gastropod fauna, which is dominated by Eastern Deciduous Forest gastropods including *Anguispira alternata* and *Neohelix albolabris* (Figures 5.2 and 5.3). One of the most striking differences between the snails living in the UMV today, and the late Pleistocene gastropod fauna is the much wider range in body size of individual shells (Figure 5.4A, 5.4B). It is also interesting to note that Foley (1984) reported *Anguispira* sp. from Moscow Fissure. The distribution of late Pleistocene *A. alternata* fossils is restricted to the Gulf Coast (Hubricht, 1985; Figure 5.3). Based on the results from this study, the typical species in late Pleistocene assemblages are considerably different than those reported from Moscow Fissure. If Moscow Fissure is full-glacial in age, it represents a remarkable gastropod refugium. However, Moscow Fissure may predate the full-glacial period (Richard Slaughter, personal communication 2006), which has considerable implications for the response of terrestrial gastropods to climate change.

5.1.2 Sedimentology and Stratigraphy

Late Pleistocene sediments within the UMV provide important insights into the depositional mechanisms that preserved an abundant gastropod fauna. The thickest and most fossiliferous deposits include clast-supported and matrix-supported diamictons along hillslopes that grade into silty and sandy alluvial sediments filling the river valleys. The depositional context of the fossiliferous sediments within the UMV provides insight into the potential age distribution and taphonomic filters that control what types of gastropod shells are preserved.

Radiocarbon data from this and previous studies suggest that hillslope mass wasting and valley aggradation were most active between approximately 24,000 and 16,000 cal yr BP. Most sediment exposures that crop out below the late Pleistocene Savanna Terrace surface show aggradational features during this period. Several sites within the Latch Valley of Trempealeau County display diverse associations of lithofacies and sedimentary structures. This pattern consists of matrix-supported diamicton and massive silts on the hillslopes that grade into laminated silt along the valley margins with sandy lithofacies closer to the valley axis. The fine colluvial silt may consist of reworked loess and some bedrock clasts, while the fine laminated silt and clay along the valley edges is characteristic of floodplain deposits with interbedded sheet sands as a result of overbank floods and slack water deposits. Root casts within the fine-grained lithofacies suggest the floodplains were vegetated. Sandy lithofacies closer to the valley axis indicate that active braided stream type aggradation was the primary mode of sediment deposition. Large trough cross-beds suggest individual channels were about 0.5-1.5 m deep and 1-3 meters wide. Two fining upward parasequences visible at Kulas Quarry suggest the active channel belt moved laterally across the floodplain, exposing previously active channels and loess might have been able to accumulate on the floodplain surface during this hiatus. The sand and gravel-sized fraction of the sediments consist of well-rounded quartz, glauconite, muscovite, and bedrock fragments. Sediment within the Latch Valley was mostly derived from weathered Cambrian bedrock (Tunnel City Group and Wonewoc Formation) although some silt was probably introduced from outside the valley as loess.

Downcutting into the Savanna Terrace surface likely began by approximately 16,100 cal yr BP based on the age data from Hideaway Lane plus additional radiocarbon data from Knox (1996; 2005). This incision does not correspond to well-constrained outburst events from glacial lake Aggasiz, long thought to have controlled much of the incision into the late Pleistocene floodplain of the UMV (Knox, 2009). Based on the red clay rip-up clasts, it is likely that the earliest incision was a result of sudden drainage of Glacial Lake Duluth or (in addition) Lake Lind, which emptied into the UMV via the St.

Croix River valley. Colluvial sedimentation continued during this initial phase of downcutting, as indicated by radiocarbon results from Limery Coulee and additional results from Mason and Knox (1997). The data from this study supports the conclusions by previous authors that most sedimentation ceased after 16,000 cal yr BP (Knox, 1996; Mason and Knox, 1997; Knox 2005).

5.1.3 Amino Acid Racemization

The results from amino acid racemization analyses (AAR) of gastropod shells demonstrate both the potential applications and sources of uncertainty for this technique. Shells from gastropod genera with "older" looking shells (*Succinea*, *Catinella*, *Discus*, *Vertigo*, *Columella*, *Pupilla*, and *Vallonia*) had D/L Asp values from 0.300 to 0.350, characteristic of late Pleistocene ages, whereas "young" shells (*Helicodiscus*, *Hawaiia*, *Glyphalina*, *Pupoides*) had D/L Asp values between 0.060 and 0.170, indicating these shells were introduced into the assemblage after its deposition, some shells could have been incorporated quite recently; only a few hundred years ago. The total variance in D/L Asp for succineid shells was less than that expected as a result of analytical uncertainty and multiple ^{14}C dates from single horizons were in close agreement. While the D/L Asp values yielded little variability, the radiocarbon results shows that there could be several hundred years difference between the ages of individual succineid shells.

Principal component analysis (PCA) of the AAR data showed that the majority of the variance (PC1) positively correlated with D/L ratios of fast-racemizing amino acids (serine, aspartic acid) and negatively correlated with the concentration of L-Ser. The next largest variance (PC2) correlated positively with Depth and negatively with slower racemizing amino acids (glutamic acid, alanine). The negative correlation between depth and D/L Glu and D/L Ala indicates that either L-Ala and L-Glu are preferentially removed (by leaching free amino acids) or D-Ala and D-Glu are introduced near the surface. D/L Asp – the most commonly used indicator of age – did not correlate, or showed a slight negative correlation with depth. Surface heating may explain stratigraphic aberrations in D/L Asp values. The anomaly in Glu and Ala may be a result of surface contamination from bacteria, as the peptidoglycan in the cell walls of many bacteria is enriched in D-Ala and D-Glu.

These results suggest that: 1) some non-analog species found within fossil deposits were introduced long after the assemblage formed. 2) Relative and ^{14}C age data suggest time averaging was less than 1000 years. 3) Variation within succineid AAR data can be attributed largely to diagenetic alteration, either leaching of D-AAs or contamination from L-Ser, heat-induced racemization, or D-Ala and D-Glu contamination (perhaps from bacterial peptidoglycan). The D-Ala, D-Glu anomaly has not previously been observed in terrestrial gastropod AAR studies, but has significant implications for future gastropod-based amino acid geochronologic studies – especially where D/L Glu is used as an independent or longer interval (e.g. beyond radiocarbon utility) estimate.

5.1.4 Paleoecology

The colluvial and alluvial sediments from Hwy-JJ and Kulas Quarry within the Latch Valley, Trempealeau Co., Wisconsin, provided an opportunity to compare the fossil gastropod assemblages within two distinct yet coeval depositional settings. These sites contained abundant terrestrial gastropod fossils and some vertebrate remains. Identifiable dental elements from small rodents include those of *Dicrostonyx* sp. a tundra-dwelling lemming. The gastropod fauna is complex, and includes taxa with modern boreal-cordilleran affinities such as *Discus shimeki*, *Columella columella alticola*, and *Vertigo modesta*, which are not found in the region today. Other gastropods include species that prefer open, xeric habitats, and those that inhabit deciduous forests such as *Hendersonia occulta*, an endangered snail that inhabits the UMV today. While most shells were recovered as both intact and broken specimens, *H. occulta* was only recovered as fragmentary pieces. This suggests that this taxon was incorporated into the deposit via an alternate taphonomic pathway. The shell fragments may be a result of preferential destruction either during transport or deposition, or the shell fragments could be reworked from older material.

Succineid gastropod shells yielded radiocarbon ages between 16,100 and 18,000 RCYBP and indicate the fauna is full-glacial in age. The differences in species richness observed between sites and samples can be largely attributed to the total number of shells within each sample. Samples with high numbers of shells per kilogram of matrix were the richest, while samples with few shells yielded few species. The rank order of abundance was nearly identical for all samples; the primary differences were between upland and floodplain samples, the former yielded a greater abundance of *Pupilla muscorum*, while the latter contained a larger number of rare species. This similarity in gastropod composition suggests a community that was largely unchanged throughout this time interval. The gastropod fauna from the Latch Valley is the northernmost full-glacial fauna in the UMV, located less than 100 km from the terminal moraine of the Chippewa Lobe of the Laurentide Ice Sheet. The age range of this deposit appears to coincide with a minor retreat of the Chippewa Lobe between the Stanley and Late Chippewa advances. These results generally agree with the ecological interpretations from other regional fossil localities of a tundra-like environment, however the presence of *H. occulta* at this site (if not reworked from older deposits) suggests the presence of minor amounts of deciduous vegetation within topographically controlled microhabitats. It is likely that the Driftless Area of the UMV served as an important refuge for temperate species during the full-glacial period, much as it serves as an important refuge for northern species today.

5.2 CONCLUSIONS

The results of this dissertation have provided much needed groundwork regarding the utility and context of late Pleistocene terrestrial gastropod fossils from the UMV. Terrestrial gastropod fossils are the most abundant biotic material within these sediments, and they have the potential to answer important questions related to the interaction between the landscape, climate, and biological communities. The fossil assemblages described in this study are late full-glacial to early late-glacial in age (ca. 24,000-18,000 and 18,000-13,000 cal yr BP respectively). In addition, there is little evidence for significant time averaging within succineid shells; age differences were undetectable with AAR and only a few hundred years separated radiocarbon dates from the same interval. Species with well-preserved shells had significantly lower D/L amino acid values compared to those species with opaque, worn shells. Burial and preservation of this fauna was largely a result of the sedimentary processes active at the time. The lack of older fossil assemblages may be due to their lack of exposure, or a reduced sedimentation rate prior to this interval.

The gastropod fauna preserved is complex; it is dominanted by species with Cordilleran and Boreal habitat affinities but also contains several taxa that prefer eastern deciduous forest habitats. Given the proximity to the Laurentide Ice Sheet, the mixture of habitat preferences within these assemblages is striking. It is probable that the strong topographic contrasts in this region provided a refuge for many species throughout the last glacial period. It is possible that the formation of the Driftless Area at some earlier point in the Pleistocene had a profound effect upon the biotic response to subsequent climatic changes.

5.3 SUGGESTIONS FOR FUTURE RESEARCH

5.3.1 Locate additional sites

These results suggest avenues for future research, some of which are underway and are described in more detail within Appendix B. Several fossiliferous sites were identified during the survey period of this study, but were not sampled or described in detail. Despite extensive exploration, I was only able to cover a fraction of the total area in the UMV and many more exposures remain to be found, especially given the recent flooding in Minnesota and Wisconsin. The highest priority exposures are those rich in species with a long record of sedimentation and sites from age ranges not covered in this project. Knox (2005) described a shelly layer 4.5 m below the Savanna Terrace from an exposure along the Grant River dated at approximately 17,000 cal yr BP. Mason (1995) and Baker et al. (1999) mentioned the presence fossiliferous sediments at Jore-1, a cutbank exposure along a tributary of the Root River in southeastern Minnesota. A spruce log, which was dated to approximately 22,400 cal yr BP. Recovery of additional material over a broad range of ages, especially prior to the last glacial maximum or from the earliest Holocene, will be helpful in determining arrival and extirpation dates for individual gastropod species.

5.3.2 Determine taphonomic influences

Fossil-based paleoenvironmental reconstruction depends on separating the climatic influences from depositional and taphonomic ones. The preferential preservation and destruction of fragile gastropod shells will have a significant impact upon the composition of the gastropod assemblage. Many important differences between regional sites may exist at scales not measured by species richness (e.g. diversity). Taphonomic filters such as preferential shell destruction may provide insight into how individual shells are incorporated into a deposit and allow for more detailed environmental interpretations.

5.3.3 Extend the chronology of amino acid racemization in Wisconsin

This project demonstrated the potential applications of amino acid racemization in Wisconsin. Future studies should consider this technique to study the chronology of Quaternary deposits that lie beyond the range of radiocarbon, such as the problematic, eroded deposits of pre-Wisconsinan glacial sediments. In addition, more work is required to characterize the potential for bacterial contamination and alteration of measured AAR results within fossil assemblages. Shells may be pitted, or contain other microscopic evidence of bacterial activity, in addition, it may be possible to culture the bacteria responsible for contamination and determine their influence on shell protein diagenesis (e.g. Child et al., 1993). Moscow Fissure (Foley, 1984) is widely cited as a full-glacial mammal fauna from southern Wisconsin. However, both the gastropod and mammal fauna are not characteristic of tundra-forest conditions. Revisiting Moscow Fissure with the purpose of radiocarbon and amino acid racemization analyses of the fossils may help resolve the anomalies within this deposit.

5.3.4 Refine gastropod biogeography

Gastropods remain an understudied group, especially in the UMV (Hubricht, 1985; Jass, 2004). In order to make useful environmental interpretations from fossils, it will be necessary to have detailed information on the modern autecology for terrestrial gastropods. I have begun collaborating with Kathryn Perez and James Theler at the University of Wisconsin – La Crosse to build a database for terrestrial gastropods in Wisconsin and expand our understanding of the fauna by conducting new surveys. As of this writing, we have received funding from the Wisconsin DNR to create GIS-based maps and predictive habitat models for the terrestrial gastropods in Wisconsin. These results are expected to aid in fossil-based environmental reconstructions of the late Pleistocene. Finally, the late Pleistocene gastropod fauna in the UMV is dominantly Cordilleran and Boreal in its composition. Combining multiple sites into a regional map may provide insight into where and when species adjusted their ranges across North America (e.g. FAUNMAP, 1996 for mammals).

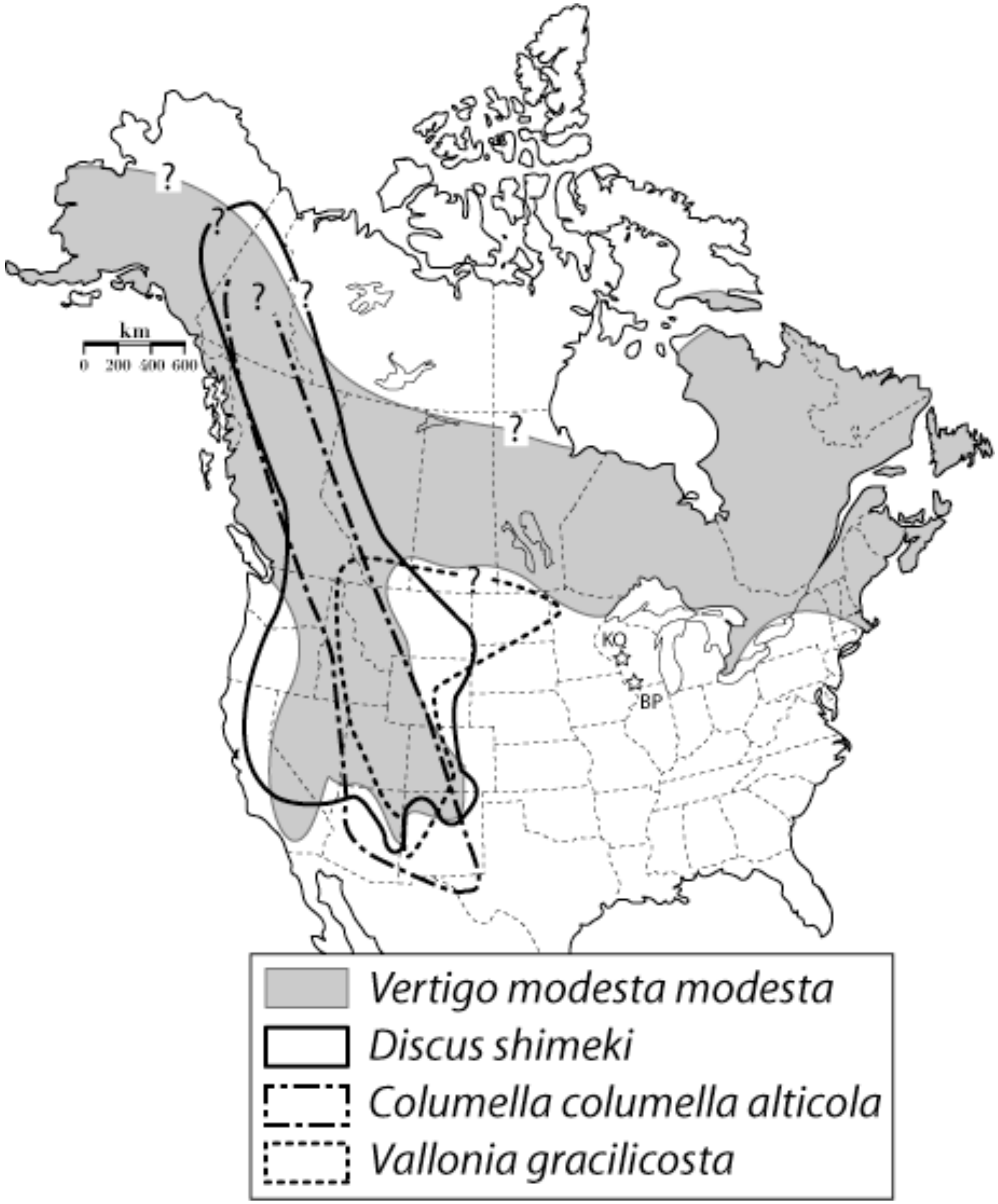

Figure 5.1. Modern distribution of gastropods that occur in the UMV as late Pleistocene fossils.

Figure 5.2. Distribution of Anguispira alternata; a common snail in the Eastern Deciduous Forest, but only found along the Gulf Coast as a late Pleistocene fossil.

Figure 5.2. Distribution of *Neohelix albolabris*; a common snail in the Eastern Deciduous Forest, that is restricted to the Gulf Coast as a late Pleistocene fossil.

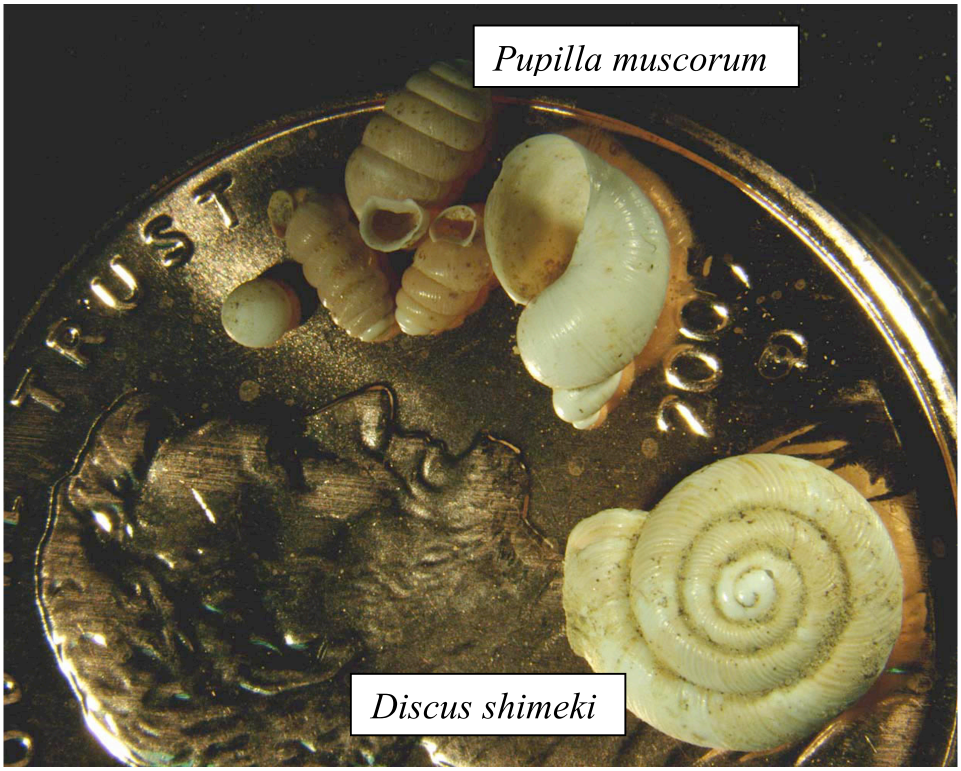

Figure 5.4A. Photograph of typical full-glacial gastropods from the UMV.

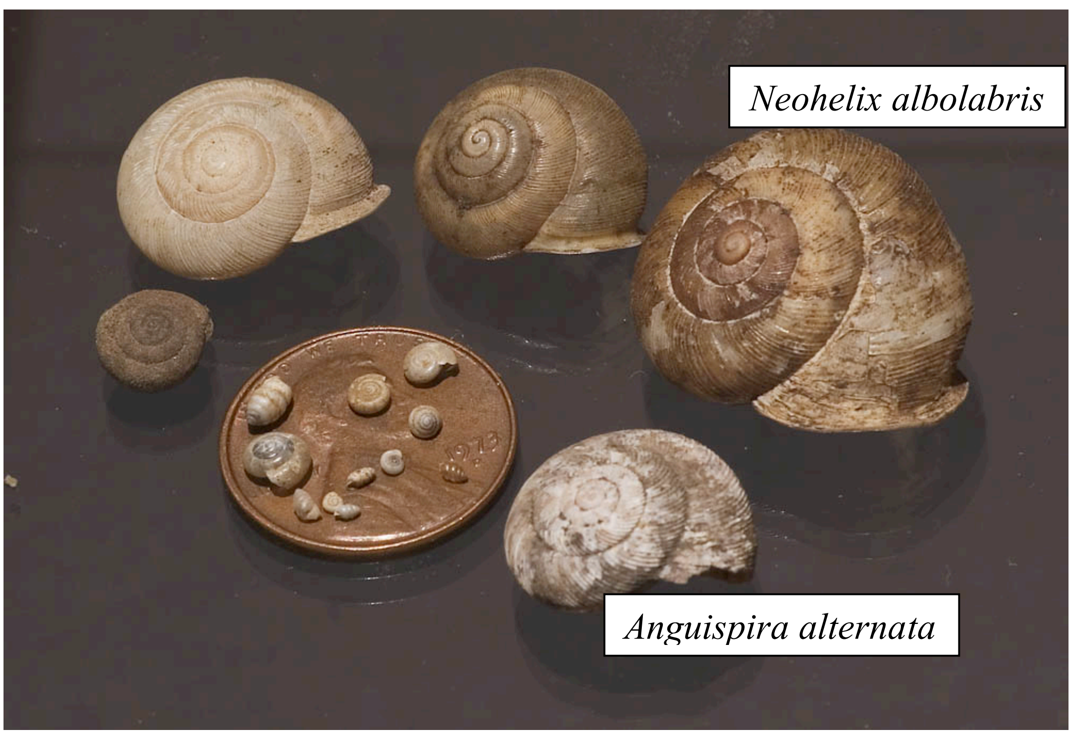

Figure 5.4B. Photograph of common gastropods found in the UMV today. Note the size range compared to the full-glacial taxa.