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Approved by:

David L. Meyer

MORPHOLOGICAL DIVERSITY OF THE BRACHIOPOD *PLATYSTROPHIA* THROUGH CHANGING PALEOENVIRONMENTS IN THE CINCINNATIAN SERIES (UPPER ORDOVICIAN)

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Abstract

The brachiopod genus *Platystrophia* is known worldwide, evidencing a wide variety of morphological variation and numerous species and subspecies designations (36 in the Cincinnatian Series alone.) *Platystrophia* is abundant within the Cincinnatian and occurs across several paleoenvironments throughout the Series. *Platystrophia*'s rich morphological variety, local outcrop abundance, and well-documented sedimentological context provides a unique opportunity to test for relationships between patterns of morphology and paleoenvironment variations.

Specimens were collected from 23 localities encompassing most of the Cincinnatian Series (Kope through Whitewater Formations). Over 27,000 morphological measurements were made on 1096 specimens. Morphologic data were subjected to multivariate analysis and resulting morphological patterns were tested against parameters such as stratigraphy, paleoenvironment, geography, and biological association.

Apart from variations in size, *Platystrophia* shows surprisingly few consistent morphological patterns with respect to the diverse set of environments it inhabited through the Cincinnatian. Change in morphology with respect to stratigraphy, based on factor analyses of both individual specimens and data averaged by locality, appears nearly random except for specimens from a few localities. Geography and biological associations appear to be stronger influences for morphological variation. Alate *Platystrophia* evidence morphological changes in relation to non-alate forms. All forms demonstrate variation related to geography, suggesting polytypic speciation as a possible cause for *Platystrophia's* noted taxonomic complexity.

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μονω σοφω θεω δια Ιησου Ξριστου ω η δοξα εισ τουζ αιωναζ, αμην.

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Introduction

Organisms are known to respond morphologically to any number of environmental influences. Among living organisms, food availability and current energy have been linked to size in certain marine species (e.g., Kristensen, 1957). Similarly, current intensity and sedimentation rates have been documented to influence the morphology of living bryozoans (e.g., Rider, 1977), and wave energy is known to affect the branching morphologies of living corals (Graus et al., 1977). Among fossil populations, environmentally related changes in size and shape have also been established (e.g., Hallam, 1965; Leighton,1995; Alexander, 1975; Daley, 1993). Nevertheless, there is still much to learn.

The Cincinnatian Series of the midwestern United States has a rich history of paleontological research and provides an ideal setting to pursue questions regarding morphological variability. As early as 1902, workers were carrying out limited quantifications of morphology among the most abundant fossil taxa, including the orthid brachiopod *Platystrophia* (Cumings, 1902). By 1919, simple qualitative patterns involving the fold and sulcus were recognized and used in classification (McEwan, 1919); the reliability of these patterns were also soon recognized from a stratigraphic standpoint, as illustrated by Willard (1930) who used quantitative measures of *Platystrophia* for determining stratigraphic distributions. The abundance and excellent preservational quality of *Platystrophia* promoted collection of the detailed data required for examination of taxonomic and biological questions of the genus using univariate and bivariate analyses (Fitzpatrick, 1972; Puchstein, 1972).

The present thesis examines the morphology of *Platystrophia* in the context of environmental and biological variables accessible to the fossil record, that might be expected to have affected the shapes of individuals. While earlier work analyzed *Platystrophia's* size (Cumings, 1903; McEwan, 1919; Willard, 1930) and, to some degree, morphological variation (Cumings, 1902; Fitzpatrick, 1972; Puchstein, 1972), this will be the first study to employ a detailed multivariate, morphometric analysis of a genus as it is tracked through most of the Cincinnatian. The central goal of this thesis is to analyze quantitatively morphological trends in shape variation in *Platystrophia* within the framework of the repeated onshore and offshore facies cycles that characterize the Cincinnatian. Two basic null hypotheses were evaluated statistically:

1. The size of *Platystrophia* does not change under varying environmental conditions.
2. *Platystrophia* exhibits no morphological change in response to environment.

Just as significantly, this study sheds light on the taxonomic confusion surrounding the genus. There have been difficulties understanding *Platystrophia's* taxonomy for nearly 100 years (Alberstadt, 1979; McEwan, 1919; Puchstein, 1972). McEwan (1919) identified 36 total species and subspecies, and it is believed that the genus is highly oversplit (Alberstadt, 1979). Despite this general impression, it has not been easy to identify appropriate morphological boundaries between species. The multivariate analysis described here provided a new perspective on this issue.

Because an analysis of the significance of changes in shell size and shape through the Cincinnatian Series requires an understanding of lithostratigraphic patterns, I first discuss the most recent sequence stratigraphic understanding of the Cincinnatian, including cyclicity of sea level fluctuations (Jennette, 1993; Holland, 1993; Holland, 1992 ; Tobin, 1982). Within this context, samples were taken from a range of localities, to test stratigraphic and geographic relationships throughout the exposed Cincinnati Arch in the Tri-state area. While stratigraphic variation is the most commonly tested pattern in morphometric studies such as this, geographic variation was also assessed to diagnose this important, yet often overlooked, factor (Gould, 1977). I also discuss methods for sample measurement, morphometric analysis and statistical comparisons. Finally, I describe the results and discuss the significance of the patterns discovered. Lack of predictable morphological response to environment was a notable result. For such a speciose genus, *Platystrophia*'s occupation of shape space was more intergradational than expected.

The Cincinnatian: Stratigraphy and Paleontology

Cincinnatian Stratigraphy

The Upper Ordovician Cincinnatian Series in its type area has been the subject of numerous studies regarding nomenclature, lithostratigraphy and sequence stratigraphy. For the purpose of this thesis, it will suffice to summarize the main features of these works.

One practical point to clarify is the issue of nomenclature. The Cincinnatian is characterized by confusing nomenclature for which there has been extensive discussion (Holland, 1990; Daley, 1993). This thesis will follow Holland's nomenclature and revised sequence stratigraphic classification (Holland, 1992; Holland, 1993)[1].

Cincinnatian Paleoenvironments

Paleocontinent position and Ramp. - North America was positioned 15° - 25° south of the equator during the Cincinnatian (Tobin, 1982; Jennette, 1986; Diekmeyer, 1992 Jennette and Pryor, 1993). The continent was rotated 45° clockwise from its present orientation (Scotese and McKerrow, 1990) and received marine sediments on a gently inclined, northward sloping, carbonate ramp (Hay, 1981; Diekmeyer, 1992). According to ancient oceanic- and wind-circulation estimates, the ramp would have received regular storm input toward the south-southwest.

[1] Holland's most recent update (in press, Journal of Geology, places the Saluda, Whitewater, Liberty, and Waynesville in C5, Oregonia and "Sunset" in C4, Mount Auburn and Corryville in C3, Bellevue and Fairview in C2, and Clays Ferry and Kope in C1.

Although the sedimentological history of the Cincinnatian appears somewhat complex (Hay, 1981), it has been conventional to refer to the concept of a ramp. Because of the ramp, lime to shale "wedges" of sediment overlie one another and thicken in a northerly direction (Hay, 1981). Deposition along the ramp ranged from offshore to supratidal, dominated by inner shelf, open marine sedimentation (Tobin, 1982). In this model, the Kope represents a deeper water sequence at approximately storm wave base, while the Bellevue was positioned above normal wave base (Diekmeyer, 1992). Hurricanes intersected the ramp perpendicularly, or at high angles, resulting in storm surges that brought coarser skeletal material offshore, depositing it atop finer, offshore muds. Such a storm-dominated model has been noted as common in other areas (e.g., Aigner, 1985; Diekmeyer, 1992) and describes the lower Cincinnatian's proximal-distal depositional patterns (Jennette, 1986; Jennette and Pryor, 1993).

Cincinnatian Cyclicity - Several types of cyclical deposition have been noted in the Cincinnatian, at the meter scale and larger. Meter scale cyclicity is found in the thin, alternating limestone and siliciclastic mudstone beds throughout the Cincinnatian and has been documented by numerous workers (Hay and et. al., 1981; Meyer and et. al., 1981; Diekmeyer, 1992; Goldman, 1992; Hay, 1992; Jennette and Pryor, 1993; Holland et al., 1997). Two proposed explanations for these cycles are changes in sea level, and interruptions of carbonate production by storm deposition (Holland, 1993; Jennette and Pryor, 1993).

The larger scale cycles are particularly relevant to this thesis. Observations regarding large scale cyclicity (40 to 200m) have led to the conclusion that the Cincinnatian contains many transgressive -- regressive suites, and these cycles define the paleoenvironmental context of *Platystrophia* in the present study (Anstey and Fowler, 1969; Hay, 1981; Tobin, 1982).

Sequence Stratigraphy - Within the last decade, Cincinnatian sedimentological patterns have been defined within a sequence stratigraphic model. Holland's work defined five, (Holland, 1990) and later six, (Holland, 1993) regressional sequences. These were lithologically correlated to time-equivalent strata in the Appalachian Basin. Sequence stratigraphy divides the stratigraphic record into relatively conformable successions of genetically related strata that are unconformity bounded. The unconformities have chronostratigraphic significance, though not all represent equal time hiatuses (Holland, 1992). Suites of these genetically related facies, or systems tracts, contain lateral facies changes in a system, all of which respond simultaneously within the system.

Holland recognized six sedimentary environments within the sequence framework (Table 1). These correspond to shore-parallel, onshore-offshore environmental suites. Facies tracts moved in the offshore direction as relative sea-level within the basin fell, leaving shoaling-upward depositional packages.

Paleoenvironment	Sedimentary Characteristics	Lithofacies	Biofacies and Morphology of Typical Biota
Bathyl	Color: black to gray. No storm beds;	Black shale; turbidites	Graptolite/trilobite: thin shelled and flat brachiopods
Offshore	Storm beds uncommon; coarser grain size	Shale dominated; medium-bedded carbonates; fine-grained clastics	Onniella: thin-shelled, flat, small brachiopods
Transition Zone	Storm beds common; coarser grain size	Mixed packstone/shale; medium-bedded carbonates; thin-bedded carbonates; fine to coarse-grained clastics	Brachiopod/bryozoa: Larger and thicker shelled brachiopods; more globose, coarsely ribbed
Shoreface	Storm beds abundant; coarser grain size; common shell breakage/abrasion	Wavy/nodular limestone; thin-bedded carbonates; coarse-grained clastics	*Hebertella*: Globose, coarsely ribbed brachiopods with large pedicle openings
Intertidal	Intense bioturbation; decreased shelly benthos; rare desiccation cracks	Bioturbated carbonate mudstone; variegated mudstone; bioturbated sandstone	Lingulid: Thin-shelled burrowing forms most common
Paralic	Desiccation cracks; rare bioturbation; absence of fossils	Laminated calcareous mudstone; unfossiliferous heterolithic facies; channeled sandstone	Lack of body fossils; rare bioturbation

Table 1. Onshore to offshore facies of Cincinnatian Series (also common to Appalachian Basin). Brachiopod fauna, in general, become larger and thicker-shelled in higher energy environments. Descriptions summarized and modified from Holland and Daley (Daley, 1993; Holland, 1990).

Most Cincinnatian strata are defined in a sequence stratigraphic context as highstand systems tracts (Holland, 1992), i.e., a system of facies with conformable contacts that are bounded below by a maximum flooding surface and above by a sequence boundary (Holland, 1992). Collections for this thesis originated predominately from highstand system tract deposits. Repeated vertical shallowing-upward packaging “suggests highstand deposition along a series of shore-parallel belts on a gently sloping, mixed-carbonate-clastic ramp” (Holland, 1992). *Platystrophia* was particularly common in, but not limited to, the shallowest subtidal facies (wavy/nodular limestone) which contained less shale. For the purpose of this study, specimens were collected from as broad a selection of environments as possible in order to maximize comparisons.

Transgressive sequences, in comparison, are relatively thin in the Cincinnatian. They are geographically restricted and often less than 2 meters in thickness (Holland, 1992). They are composed of bioclastic packstones and taphonomically degraded fossil material (Holland, 1993). Such sequences offered little fossil material and were not as useful for the present study.

Using a sequence stratigraphic framework for the Cincinnatian has the advantage of viewing the data in terms of laterally continuous depositional environments each of which serves as a measure of onshore-offshore faunal response to individual depositional systems (Daley, 1993). Each shoaling-upward highstand tract serves as a type of replicated experiment against which paleontological patterns can be tested. This thesis will use these natural cycles as a basis for comparing morphological variation in *Platystrophia*.

Paleontology within the Stratigraphic Context of the Cincinnatian

The Cincinnatian has long been used as a setting in which to study the effect of physical environment on biological inhabitants. For example, Alexander (1975) undertook a quantitative study to document size, and to some degree shape, variation in the strophomenid brachiopod *Rafinesquina alternata*. Shape change was approximated by a combination of linear measures, and Alexander found that there were environmentally induced morphological changes in *R. alternata*. Soon after that investigation, the stratigraphic picture of the Cincinnatian was refined.

In the last decade, against the backdrop of the improved sequence stratigraphic framework, increasingly precise patterns of stratigraphic faunal variation have been documented. For example, Diekmeyer examined large scale stratigraphic and faunal abundance patterns in the Kope through Bellevue formations (Diekmeyer, 1990), and Daley tracked several Cincinnatian taxa within the context of Holland's model (Daley, 1993; Daley, in press); this latter study was noteworthy in finding that the bivalve *Ambonychia* exhibited statistically significant size increases in three shoaling upward cycles.

Recently, the effects of sedimentation and biological interaction were documented in some Richmondian brachiopods. Leighton (1995) completed Alexander's earlier survey on the morphometrics of *Rafinesquina*. Geniculation in Richmondian *Rafinesquina* was found to have varied in response to the physical environment, demonstrating that *Rafinesquina* was phenotypically plastic in a fashion that appeared to be both functional and adaptive. At the same time, *R. alternata* specimens demonstrated character displacement in the presence of *Strophomena planumbona*. Thus, Leighton's work provided detailed evidence within the Cincinnatian of biological variation in direct response both to sedimentation and biological interaction (Leighton, 1995).

The relation of morphology to environment: some caveats At the outset, two caveats should be noted. First, functional considerations constitute only one factor controlling morphological variation, albeit the most testable in this type of study. Two other factors include phylogenetic history and constructional artifacts, remnant products of construction neutral to selection (Seilacher, 1970). Neither of these possibilities is amenable to analysis here and they will be assumed, for now, to be negligible in governing *Platystrophia*'s morphology on a local scale. However, if significant morphological variation is discovered that is found not to reflect environmental variation, it would suggest that phylogenetic and artifactual constraints may be responsible.

Second, because of these other influences, it is possible to attribute functional explanations to morphology where none actually exist (Gould and Lewontin, 1979). For example, it has been proposed that brachiopod alae are optimizations ("wings") for life on soft substrates (Rudwick, 1970). However, because (1) alation has many proposed "functions," (2) alate forms exist across a wide range of environments, and (3) extant alate brachiopods are known to live alongside globose forms, conclusions about alae function in extinct brachiopods must be drawn cautiously (Thayer, 1977). Without the aid of functional morphological analysis, arguing that shell morphology is designed for certain environments based solely on association risks the *ad hoc* argumentation of the "adaptationist programme" (Fisher, 1985). I will, therefore, not equate correlation with causation. Instead, I will make the clarification that the aim of this thesis is to document patterns of *association* between morphology and environment.

Autecology and Functional Morphology of *Platystrophia*: The Interface Between Environment and Morphology

Given its abundance in the Cincinnatian, *Platystrophia* has received surprisingly little attention in the literature. In 1972, Richards described the autecology of several Richmondian brachiopods, including *P. clarksvillensis* and *P. acutilirata*. Six assemblages were described in which *Platystrophia* were believed to have been in their original substrate and living orientations (Richards, 1972). Of these six, *Platystrophia* was found attached to bryozoans in three. Nearly all were found in life position with the beak down and immediately above a shale zone containing bioclastic material, indicating that they were growing with the commissure in a vertical orientation with a short pedicle attachment to a shell, or other bioclast, on or above the substrate. Approximately 50% had epizoan coverage. Outside of this, little is known of *Platystrophia* autecology.

The purpose of this section is two-fold. First, I will provide a review of the previous work on the autecology and functional morphology of *Platystrophia* as a step in establishing a link between *Platystrophia's* environment and morphology. Second, I will present a limited test of an earlier hypothesis that wide-hinged forms of *Platystrophia* exhibited left-right bilateral asymmetry, a conclusion that may bear on the question of the feeding orientation among these forms (Branstrator, 1991). This test confirms the previous hypothesis and, thus, may confirm Branstrator's suggestion regarding feeding behavior in wide-hinged forms. However, since I also found that narrow-hinged forms exhibited the same asymmetry, this questions Branstrator's earlier functional interpretation. I suggest that something other than function was the cause of this phenomena.

Platystrophia

Platystrophia is found on several continents, with the most abundant varieties in North America. Its generic identification is based on internal features, while species level distinctions are based on external features (Fitzpatrick, 1972). Nine traits are most commonly used for such identifications (Alberstadt, 1979). Five shape categories have been recognized by Fitzpatrick, and include (1) transverse, (2) subquadrate, (3) rostrate, (4) acuminate, and (5) mucronate (Fitzpatrick, 1972) (Fig. 1). Each of the five categories contain a rich variety of subtle, intergrading variations. For example, *P. lynx* is a subquadrate form that has long been observed to display a range of variants (Cumings, 1903). The effect of this variation is to produce a spectrum of overlapping forms that are difficult to separate into discrete groups -- one possible reason for the current taxonomic confusion in the genus. This issue will be addressed later in the thesis.

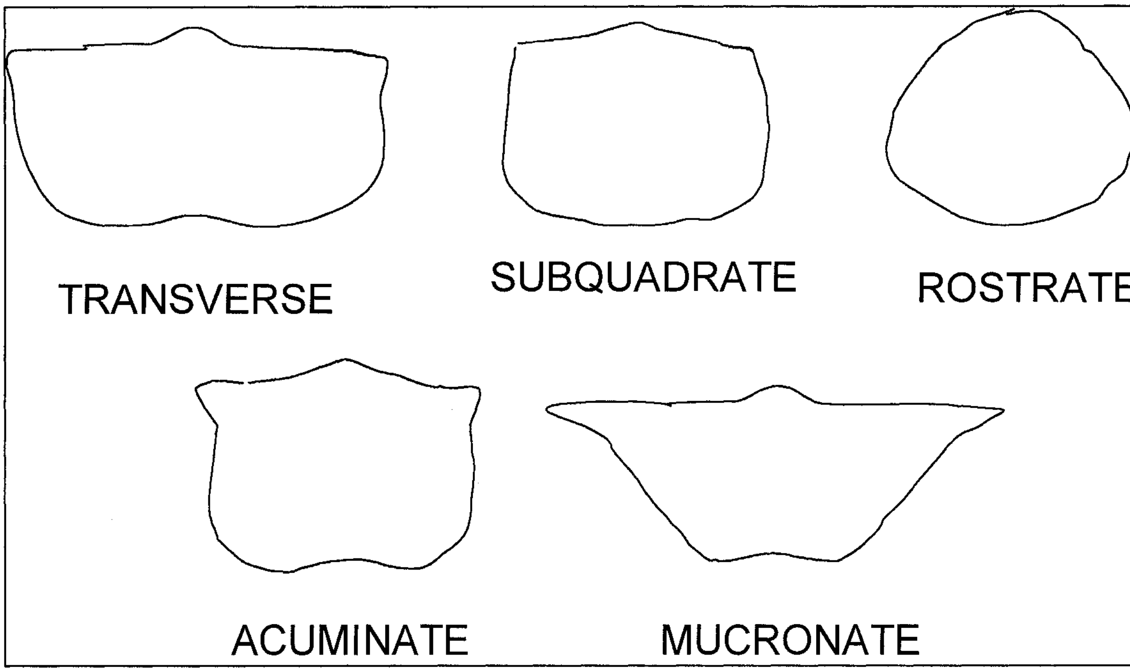


Figure 1. The five general shapes of *Platystrophia* as described in Fitzpatrick, 1972 (viewed dorsally). Shapes are described as transverse (e.g., *P. hermitagensis*); subquadrate (*P. crassa*); rostrate (*P. ponderosa auburnensis*); acuminate (*P. trentonensis*); and mucronate (*P. cumingsi*).

Functional morphology

As a convention, morphology is assumed to have an adaptive purpose. But, as noted earlier, caution must be exercised when applying functional morphology. Such analysis can often provide linkages of shape to function but such plausibility must not be confused with demonstration of true adaptive function (Savarese, 1995). Problems, such as defining an optimal shape, multiple function, stochastic processes in evolution, and the numerous difficulties in understanding the environment and biology of extinct organisms all contribute to the difficulty of understanding structures (Levinton, 1984; Lugar, 1990).

Laboratory Experiments. - Certain constructional designs in brachiopods appear and reappear over time, suggesting that the body plans have functional significance. Cuffey (1993) has documented seven distinct, recurring forms and flume experiments have suggested that certain constructional designs were beneficial for various brachiopod modes of life. Experiments show that the relief of the fold above the plane of the commissure probably helped to separate lateral margin inhalant flow and anterior-medial exhalant flow (Alexander, 1995). Such a function corroborates the study of Fürsich and Hurst (1974) in which high-folded forms were often found in quiet waters. Lower energy environments would provide less ambient current separation, leaving any such separation to be accentuated by shell morphology.

Alate design in *Platystrophia* has been shown to assist in what may be termed "current augmented feeding," where flow direction around the shell creates backflow currents that retain food particles near the incurrent gapes (Branstrator, 1991). An orientation of the anterior-posterior axis in a direction diagonal to oncoming currents is thought to facilitate this function, simultaneously assisting both incurrent flow and excurrent water flow (Fig. 2). Studies on living brachiopods confirm the utility of this arrangement by showing that currents flowing directly into the incurrent chamber (i.e., parallel to the anterior-posterior axis) create too much pressure for effective expulsion elsewhere (LaBarbera, 1977). In addition, several types of living brachiopods have been observed to orient themselves according to current direction (LaBarbera, 1977; LaBarbera, 1978).

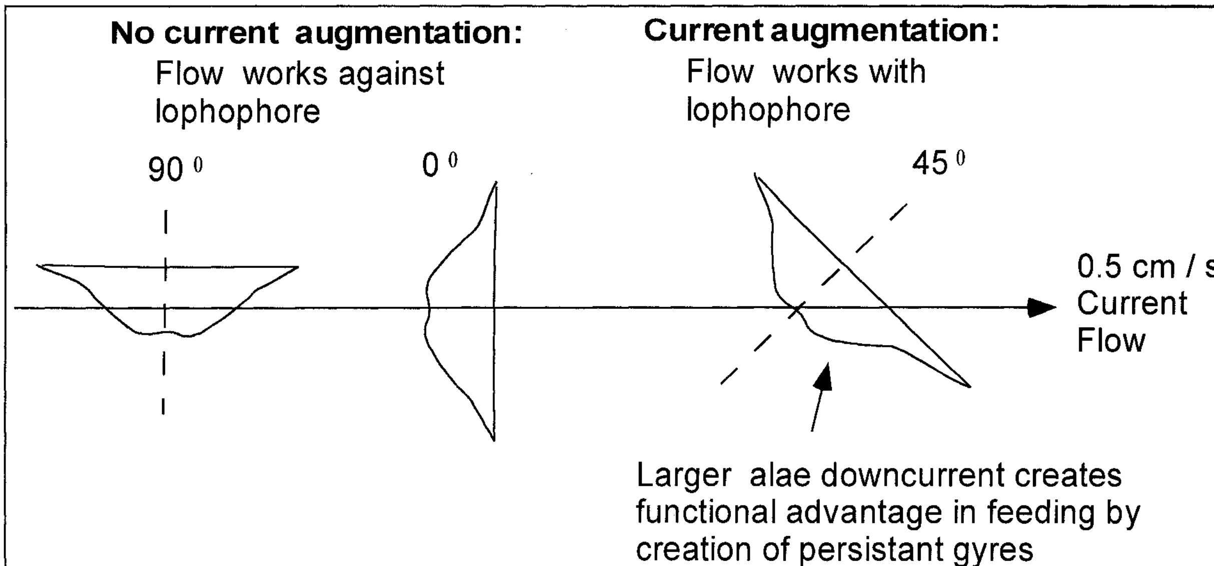


Figure 2. Diagram depicting "current augmented feeding" in *Platystrophia*. Flume tank experiments demonstrated the functional advantages of shell position in relation to water current and possible explanation for asymmetry in alae length (from Branstrator, 1991). Shell position at 90° neither allows current to effectively bring food in, nor remove wastes; shell oriented at 0° brings food into shell, but inhibits removal of wastes. The median position facilitates both feeding and waste removal. In addition, when longer alae were oriented downcurrent they may have created water gyres over shell. This would have been useful in entrainment of food.

Studies also show that ribs on the alae enhanced water flow with no increase in energy expenditure to the animal. Flume experiments on *P. laticosta, P. ponderosa,* and *Paraspirifer bownockeri* have shown that rotational flow around the shell is increased while creating food entrainment near the lateral edges (Slaughter et al., 1987). At the same time, ribs also aid in separating incurrent and excurrent water pathways. Overall, it is clear in the above cases that shell morphology can assist life functions while minimizing waste of energy by the animal, thus serving to budget energy needs.

In the context of alae function, one simple functional test made on *Platystrophia* involved reported bilateral asymmetry of alae -- an adaptation assumed to enhance downcurrent feeding (Branstrator, 1991). Branstrator found that water motion over alae of wide-hinged forms enhanced feeding and may have been a reason for bilateral asymmetry. However, this important claim about alae asymmetry was not quantified. That the alae were used possibly for downcurrent feeding is one of the very few published claims about *Platystrophia*'s functional morphology. As a sidelight to this thesis, such an evaluation was conducted on *Platystrophia*; the results also serve as an illustration of the difficulty in establishing functional claims. This investigation is described below.

Asymmetry test. - Specimens used in this test comprise those collected from this thesis and range from the Kope through Whitewater formations (see below). Morphometric data were collected in the form of landmarks and were converted into distance measurements between the points in question. (Data collection and analysis procedures are described in the "Materials and Methods" section, below). To measure the alae, three landmarks -- both alae tips and the umbo position -- were taken directly off of the video image on the computer screen by locating the desired points with the mouse and clicking landmark locations. Data was transferred to a *Microsoft Excel* spreadsheet for manipulation and statistical analysis. Asymmetry was designated as any difference in shell length, right side minus left side (R-L), as viewed ventrally. Differences examined were (1) across the inclusive data set, (2) for wide and narrow-hinged forms separately, and (3) by locality.

Results. - Bilateral asymmetry of both wide- and narrow-hinged shells was verified here. Wide-hinged forms are defined as those whose hinge-length forms the maximum component of shell width. Two interesting features of this asymmetry are evident from the data (Table 2 and Fig. 3). The type of asymmetry observed in the inclusive data set does not show a dominance toward one particular side of the shell (Table 2, both descriptive statistics and paired t-test results; raw data are tabulated in Appendix A). R-L differences also randomly fluctuate around a mean near 0 with a variance of about 5mm in either direction (Fig. 4; Table 2)

Based on these results it is unclear if Branstrator's suggestion of selection of asymmetry is warranted. First, compactional deformation can create asymmetry which is hard to distinguish from the original biological asymmetry. Vertical and lateral shape changes are common among many fossil groups, including brachiopods (Ferguson, 1962; Webster and Hughes, 1999). Second, even assuming the biological asymmetry is preserved the pattern of differences creates a normal-shaped distribution around the value of 0. It is, therefore, more likely that any selection in these specimens is for 0 difference in alae length (i.e., selection for "symmetry"). It may be possible that a functional advantage is conferred upon specimens displaying asymmetry in alae length, but this does not appear to be a target of selection -- rather, the most strongly asymmetric forms are outliers (Figs. 3-5).

Descriptive Statistics		t-Test: Paired Two Sample for Means		
			Right	Left
Mean	-0.01658	Mean	11.12477	11.14135
Standard Error	0.044186	Variance	16.55615	17.02835
Median	-0.00411	Observations	714	714
Standard Deviation	1.180676	Pearson Correlation	0.958588	
Kurtosis	2.444776	Hypothesized Mean Difference	0	
Skewness	0.27509	df	713	
Range	10.17266	t Stat	-0.37525	
Minimum	-4.5898	P(T<=t) one-tail	0.353792	
Maximum	5.582858	t Critical one-tail	1.646995	
Count	714	P(T<=t) two-tail	0.707584	
		t Critical two-tail	1.963299	

Table 2. Descriptive statistics for alae asymmetry data and paired t-test for length of right vs. left alae. Length of alae on right side are statistically indistinguishable from those on the left. (Fig. 4 histogram provides a graphical representation).

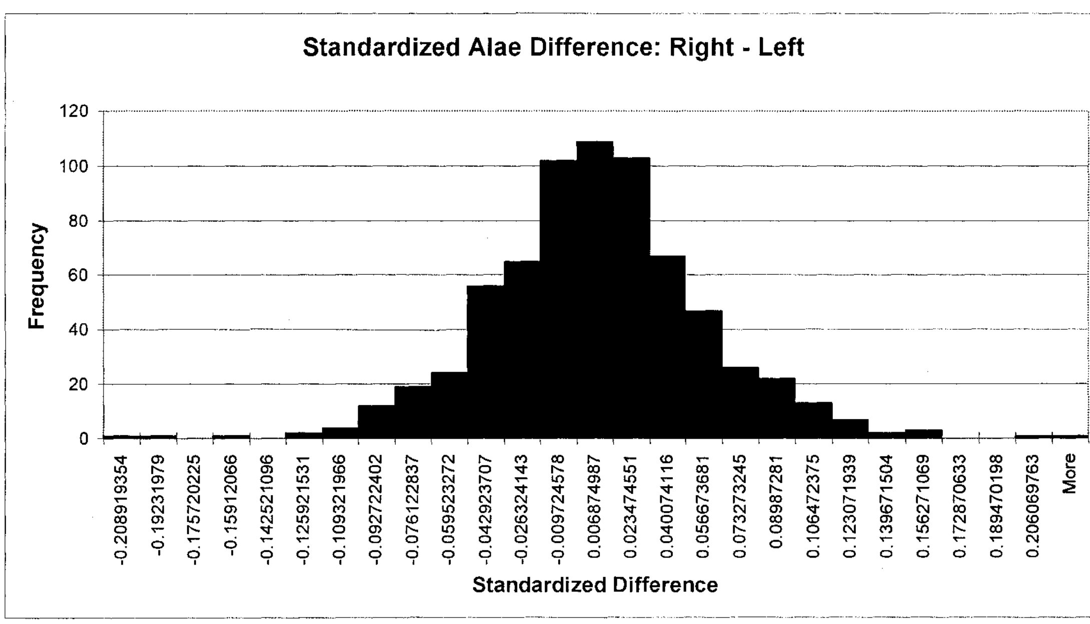


Figure 3. Histogram for the distribution of size standardized Right - Left (R-L) differences in the inclusive *Platystrophia* data set. Asymmetry in data are normally distributed and therefore randomly fluctuating. Note the strong symmetry around mean 0.

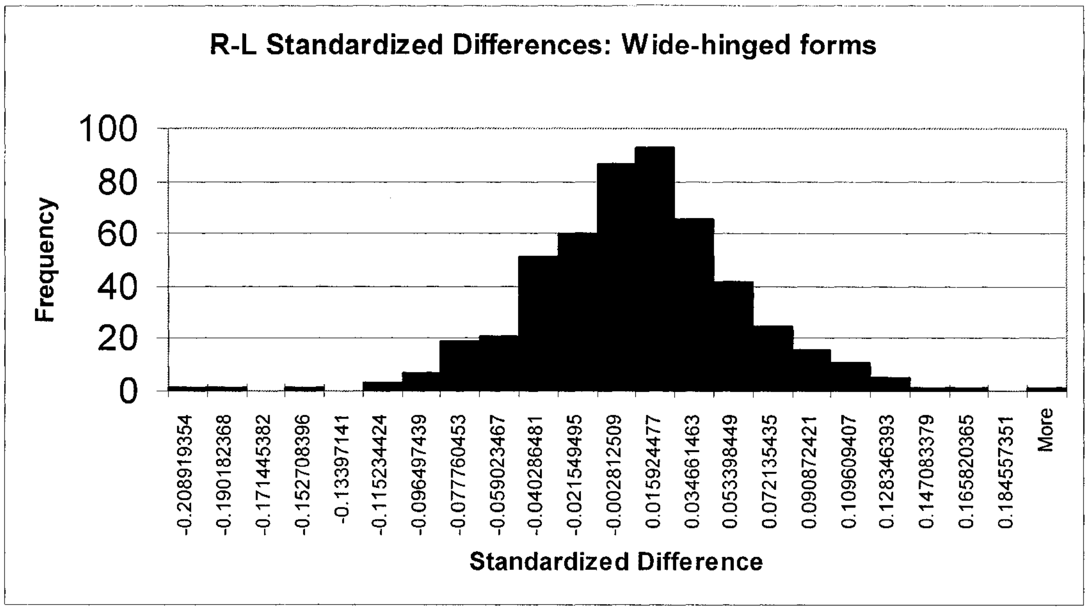


Figure 4. Histogram of R-L size standardized differences for wide-hinged Platystrophia. The normal distribution indicates a randomly fluctuating variation around a mean of 0.

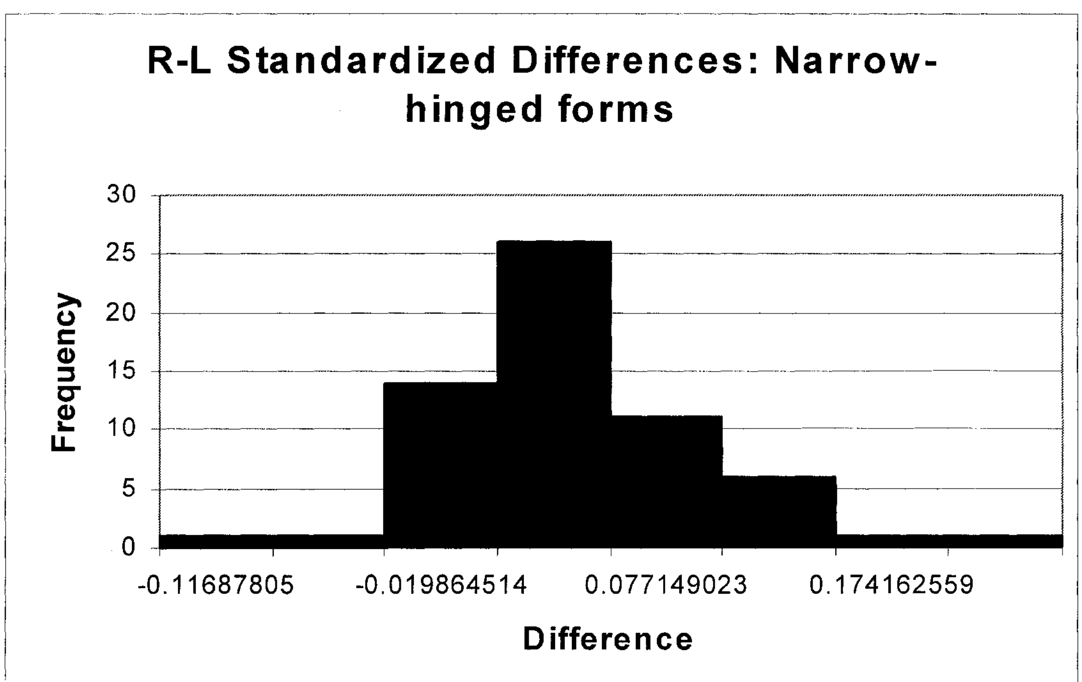


Figure 5. Histogram of R-L differences for narrow-hinged *Platystrophia* (Mt. Auburn Formation). The distribution indicates a nearly randomly fluctuating variation around a mean of 0.3 mm. If wide-hinged forms display asymmetry for functional reasons (Branstrator, 1991) it is unclear why asymmetry is as common in the narrow-hinged forms for which currents would have much different affects.

Assuming a biological pattern is preserved, a non-functional interpretation is also possible. This does not preclude a functional role to alar asymmetry, but may be a more reasonable interpretation given the strong tendency in the data for symmetry. Asymmetry has been interpreted in recent years as genetic in origin and with implications important to macroevolution. Fluctuating Asymmetry (FA) is one of three types of organismal bilateral asymmetry and is seen as a possible indication of high genetic homozygosity (Smith, 1994; Palmer, 1986).

Since Branstrator's original functional claim involved only wide-hinged brachiopods, any presence of asymmetry in narrow-hinged forms would raise the possibility that this asymmetry may transcend function (assuming the functional advantage is lost in the narrow-hinged forms). To test this, asymmetry among narrow-hinged forms was investigated alongside that of wide-hinged forms.

Indeed, wide-hinged forms display a pattern of asymmetry that is rather similar to narrow-hinged forms (compare Fig. 4 and 5). A Mann-Whitney rank sum test yielded no statistical difference between these two populations. Group medians are similar and comparisons between groups yields a p-value of 0.248 (Table 3; Fig. 6). There are two implications for these results, both of which cast doubt on Branstrator's view of asymmetry function. First, if wide-hinged forms manifested asymmetry for functional reasons then narrow-hinged forms displaying a similar phenomena would be expected to do so for the same reason. However, because of the great difference in overall morphology, the flow geometry of water around the two forms is most certainly different. The wide-hinged forms that Branstrator tested assume Fitzpatrick's "transverse" or

Mann-Whitney Rank Sum Test: Asymmetry of Wide vs. narrow-hinged *Platystrophia*			
Group	N		
Wide-hinged	519		
Narrow-hinged	62		
Group	Median	25%	75%
Wide-hinged	-0.0464	-0.693	0.528
Narrow-hinged	0.0548	-0.728	1.374
T = 19487.0 n(small)= 62 n(big)= 519 (P = 0.2476)			
P = 0.248			

Table 3. Results for Mann-Whitney rank sum test on differences between wide and narrow-hinged *Platystrophia*. Wide-hinged and narrow-hinged forms show no statistically significant differences. There is equal asymmetry in both narrow and wide-hinged forms, suggesting something other than functional reasons as the cause.

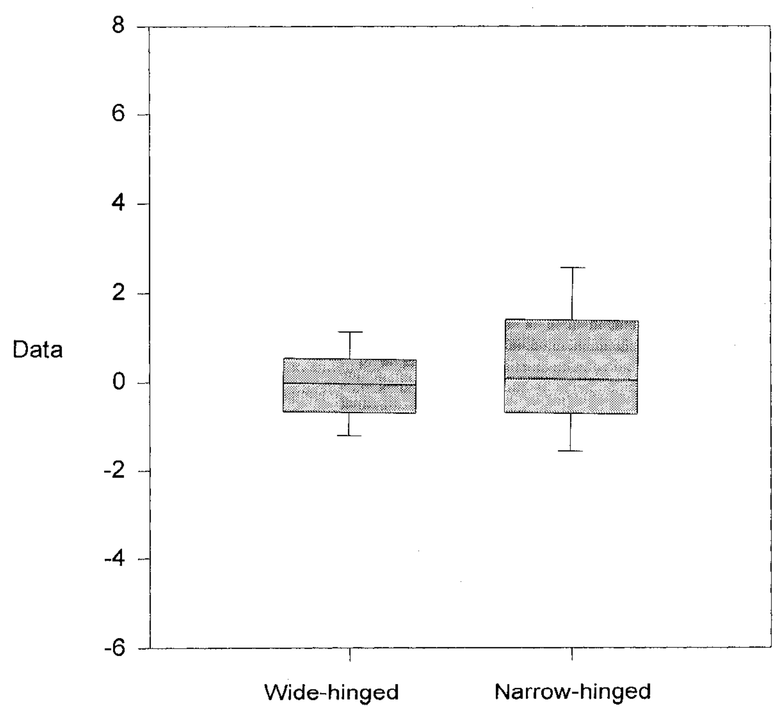


Figure 6. Mann-Whitney rank sum box chart depicting differences among wide and narrow-hinged *Platystrophia*. No significant difference is seen between these two populations.

"mucronate" morphologies. In contrast, the narrow-hinged forms assume the "rostrate" morphology (Fig. 1). It seems unlikely that water flow around such different shell geometries would be similar, but this needs to be tested before discounting it.

The other possibility is simply that the asymmetry is a result of some non-functional cause, such as fluctuating asymmetry. If this is the case, then Branstrator's earlier claims must be held as tentative since genetic variability might be swamping out -- at least some of -- the functionally adaptive effects of *Platystrophia*'s shell morphology. As a result, for this thesis, I cannot make *a priori* assumptions regarding *Platystrophia*'s particular functional designs; rather, I will assume that generally known principles of brachiopod design apply (e.g., Rudwick, 1970; Fürsich and Hurst, 1974). Either way, *Platystrophia* warrants further study, both in terms of function and fluctuating asymmetry.

Methods

Field Collections and Preparation

A total of 1096 *Platystrophia* specimens were sampled from 23 Cincinnatian localities in the tri-state area of Indiana, Kentucky, and Ohio (Fig. 7). Specimens were collected from a wide stratigraphic and geographic range to sufficiently sample *Platystrophia*'s Cincinnatian variation. Samples were coded by locality and are keyed to Appendix C (Fig. 7, Table 4). The goal of collection procedures was to acquire a representative sampling of *Platystrophia* in sufficient numbers for a thorough statistical analysis of the morphological data.

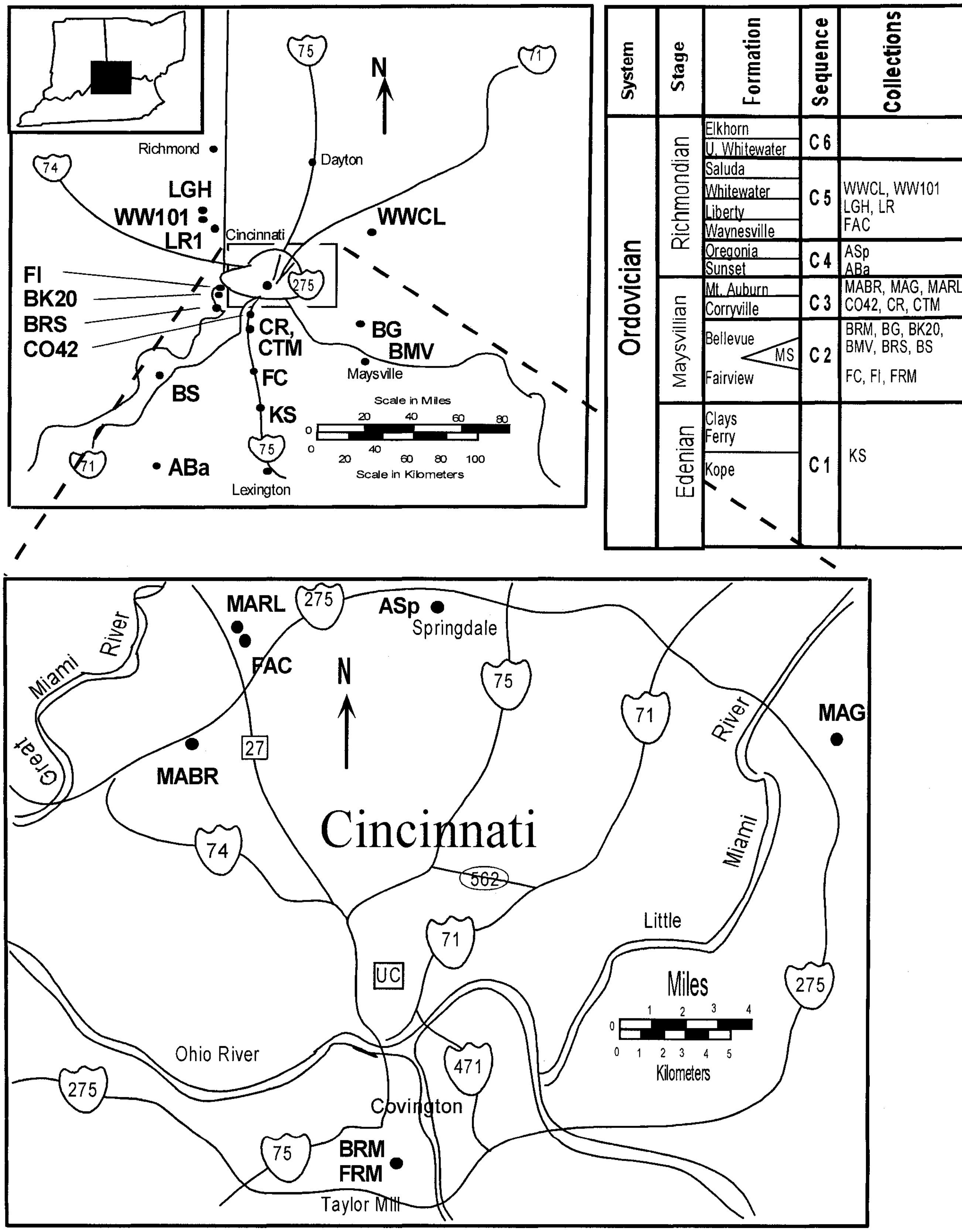


Figure 7. Collection localities throughout the exposed Cincinnati arch. Tri-state region in upper left, with expanded area surrounding Cincinnati, below. Localities are coded to Table 1 and described in Appendix C. Stratigraphic placements of *Platystrophia* collections, upper right (modified from Holland, 1993).

Code	*Locality*	*Formation*	*Specimen No.*
Aba	Bardstown, Kentucky	Sunset **	975-979
Asp	Springdale, Ohio	Oregonia	980-983
BRM	Reidlin/Mason Road, Covington, Kentucky	Bellevue	594-629
BG	Georgetown, Ohio	Bellevue††	681-743
BK20	Exit 20, Petersburg, Kentucky	Bellevue	661-680
BMV	Maysville, Kentucky	Bellevue*†	630-660
BRS	Rising Sun, Indiana	Bellevue	744-809
BS	Sulphur, Kentucky	Bellevue*	1-186
CO42	Old 42, Florence, Kentucky	Corryville	829-871
CR	Richwood, Kentucky	Corryville	810-828
CTM	Thomas More Parkway, Covington, Kentucky	Corryville	872-897
F1s3	Corinth, Kentucky	Fairview	531-560
FACA	Cincinnati, Ohio	Waynesville	984-1005
FI	Idlewild, Kentucky	Fairview	481-530
FRM	Reidlin/Mason Road, Covington, Kentucky	Fairview†	561-593
KS	Sadieville, Kentucky	Kope	187-196
LGH	Garr Hill, Brookville, Indiana	Liberty	1030-1061
LR	Route 1, South Gate, Indiana	Liberty	1006-1029
MABR	Blue Rock Road, Cincinnati, Ohio	Mt. Auburn	901-942
MAG	Goshen, Ohio	Mt. Auburn	958-974
MARL	Rumpke landfill, Cincinnati, Ohio	Mt. Auburn	943-957
WW101	Route 101, Brookville, Indiana	Whitewater	1062-1096
WWCL	Cowan Lake, Ohio	Whitewater	197-480

* Replaces traditional "Grant Lake" (Holland, 1992)
** Holland (1992) suggests renaming of "Sunset"
† Denotes lumping of two or more nearby beds
†† Denotes lumping of two nearby localities

Table 4. Localities, formation, and specimen numbers for collections. Location names are coded to map (Fig. 1) and Appendix C. Descriptions of collection sites are found in Appendix C.

Information on lithology and stratigraphic position was logged for each collection. Detailed measured sections of previous workers were consulted when available (e.g., Diekmeyer, 1992). Samples were labeled by letters corresponding to Formation and locality (Table 4) and are included on the locality maps and generalized stratigraphic section (Fig. 7). For example, WWCL represents the Whitewater Formation (WW) at Cowan Lake (CW) and is located on the upper tri-state map, as well as the adjoining stratigraphic chart next to "Whitewater"; likewise, MABR represents Mt. Auburn (MA) at Blue Rock Road (BR) in Cincinnati and can be seen on the lower Cincinnati map and adjoining stratigraphic chart.

Platystrophia collection sites are numerous within the type Cincinnatian, but not all were ideal for this project. Since the purpose of this thesis was to examine patterns in morphological variation statistically, several features pursuant to the goals of the study were sought. These were (1) wide geographic distance between collections in the same formation (at least two distant sites per formation were sought), (2) a large number of available specimens (at least 25-30 high quality specimens) per site, and (3) confinement to a single bedding plane, to minimize as much as possible, the problem of time averaging. Some sites (Table 4) combine collections from different beds (e.g., Maysville) and, in one collection, I combined specimens from two locations in very close proximity (Georgetown, Ohio). This was done to explore differences between single horizon vs. multiple horizon sites. Since data collected from single horizons expressed the same variability as those from multiple horizons, they can be viewed as equivalent in this case (see below).

Most specimens were found as free-lying individuals. These were collected, bagged, labeled and taken back to the laboratory for preparation. Because of their high quality and quantity, many specimens required little preparation. Matrix on specimens was removed by chiseling; mud was removed through soaking in water and vigorous scrubbing. Since landmark analysis (see below) only required the visibility of certain morphological points, not every piece of exterior matrix had to be cleaned off every fossil, thus minimizing preparation time.

Because examination of morphology was the primary focus here, the possibility of post-mortem compaction has to be considered. However, the likelihood of compaction is minimal because *Platystrophia*: (1) is found in predominately coarse-grained limestones, rather than shales, (2) has a thick recrystallized shell, and (3) is oriented randomly within beds (easily testable though not tested here). The rigidity of the limestone bedding in which the majority of specimens was found limited the amount of compaction. The degree of compaction in calcareous sediments, particularly in fossil rich sediments, is much less than in non-calcareous sediments (Ferguson, 1962; 1963). Further, random orientation of fossils eliminated preferential compactional distortions. For instance, if all fossils on a bedding plane were oriented with the ventral side down and experienced a single direction of deformation (e.g., in a dorso-ventral direction), then all specimens would have a uniformly distorted height. Such uniform compaction in a suite of *Platystrophia* could have been confused with a true shape characteristic in some *Platystrophia* (i.e., flattened, as opposed to globose, dorso-ventral inflation -- an important morphological distinction). However, since specimens were randomly oriented within rock units, a singular compaction direction would create randomly diverse deformation features in individuals-- a feature that would show up as high variance in morphological shape around a central mean (Bambach, 1973). Finally, all specimens were examined visually for compaction prior to collection, and again before measurement. Compaction in Cincinnatian *Platystrophia* was most commonly manifested as obvious asymmetric distortions in shape -- similar to the appearance of melted plastic. Those exhibiting such distortion were not measured.

Morphological Data -- Materials and Methods

Samples were measured using the image analysis capabilities of a Power Macintosh 7100/66, Power PC, connected to a Sony CCD-IRIS/RGB color video camera. The camera was mounted with a telescopic lens to capture images of the brachiopods mounted directly below on the surface of a cubic orienting surface. Images from the camera were captured in the Power PC on the NIH Image 1.45 software package.

Images were viewed in two orthogonal positions to most efficiently capture all landmarks of interest (15 points on the anterior face; 6 on the ventral surface; Fig. 8). A procedure was developed that enhanced both speed and efficiency. For the measuring procedure, landmarks difficult to spot were pre-marked with a

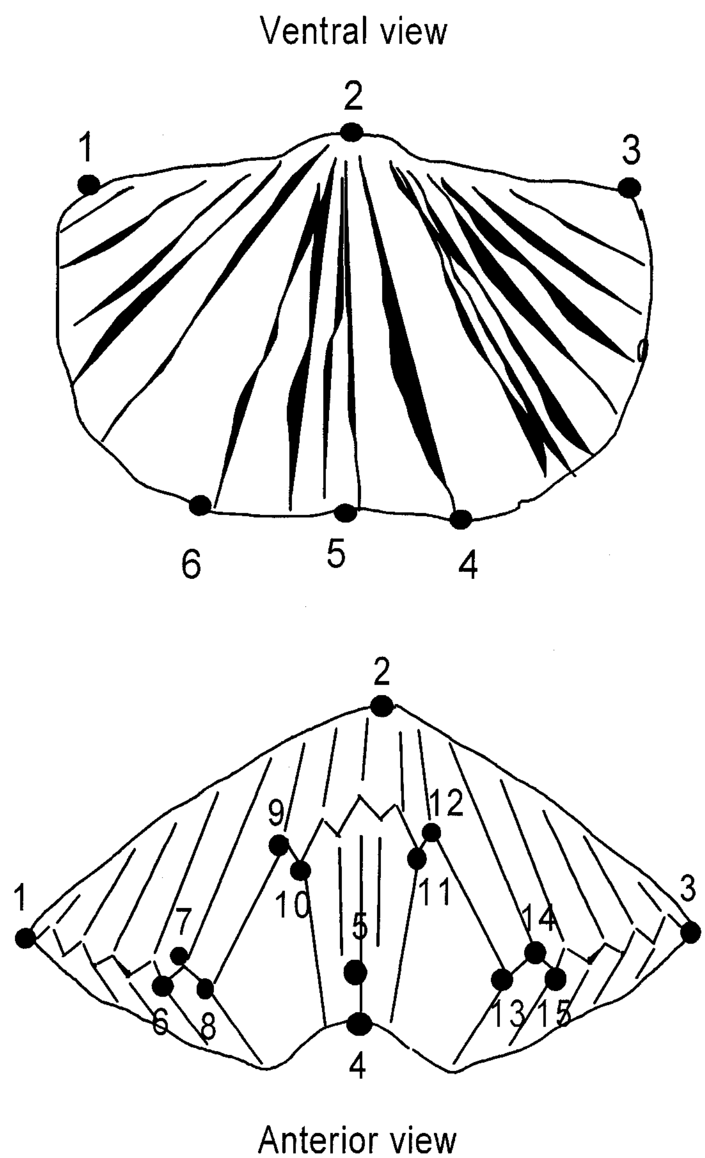


Figure 8. Generalized ***Platystrophia*** **shells showing morphological landmarks. Ventral view: 1, left alae extremal point; 2, umbo; 3, right alae extreme; 4, conjunction of commissure and right edge of sulcus; 5, median anterior extreme; 6, conjunction of commissure and left edge of sulcus. Anterior view: 1, left extreme; 2, dorsal extreme; 3, right extreme; 4, ventral extreme; 5, intersection of projected median axis and plane of commissure; 6, shell conjunction of rib and commissure for first, 7, second, and 8, third commissure point on left side; 9 and 10, conjunction of commissure, rib, and sulcus for dorsal left side of shell; 11 and 12, mirror of 9 and 10, for right dorsal commissure conjunctions; 13-15, conjunction of rib, commissure, and sulcus for the right side.**

Uniball Micro pen. Specimens were then mounted upon the orienting platform by placing the dorsal surface within clay while using the cube's orthogonal faces as guides for specimen orientation. Specimens were mounted with the plane of the commissure parallel to the "top" plane of the orienting surface while the plane of the sulcus gape was oriented parallel to the "front" face of the cube. This posture allowed quick, unhindered view of all landmarks with only one rotation of the orienting platform. To verify the accuracy and consistency of this procedure, a test specimen was measured multiple times and the results plotted; they are discussed below.

Landmark Analysis

The morphometric description of *Platystrophia* was based on landmark locations. Landmarks are discrete points of anatomical similarity and are commonly used in studies of morphological variation (e.g., Bookstein, 1991; Foote, 1991). The chosen landmarks represent ten extremal points and eleven anatomical conjunctions (Fig. 8). Landmarks were chosen to give extensive morphological coverage of individual specimens in a way that could be captured for all *Platystrophia* specimens. Each location had to be defined clearly, present on all measured specimens, and easy to locate via image analysis. Some landmarks were chosen because they represented morphological size delimits (i.e., extremal points). Others were chosen because they marked the conjunctions of anatomical features that merited attention (i.e., intersection of commissure and ribs). Landmarks were also chosen to reflect bilateral symmetry in both the ventral and anterior views for the purpose of comparing asymmetry among specimens. For example, landmarks 16 and 21 on the left side, mirror landmarks 18 and 19 on the right side (as projected across the anterior-posterior medial plane represented by points 17 and 20).

In landmark analysis, homologous points are chosen to allow comparison between different specimens. The tremendous morphological variability of *Platystrophia* created difficulty for some landmark choices. Because of this, a few landmarks expanded the conventional landmark definitions to account for *Platystrophia*'s range in variability. Rib numbers are one instance. Rib number within the sulcus are an important feature on many brachiopods. For *Platystrophia*, this number varies from 1 to 7, with 82% having 3 ribs. In order to accommodate this, landmarks 8-10 and 11-13 were chosen in order to describe the first groove inside the sulcus, left and right side respectively. In this way, the specimens with non-homologous rib numbers could be included. At the same time, rib counts and distance across the sulcus preserved the features as separate variables. Another problem for many specimens was the extension of alae relative to overall width. For these morphologies, landmarks 16 and 18 were equated with 1 and 3 (overall width) when viewed anteriorly. In order to preserve the distinction between overall width and alae length, alae length was measured from the ventral perspective and included as a separate variable. A third non-conventional landmark assignment was point 5, a projection in space. This was chosen to capture the height of the sulcus above the medial plane (points 5 to 2). It was chosen due to large variations in sulcus height among some forms. This point showed some redundancy with overall specimen thickness (points 4 to 2) for principal component 2, but showed separation on component 3.

Morphospace representation of specimens was recorded as both landmark distances and scaled Cartesian coordinates. The first approach involved simple distance estimates between two landmarks to acquire raw distances such as organism width (Fig. 9). For most questions this approach was sufficient. A table of raw measures for all data is given in Appendix B.

The second approach involved scaling specimens by two landmarks and deriving Cartesian coordinates for all landmarks, all oriented to a common specimen orientation. The morphometric variables in this approach are the Cartesian coordinates for each landmark rather than the distances (Tabachnick and Bookstein, 1990; Bookstein, 1991; Foote, 1991). The fifteen anterior landmarks and six ventral landmarks are translated such that, in an *X/Y* coordinate plot, one point represents (0,0) and a second (0,1) with all subsequent points scaled to this unit distance. Geometrically, the transformation of landmarks to a common baseline is accomplished by two simple formulas:

$$v_1 = \frac{(X_B - X_A)(X_C - X_A) + (Y_A - Y_B)(Y_C - Y_A)}{(X_B - X_A)^2 + (Y_B - Y_A)^2}$$

$$v_2 = \frac{(X_B - X_A)(X_C - X_A) + (Y_B - Y_A)(X_C - X_A)}{(X_B - X_A)^2 + (Y_B - Y_A)^2}$$

where v_1 and v_2 are the transformed x and y coordinates of landmark “C” with regard to baseline A (0,0) and B (0,1).

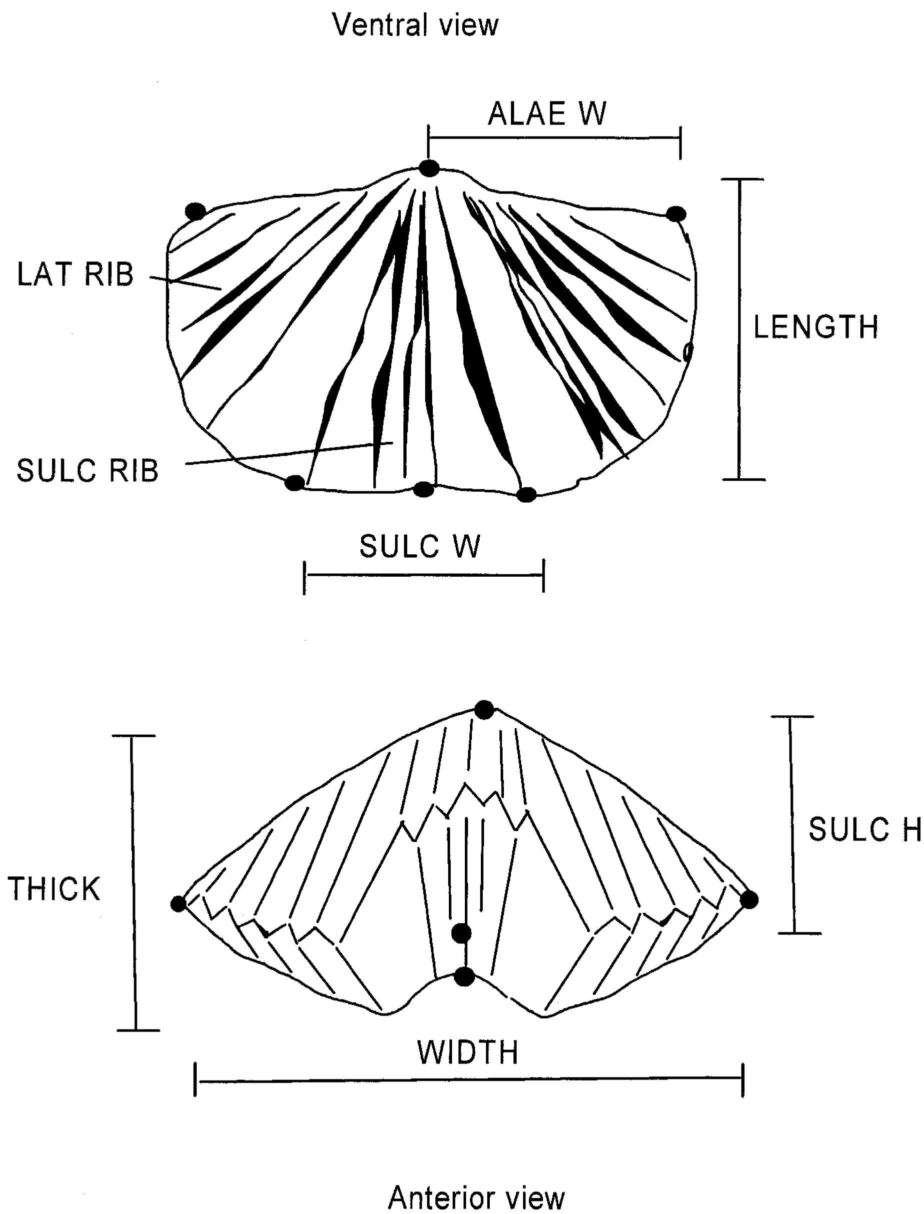


Figure 9. The variables measured from *Platystrophia*'s landmarks are the basis for most analyses. Ventral view: ALAE W, width of alae or distance between umbo and alae tip; LENGTH, or distance from umbo to medial anterior point; SULC W, the width of the sulcus, defined as the point where the commissure flexes dorsally as it crosses into the sulcus; LAT RIB, lateral rib number from edge of sulcus to alae; SULC RIB, rib number within the sulcus. Anterior view: WIDTH, distance between left and rightmost extreme end of shell; THICK, thickness, or dorso-ventral inflation; SULC H, distance between anterior extreme and projected intersection of commissural plane with dorso-ventral medial plane.

In this study, landmarks 8 and 13 represent the unit distance for the anterior face, while landmarks 4 and 6 comprise the unit distance for the ventral face. An example of landmark Cartesian coordinate data is prescribed in Appendix D. These points were chosen for two reasons. First, a feature visible in both anterior and ventral views was needed in order to relate all landmarks to a common distance. This would allow landmarks in both views to have a common scale. Second, the overall width, though visible in both measuring orientations, could not be chosen due to the problem of landmark overlap in wide-hinged specimens.

To assess the repeatability of measurements, a single specimen was re-measured at random times through the study (No. 33, at the Sulfur locality). This procedure provided a measure of inconsistencies in the imaging and specimen remounting process. Assuming perfect measurement methodologies, random re-measurement of a single specimen would result in the exact landmark coordinates each time. Within-specimen replications showed a negligable amount of scatter (Fig. 10) with small standard deviations (Table 5). Between-specimen variation is at least an order of magnitude greater than within-specimen variation. Small variation within the test specimen measurements combined with substantially less variation in comparison with the overall data indicate consistency in the imaging, mounting and measuring process.

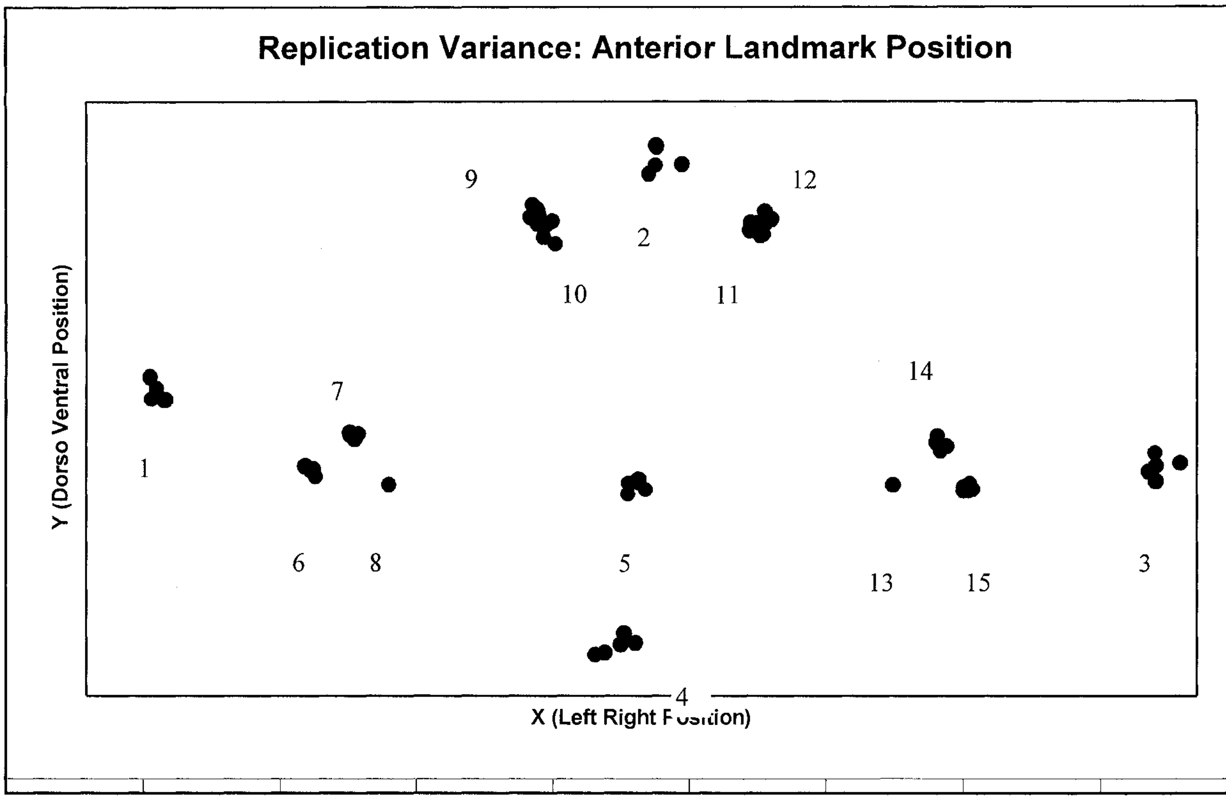


Figure 10. Scaled Cartesian coordinate positions for five replicate measures of *Platystrophia*'s fifteen anterior landmarks on a single specimen. Ideally, all points should share the same coordinate values. The tight clustering of points demonstrates high repeatability of measures. Numbers are keyed to landmarks in Fig. 8.

	Landmark Number				
X Values	*1*	*2*	*3*	*4*	*5*
Mean	-0.45952	0.538083	1.525555	0.45106	0.490835
Median	-0.46154	0.530256	1.518193	0.460454	0.495054
Standard Deviation	0.013496	0.025185	0.024042	0.03197	0.014917
Sample Variance	0.000182	0.000634	0.000578	0.001022	0.000223
Range	0.029567	0.065183	0.062227	0.080213	0.035269
Minimum	-0.47428	0.516537	1.505022	0.409819	0.474951
Maximum	-0.44471	0.581719	1.567248	0.490032	0.51022
Count	5	5	5	5	5
Y Values	*1*	*2*	*3*	*4*	*5*
Mean	0.214082	0.763981	0.042115	-0.38189	-0.00373
Median	0.199667	0.751667	0.045058	-0.37996	0.001936
Standard Deviation	0.023514	0.029519	0.024101	0.020083	0.014095
Sample Variance	0.000553	0.000871	0.000581	0.000403	0.000199
Range	0.053255	0.067783	0.064952	0.050319	0.035852
Minimum	0.197522	0.72915	0.00896	-0.40323	-0.02294
Maximum	0.250777	0.796934	0.073912	-0.35292	0.012909
Count	5	5	5	5	5

Table 5. Descriptive statistics for replication variance in landmarks 1 - 5: the most crucial locations used in this study (data for Figure 10).. Note low standard deviations.

Statistical Methods

Several types of statistical methods were employed to analyze landmark data. In general, multivariate and bivariate tests were used to analyze larger patterns in the data while multiple and single group comparisons were used to distinguish significant differences among groups of specimens identified in multivariate analysis.

Multivariate Methods

Principal Component Analysis -- Data were entered into the *SYSTAT 5.2.1* statistical software package and analyzed for principal components. The purpose was to transform morphological parameters into representations of the most important, or principal, features of the data (Davis, 1973). Associations among morphology and time, space, and other specimens were determined in scatter plots of component scores. This was performed by entering scores into *Harvard Chart XL 2.0* and symbol-coding specimens by formation, locality, and biological association. Colored scatter points were viewed in three dimensions -- as three perpendicular component axes -- and associations examined for patterns. Principal component analysis defined groupings of specimens the significance of which were assessed by paired and group comparison statistics.

Comparison Statistics

Hypothesis Testing -- Many questions addressed in this thesis were in the form of a comparison among two or more populations of brachiopods. It was important to know when samples were significantly different. For this reason, techniques were used that tested a null hypothesis that was either rejected or accepted (fail to reject) based on a probability (*p* value). If a *p* value was extremely small, it was considered that the populations were different (i.e., the null hypothesis was rejected). By convention, a probability of less than 0.05 was considered small enough to reject the null hypothesis -- only 5% of true null hypotheses are rejected at this value. Probabilities larger than these were considered products of chance and such populations were deemed not significantly different with regard to those features.

Mann-Whitney Rank Sum and t-Tests -- Two populations that appeared to score differently by principal component analysis were tested to determine whether the differences were significant. Mann-Whitney Rank Sum tests were used most frequently since principal component scores were regarded as non-parametric data. In Mann-Whitney tests significant differences in sample medians are identified rather than means (as in t-tests); (Siegel and Morgan, 1996). T-tests were used to confirm Mann-Whitney results when on possible. When parametric tests can be used they provide more sensitive tests than non-parametric tests (such as Mann-Whitney Rank Sum tests).

Kruskal Wallis and Analysis of Variance (ANOVA) -- Differences in component scores were tested for groups sorted by geography, locality, or biological association. As with paired comparison data, the component data required a non-parametric procedure. In the Kruskal-Wallis test the average rank is used to derive the test statistic *H*. Large *H* values indicate that there are statistically significant differences among at least some of the groups (Siegel and Morgan, 1996). Kruskal-Wallis differences were isolated by Dunn's Pairwise comparison methods (Dunn, 1964) to determine which samples were statistically unique.

Bivariate

Linear Regression – Least-squares linear regression was used to assess relationships among pairs of size variables. In least-squares linear regression, the magnitude of a dependent variable is considered to be a function of the magnitude of an independent variable, and the significance of this relationship can be assessed statistically.

Results and Discussion

Size and Paleoenvironment

Correlations among paleoenvironment and morphology were examined with both univariate and multivariate data. Specifically, the cyclicity of the Cincinnatian Series' onshore/offshore facies tracts were tested against size related morphological factors to determine whether statistically significant differences were evident. Size related morphometric parameters were plotted against stratigraphic position and examined for correspondence.

Size Parameters

To test body size changes in *Platystrophia*, an appropriate univariate proxy for size was chosen to compare with stratigraphic position. Of the morphometric data collected, three variables provided information on overall size -- width, length, and thickness. Regression analysis was performed in order to assess relationships among these variables. Significant correlation for these parameters would validate their interchangeability as proxies for body size; lack of correlation would signify complex ontogenetic histories and complicate the interpretation of these parameters as purely size related measures.

Use of logarithmic transformations for determining shape changes is a common morphometric technique (e.g., Imbrie, 1956, Gould, 1966, McKinney, 1984). For most organisms, the power function $y = bx^k$ (where x and y are morphological variates) approximates shape change. Logarithmic transformation of this equation allows analysis of the variates in terms of linear relationships. The equation then becomes *log y = log b + k(log x)*. where *k* represents the growth ratio of shape change (i.e., *y* relative to *x*). Least squares linear regression was used to estimate *k*. In this analysis, thickness and length were plotted as functions of width with *k* representing rates of change. Tables 6 and 7 shows basic descriptive data for the three variables.

Thickness vs. Width. - Considerable overlap among *Platystrophia* specimens is evident in the thickness (dorso-ventral separation) versus width scatterplot presented in Figure 11. The implications of this observation for recognition of discrete species will be discussed later. Overall, there is a strong fit of the data to the best fit line (r^2 = 86.8%; Table 6), with a positive allometric growth relationship (slope = 1.22). indicating that the thickness grew at a faster rate than overall shell width for all *Platystrophia* specimens. Thus, scaled for size, larger *Platystrophia* specimens had slightly greater dorso-ventral inflation than smaller specimens.

Length vs. Width. - Likewise length (anterior-posterior distance) and width showed a strong correspondence (Fig. 12; Table 7). The variables showed high correlation (r^2 = 88.5%) while demonstrating a nearly isometric relationship (slope = 0.985). Since an isometry of 1 indicates perfect correlation between two variables, *Platystrophia's* overall length and width demonstrates a nearly identical rate of change during growth. Thus, there is strong ontogenetic continuity among these parameters and all can be used as proxies for body size. Some allometry is present, but substantially less than with thickness (Fig. 11).

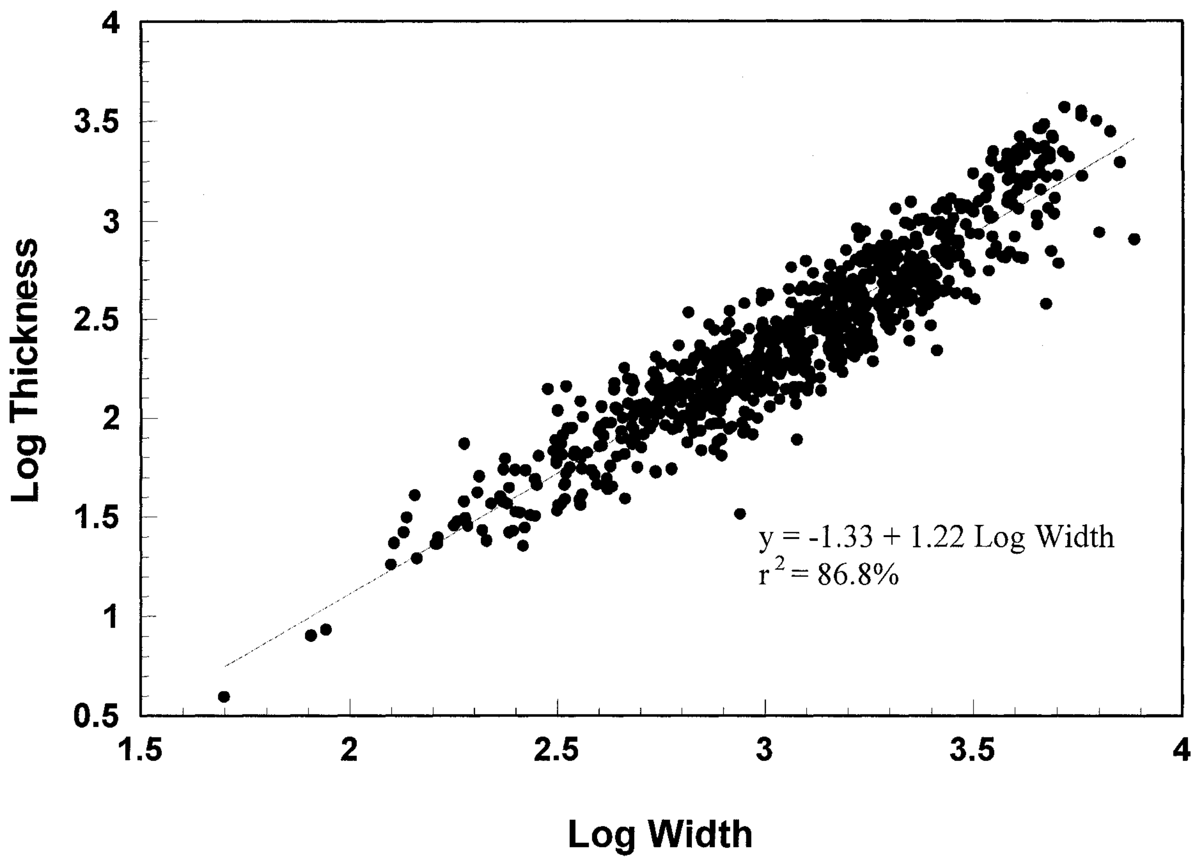


Figure 11. Scatter plot of log shell thickness vs. log shell width for all specimens. Thickness and width showed close correspondence. Ontogenetic continuity is suggested by the high correlation.

The regression equation is
Log Thickness = - 1.33 + 1.22 Log Width

Predictor	Coef	StDev	T	P
Constant	-1.32716	0.05152	-25.76	0.000
Log Width	1.21972	0.01667	73.17	0.000

S = 0.1671   R-Sq = 86.8%   R-Sq(adj) = 86.8%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	1	149.52	149.52	5354.31	0.000
Residual Error	811	22.65	0.03		
Total	812	172.17			

Table 6. Descriptive statistics for log thickness on log width.

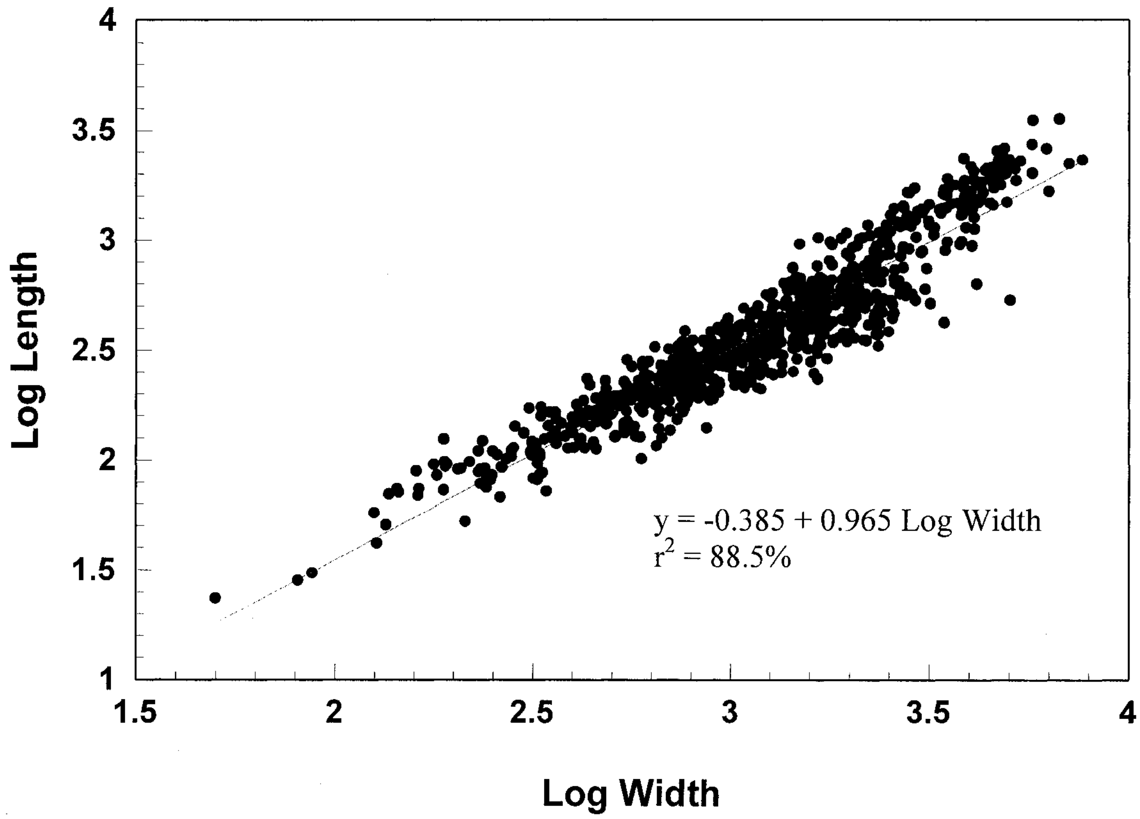


Figure 12 Scatter plot of log shell length vs. log shell width for all specimens. Length and width of demonstrate close correspondence. Ontogenetic continuity is suggested by the high correlation.

```
The regression equation is
y = - 0.386 + 0.965 x

Predictor     Coef     StDev      T     P
Constant   -0.38561   0.03758   -10.26  0.000
x        0.96454   0.01215   79.39  0.000

S = 0.1220   R-Sq = 88.5%   R-Sq(adj) = 88.5%

Analysis of Variance

Source       DF      SS      MS      F     P
Regression     1   93.777   93.777  6303.47  0.000
Residual Error  819   12.184    0.015
Total       820   105.961
```

Table 7. Descriptive statistics for regression of log length on log width

Thickness vs. Length. – Thickness demonstrates an anisometric relationship with length (Fig. 13; Table 8). The variables showed good correlation (r^2 = 84.4%) with positive allometry (slope = 1.18). Thickness likewise showed positive allometry in relation to width, suggesting that specimen thickness increases at a faster rate than either width or length. This suggests that a large degree of shape variation noted in *Platystrophia* may be directly related to thickness, and by extension, the morphology of the fold.

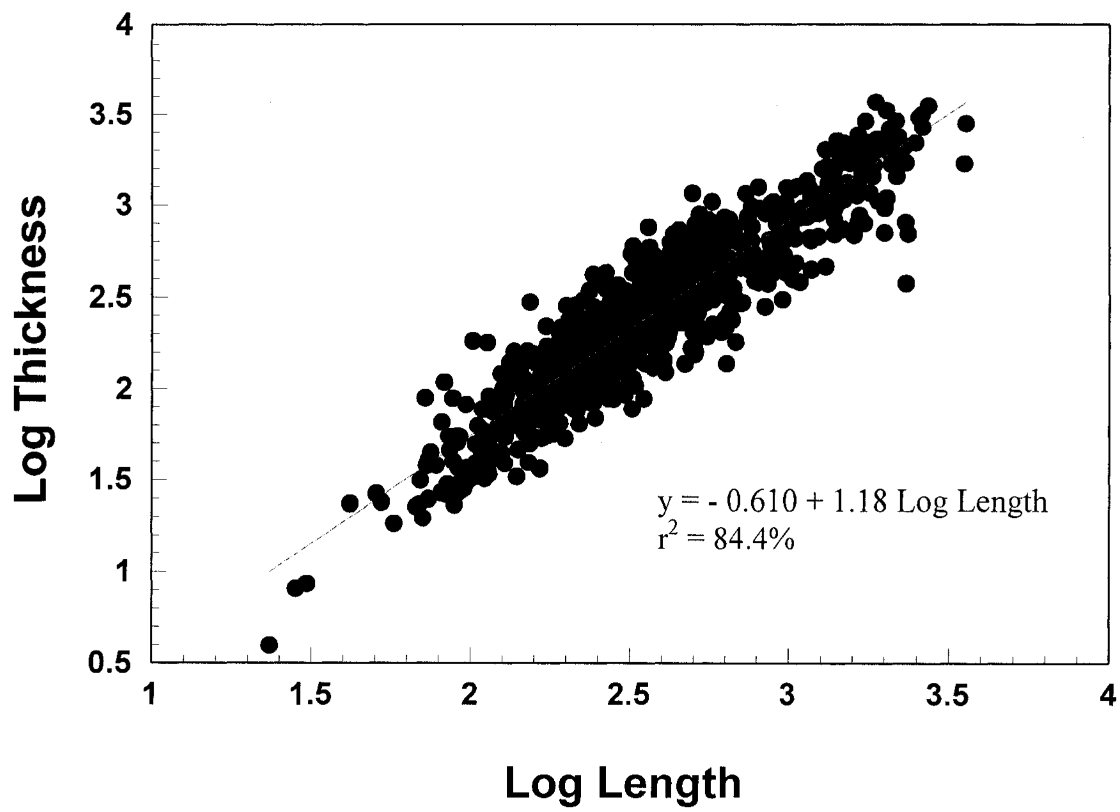


Figure 13 Scatter plot of log shell thickness vs. log shell length for all specimens. Thickness shows a positive allometric relationship to length indicating thickness grows at a faster rate.

```
The regression equation is
y = - 0.610 + 1.18 x

Predictor        Coef       StDev          T        P
Constant     -0.61034     0.04625     -13.20    0.000
x             1.17558     0.01778      66.12    0.000

S = 0.1819      R-Sq = 84.4%     R-Sq(adj) = 84.4%

Analysis of Variance

Source            DF          SS          MS         F         P
Regression         1      144.60      144.60   4371.89     0.000
Residual Error   807       26.69        0.03
Total            808      171.29
```

Table 8 Descriptive statistics for log thickness on log width.

Onshore-Offshore Patterns

<u>Size and Stratigraphic Position</u>.- Given the results of the previous sections, I chose width as the size variable to evaluate with respect to sample locality (Fig. 14). *Platystrophia*'s width showed clear variation in regard to

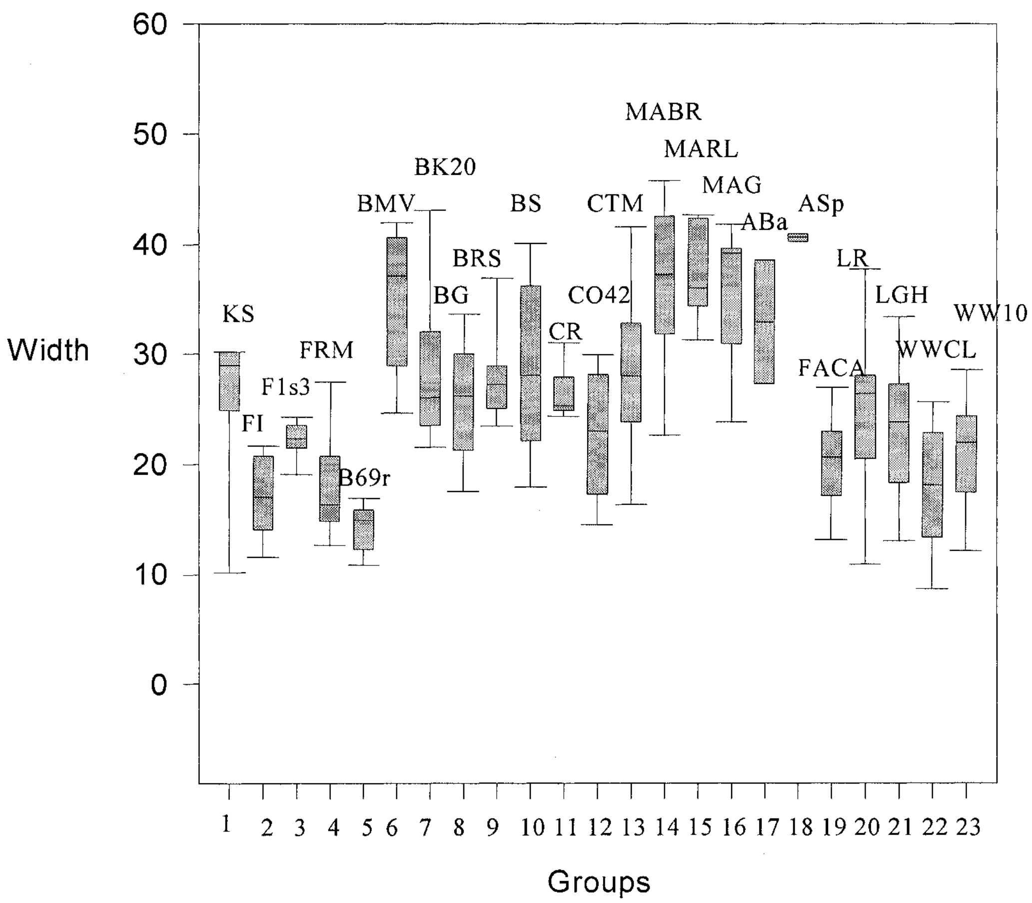


Figure 14 Box diagram illustrating range of differences between median width values for specimens by locality. Boxes represent upper 75% and lower 25% bounds of data, while error bars mark upper and lower 10% ranges of data. Letter codes above boxes represent.

localized stratigraphy. A Kruskal-Wallis one way analysis was used to compare differences among localities. The H value, 280.6, with 22 degrees of freedom strongly rejects the null hypothesis of equality of medians among localities ($P = <0.0001$). Differences among localities were evaluated further with a Dunn's pairwise multiple comparison procedure.

The plotted median values of width exhibited cycles in association with onshore and intermediate/offshore facies tracts. Onshore is defined by the shallowest environments (<1.5 m), while intermediate (6-8 m) and offshore (8 m) represent the deeper water settings. There is a smaller relative width for specimens from most intermediate/offshore facies tracts -- Kope (KS), Fairview (FI, F1s3, FRM), and Corryville (CR, CO42, CTM) -- in comparison to the onshore facies tracts -- Bellevue/Grant Lake (BMV, BK20, BG, BRS, BS) and Mt. Auburn (MABR, MARL, MAG).

General size trends were documented by pooling specimens within a formation and categorizing them into deep and shallow water associations (i.e., shallow for less than 1.5 m, and deep as greater than 1.5 m). Using these categories, shallow and deep water populations were compared by two group comparison tests (Mann-Whitney or t-test). Fursich and Hurst (1974) observed that brachiopods with simple lophophores, such as Orthida, have smaller sizes in deeper water. Sequences C2 and C3 evidenced smaller sizes for deeper water specimens as predicted (Table 9). All results were significant at the $p < 0.0001$ level. Likewise, the overall summation of data from all formations yielded significantly larger shallow than deep specimens.

Sequence	Location	Formation	N	Median	25%	75%	Test	p Value
C2	Deep	Fairview	83	19.5	15.5	21.7	Mann-Whitney	<0.0001
	Shallow	*Bellevue*	*205*	*27.0*	*22.1*	*33.7*		
C3	Deep	Corryville	56	25.4	19.2	29.1	Mann-Whitney	<0.0001
	Shallow	*Mt. Auburn*	*49*	*36.7*	*32.7*	*41.7*		
C4	Deep	Sunset	Not enough data******************************					
	Shallow	Oregonia	Not enough data******************************					
C5	*Deep*	*Ft. Ancient/Liberty*	*44*	*23.2*	*18.4*	*27.5*	Mann-Whitney	<0.0001
	Shallow	Whitewater	*172*	*18.6*	*13.7*	*23.3*		
Overall	Deep		183	21.0	16.6	25.6	Mann-Whitney	0.0001
	Shallow		*426*	*24.1*	*17.7*	*30.6*		

Table 9. Size comparisons (width) for deep vs. shallow specimens. Shallow specimens are larger for C2 and C3 while the deep is larger for C5 (italicized). C4 did not have sufficient data for comparison. Note that the pattern for C5 yield the opposite expectation.

However, data were not entirely consistent with an interpretation that brachiopods from shallow settings are larger than those from deep settings. Deeper water Kope (KS) and shallow water Whitewater specimens (WWCL, WW101) were respectively larger and smaller than what was expected. Some localities also exhibited a fair degree of variability. One Fairview locality (F1s3) had median specimen sizes noticeably larger than the rest. Bellevue specimens of locality B69r were significantly smaller than those of other Bellevue localities. Similar, yet more subtle, differences were found in the Whitewater Formation. Whitewater Route 101 specimens had a median width nearly equivalent to the upper 75% of those found at Cowan Lake. Perhaps most notably, formations within sequence C5 (Ft. Ancient - Whitewater) exhibited a pattern that was the reverse of that in other sequences, as well as the overall data set. Deep specimens were significantly larger than those from shallow settings (p = <0.0001). One reason for this may be that sampled localities in C5 may not have been representative of the environments at that time. Another possibility may be that the post-Waynesville sections experienced climatic changes (Holland and Patzkowsky, 1996), and are recognized to have a different biotic make-up than earlier Cincinnatian sequences. These observations may contribute to reversal in the predicted size trend.

Progressive Mean Size Increase

Correlation analyses of mean shell size with formation and depositional environment yield another interesting pattern. Mean shell width generally showed cyclic variation in response to sea level as documented previously for *Ambonychia* (Daley, 1993; in press). However the pattern exhibited some complexity. In sequence C2, the Fairview assemblage was significantly smaller than that of the shallow Bellevue (Fig. 15). Likewise, sequence C3 comprising the smaller Corryville (deep) and larger Mt. Auburn (shallow) samples, showed a significant difference between mean widths; the Corryville equaled the mean size of the shallow Bellevue from the lower sequence. The repetition of this effect through sequence C4 thus exhibits a progressive size increase from sequence to sequence in a “stepped” pattern.

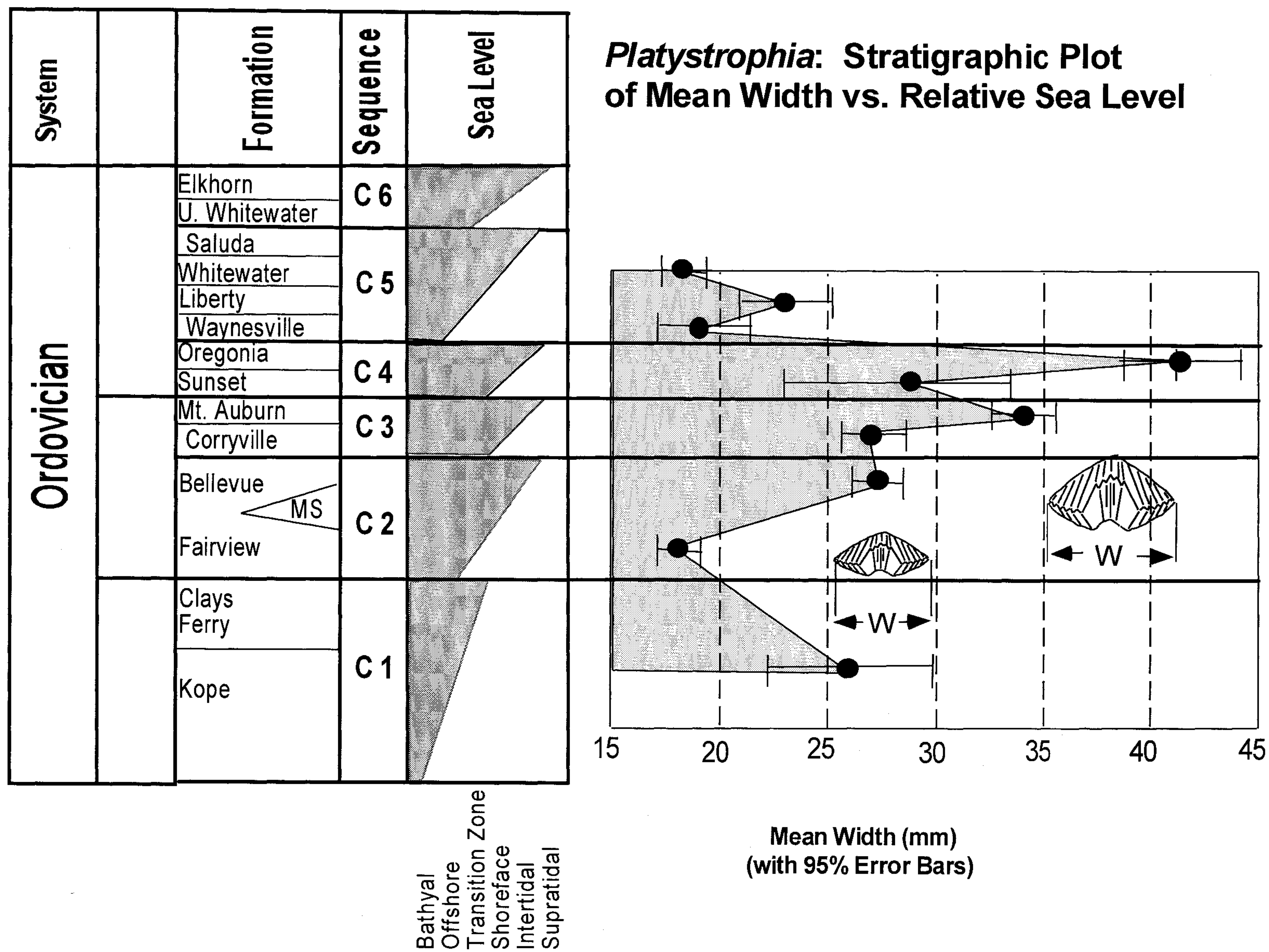
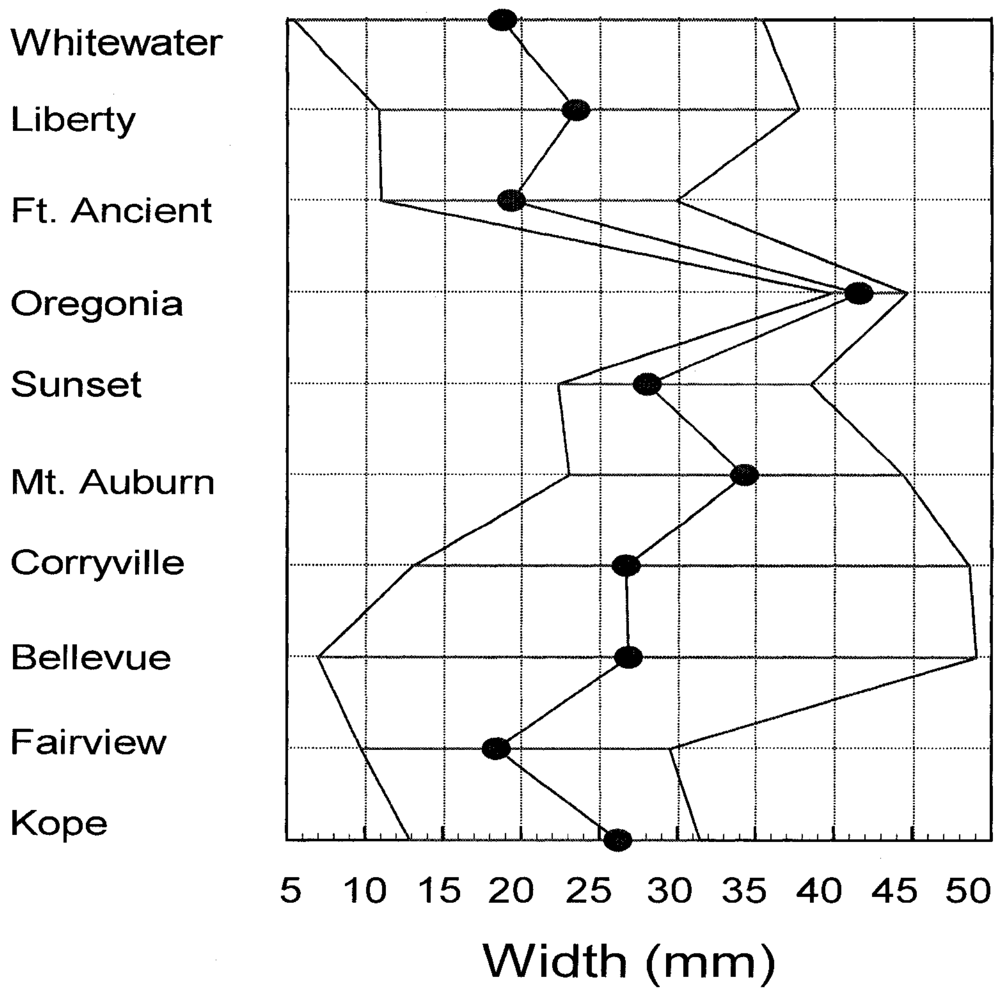


Figure 15 Stratigraphic plot of mean shell width (with 95% error bars) and relative sea level (after Holland, 1993). Width progressively increases until sequence C5, then abruptly decreases.

However, this trend reversed abruptly in C5. Mean *Platystrophia* widths were nearly half what they were in C3 and C4. Moreover, patterns did not match expectations from older sequences in that the shallow Whitewater sample was significantly smaller than the more deep Liberty sample.

Two issues should be addressed in relation to the data. One caution in interpreting this pattern is the insufficient sample size for the formations in Sequence C4. Ranges in width values for the Sunset were small compared to other formations (Fig. 16); likewise, Coefficient of Variation (CV, standard deviation divided by mean width, expressed as percent) values were unusually high for the Oregonia, and to a smaller degree, the Mt. Auburn. Apart from these cautions, the strong oscillation pattern is clear. Data from both *Platystrophia* and *Ambonychia* (Daley, 1993) indicate that sea level in the Cincinnatian had strong influence on size for some taxa.

The second point regards absence of juvenile forms and its effect on the data. Lack of juveniles is a recurring observation for Cincinnatian taxa (e.g., Daley, 1993). High juvenile mortality is one possibility. However, for this data set, two reasons suggest absence of juveniles may be a statistical artifact and not a concern for the size trends in Figure 15. Individual collection localities, and therefore pooled formations, contained largely normal distributions (see Fig. 14 for median and percentile differences; Fig. 16 for mean and ranges). In addition, CV values do not change as a function of mean width. Figure 16 shows rough equality of CVs regardless of



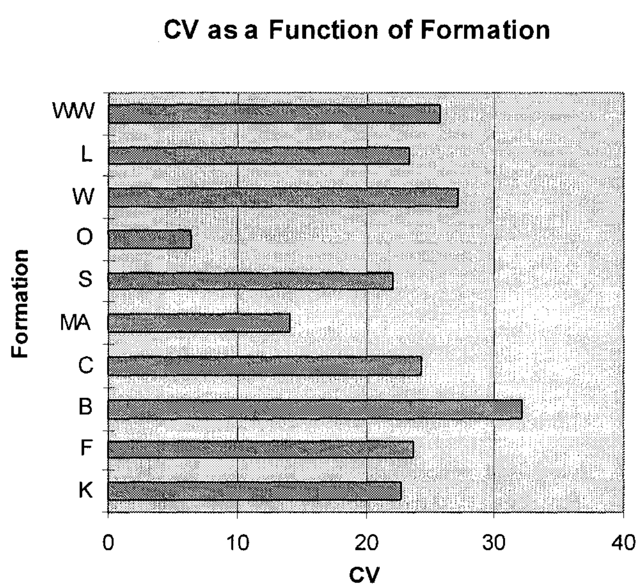


Figure 16. Comparison of width ranges and CV as a function of formation. The top figure illustrates minimum, mean, and maximum width values by formation. All formations include wide sample ranges except for the Sunset. CV values plotted according to formation (bottom) are consistent with the exception of the Mt. Auburn and Oregonia.

formation. Approximately equal values of CV compared to mean width indicate that specimen standard deviation was increasing proportionally with mean size. Absence of juveniles therefore reflects a decreasing probability of finding smaller size classes as mean size increases (note parallel between minimum size ranges and mean in Fig. 16).

Shape and Paleoenvironment

To allow a graphical representation of the morphological data, I have determined the principal components (PCs) for *Platystrophia's* morphospace based on the distance measures (Fig. 17; Table 10). PCs were performed with and without rib data. Yet sulcus and lateral rib data, important in early taxonomies, provided no information helpful to understanding morphology, species or environment and were not included here. The procedure used the "Factor" routine on the *Systat 5.2.1* statistical package and the results were confirmed on *S-PLUS*. Principal components were calculated using the correlation matrix on the raw data. The correlation matrix was used because variables are assigned equal importance, minimizing the effect of size differences. PCs 1-3 represent 97.5% of the variance for the 6 distances (Table 10). Varimax rotation was performed on the principal components in order to further distribute the variation among the component axes and make interpretation easier (Table 10; Fig. 18). Rotated PCs were used for analyses of shape in relation to paleoenvironment; non-rotated and rotated axes will be discussed in turn.

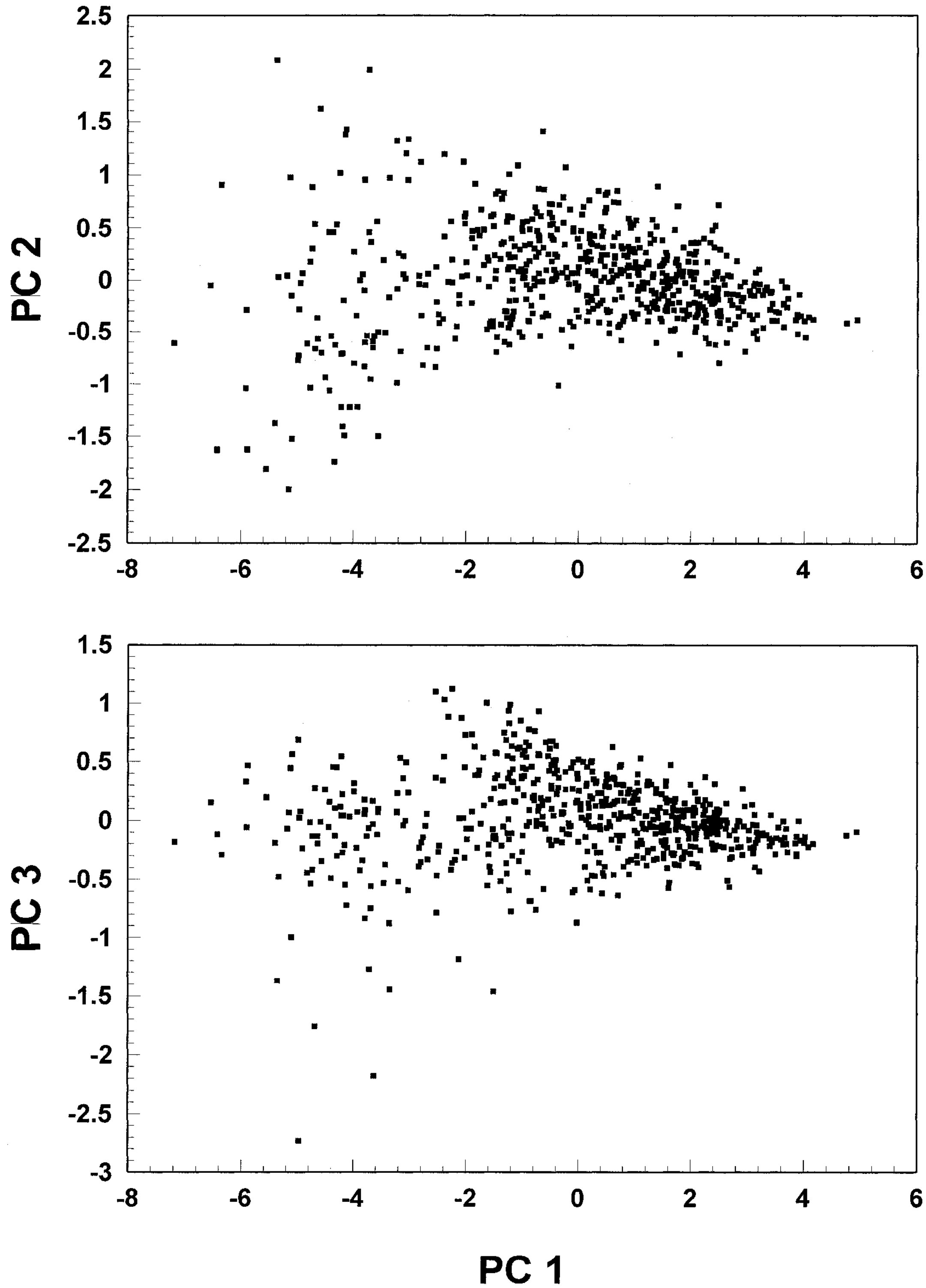


Figure 17. Ordination of Cincinnatian *Platystrophia* along first, second, and third principal component (PCs). The dominant component of variation, PC 1 shows increase of size. Size explains 91.4% of all variation. PC 2 describes rounding in terms of thickness and width

LATENT ROOTS (EIGENVALUES); VARIANCE EXPLAINED BY COMPONENTS

1	2	3	4	5	6
5.486	0.243	0.148	0.071	0.029	0.023

PERCENT OF TOTAL VARIANCE EXPLAINED

1	2	3	4	5	6
91.430	4.056	2.461	1.187	0.477	0.389

COMPONENT LOADINGS

	1	2	3	4	5	6
VAR1 (Width)	0.983	-0.117	-0.003	-0.046	-0.077	-0.111
VAR2 (Thickness)	0.962	0.228	0.079	0.019	-0.103	0.069
VAR3 (Sulc W)	0.971	-0.005	-0.102	-0.209	0.047	0.039
VAR4 (Sulc H)	0.954	0.208	0.186	0.040	0.095	0.045
VAR5 (Length)	0.948	0.038	-0.283	0.137	0.025	0.000
VAR6 (Alae W)	0.918	-0.365	0.128	0.067	0.017	0.052

VARIANCE EXPLAINED BY ROTATED COMPONENTS

1	2	3	4	5	6
2.137	1.860	1.368	0.560	0.029	0.046

PERCENT OF TOTAL VARIANCE EXPLAINED

1	2	3	4	5	6
35.615	31.007	22.801	9.329	0.476	0.771

ROTATED LOADINGS

	1	2	3	4	5	6
VAR1 (Width)	0.514	0.626	0.447	0.320	0.015	0.202
VAR2 (Thickness)	0.765	0.392	0.422	0.246	0.140	0.051
VAR3 (Sulc W)	0.520	0.491	0.473	0.514	0.008	0.027
VAR4 (Sulc H)	0.800	0.430	0.347	0.212	-0.093	0.031
VAR5 (Length)	0.474	0.430	0.734	0.225	0.003	0.033
VAR6 (Alae W)	0.388	0.839	0.329	0.193	0.012	0.003

Table 10. Eigenvalues, percentages of variance accounted for by each principal component, and loadings with principal components for each variable. Results are for the principal component data (top), and Varimax rotated principal componets (bottom).

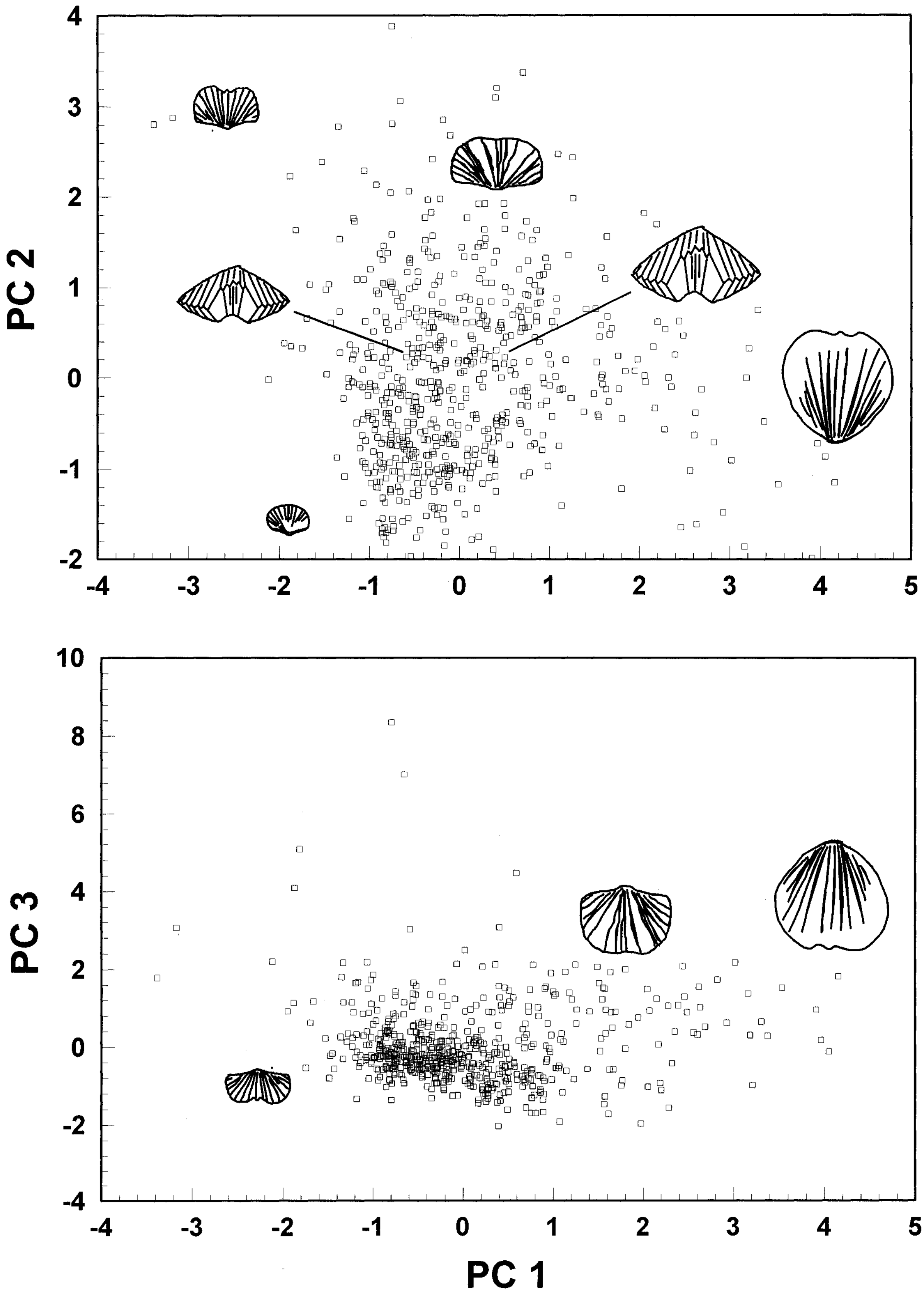


Figure 18. Ordination of Cincinnatian *Platystrophia* along first, second, and third principal component (PCs) with Varimax rotation. In general, PC 1 shows increase of size; PC 2 increase in alation; PC 3 increase in length. Note relative isolation of the rounded morphologies on right side of charts.

The loadings of each variable on PC 1 are all approximately equal, positive and strongly correlated (Table 10). Most of the variance is accounted for by changes in size. PC 2 accounts for 4% of the variation. Variables that load most strongly on this axis are two orthogonal paired features of shape: thickness and sulcus height loading positively, and width and alae width loading negatively. These variables working in opposition account for rounding and flattening in *Platystrophia*'s morphology. Loadings on PC 3 account for 2.5% of the variation and also indicate opposing paired variables: sulcus height and alae width loading positively, and length and sulcus width loading negatively. This suggests a relationship between the notable alae morphology of many *Platystrophia* with other aspects of shape. PCs 4-6 most likely account for random variations in shape such as compaction or measurement error. The small amount of variation explained (less than 2%) and the patterns expressed by the loadings suggest these variations are not biologically meaningful.

The PC axes were rotated (Varimax rotation in *Systat*) to facilitate interpretation in terms of variables. After rotation, PC 1 again loaded positively, with two variables accounting for slightly greater amounts of variation: sulcus height and specimen thickness (Table 10). Rotated loadings for PC 2 indicate that alae length was the variable most responsible for variation on that axis. Length had the strongest loadings on PC 3. *Platystrophia* ordinations based on the loadings of the rotated variables are illustrated within PC space (Fig. 18) and serve as the basis for the morphological analyses used throughout.

Ordinations of specimens were constructed as bivariate scatter plots with axes representing PC scores. The positions of several basic *Platystrophia* forms in the scatter are depicted by drawings of the shells within their respective principal component space (Fig. 18). Clearly, this type of analysis successfully separates forms with different appearances into different parts of PC space. An example of this is the separation of the rostrate ("rounded") morphologies of *P. ponderosa auburnensis* on the right side of both scatter plots.

Intergradation of specimens in PC space suggest a considerable amount of oversplitting has occurred in the species taxonomy of *Platystrophia* (Fig. 17 and 18). This observation supports earlier concerns of Alberstadt (1979) and will be addressed later. Even assuming that *Platystrophia'* s taxonomy is reasonable, the cause for such high speciation rates is an important question. For either scenario, paleoenvironment is an important factor. To test the expectation that paleoenvironment influenced the morphology of *Platystrophia*, environmental associations were examined directly. Correlations of *Platystrophia'*s morphology with paleoenvironment, comparisons between specimens in similar paleoenvironments, and relationships with water depth were all tested. The hypothesis is that *Platystrophia* morphology may have exhibited a form of phenotypic plasticity in relation to external conditions (e.g., either conditional or polyphenic phenotypic plasticity; West-Eberhard, 1989). For example, substrate differences alone have been known to produce pronounced morphological differences in coiling in some snails (Gould, 1968).

The Effect of Environment on Morphology

Formation and morphology. -Enough is known about general brachiopod morphology with respect to environment that a hypothetical “expected” PC ordination could be constructed. Such a model was then compared to actual ordinations. For example, since brachiopod size tends to increase, but alae (wing) size tends to decrease in shallow water environments (Fürsich and Hurst, 1974), an expected centroid for a formation could be placed on the PC plot (Fig. 19, top). By comparing the ideal expectation to actual centroids for each formation it could be shown how well Cincinnati *Platystrophia*'s adheres to expectation (Fig. 19, bottom).

The comparison of ideal and actual centroids yielded almost no correlation: formations were distributed nearly randomly with respect to anticipated ordinations. For example, the prediction for a deep water form such as the Ft. Ancient would be small size with (PC 1) and well defined alae (PC 2). However, the actual centroid for the Ft. Ancient meets the expectation for small size, but not for strongly developed alae. Of all formations, the shallow water Mt. Auburn formation most closely approximates the prediction with large size and globose morphology.

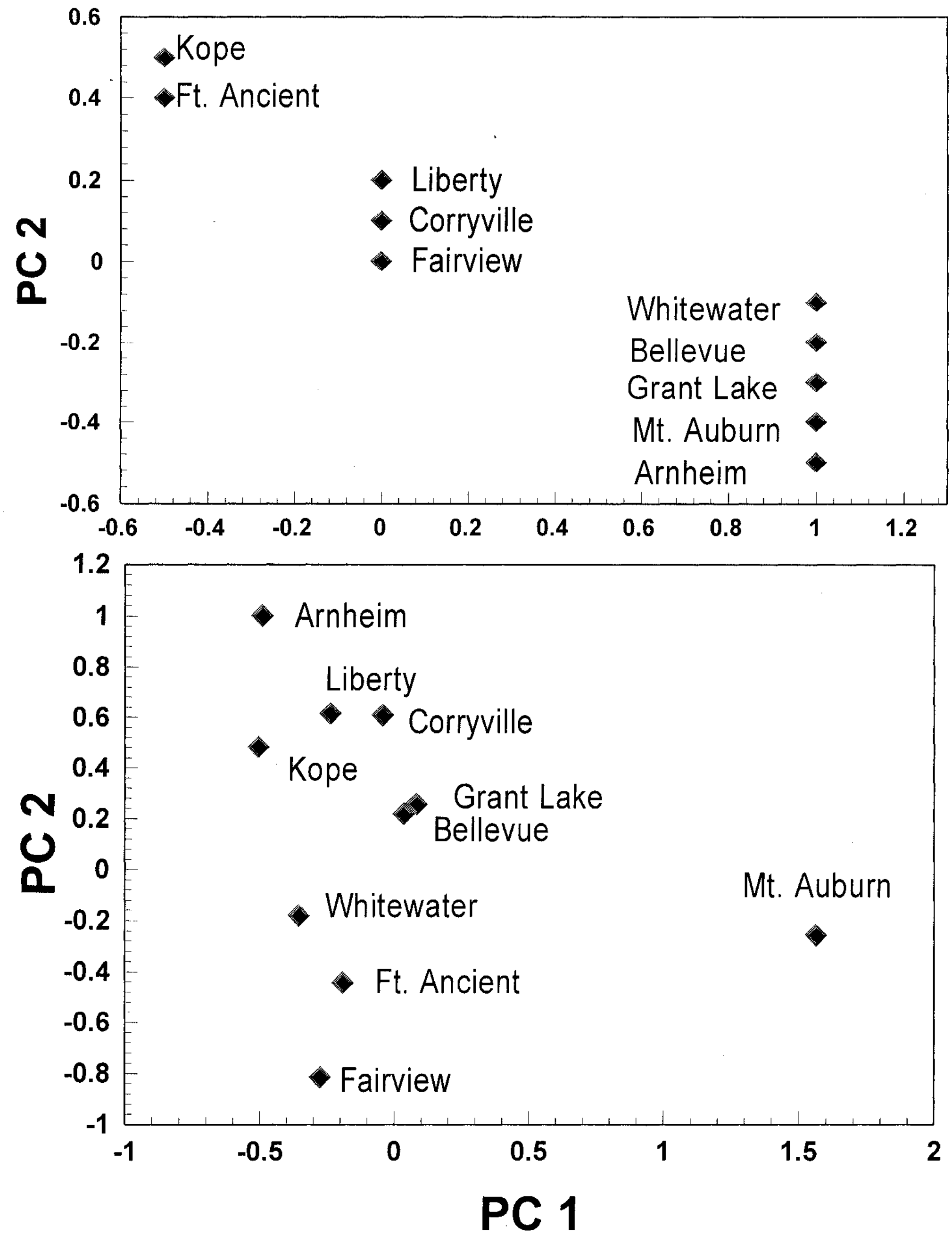


Figure 19. Centroids for predicted morphospace occupation (top) and actual results (bottom), by formation. Centroids for predicted morphospace occupation show three associations based on size and alation -- features believed to be environmentally-controlled in brachiopods. Actual centroids yielded nearly no correlations between morphology and paleoenvironment. Specimen centroids displayed nearly random distribution, with respect to the prediction. The only exception was the Mt. Auburn specimens that were both large and lacking in alation, as hypothesized.

Morphological Variation among forms in similar environments. - Another way to test for relationship between morphology and environment is to compare the morphologies of *Platystrophia* from similar environments. If environment is responsible for morphological patterns, then similar environments should contain specimens with similar forms. For example, shallow water settings usually yield brachiopods morphologies exhibiting large size, inflation, and reduced alae. (Fig. 19, top). According to this expectation, since "Grant Lake" and Bellevue specimens inhabited very similar environments they should, therefore, yield similar morphologies.

Ordinations of PC scores were plotted for the first and third axis of "Grant Lake" and Bellevue specimens. Specimens belonging to the Grant Lake were found in Sulfur, KY (BS) and Maysville, KY (BMV). For the purpose of this thesis they were included with the Bellevue in Figure 7 and Table 4, but tests were conducted to determine if differences existed. Figure 20 illustrates the more confined range of Bellevue specimens (black) in relation to the Grant Lake for PCs 1 and 3. A Mann-Whitney Rank Sum test results rejects the null hypothesis of equality of medians between these formations ($p = < 0.0001$; Table 10), based on the PC scores.

Both populations also exhibit some degree of allometry for these axes. Figure 20 shows a slight curvature in the scatter plot that reflects the allometry displayed in figures 12 and 13. The rotated loadings for PC 1 are strongest on thickness and sulcus height. PC 3 loads most strongly on length. The relationship between these axes reflects the faster change in growth for thickness and sulcus

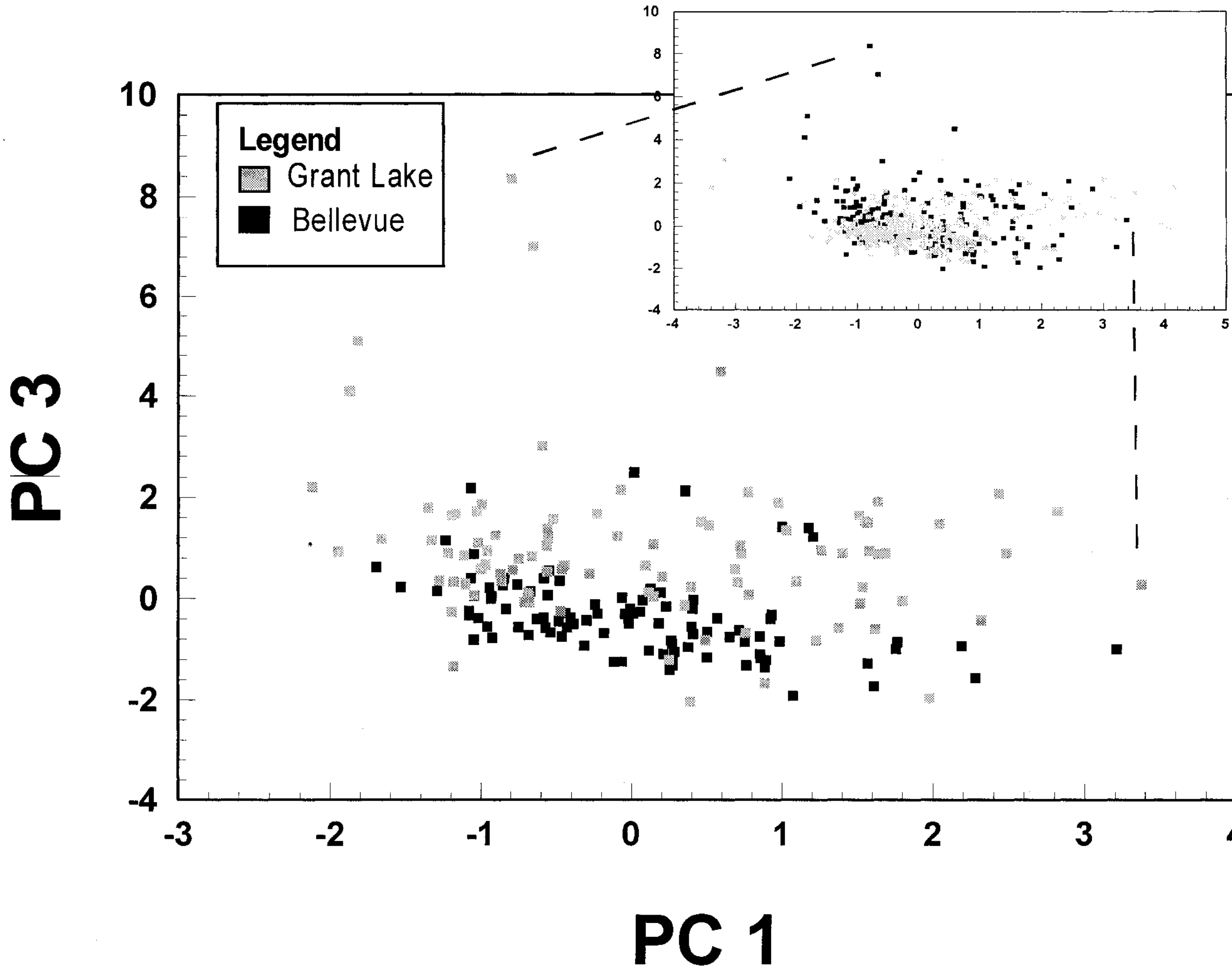


Figure 20. Comparison of Grant Lake and Bellevue forms yields significant differences for the third PC (length). Inset in upper right shows both formations (black points) in relation to entire data set for comparison. Expanded view of Grant Lake and Bellevue removed from larger data set (bottom) allows relationship to be seen more clearly. In addition to smaller shell lengths of Bellevue (black), note more constrained range compared to Grant Lake (gray).

Grant Lake and Bellevue: Mann-Whitney Rank Sum Test

Normality Test: Failed (P = <0.0001)

Group	N
PC 3: Bellevue	99
PC 3: Grant Lake	96

Group	Median	25%	75%
PC 3: Bellevue	-0.429	-0.875	0.0393
PC 3: Grant La	0.866	0.172	1.5085

T = 12502.5 n(small)= 96 n(big)= 99 (P = <0.0001)

Table 11. Mann-Whitney Rank Sum test results for the Grant Lake and Bellevue yields statistically significant differences for the third PC.

height displayed earlier. Both Grant Lake and Bellevue show similar growth trajectories, yet are statistically distinct populations in regard to PC 3 (Table 11).

Forms from similar environments in different sequences were also compared. The Bellevue (Sequence C2), Mt. Auburn (C3) and Whitewater formations (C5) were all shoreface environments and were compared for the first three component axes (Fig. 21); all three formations exhibit separation with size along PC 1 (for comparison, differences in overall width also illustrated in Fig. 15). The null hypothesis for equality of medians was rejected by Kruskal-Wallis and Dunn's pairwise comparison tests (p =<0.0001; p <0.05; Table 12). Thus, rather strong size differences existed within similar environments at different times.

Shape was also variable. PC 2 illustrates differences among alation between Bellevue versus other specimens. Specimens from the Bellevue showed much greater alation despite inhabiting shallow water (differences for median values are significant with p = 0.0022; Table 13). Moreover, anterior-posterior length was greater for the Mt. Auburn formation than either the Whitewater or Bellevue (PC 3 in Fig. 21), median length values were significantly different at p <0.0001; Table 14. Mt. Auburn specimens are known for their near spherical morphologies and large size, yet this was in spite of inhabiting an environment similar those of non-globose *Platystrophia* in other formations. One key to understanding shape differences may be provided in the graph of the Whitewater specimens. Curvature in the scatter plot may indicates allometry in

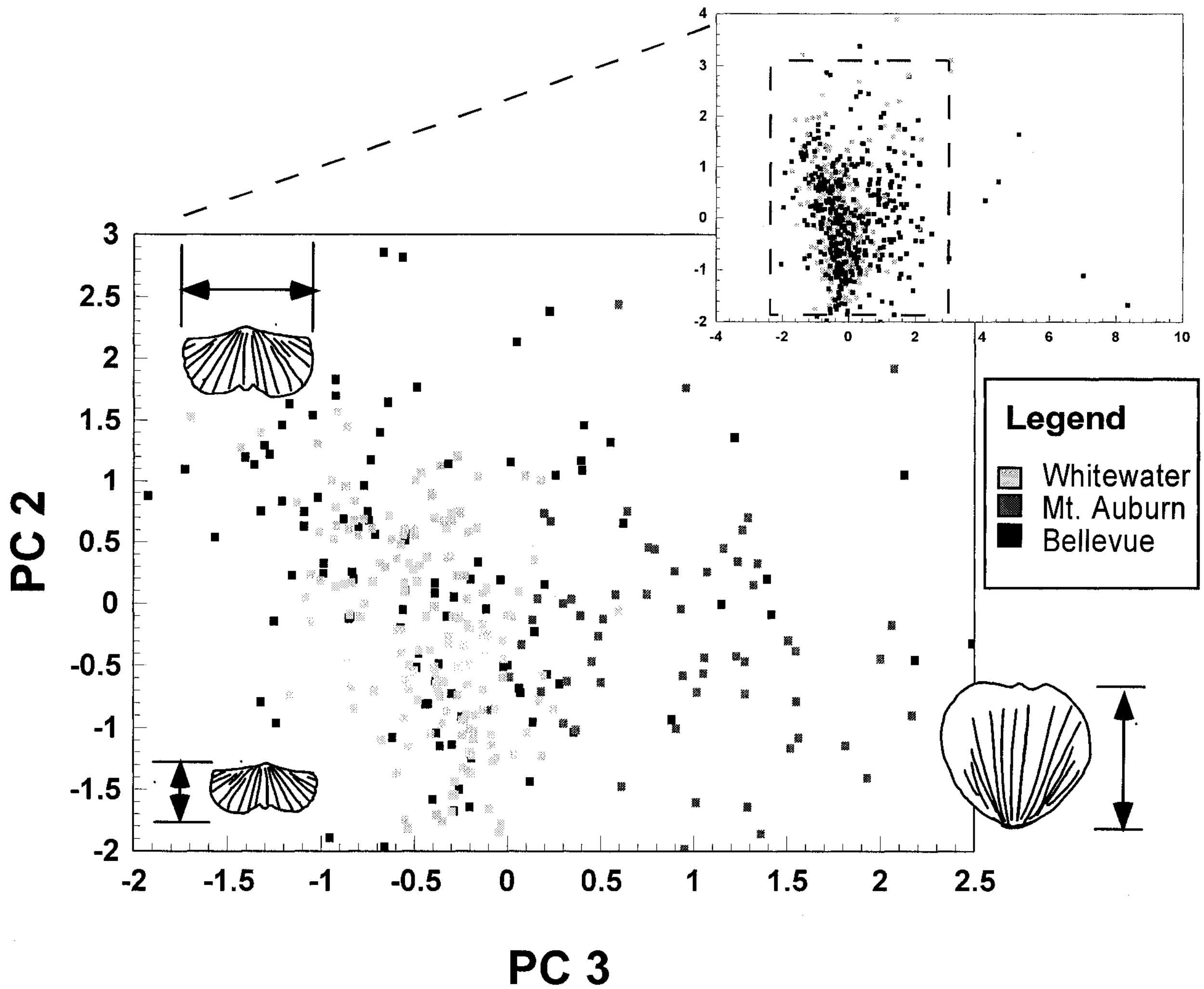


Figure 21. Shape differences within shallow water environments illustrated by separation within PC space. Inset (top) gives the position of all shallow water specimens within the overall data set (black) for comparison. Shallow water forms do not inhabit a unique morphospace relative to other *Platystrophia* (top), yet the shoreface formations show significant differences among themselves. PC 2 values indicate strong differences in alation while PC 3 shows differences in length. Note morphological separation of Mt. Auburn specimens (gray).

Kruskal-Wallis and Dunn's Pairwise Comparison Tests: Shoreface Environment Forms Significantly Different for PC 1

Kruskal-Wallis One Way Analysis of Variance on Ranks

Normality Test: Failed (P = 0.0002)

Group	N
Bellevue	195
Whitewater	168
Mt. Auburn	59

Group	Median	25%	75%
Bellevue	-0.0190	-0.781	0.7588
Whitewater	-0.4600	-0.762	-0.0735
Mt. Auburn	1.2530	0.572	2.5338

H = 98.3 with 2 degrees of freedom. (P = <0.0001)

The differences in the median values among the treatment groups are greater than would be expected by chance; there is a statistically significant difference (P = 4.51E-022)

All Pairwise Multiple Comparison Procedures (Dunn's Method) :

Comparison	Diff of Ranks	p	Q
Mt. Auburn vs Whitewater	182.9	3	9.91
Mt. Auburn vs Bellevue	139.8	2	7.71
Bellevue vs Whitewater	43.1	2	3.36

Comparison	P<0.05
Mt. Auburn vs Whitewater	Yes
Mt. Auburn vs Bellevue	Yes
Bellevue vs Whitewater	Yes

Table 12. Results for Kruskal-Wallis and Dunn's Pairwise Comparisons on Shallow Water Specimens.

Kruskal-Wallis and Dunn's test: Shoreface Environment Forms Significantly different for PC 2

Kruskal-Wallis One Way Analysis of Variance on Ranks

Normality Test: Passed (P = 0.3188)

Equal Variance Test: Failed (P = 0.0097)

Group	N
PC 2: Bellevue	99
PC 2: Whitewate	168
PC 2: Mt. Aubur	59

Group	Median	25%	75%
PC 2: Bellevue	0.192	-0.613	1.079
PC 2: Whitewate	-0.156	-0.815	0.541
PC 2: Mt. Aubur	-0.329	-0.773	0.256

H = 12.2 with 2 degrees of freedom. (P = 0.0022)

The differences in the median values among the treatment groups are greater than would be expected by chance; there is a statistically significant difference (P = 0.00220)

To isolate the group or groups that differ from the others use a multiple comparison procedure.

All Pairwise Multiple Comparison Procedures (Dunn's Method) :

Comparison	Diff of Ranks	p	Q
PC 2: Bellevue vs PC 2: Mt. Aubur	46.9	3	3.028
PC 2: Bellevue vs PC 2: Whitewate	35.8	2	3.001
PC 2: Whitewate vs PC 2: Mt. Aubur	11.1	2	0.778

Comparison	P<0.05
PC 2: Bellevue vs PC 2: Mt. Aubur	Yes
PC 2: Bellevue vs PC 2: Whitewate	Yes
PC 2: Whitewate vs PC 2: Mt. Aubur	No

there is a statistically significant difference (P = 2.59E-026)

Table 13. Results for Kruskal-Wallis and Dunn's Pairwise Comparisons on Shallow Water Specimen ordinations for PC 2.

Kruskal-Wallis and Dunn's test: Shoreface Environment Forms Significantly different at PC 3

Kruskal-Wallis One Way Analysis of Variance on Ranks

Normality Test: Failed (P = <0.0001)

Group	N
PC 3: Bellevue	99
PC 3: Whitewate	168
PC 3: Mt. Aubur	59

Group	Median	25%	75%
PC 3: Bellevue	-0.429	-0.875	0.0393
PC 3: Whitewate	-0.369	-0.595	-0.2040
PC 3: Mt. Auburn	0.940	0.406	1.2895

H = 117.8 with 2 degrees of freedom. (P = <0.0001)

The differences in the median values among the treatment groups are greater than would be expected by chance;To isolate the group or groups that differ from the others use a multiple comparison procedure.

All Pairwise Multiple Comparison Procedures (Dunn's Method) :

Comparison	Diff of Ranks	p	Q
PC 3: Mt. Aubur vs PC 3: Bellevue	147.578	3	9.5202
PC 3: Mt. Aubur vs PC 3: Whitewate	146.944	2	10.3022
PC 3: Whitewate vs PC 3: Bellevue	0.634	2	0.0531

Comparison	P<0.05
PC 3: Mt. Aubur vs PC 3: Bellevue	Yes
PC 3: Mt. Aubur vs PC 3: Whitewate	Yes
PC 3: Whitewate vs PC 3: Bellevue	No

Table 14. Results for Kruskal-Wallis and Dunn's Pairwise Comparisons on Shallow Water Specimen ordinations for PC 3.

PCs 2 and 3. Size related allometry alone may account for shape difference when size differences exist and may be responsible for some shape differences.

Water Depth - Perhaps a more discrete proxy for paleoenvironment within the Cincinnatian is water depth. Specimens were collected from three general water depth zones, as estimated with a three zone categorization: shallow (1.5-1.0 m), intermediate (6-8 m) and deep (> 10 m) (Cuffey, 1992a; Cuffey, 1992b; Diekmeyer, 1992; Hay, 1981; Hay, 1992; Holland, 1992; Holland, 1993). If physical conditions related to water depth (e.g., wave energy) influenced morphology in *Platystrophia*, as has been documented in other organisms, then a correlation between water depth and shape would be expected. This was tested by grouping specimens according to water depth and examining resultant patterns (Fig. 22; Table 15). None were evident based on this association indicating specimen morphologies were distributed randomly with respect to water depth. A Kruskal-Wallis test for median values failed to distinguish significant differences among populations for any of the first three PCs (Table 15). Greater variation among the shallow water forms for PCs 1 and 3 was accounted for by the Mt. Auburn specimens. Their unique morphologies will be discussed later.

Discussion. - Environmental attributes have always been viewed as important factors in understanding the morphologies and life modes of marine organisms. One parameter, wave energy, has been shown to be particularly important in determining the morphology of bryozoans and corals (e.g., Graus et al., 1977; Rider and Cowen, 1977). Another Cincinnatian brachiopod,

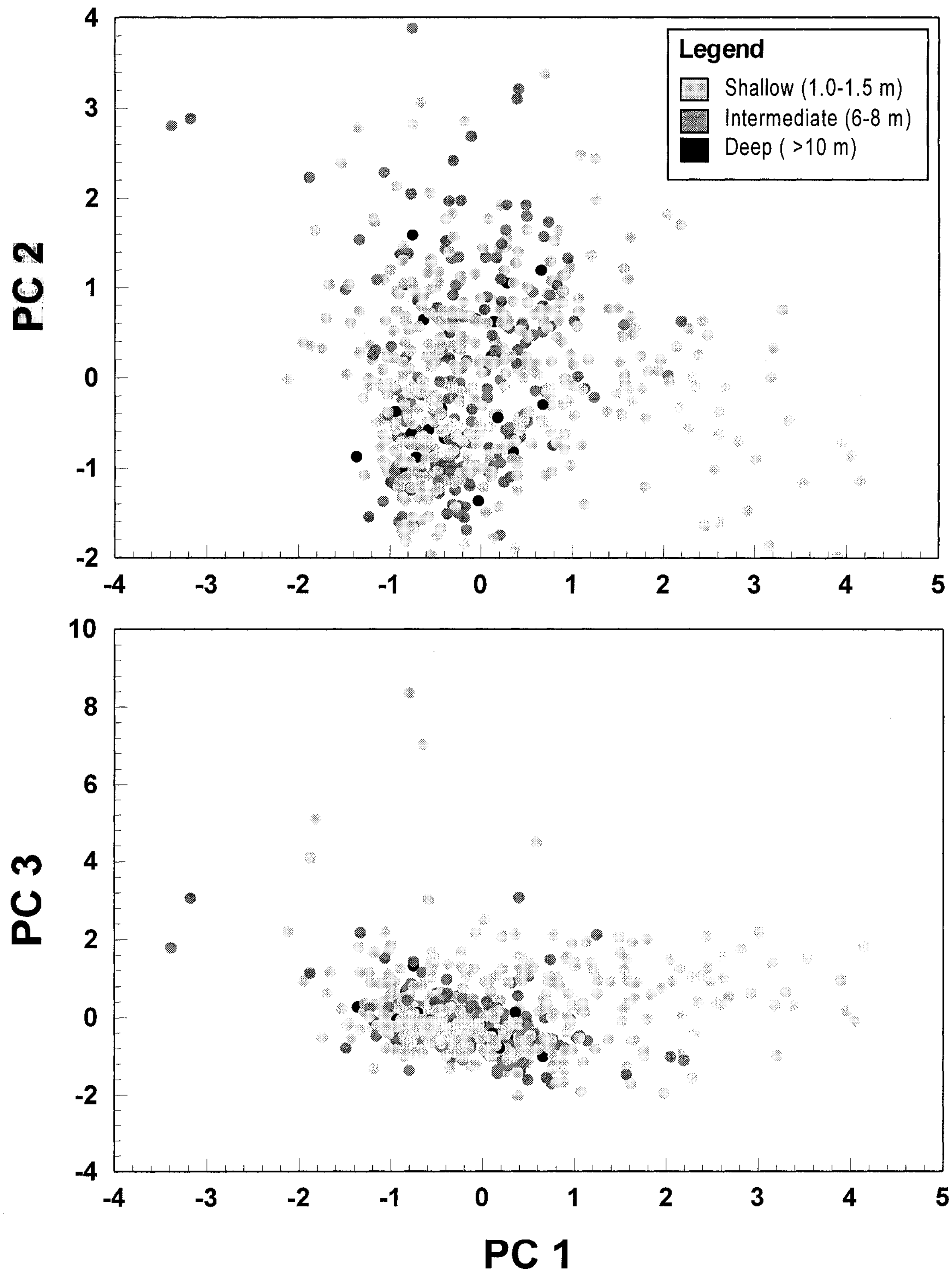


Figure 22. Ordination of *Platystrophia* along first three principal components, coded by relative water depth. Black points indicate deepest water (>10 m), dark gray represents intermediate depths (6-8 m) and light gray the shallowest water (< 1.5 m). There are no statistical differences between samples according to water depth.

Kruskal-Wallis on Water Depth

First Principal Component
Normality Test: Failed (P = <0.0001)

Group	N
1.000	19
2.000	187
3.000	426

Group	Median	25%	75%
1.000	-0.430	-0.760	0.176
2.000	-0.250	-0.615	0.217
3.000	-0.177	-0.680	0.706

H = 4.51 with 2 degrees of freedom. (P = 0.1049)
The differences in the median values among the treatment groups are not great enough to exclude the possibility that the difference is due to random sampling variability; there is not a statistically significant difference (P = 0.105)

Second Principal Component

Normality Test: Failed (P = 0.0016)

Group	N
1.000	19
2.000	187
3.000	426

Group	Median	25%	75%
1.000	-0.3770	-0.783	0.632
2.000	-0.2060	-0.948	0.641
3.000	-0.0465	-0.711	0.628

H = 1.01 with 2 degrees of freedom. (P = 0.6044)
The differences in the median values among the treatment groups are not great enough to exclude the possibility that the difference is due to random sampling variability; there is not a statistically significant difference (P = 0.604)

Third Principal Component

Normality Test: Failed (P = 0.0016)

Group	N
1.000	19
2.000	187
3.000	426

Group	Median	25%	75%
1.000	-0.3770	-0.783	0.632
2.000	-0.2060	-0.948	0.641
3.000	-0.0465	-0.711	0.628

H = 1.01 with 2 degrees of freedom. (P = 0.6044)
The differences in the median values among the treatment groups are not great enough to exclude the possibility that the difference is due to random sampling variability; there is not a statistically significant difference (P = 0.604)

Table 15. Kruskal-Wallis results for populations grouped by water depth. There are no statistical differences between shallow (1), intermediate (2), and deep water (3) forms.

Rafinesquina alternata, has been shown to be highly responsive to sedimentological conditions (Alexander, 1975; Leighton, 1995). Prior to this study, such observations have been noted, though not rigorously, with *Platystrophia* as well (Cumings, 1903).

For brachiopods in general, one important aspect of the relationship between morphology and environmental distribution centers on food acquisition. Morphological adaptations in brachiopods most often serve either to increase the feeding efficiency of the lophophore or to accommodate physical conditions of the environment (Fürsich and Hurst, 1974). Adaptations for feeding include changes in ribs, sulcus size, or wing dimensions. Likewise, additional variations to accommodate adverse physical conditions may include changes in shell thickness. According to Fürsich and Hurst, deeper water settings have far less food (perhaps only 1/50th of nearshore) and, therefore, require more complex lophophores to furnish sufficient quantities. Because of this restriction, they found that Silurian brachiopods with simple lophophores (e.g., Orthida) decreased in size as water deepened. Further, the lophophore (and hence feeding demands) is so inextricably linked to brachiopod size and shape variation that it has been suggested that it even controls shell morphology (Grant, 1972).

Whatever combination of effects ultimately determines shell morphology, most brachiopods have been reported to manifest clear associations between environment and morphology. Fürsich and Hurst (1974) found such association for several brachiopod groups: Orthida, Strophomenida, Rhynchonellida, Pentameridina and Spiriferida. For example, they showed that thick-ribbed brachiopods with strong pedicle valves are often found in turbulent environments. Morphological features appear to be selected in those settings on the basis of shell durability in the presence of adverse conditions. Quiet waters, in contrast, yielded alae, strong sulcus definition, and thin shells. Finally, large, flat resting surfaces are most commonly found in brachiopods from soft substrates. This morphology aids in keeping the organism above the substrate and allows free water flow into and out of the commissure.

However, as logical as such patterns may seem, exceptions have been recognized in other studies. For example, among living terebratulids, Thayer (1977) found a range of morphologies -- from globose to alate -- co-existing in a modern community -- even side by side under the same rocks. Such collateral existence of diverse morphologies was also common among *Platystrophia* in the present study. As with Thayer's terebratulids, it appears that the relationship between morphology and environment is not straightforward. It could be posited that microenvironmental factors were responsible for the diversity of morphologies existing in association. Yet, in the absence of clear functional or environmental reasons, this explanation is *ad hoc*. Therefore, until clear functional reasons can be determined for such associations, it can only be maintained that the patterns observed here appear to not follow the expectations based on other brachiopods.

Even the structural features on *Platystrophia* that seemed easiest to associate with environment, the alae, yielded no clear correlations. Alae in brachiopods have been the subject of numerous observations and speculations

(Rudwick, 1970; Thayer, 1977). Most workers place alate brachiopods in deep, muddy, and quiet water. One suggestion was that alae function as "snow shoes" and provide support on such soft substrates (Rudwick, 1970). This was consistent with the environmental correlations of Fürsich and Hurst, since wide-hinged brachiopods were often found in muddy, quiet water settings. In a similar vein, an increase in distance between the inhalant and exhalant portions of the shell would help reduce current mixing (McGhee, 1980), which would pose a threat to a filter feeding organism in a quiescent setting. Other possible functions of alae relate to the minimizing of lophophore fouling (again, not inconsistent with life in a quiet water, muddy setting). The greater area created in these lateral portions of the shell could have served as sediment traps to allow suspended sediments an opportunity to settle out (Westbroek et al., 1980). The greater distance of the extended alae tips also could have provided an "early warning system" to give the animal time to close the commissure upon encountering episodes of rapid sedimentation, while the greater available area of punctae could provide for better respiration during episodes of valve closure (Thayer, 1986). Yet even these well-documented interpretations must be tempered, since spiriferid brachiopods of the Devonian, like the *Platystrophia* of this study, lived in a wide array of environments ranging from intertidal to deep water (Faber et al., 1977; McGhee, 1976). It is clear from this study that the interpretation of the alae on *Platystrophia* is not as straightforward as those on other types of brachiopods.

Platystrophia's alate forms were not necessarily restricted to quiet, offshore settings. On the contrary, the Whitewater formation yielded only alate

Platystrophia despite being a shallow and high energy setting. *Platystrophia*'s shell morphology also did not exhibit the same sensitivity to change that Alexander found in *Rafinesquina* (Alexander, 1975). *Rafinesquina* exhibited differences in aspects such as geniculation in response to sedimentological fluctuations at the same time that *Platystrophia* exhibited no apparent correlation to water depth.

Thus, this study suggests caution in emphasizing the link between functional morphology and environment in *Platystrophia*, as further corroborated recently in a study of Ordovician brachiopods of South America. Lower Ordovician brachiopods of the San Juan Formation in the Argentine Precordillera, including *Platystrophia*, failed to show linkage between morphology and environment (Sanchez and Toffolo, 1996). Sanchez and Toffolo (1996) tested twelve genera of articulate brachiopods and the results were similar to this study. Different morphologies coexisted in the same environment. They concluded that some morphological features did not have functional significance and were probably the consequences of neutral mutations. Based on the present study, I would not assert that *Platystrophia*'s morphologies had *no* functional purposes. However, with respect to environment I would suggest random occupation of morphospace cannot be ruled out as an explanation for the observed patterns.

The Effects of Biological Association and Geography

Patterns based on biological associations

Five basic forms (Fig. 1) have been used to describe *Platystrophia*'s morphology. One question to address is whether the morphology of some forms were affected by the presence or absence of other forms. Some organisms exhibit competitive interspecific interaction for limited resources, adapting morphology to gain an advantage. This has been observed in the Cincinnatian brachiopod *Rafinesquina* (Leighton, 1995). Fitzpatrick's (1972) five groups can be lumped into two basic *Platystrophia* morphologies that are common, easy to identify, and – assumed to be -- functionally distinct: alate (or mucronate), and non-alate forms (transverse, acuminate, and subquadrate). This distinction was chosen for examination because these two groups were found in several contrasting associations: (1) alate forms geographically and temporally coexistent with non-alate forms (presumably living together, e.g., certain Bellevue localities), (2) alate forms temporally coexistent with, but geographically isolated from non-alate forms, and (3) temporal isolation of alate from non-alate forms (e.g., the Richmondian). Paired tests between these associations were conducted using the temporally isolated forms as a "control" group for comparison.

Figures 23 and 24 illustrate differences in morphospace occupation based on these general associations. As a criterion to identify morphological differentiation, it was successful. The alate morphologies evidenced clear

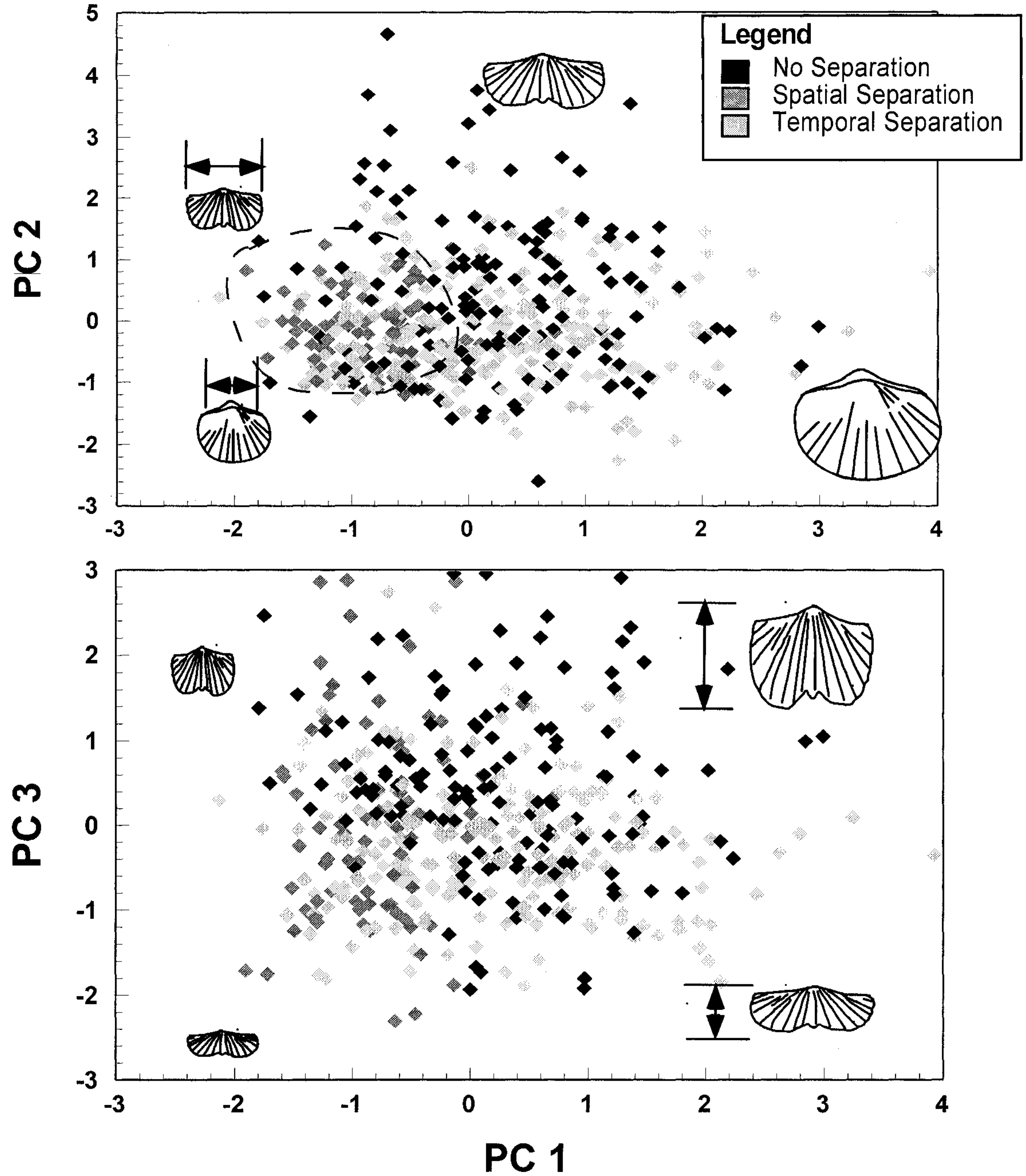


Figure 23. Ordination of alate *Platystrophia* along first three principal components, coded by brachiopod associations. The black squares represent alate brachiopods that were found alongside non-alate forms in the same beds, and thus have the greatest amount of; dark gray indicates alate forms found spatially separated from non-alate forms (note tight cluster marked by enclosure in top chart); light gray represents alate forms found when no non-alate forms existed and, thus, had no association (Sequence C5).

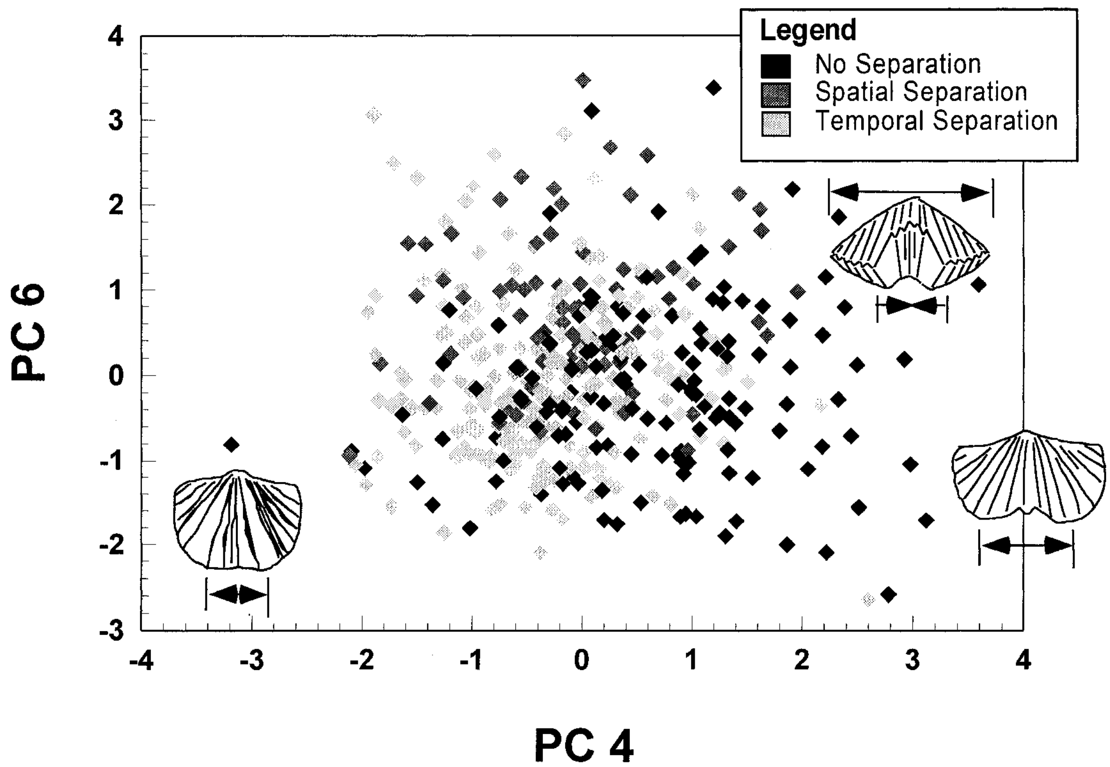


Figure 24. Ordination along PC 4 and PC 6 showing the differences between alate forms. All three associations differ significantly along PC 4 (sulcus width). For PC 6 only the alates existing along-side non-alates demonstrated significant differences (sulcus width decreases relative to overall width). Both axes demonstrate changes in the functionally important sulcus region. Since sulcus morphology is strongly tied to feeding, changes in this region may indicate adaptations to assist in the acquisition of limited resources in the presence of other competitors.

separations on all shape-related axes. Alate forms that were spatially, but not temporally, isolated were significantly smaller than other alate forms (Figure 23; Table 16) and had larger sulcus width/width ratios (Figure 24; Table 19). At the same time, definition of alae, length, and sulcus width were much stronger among forms that existed along-side non-alate forms (Figures 23 and 24; Tables 17 -20).

Kruskal-Wallis One Way Analysis of Variance on Ranks: Alates for PC 1

Normality Test: Failed (P = 0.0347)

Group	N
Temporal Separation	219
Spatial Separation	77
No Separation	143

Group	Median	25%	75%
Temporal Separation	0.113	-0.607	0.835
Spatial Separation	-0.850	-1.213	-0.513
No Separation	0.229	-0.323	0.800

H = 80.9 with 2 degrees of freedom. (P = <0.0001)

The differences in the median values among the treatment groups are greater than would be expected by chance; there is a statistically significant difference (P = 2.71E-018)

To isolate the group or groups that differ from the others use a multiple comparison procedure.

All Pairwise Multiple Comparison Procedures (Dunn's Method) :

Comparison	Diff of Ranks	p	Q
No Separation vs. Spatial Separation	153.2	3	8.54
No Separation vs. Temporal Separation	19.6	2	1.44
Temporal Separation vs. Spatial Separation	133.6	2	7.95

Comparison	P<0.05
No Separation vs. Spatial Separation	Yes
No Separation vs. Temporal Separation	No
Temporal Separation vs. Spatial Separation	Yes

Table 16. Kruskal-Wallis results for populations grouped by association for principal component 1. Alate forms living alongside non-alate forms were significantly larger than the others.

Kruskal-Wallis One Way Analysis of Variance on Ranks: Alates for PC 2

Normality Test: Failed (P = 0.0007)

Group	N
Temporal Separation	219
Spatial Separation	77
No Separation	143

Group	Median	25%	75%
Temporal Separation	-0.309	-0.805	0.311
Spatial Separation	-0.199	-0.539	0.117
No Separation	0.328	-0.609	1.295

H = 23.1 with 2 degrees of freedom. (P = <0.0001)

The differences in the median values among the treatment groups are greater than would be expected by chance; there is a statistically significant difference (P = 0.00000979)

To isolate the group or groups that differ from the others use a multiple comparison procedure.

All Pairwise Multiple Comparison Procedures (Dunn's Method) :

Comparison	Diff of Ranks	p	Q
No Separation vs. Temporal Separation	63.98	3	4.691
No Separation vs. Spatial Separation	55.15	2	3.075
Spatial Separation vs. Temporal Separation	8.83	2	0.525

Comparison	P<0.05
No Separation vs. Temporal Separation	Yes
No Separation vs. Spatial Separation	Yes
Spatial Separation vs. Temporal Separation	No

Table 17. Kruskal-Wallis results for populations grouped by association for principal component 2. Alate forms living alongside non-alate forms had significantly larger alae.

Kruskal-Wallis One Way Analysis of Variance on Ranks: Alates for PC 3

Kruskal-Wallis One Way Analysis of Variance on Ranks

Normality Test: Failed (P = 0.0020)

Group	N
Temporal Separation	219
Spatial Separation	77
No Separation	143

Group	Median	25%	75%
Temporal Separation	-0.2690	-0.754	0.108
Spatial Separation	-0.0350	-0.940	0.797
No Separation	0.4180	-0.315	1.093

H = 44.6 with 2 degrees of freedom. (P = <0.0001)

The differences in the median values among the treatment groups are greater than would be expected by chance; there is a statistically significant difference (P = 0.000000000205)

To isolate the group or groups that differ from the others use a multiple comparison procedure.

All Pairwise Multiple Comparison Procedures (Dunn's Method) :

Comparison	Diff of Ranks	p	Q
No Separation vs. Temporal Separation	91.1	3	6.68
No Separation vs. Spatial Separation	58.7	2	3.27
Spatial Separation vs. Temporal Separation	32.3	2	1.92

Comparison	P<0.05
No Separation vs. Temporal Separation	Yes
No Separation vs. Spatial Separation	Yes
Spatial Separation vs. Temporal Separation	No

Table 18. Kruskal-Wallis results for populations grouped by association for principal component 3. Alate forms living alongside non-alate forms had significantly greater shell lengths.

Kruskal-Wallis One Way Analysis of Variance on Ranks: Alates for PC 4

Normality Test: Failed (P = 0.0488)

Group	N
Temporal Separation	219
Spatial Separation	77
No Separation	143

Group	Median	25%	75%
Temporal Separation	-0.3520	-0.906	0.136
Spatial Separation	-0.0710	-0.531	0.410
No Separation	0.5880	-0.107	1.305

H = 75.1 with 2 degrees of freedom. (P = <0.0001)

The differences in the median values among the treatment groups are greater than would be expected by chance; there is a statistically significant difference (P = 4.84E-017)

To isolate the group or groups that differ from the others use a multiple comparison procedure.

All Pairwise Multiple Comparison Procedures (Dunn's Method) :

Comparison	Diff of Ranks	p	Q
No Separation vs. Temporal Separation	118.1	3	8.66
No Separation vs. Spatial Separation	76.9	2	4.29
Spatial Separation vs. Temporal Separation	41.3	2	2.46

Comparison	P<0.05
No Separation vs. Temporal Separation	Yes
No Separation vs. Spatial Separation	Yes
Spatial Separation vs. Temporal Separation	Yes

Table 19. Kruskal-Wallis results for populations grouped by association for principal component 4. All three associations exhibit statistically significant differences in sulcus width.

Kruskal-Wallis One Way Analysis of Variance on Ranks: Alates for PC 6

Normality Test: Failed (P = 0.0161)

Group	N
Temporal Separation	219
Spatial Separation	77
No Separation	143

Group	Median	25%	75%
Temporal Separation	-0.226	-0.789	0.401
Spatial Separation	0.785	0.135	1.242
No Separation	-0.333	-0.930	0.359

H = 54.1 with 2 degrees of freedom. (P = <0.0001)

The differences in the median values among the treatment groups are greater than would be expected by chance; there is a statistically significant difference (P = 1.76E-012)

To isolate the group or groups that differ from the others use a multiple comparison procedure.

All Pairwise Multiple Comparison Procedures (Dunn's Method) :

Comparison	Diff of Ranks	p	Q
Spatial Separation vs. No Separation	125.0	3	6.97
Spatial Separation vs. Temporal Separation	109.7	2	6.53
Temporal Separation vs. No Separation	15.3	2	1.12

Comparison	P<0.05
Spatial Separation vs. No Separation	Yes
Spatial Separation vs. Temporal Separation	Yes
Temporal Separation vs. No Separation	No

Table 20. Kruskal-Wallis results for populations grouped by association for principal component 6. Alate forms that existed alongside non-alate forms (Col. 10) demonstrated significantly different morphology for this axis.

Most striking was the pattern of differences exhibited between all three associations for three of the PC axes. Box plots for Kruskal-Wallis test results illustrate them (Figure 25). A relative increase in difference is found along principal components in relation to proximity of alate and non-alates in space and time. In all three plots, the alate forms most isolated from non-alate forms -- those temporally isolated -- showed the lowest score for three morphological factors. Conversely, those living along-side non-alate forms exhibited the largest values. Spatially separated forms had intermediate values. Thus, the alate forms that likely lived side-by-side with non-alate forms exhibited the strongest alation definition, the largest length, and the largest sulcus width (Fig. 23; Tables 17-19).

The most plausible explanation for these patterns is that the morphology of alate *Platystrophia* was influenced by character displacement. It is well established in biology that overlap in geographic range between two otherwise similar species produces morphological, behavioral, or physiological differences among the populations. Brown and Wilson (1956) have described the phenomenon of character displacement;

> Two closely related species have overlapping ranges. In the parts of the ranges where one species occurs alone, the populations of that species are similar to the other species and may even be difficult to distinguish from it. In the area of overlap, where the two species occur together, the populations are more divergent and easily distinguished, i.e., they "displace" one another in more characters. The characters involved can be morphological, ecological, behavioral, or physiological; they are assumed to be genetically based.

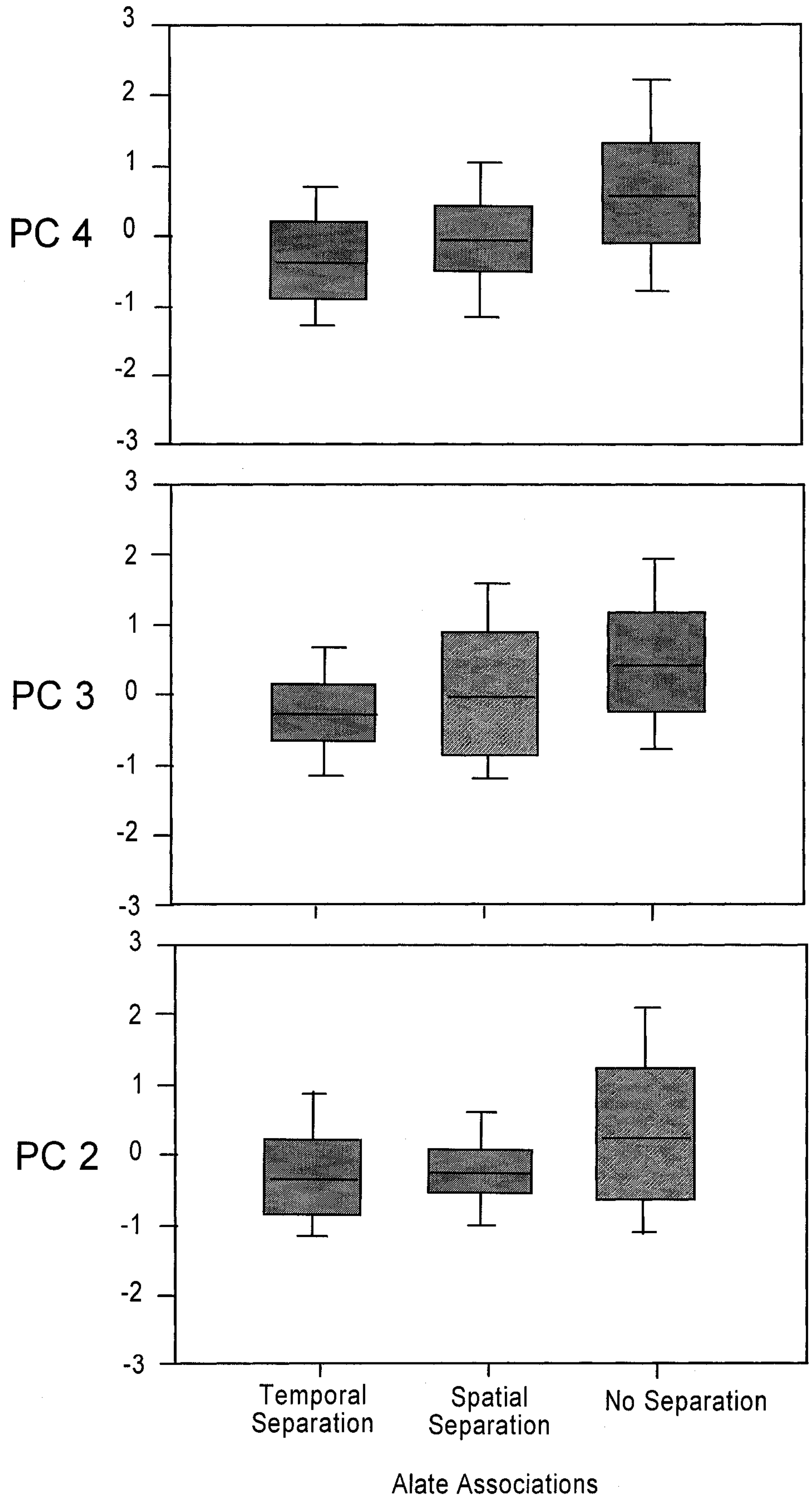


Figure 25. Box plots of Kruskal-Wallis test results for alate associations. PC 2, PC 3 and PC 4 demonstrate progressive changes in alate *Platystrophia* morphology with closer temporal and spatial proximity with non-alate forms.

Character displacement is a taxonomically ubiquitous phenomenon, as well as wide-ranging in terms of traits potentially affected. Examples have been documented clearly among a wide variety of taxa, including amphibians (Blair, 1974), reptiles (Schoener, 1970), insects (Wilson, 1975), Hominidae (Schaffer, 1968), and birds, including Darwin's Galapagos finches (Brown and Wilson, 1956; Lack, 1947). Morphological diversity, such as changes in size (Wilson, 1975) as a result of spatial relationships has been well-defined (Pianka, 1967). But the phenomenon has been documented for other biological characteristics as well, including behavior, ontogenetic development, feeding, and mating calls (Blair, 1974; Fenchel, 1975; Huey and Pianka, 1974). As would be expected, such a common biological observation is not without corollary in the fossil record. Instances of character displacement have been cited in the paleontological literature among gastropods (Eldredge, 1968; Schindel and Gould, 1977), trilobites (Eldredge, 1974), and brachiopods, including Cincinnatian *Lepidocyclus* and *Rafinesquina* (Alexander, 1976; Leighton, 1995).

Fossil communities have been deemed a potentially rich area for the study of character displacement (Eldredge, 1974). However, since crucial biological information cannot be tested in fossil populations (e.g., genetic data) the character displacement interpretation must be held cautiously. Rigorous testing of this phenomenon can occur only with living populations (Connell, 1980), and some paleontological examples have been called into question (Fagerstrom, 1978). *Platystrophia* provides additional problems since the species designations are not clear, especially among alate forms.

Geographic Variation

Comparisons among localities indicate that geographic variation was a common feature among Cincinnatian *Platystrophia* populations. Further, this variation may provide a partial explanation for the taxonomic confusion surrounding species designations within the genus.

Bellevue Localities - Figure 26 illustrates geographic variation among the four Bellevue localities. In particular, Riedlin/Mason Road (Covington, Kentucky) differs most substantially as an individual site (Table 21). Kruskal-Wallis tests show significant differences between Riedlin/Mason and all three other localities for PC 2 ($p < 0.05$). Alae width is significantly smaller at this locality than for the other sites. Likewise, alae width was significantly different between the two most geographically separated Bellevue sites: Georgetown, Ohio and Rising Sun, Indiana. Georgetown specimens exhibited significantly smaller alae than did Rising Sun specimens. Differences among separated localities suggest the presence of a geographic gradient. However, since the most unique population, Riedlin/Mason, was geographically central, there is no indication of a clear geographic gradient.

Mt. Auburn localities - The Mt. Auburn specimens demonstrated both size and shape differences with respect to locality (Figure 27; Table 22). Goshen locality specimens scored significantly higher for PC 1 than Blue Rock Road specimens ($p = 0.0009$). At the same time, Mann-Whitney test results show that the Blue Rock Road population had significantly larger factor scores for PC 2 ($p = 0.0268$).

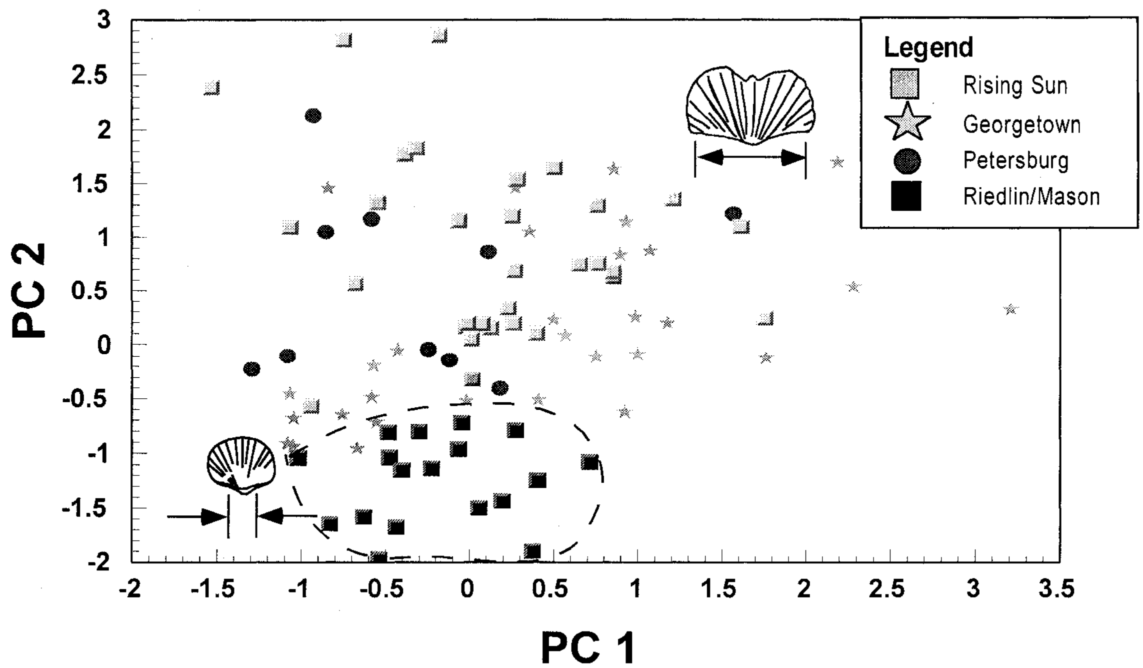


Figure 26. Ordination of Bellevue *Platystrophia* coded by locality. Differences indicate geography as a factor underlying morphological variation. Riedlin/Mason Road locality (enclosed black squares) forms a tight outlying cluster among the localities along PC 2 (smaller relative alae width). Rising Sun specimens (light gray squares) differ significantly from Georgetown collections (represented as stars). Geographic location is a factor in variation for populations within the same formation in Sequence C2.

Geographic Variation in Bellevue for PC 2

Kruskal-Wallis One Way Analysis of Variance on Ranks

Normality Test: Passed (P = 0.1649)
Equal Variance Test: Failed (P = 0.0478)

Group	N
Covington	19
Rising Sun	39
Georgetown	34
Petersburg	11

Group	Median	25%	75%
Covington	-1.1430	-1.585	-0.965
Rising Sun	0.7490	0.240	1.319
Georgetown	-0.0530	-0.511	0.679
Petersburg	0.4085	-0.142	1.166

H = 52.2 with 3 degrees of freedom. (P = <0.0001)

The differences in the median values among the treatment groups are greater than would be expected by chance; there is a statistically significant difference (P = 2.77E-011)

To isolate the group or groups that differ from the others use a multiple comparison procedure.

All Pairwise Multiple Comparison Procedures (Dunn's Method) :

Comparison	Diff of Ranks	p	Q
Rising Sun vs Covington	58.7	4	7.14
Rising Sun vs Georgetown	21.4	3	3.14
Rising Sun vs Petersburg	10.4	2	1.02
Petersburg vs Covington	48.3	3	4.27
Petersburg vs Georgetown	11.1	2	1.07
Georgetown vs Covington	37.3	2	4.43

Comparison	P<0.05
Rising Sun vs Covington	Yes
Rising Sun vs Georgetown	Yes
Rising Sun vs Petersburg	No
Petersburg vs Covington	Yes
Petersburg vs Georgetown	No
Georgetown vs Covington	Yes

Table 21. Kruskal-Wallis results for Bellevue samples for PC 2. Covington samples (Riedlin/Mason Road) vary significantly from all other samples. Rising Sun *Platystrophia* samples vary significantly from Georgetown.

Blue Rock Road and Goshen: PC 1

Mann-Whitney Rank Sum Test

Normality Test: Passed (P = 0.2115)
Equal Variance Test: Passed (P = 0.9195)

Group	N
Blue Rock Rd.	31
Goshen	16

Group	Median	25%	75%
Blue Rock Rd.	0.798	0.394	1.58
Goshen	2.559	1.696	3.04

T = 480.0 n(small)= 15 n(big)= 30 (P = 0.0012)

The differences in the median values among the two groups are greater than would be expected by chance; there is a statistically significant difference (P = 0.00120)

Blue Rock Road and Goshen: PC 2

Mann-Whitney Rank Sum Test

Normality Test: Passed (P = 0.2440)
Equal Variance Test: Passed (P = 0.3630)

Group	N
Blue Rock Rd.	31
Goshen	16

Group	Median	25%	75%
Blue Rock Rd.	-0.0710	-0.636	0.448
Goshen	-0.5640	-1.559	-0.127

T = 256.0 n(small)= 15 n(big)= 30 (P = 0.0331)

The differences in the median values among the two groups are greater than would be expected by chance; there is a statistically significant difference (P = 0.0331)

Table 22. Mann-Whitney results for Blue Rock Road and Goshen localities. Localities show significant differences for both PC 1 and PC 2.

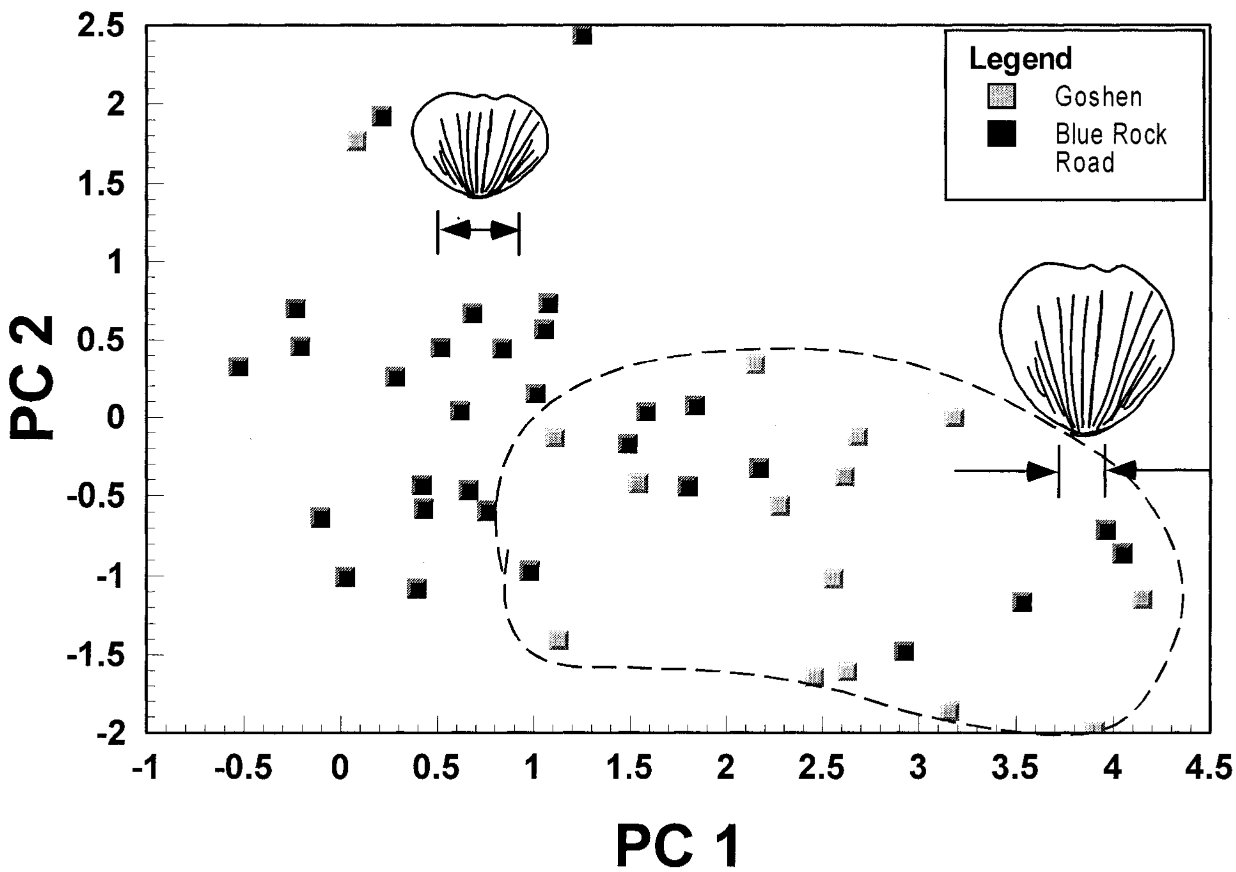


Figure 27. Ordination of Mt. Auburn localities Blue Rock Road and Goshen demonstrate geographic variation within the same formation of Sequence C3. Both localities show significant separation along both PC 1 and PC 2 (size and shape variation). Blue Rock Road specimens are smaller in overall size but have wider alae than specimens from the Goshen locality.

Whitewater localities - Among Whitewater specimens comparisons between Brookville, Indiana site at Route 101 and Cowan Lake, Ohio also yielded morphological separation (Fig. 28; Table 23). The Brookville population had both larger alae (p = 0.0441) and greater anterior-posterior lengths (p = 0.0371). Thus, like the Bellevue and Mt. Auburn formations, the Whitewater populations exhibit intra-formational geographical variation. An additional paleoenvironmental factor should be considered with the geographic

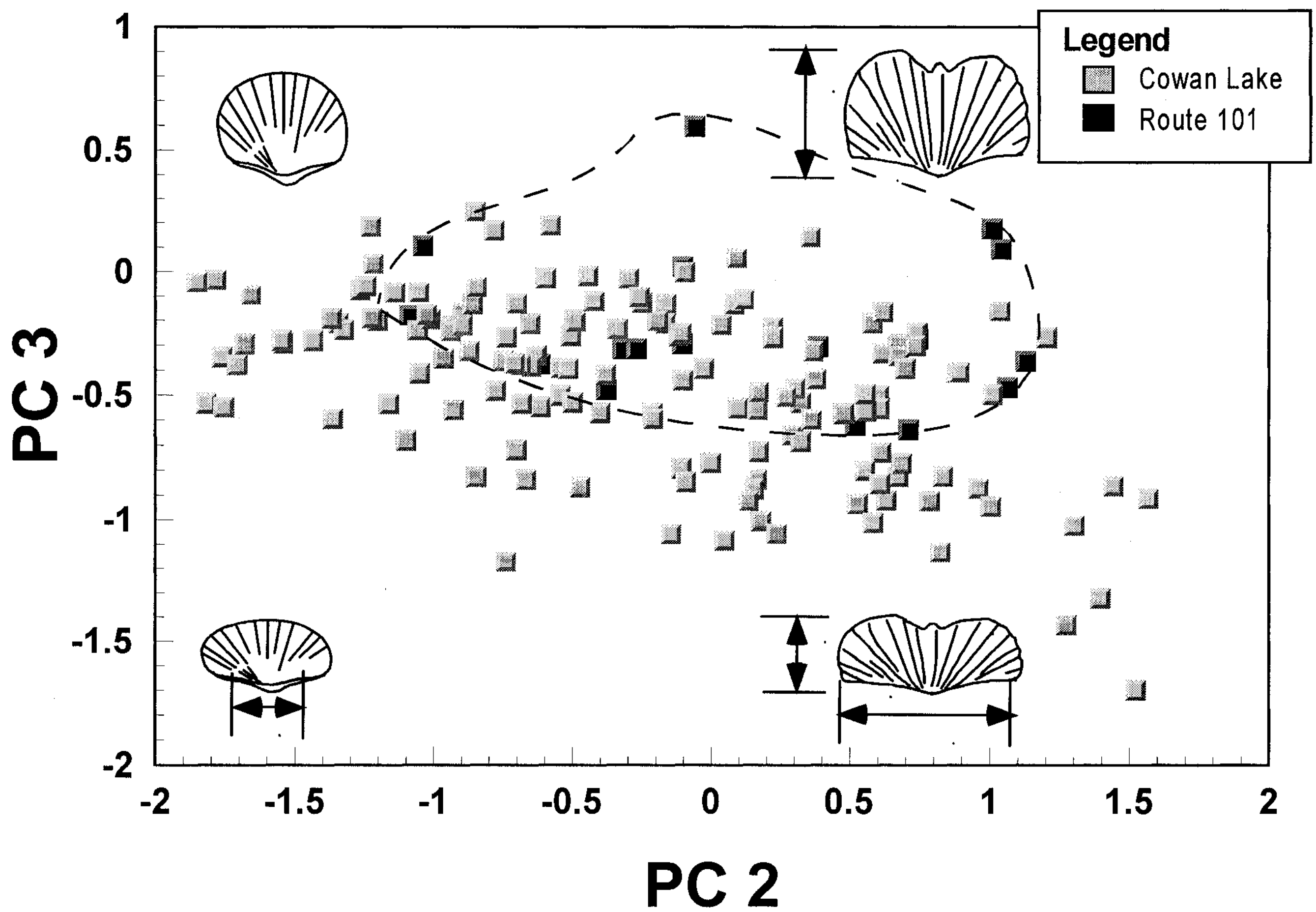


Figure 28. Ordination for Whitewater localities Cowan Lake and Route 101. Both PC 2 (alae width) and PC 3 (length) are significantly larger for Route 101, making it appear as an end-member of the Cowan Lake population . Geographic variation is therefore an important factor for specimens in Sequence C5.

Cowan Lake and. Route 101: PC 2

Mann-Whitney Rank Sum Test

Normality Test: Passed (P = 0.0988)
Equal Variance Test: Passed (P = 0.5574)

Group	N
Cowan Lake	150
Brookville	18

Group	Median	25%	75%
Cowan Lake-	0.203	-0.851	0.377
Brookville	0.162	-0.321	0.743

T = 1932.5 n(small)= 18 n(big)= 150 (P = 0.0351)

The differences in the median values among the two groups are greater than would be expected by chance; there is a statistically significant difference (P = 0.0351)

Cowan Lake and. Route 101: PC 3

Mann-Whitney Rank Sum Test

Normality Test: Failed (P = 0.0243)

Group	N
Brookville, IN	18
Cowan Lake, OH	150

Group	Median	25%	75%
Brookville, IN	-0.300	-0.376	0.0210
Cowan Lake, OH	-0.389	-0.681	-0.2060

T = 1928.0 n(small)= 18 n(big)= 150 (P = 0.0371)

The differences in the median values among the two groups are greater than would be expected by chance; there is a statistically significant difference (P = 0.0371)

Table 23. T-test and Mann-Whitney Rank Sum results for Whitewater localities. Cowan Lake and Route 101 show significant differences for PC 2 and PC 3.

separation. According to Holland (1993) Cowan Lake was located slightly downramp of Brookville, Indiana. It could be postulated that differences in location on the Cincinnati ramp introduced paleoenvironmental factors that were responsible for these changes (as opposed to, or in addition to geographic factors.) Thus, geographic separation may sometimes be association with different paleoenvironmental settings.

Implications of this Study for the Designation of Platystrophia *Species*

Although taxonomic questions were not primary foci of this thesis, the data evaluated herein raise questions about the delineation of *Platystrophia* species in the type Cincinnatian. When considered *en masse*, the *Platystrophia* specimens form a continuous, intergrading cloud of data points in multivariate space (Figs. 17, 18, and 28). Clear separations among the numerous named species and subspecies (McEwan, 1919) were not visible in PC space. The only exception was *P. ponderosa auburnensis* from the Mt. Auburn formation (Fig. 29) All PC axes and morphometric distances for this subspecies showed significant separation (Table 24).

There are three principal reasons why individual species of a genus might not be visible. 1) Identification of species is sometimes difficult from morphology alone. This is true in the snail genus *Cerion* that has been better identified by electrophoretic than morphological data (Woodruff and Gould, 1987). Interestingly, *Cerion* was highly oversplit based on the morphological data alone. But in other cases, the morphology is an accurate indicator of genetic constitution. The coral *Porites* showed 90% consistency between landmark analysis and allozyme electrophoresis, while the gastropod *Amalda* showed 85-98% certainty (Budd et al., 1994; Kowalewski et al., 1997; Michaux, 1989). In any case, the delineation of all *Platystrophia* species has been based on morphological characteristics. The data here show strong intergradations among species for many of the characters originally used to define *Platystrophia*.

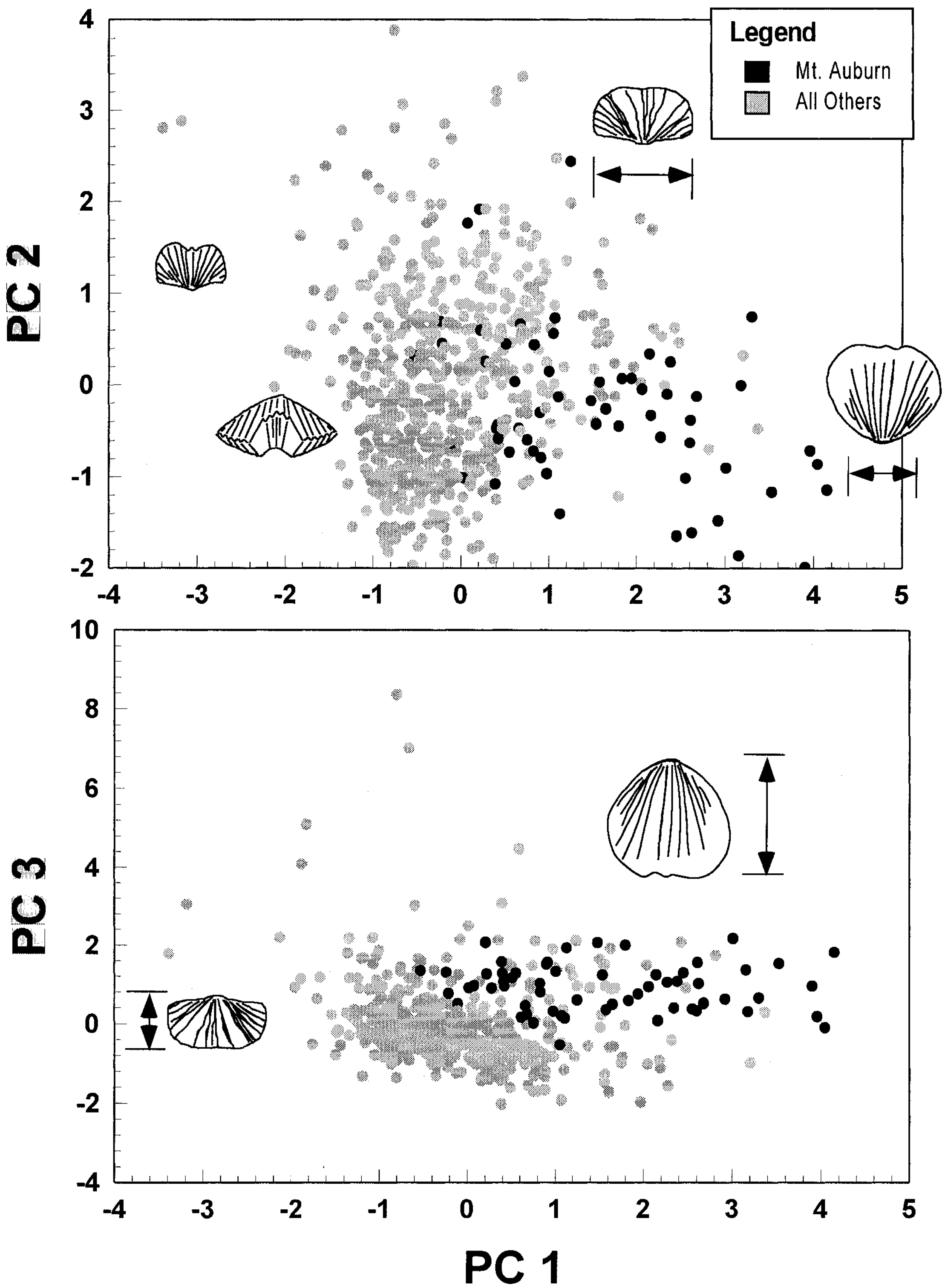


Figure 29. Ordinations of all *Platystrophia* collections highlighting the Mt. Auburn specimens, *Platystrophia ponderosa auburnensis*. Only this "sub-species" showed distinct separation from the rest of the *Platystrophia* species. All other morphologies display tight clustering and overlap in morphospace occupation. *P. ponderosa auburnensis* displayed a consistently large size (PC 1), little to no alation (PC 2), and significantly longer length (PC 3). These parameters are responsible for giving the *auburnensis* specimens their distinctive spherical morphology.

Statistics for *Platystrophia ponderosa auburnensis* Mann-Whitney Rank Sum Tests				
	Width			
	N	Median	25%	75%
All *Platystrophia*	573	21.8	17.2	27.3
P. ponderosa auburnensis	59	35.7	30.2	37
	Thickness			
	N	Median	25%	75%
All *Platystrophia*	573	11.1	8.5	14.9
P. ponderosa auburnensis	59	24.9	19.83	27.4
	Sulcus Width			
	N	Median	25%	75%
All *Platystrophia*	573	10.6	8.15	13.4
P. ponderosa auburnensis	59	18.2	15.24	19.9
	Sulcus Height			
	N	Median	25%	75%
All *Platystrophia*	573	8	5.85	10.7
P. ponderosa auburnensis	59	15.41	11.79	17.7
	Length			
	N	Median	25%	75%
All *Platystrophia*	573	12.9	10.4	15.8
P. ponderosa auburnensis	59	23.5	20.6	25.9
	Lateral Rib Number			
	N	Median	25%	75%
All *Platystrophia*	573	7	7	8
P. ponderosa auburnensis	59	8	7	9

Table 24. Mann-Whitney Rank Sum test results comparing six morphological parameters of *P. ponderosa auburnensis* to the genus as a whole. All tested parameters are significantly different.

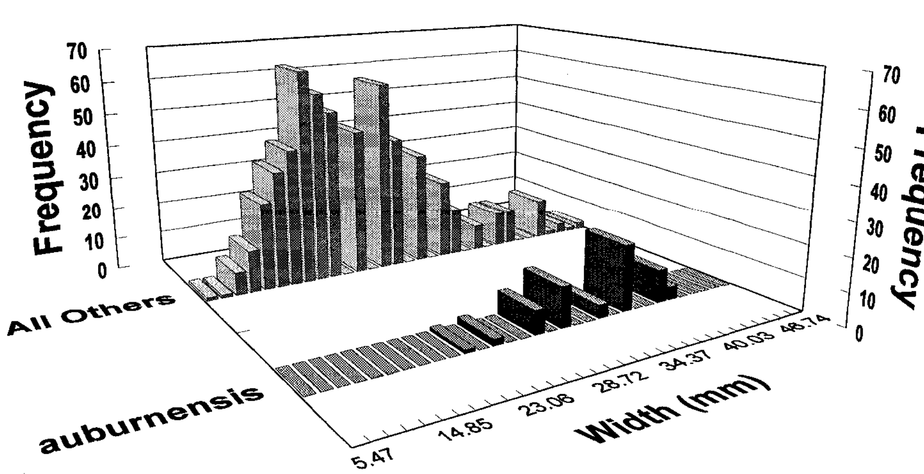


Figure 30. Histogram comparing width of *P. p. auburnensis* with all other *Platystrophia* species.

2) Morphological variables and descriptions used here were insufficient. It is certain that the morphological variables chosen for this study do not exhaustively describe all morphological subtleties of the genus. However, distinctions could still be recognized among some species (e.g., those that were "globose" in shape). As already mentioned *P. p. auburnensis* can be distinguished. If these taxonomic designations are accurate, then the morphological variables chosen for this study were sufficient to distinguish differences at the level of subspecies for at least some of the proposed species (since *P. p. auburnensis* would be a subspecies of *P. ponderosa*). Though tentative because of small sample size, a second *ponderosa* subspecies was probably distinguished by PCs as well. *P. p. arnheimensis* was compared to the most stratigraphically and geographically proximate specimens of *ponderosa* and found to be statistically different for the fourth PC. (See below).

Alate forms were not as easily separated in PC space by the variables used here. This was at least partly the result of the choice of characters for measurement. Diagnostic characteristics for alate forms, as chosen by workers who assigned the species designations, tended to be traits non-amenable to landmark selection (Table 25). In this case, distinctions would have been blurred as a result of the data collection methodology. On the other hand, many of the characters seen as diagnostic by these earlier workers appeared more subjective than those conducive to landmark analysis. My qualitative observations of characteristics such as slope convexity near the sulcus (e.g., a diagnostic trait for

Diagnostic Morphological Characteristics for *Platystrophia* Species			
Characteristics covered by landmark analysis		**Characteristics not covered by landmark analysis**	
Character	**Example**	**Character**	**Example**
1. Fold height	*P. sublaticosta*	1. Strength of certain ribs	*P. sublaticosta*
2. Lateral rib count	*P. preponderosa*	2. Inflation of shell near umbo	*P. moritura*
3. Relative width	*P. clarksvillensis*	3. Depth of sulcus	*P. moritura*
4. Hinge line/width	*P. clarksvillensis*	4. Inflation of slope	*P. acutilirata*
5. Fold ribs	*P. ponderosa*	5. Compression of pedicle valve	*P. acutilirata*
6. Hinge extension	*P. acutilirata*	6. Beak curvature	*P. acutilirata*
7. Fold relief	*P. profundosulcata hopensis*	7. Outline shape	*P. profundosulcata hopensis*
8. Thickness, height, hinge, width	*P. preponderosa*	8. Slope convexity near sulcus	*P. laticosta*
9. Globosity	*P. ponderosa auburnensis*	9. Rib width	*P. ponderosa arnheimensis*
		10. Lengthwise convexity of lateral slopes	*P. laticosta*

Table 25. Diagnostic characteristics for *Platystrophia* species. The left side shows characteristics that were incorporated by landmark analysis; those on the right are those that could not have been defined by landmarks (or could only with great difficulty). Most species with alae are described by characters on the right side -- those difficult for landmark analysis (boxes representing alate species shaded gray). Characteristics given are those of McEwan (1919) and original type references.

P. laticosta, McEwan, 1919; Table 25) suggest they would probably fail to provide further distinction, even when quantified. If this is the case, then distinctions between many of the alate forms may have been largely overstated. Alberstadt's reassessment of McEwan's 1919 classification lumped several such alate species for this reason (Alberstadt, 1979). Further morphometric and taxonomic work employing different techniques (e.g., Fourier analysis, use of discriminant analysis) needs to be done to clarify this issue.

3) The patterns are real and reflect a more complex biological signal. The intergradation of specimen morphology would indicate that the genus has been oversplit at the species level. The fact that at least some oversplitting has occurred is consistent with taxonomic work on the genus since McEwan's work (Alberstadt, 1979). Brachiopods of a similar morphology, *Mucrospirifer*, also once showed a considerable amount of overlap in its variation and, as a result, species numbers were reduced (Tillman, 1964). Further, morphometric work on *Mucrospirifer* employing multivariate analysis suggested even further reduction based on geographic patterns (Welch, 1991). *Platystrophia* appears analogous in some ways both for taxonomic and geographic patterns.

Principal Components and species resolution: Simulation

Bootstrapping -- "Bootstrapping" is a nonparametric, computer-intensive approach to statistical inference that can be applied when the underlying distribution of a population is not known. Sampling of the data is conducted with replacement to create a new population of pseudo-samples. In conventional parametric statistics, one assumes the form of the underlying distribution. In bootstrapping, the observational data, or numbers calculated from them, are used to construct a distribution and the statistical properties of this distribution are learned (Hubbard and Gilinsky, 1992). Bootstrapping has proved to be an effective tool for situations where data are limited (Gilinsky, 1991; Gould et al., 1985).

Figure 30 provides a schematic representation of the bootstrapping approach employed for the *P. p. arnheimensis* samples. Even though the fourth

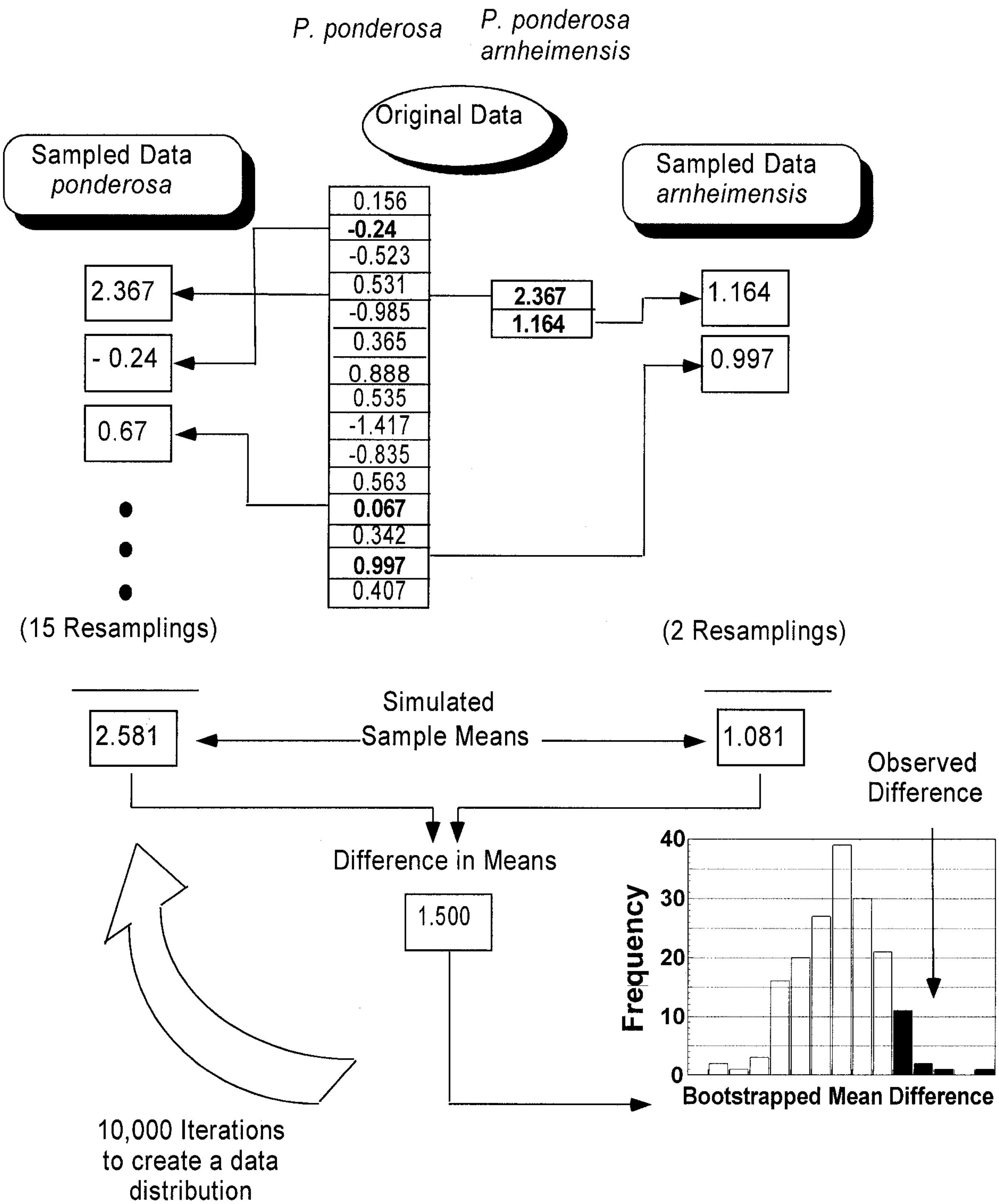
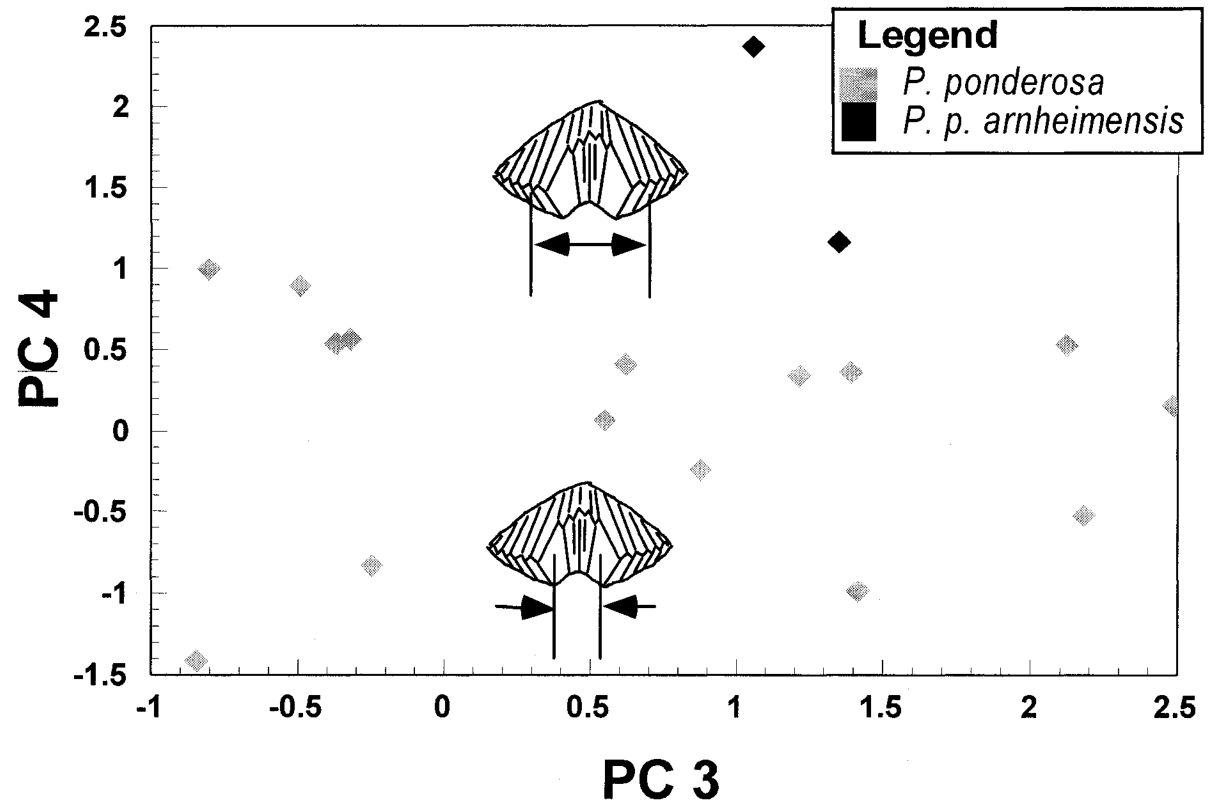


Figure 31. Schematic description of the bootstrapping method applied to the principal component scores of *P. ponderosa* and *P. p. arnheimensis*. In the bootstrapping method, the original data set is chosen randomly and with replacement from each data category and these are averaged to create bootstrapped population means for each species. The purpose is to determine how many times a difference in population means is created that is more than the observed difference. An example of this sampling is depicted. Repeating this process many times (I performed 10,000 cycles) creates a distribution of bootstrapped values that can be used to assess the value of the observed difference (seen in sample histogram on lower right; outliers shaded black for illustration).

principal component scores for *arnheimensis* appeared different from other *ponderosa* specimens, this could not be stated in a valid statistical fashion given the small data set (Fig. 31). Only two specimens were available for comparison, and conventional parametric and nonparametric approaches could not be employed.

To address this question, a null model was hypothesized where the scores for PC 4 were a product of chance, and not unusual. In this model, the difference in population means between the 15 *P. ponderosa* (chosen for geographic and stratigraphic proximity) and the two *P. p. arnheimensis* are assumed to be no larger than random sampling differences. Figure 31 illustrates the sampling procedure. Scores were randomly chosen from *ponderosa* and *p. arnheimensis* data and re-assigned to one of two "new" populations: 15 for *ponderosa* and 2 for *arnheimensis*. These new populations were averaged and the differences calculated, thus assigning mean population difference as a test statistic (Fig. 32; Appendix F; Appendix G). The computer again chose another set of samples, averaged the sums, and determined mean differences -- 10,000 repetitions in all to create a distribution of test statistics.

By accumulating the calculated sample mean differences the frequency with which a certain sample mean difference occurred could be determined. If the frequency was less than 500 in 10,000 simulations (0.05) then it was assumed to be significant. Expressed as a decimal, this frequency is equivalent to the probabilities for significance, or *p*-values, used in conventional parametric tests (Hubbard and Gilinsky, 1992). As in conventional tests, a small *p*-value



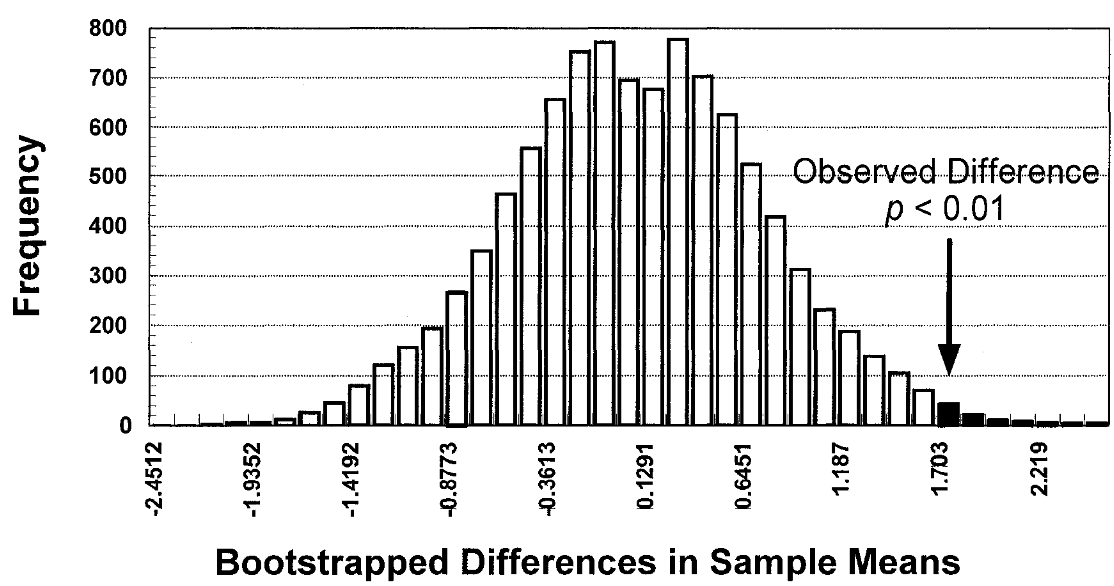


Figure 32. Bootstrapping results for *P. p. arnheimensis.* Top: Ordination of *P. ponderosa* and *P. p. arnheimensis* for PC 4 illustrate the sensitivity of PC results at the level of subspecies on an important region of shell anatomy. Bottom: The observed sample mean difference of 1.7088 is an outlier. Bootstrapped sample mean differences this large occurred less than 100 times in 10,000 samplings ($p < 0.01$).

generated by the bootstrapping method was considered a statistical outlier (Appendix G). Bootstrapping results indicated sulcus width for *p. arnheimensis* is larger than that of *ponderosa*. These results show that principal component scores were sensitive enough to distinguish seemingly small morphological differences. Such a distinction may have been suggested in the original type description of *p. arnheimensis* (e.g., transverse shape, McEwan, 1919). Yet most of the taxonomic difficulties for *Platystrophia* reside with the alate forms. It is safe to say additional analyses must be brought to bear on that question.

Discussion: Geographic variation, species, and polytypic species.

Living species that have been quantitatively analyzed often demonstrate geographic variation in morphology. One-half to two-thirds of known species display geographic variation in one or more characters (Mayr, 1970). This is because populations within a single species differ genetically and phenotypically. Analysis of morphological data in *Mucrospirifer* reveals clear geographic trends (Welch, 1991). Studies of *Lingula* show morphogroups based on geography; geography for *Lingula* is more of a factor in morphology than even substrate (Kowalewski et al., 1997).

One concept that combines the observations of geographic variation and blurred species distinctions is Mayr's concept of polytypic species. A polytypic species is one in which local populations within the species differ from one another (Mayr, 1970). Situations where many subspecies comprise a single species is common (Mayr, 1969). One illustrative case is the song sparrow

Passerella melodia. Prior to the nineteenth century, geographic variation was not an important component of biological research and species designations abounded (Mayr, 1970; Welch, 1991). Since geographical variation is fundamental to the concept of a polytypic species, a lack of understanding of geographical relationships within *P. melodia* resulted in the naming of over 30 separate species. Up to the early 1800s, four sparrow species were identified in eastern North America. By the middle of the nineteenth century, four new "species" were discovered in the west. Eventually, a series of intermediate "species" were discovered in the mid-continent, connecting the eastern and western varieties. All were eventually combined into a single polytypic species. Today there are 34 subspecies of *P. melodia* found throughout North America. Within fossils, a similar situation may be present in the trilobite genus *Dikelocephalus* (Labandeira and Hughes, 1994). Though *Platystrophia* may not comprise a *single* polytypic species (e.g., *P.p auburnensis* in Table 24), the ubiquity of polytypy in the biological world makes the consideration reasonable.

Population structures of most organisms are complex and the product of a variety of factors. Most species are influenced by geographic, ecological, genetic, developmental and historical factors. Mayr (1970) divided organismal populations into three basic components: clines, geographical isolates, and hybrid belts. The confusion concerning *Platystrophia* probably results from its populations being the combination of several such components. Clines are evident when species show gradual changes along a line of connected populations. This would create an intergradation of morphological forms. Geographical isolates occur when a population is separated from the main range of a population, resulting in unique morphologies. The Mt. Auburn may be suggestive of such an event, owing to its morphological distinctiveness. (However, there are no known physical barriers that would explain isolation of the Mt. Auburn). Hybrid belts would be more difficult to detect in the fossil record due to their temporal transience. Hybridization, a feature difficult to detect, may have been recognized in fossil snails and crinoids (Ausich and Meyer, 1994; Geary, 1992) but no instance is known in *Platystrophia.*

Application of some of these concepts has been lacking in many organisms, particularly invertebrates (Mayr, 1970). Brachiopods are good candidates for the study of polytypic species. The number of fossil brachiopod species exceeds 30,000, while there are only 400 living; understanding of geographic variation might reduce this number substantially (Welch, 1991). Life mode and limited larval dispersal in articulate brachiopods create ideal conditions for phenotypic localization. Articulate brachiopods are sedentary, substrate dependent, and often brood their larvae (Rudwick, 1970). Their limited larval dispersal capabilities help create the patchy ecological distributions that are conducive to producing both geographic variation and speciation. *Platystrophia*'s variability, at least in part, may be the product of such factors.

The taxonomic issues ultimately point to a choice between the existence of many highly "plastic" species, a combination of plastic species and geographic variability, or relatively few polytypic species. The question for *Platystrophia* is then whether the high number of species designations is a product of mistaking geographically separated end-members for species. If the original species were end-member variants of a polytypic species, then type-specimens would be expected to exist in a variety of geographic locations. For example, the three *ponderosa* forms were collected at different stratigraphic levels and geographic localities and show clear morphological differences (e.g., Figs. 21, 31). However, the greatest taxonomic confusion resides among alate forms (Alberstadt, 1979). Type localities are often geographically distant, as would be expected if geography was a causal factor. On the other hand, proposed species ranges overlap and often cover large areas of the Cincinnatian. Such overlap contradicts the expectation of geographically based variation. More research is required to understand the relationship between proposed alate species, their geographic ranges, and morphology.

Conclusions

1. Size in *Platystrophia*: Mann-Whitney Rank Sum tests and t-tests revealed significant size increases in the onshore versus offshore facies in the C2 through C4 sequences of the Cincinnatian Series. Sequence C5 showed the opposite relationship.

Mean size plotted against stratigraphic position revealed an increasing mean size from sequence C2 through C4, followed by an abrupt decrease in C5.

2. Morphology in *Platystrophia*: shell morphology exhibited a continuous morphospace for all variables in principal component analysis. There was no consistent correlation between morphology and paleoenvironment. Specimens from similar environments often exhibited statistically different morphological features.

Alate and non-alate *Platystrophia* were compared on the basis of association. Alate forms collected from beds in which non-alate forms were present -- and presumably coexisted with non-alate forms -- were found to be statistically different from alate forms living in isolation. This was true for a number of morphological variables. This pattern suggests the presence of character displacement among competing morphs of *Platystrophia*.

Geographic differences were common. Specimens from the same formation were often statistically different when their collection localities were geographically distant. This pattern, combined with continuous morphospace occupation when all forms are considered together, suggests the occurrence of polytypic species within the genus *Platystrophia*. Additional methodologies must be brought to bear on differentiating geographic variation from the existence of highly plastic species morphologies.

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APPENDIX A

Raw data -- asymmetry

Specimen	Right alae	Left Alae	Total Width	R-L
2	17.84791	15.12360	32.97151	2.7243
3	12.86405	13.73433	26.59837	-0.8703
4	16.12385	16.52366	32.64751	-0.3998
5	13.35658	12.32845	25.68502	1.0281
10	13.44385	14.92665	28.37050	-1.4828
11	16.66016	16.48530	33.14546	0.1749
13	22.73211	21.28032	44.01243	1.4518
14	14.07015	13.87332	27.94347	0.1968
15	16.53494	15.77254	32.30748	0.7624
16	19.07531	20.55000	39.62531	-1.4747
17	13.28899	13.95797	27.24696	-0.6690
19	15.63289	16.03278	31.66567	-0.3999
20	22.91928	22.62707	45.54635	0.2922
21	9.21180	9.68282	18.89462	-0.4710
22	13.18856	12.48623	25.67479	0.7023
25	12.28088	12.44319	24.72407	-0.1623
26	16.45824	15.28219	31.74043	1.1761
28	18.71116	17.83203	36.54318	0.8791
30	14.98051	14.57222	29.55273	0.4083
31	13.75899	14.65202	28.41101	-0.8930
32	10.30053	11.04660	21.34713	-0.7461
33	12.27243	12.72118	24.99361	-0.4488
36	19.38123	19.41804	38.79927	-0.0368
40	12.46477	13.83425	26.29902	-1.3695
41	11.13361	10.48563	21.61924	0.6480
43	11.11767	11.54349	22.66116	-0.4258
45	12.79681	12.86372	25.66054	-0.0669
47	9.04702	8.99981	18.04682	0.0472
48	10.30597	10.86595	21.17192	-0.5600
49	11.65182	11.65661	23.30842	-0.0048
52	9.37032	9.95064	19.32096	-0.5803
55	8.61006	9.78645	18.39651	-1.1764
57	11.42031	12.21221	23.63252	-0.7919
58	5.04296	4.84286	9.88582	0.2001
59	11.04345	11.14713	22.19058	-0.1037
61	8.18211	7.64731	15.82942	0.5348
63	20.91541	18.68108	39.59649	2.2343

Specimen	Right alae	Left Alae	Total Width	R-L
64	18.24281	17.11637	35.35917	1.1264
65	19.38128	19.54705	38.92834	-0.1658
66	18.44389	18.07547	36.51935	0.3684
67	15.56444	16.78352	32.34796	-1.2191
68	16.59164	15.81276	32.40440	0.7789
69	11.29712	10.86595	22.16307	0.4312
70	8.94598	10.39785	19.34383	-1.4519
71	13.88416	13.95793	27.84209	-0.0738
73	10.98089	10.84083	21.82172	0.1401
74	14.49671	14.58969	29.08640	-0.0930
77	5.72205	5.45601	11.17805	0.2660
78	12.94005	14.11979	27.05985	-1.1797
79	7.02738	7.08131	14.10868	-0.0539
81	10.42785	9.30473	19.73258	1.1231
83	12.50122	13.78513	26.28635	-1.2839
84	12.91201	11.18059	24.09260	1.7314
87	17.76669	16.93278	34.69947	0.8339
88	12.35115	10.58050	22.93165	1.7707
97	8.22951	9.08089	17.31040	-0.8514
98	17.57116	17.56298	35.13414	0.0082
100	11.18003	10.53399	21.71402	0.6460
101	8.34197	5.80490	14.14688	2.5371
103	7.67454	7.01441	14.68895	0.6601
104	18.67650	20.48613	39.16263	-1.8096
105	12.89002	14.12631	27.01632	-1.2363
106	10.07931	9.43575	19.51506	0.6436
107	17.03303	16.60817	33.64120	0.4249
109	14.94590	14.39253	29.33844	0.5534
112	9.91073	8.91009	18.82082	1.0006
113	35.86486	35.79661	71.66147	0.0683
114	19.24299	18.83152	38.07450	0.4115
115	7.21907	8.21051	15.42958	-0.9914
116	14.11102	10.05497	24.16600	4.0561
118	12.12426	12.87622	25.00048	-0.7520
119	8.39421	7.68005	16.07426	0.7142
120	12.67991	12.19322	24.87312	0.4867
121	12.25826	13.13092	25.38918	-0.8727
123	9.75247	7.83195	17.58441	1.9205
124	11.18612	11.08843	22.27455	0.0977
125	5.94215	7.05294	12.99510	-1.1108
127	21.60600	23.83672	45.44272	-2.2307
128	18.64434	18.45824	37.10258	0.1861
129	14.73647	13.76400	28.50047	0.9725

130	15.32512	14.70577	30.03089	0.6193
136	11.64189	11.12964	22.77153	0.5123
137	14.17525	13.83683	28.01208	0.3384
139	14.78814	14.01633	28.80447	0.7718
140	16.04227	15.82539	31.86766	0.2169
141	17.27869	15.71244	32.99113	1.5662
143	17.19200	18.69805	35.89005	-1.5060
144	22.35686	20.04591	42.40277	2.3110
145	13.72126	13.72468	27.44594	-0.0034
146	12.49548	11.97132	24.46680	0.5242
147	16.33391	18.30257	34.63647	-1.9687
150	10.62568	11.14487	21.77055	-0.5192
151	18.85397	17.59121	36.44517	1.2628
152	16.81295	14.66249	31.47543	2.1505
154	17.69277	15.39039	33.08316	2.3024
155	19.62377	18.27675	37.90053	1.3470
156	15.38983	16.49165	31.88148	-1.1018
157	9.90590	8.77796	18.68385	1.1279
159	19.50801	18.08878	37.59679	1.4192
161	7.75118	7.68960	15.44078	0.0616
162	11.81989	12.86083	24.68072	-1.0409
163	13.77216	14.64405	28.41621	-0.8719
165	13.72132	14.99357	28.71489	-1.2723
166	8.63245	9.45476	18.08721	-0.8223
168	11.85838	10.15025	22.00863	1.7081
169	13.97650	12.40191	26.37841	1.5746
170	8.57021	7.76941	16.33962	0.8008
172	16.67566	16.27232	32.94798	0.4033
174	9.57747	10.01024	19.58772	-0.4328
175	9.88284	10.33001	20.21285	-0.4472
177	6.67540	6.40863	13.08402	0.2668
179	8.32386	7.99606	16.31992	0.3278
181	10.10602	11.05721	21.16322	-0.9512
188	7.62539	6.37420	13.99958	1.2512
189	11.66601	11.50805	23.17406	0.1580
190	6.10320	6.27090	12.37410	-0.1677
191	12.33184	11.73448	24.06632	0.5974
192	13.37163	13.86741	27.23904	-0.4958
193	13.88895	13.36451	27.25345	0.5244
194	15.05420	15.12765	30.18185	-0.0735
195	11.49332	10.84887	22.34219	0.6444
196	10.47071	12.88398	23.35469	-2.4133
197	5.86680	6.83081	12.69762	-0.9640
198	10.70640	9.73062	20.43702	0.9758
199	11.03816	11.41542	22.45358	-0.3773
200	11.02343	10.35168	21.37511	0.6718
201	11.15431	11.00266	22.15697	0.1516
202	9.91811	10.19649	20.11461	-0.2784
203	10.72739	8.90174	19.62913	1.8256
204	8.56171	8.34882	16.91053	0.2129

205	9.52551	8.42095	17.94646	1.1046
206	10.22187	10.53347	20.75534	-0.3116
207	10.01150	11.76322	21.77472	-1.7517
208	12.00121	11.98550	23.98671	0.0157
209	7.02638	7.14358	14.16996	-0.1172
210	12.82524	13.22647	26.05171	-0.4012
211	13.38576	13.19238	26.57813	0.1934
212	11.54629	10.77423	22.32052	0.7721
213	6.82807	6.72486	13.55292	0.1032
214	11.22683	12.25767	23.48450	-1.0308
215	10.63931	11.23855	21.87786	-0.5992
216	13.52424	13.33975	26.86398	0.1845
217	8.66076	7.22698	15.88775	1.4338
218	9.30369	10.07459	19.37827	-0.7709
219	8.34865	8.15987	16.50852	0.1888
220	6.97878	7.01351	13.99229	-0.0347
221	6.44773	6.57116	13.01888	-0.1234
222	7.65222	7.89502	15.54724	-0.2428
223	6.84251	6.67991	13.52242	0.1626
224	12.03587	10.00462	22.04049	2.0312
225	8.62566	7.04569	15.67135	1.5800
226	11.08300	10.40870	21.49169	0.6743
227	10.72689	7.70222	18.42911	3.0247
228	12.72623	12.58917	25.31540	0.1371
229	13.10696	12.88507	25.99203	0.2219
230	12.39436	11.66908	24.06344	0.7253
231	8.01230	9.25246	17.26476	-1.2402
232	10.33389	10.39947	20.73336	-0.0656
233	8.60133	8.08507	16.68640	0.5163
234	13.01125	12.05931	25.07055	0.9519
235	8.42640	8.78406	17.21046	-0.3577
236	9.75562	10.71385	20.46947	-0.9582
237	7.99365	9.36735	17.36100	-1.3737
238	12.15015	9.63077	21.78092	2.5194
239	9.99232	8.84109	18.83341	1.1512
240	8.88173	7.87820	16.75993	1.0035
241	8.64560	9.03299	17.67859	-0.3874
242	9.05302	8.03764	17.09066	1.0154
243	8.74757	8.71519	17.46276	0.0324
244	17.64518	18.23457	35.87975	-0.5894
245	9.12404	9.01772	18.14176	0.1063
246	12.11882	11.75393	23.87275	0.3649
247	11.69373	12.13036	23.82410	-0.4366
248	11.30218	11.07662	22.37881	0.2256
249	11.88549	12.36918	24.25466	-0.4837
250	11.08747	12.00652	23.09399	-0.9190
251	9.14576	8.20441	17.35018	0.9414
255	8.42940	9.58754	18.01694	-1.1581
269	7.77692	7.45077	15.22769	0.3261
274	7.60669	6.97923	14.58593	0.6275

275	8.33787	6.94447	15.28234	1.3934
281	11.82029	11.31751	23.13780	0.5028
289	11.12347	10.37108	21.49456	0.7524
305	9.12742	10.04520	19.17262	-0.9178
317	9.14166	8.15966	17.30132	0.9820
322	8.60558	7.58222	16.18780	1.0234
324	8.53851	9.71290	18.25141	-1.1744
331	6.67083	8.25637	14.92721	-1.5855
333	6.39175	6.12794	12.51970	0.2638
335	11.51594	11.80072	23.31666	-0.2848
345	7.75426	9.16758	16.92184	-1.4133
350	11.46028	12.37579	23.83607	-0.9155
354	8.01948	9.90083	17.92031	-1.8813
364	10.84030	11.25541	22.09571	-0.4151
365	12.17888	13.25990	25.43878	-1.0810
368	6.97874	5.70481	12.68355	1.2739
369	11.72534	7.60608	19.33142	4.1193
378	13.80402	14.75286	28.55688	-0.9488
382	10.11578	8.20730	18.32308	1.9085
383	13.92579	15.57225	29.49804	-1.6465
384	11.55689	11.49416	23.05105	0.0627
385	6.02857	4.74318	10.77176	1.2854
386	10.28802	9.69417	19.98220	0.5938
389	12.46254	11.52063	23.98317	0.9419
390	6.12330	6.90609	13.02939	-0.7828
391	11.18514	10.99633	22.18147	0.1888
392	12.35147	12.38125	24.73272	-0.0298
393	9.59960	9.42603	19.02563	0.1736
394	8.62117	8.66761	17.28877	-0.0464
395	11.10204	13.19709	24.29914	-2.0950
397	7.55249	7.19942	14.75191	0.3531
398	11.99534	11.38653	23.38187	0.6088
399	10.55150	9.84758	20.39908	0.7039
400	10.72553	11.38961	22.11514	-0.6641
401	7.52511	8.74314	16.26825	-1.2180
402	6.36228	6.86844	13.23071	-0.5062
403	6.15978	6.17573	12.33552	-0.0160
404	7.06884	6.76043	13.82927	0.3084
405	12.95361	13.16007	26.11368	-0.2065
406	11.66253	12.78891	24.45143	-1.1264
407	11.20482	10.27823	21.48305	0.9266
408	9.43443	10.03538	19.46981	-0.6010
409	10.86485	11.92665	22.79150	-1.0618
410	10.36539	12.20552	22.57091	-1.8401
411	3.80316	3.66715	7.47031	0.1360
412	7.20312	7.58222	14.78534	-0.3791
413	10.43157	8.96171	19.39328	1.4699
414	10.06032	8.24568	18.30600	1.8146
415	10.46237	9.81723	20.27961	0.6451
416	9.17951	9.01967	18.19918	0.1598

417	4.52250	5.39698	9.91948	-0.8745
418	11.95017	12.76248	24.71265	-0.8123
419	10.65623	10.10782	20.76406	0.5484
420	8.86648	8.03210	16.89858	0.8344
421	15.10257	15.34703	30.44960	-0.2445
423	10.38550	10.46359	20.84909	-0.0781
424	11.13968	11.10158	22.24126	0.0381
425	8.53234	9.65697	18.18930	-1.1246
426	7.96935	8.85124	16.82059	-0.8819
427	4.76471	7.97228	12.73700	-3.2076
428	5.35564	6.04653	11.40217	-0.6909
430	4.83389	5.04061	9.87450	-0.2067
431	10.26123	10.92099	21.18222	-0.6598
432	6.67066	7.78807	14.45873	-1.1174
433	10.30124	8.75865	19.05990	1.5426
434	8.72886	9.51874	18.24760	-0.7899
435	9.54667	10.46423	20.01090	-0.9176
438	7.91420	8.80366	16.71786	-0.8895
439	7.64084	6.39325	14.03409	1.2476
440	8.84621	9.24131	18.08752	-0.3951
441	9.90790	9.79656	19.70446	0.1113
442	8.55767	8.99782	17.55549	-0.4402
443	7.05485	7.17869	14.23354	-0.1238
444	4.89461	4.10542	9.00003	0.7892
445	4.79029	5.06585	9.85614	-0.2756
447	5.53268	7.19851	12.73119	-1.6658
449	5.82074	5.75733	11.57807	0.0634
450	5.21878	4.51948	9.73826	0.6993
451	5.79666	5.87531	11.67198	-0.0786
454	3.58108	4.29795	7.87903	-0.7169
455	4.73972	4.74195	9.48167	-0.0022
456	5.60059	5.88151	11.48210	-0.2809
457	6.66335	6.56757	13.23092	0.0958
459	4.69591	4.34816	9.04407	0.3478
460	9.31988	9.67378	18.99366	-0.3539
461	6.68180	5.45971	12.14150	1.2221
462	5.04526	4.72217	9.76743	0.3231
463	2.69236	3.79606	6.48842	-1.1037
464	7.90335	5.95785	13.86120	1.9455
465	7.20647	6.38042	13.58689	0.8260
466	3.98743	4.17771	8.16514	-0.1903
467	4.53310	4.48938	9.02248	0.0437
468	5.58252	6.06000	11.64252	-0.4775
469	2.69462	2.29452	4.98914	0.4001
470	6.55430	5.78218	12.33648	0.7721
471	7.01342	7.74010	14.75353	-0.7267
474	7.24630	5.57129	12.81759	1.6750
475	3.72930	3.57315	7.30245	0.1562
476	4.07029	4.20345	8.27375	-0.1332
477	4.43095	3.93878	8.36973	0.4922

481	8.39193	7.22534	15.61727	1.1666
482	10.17283	10.64347	20.81630	-0.4706
483	9.29852	9.80386	19.10238	-0.5053
484	8.06796	7.75144	15.81940	0.3165
485	8.14377	7.31564	15.45941	0.8281
486	8.52911	8.76891	17.29802	-0.2398
487	6.63641	6.46866	13.10508	0.1678
488	7.01208	7.29559	14.30767	-0.2835
490	6.41580	6.69738	13.11318	-0.2816
491	7.01691	6.68845	13.70536	0.3285
492	7.98912	8.72833	16.71745	-0.7392
493	7.08083	7.29674	14.37757	-0.2159
494	8.08353	9.07026	17.15379	-0.9867
495	5.53484	5.68340	11.21823	-0.1486
496	4.83793	4.79738	9.63532	0.0405
497	8.42170	8.05501	16.47671	0.3667
498	6.92931	6.29929	13.22860	0.6300
499	8.43610	8.68233	17.11843	-0.2462
500	8.29810	8.03127	16.32937	0.2668
501	7.77602	7.37694	15.15296	0.3991
502	6.37887	5.81808	12.19695	0.5608
503	4.46534	5.17790	9.64324	-0.7126
504	6.85328	6.60286	13.45614	0.2504
505	6.52694	6.35689	12.88383	0.1701
506	5.91684	5.86366	11.78050	0.0532
507	6.01057	6.73104	12.74161	-0.7205
509	6.93566	5.55169	12.48735	1.3840
510	6.65544	7.04081	13.69625	-0.3854
511	9.00414	9.23139	18.23552	-0.2272
512	6.08358	6.55687	12.64045	-0.4733
513	7.78597	9.27140	17.05737	-1.4854
514	7.36468	8.26641	15.63109	-0.9017
515	9.74295	9.71952	19.46246	0.0234
516	7.43471	7.35517	14.78988	0.0795
517	8.00053	8.17063	16.17116	-0.1701
518	6.49554	6.28160	12.77714	0.2139
521	8.74778	9.00056	17.74834	-0.2528
522	7.74186	7.41367	15.15553	0.3282
523	3.97619	4.21258	8.18877	-0.2364
525	6.87780	6.79003	13.66783	0.0878
526	5.49506	5.28992	10.78499	0.2051
527	6.07001	6.51777	12.58778	-0.4478
528	8.02432	8.34101	16.36533	-0.3167
529	5.64228	6.09765	11.73992	-0.4554
530	9.37713	9.84961	19.22674	-0.4725
532	9.83379	9.97481	19.80860	-0.1410
533	8.00952	8.38458	16.39410	-0.3751
536	9.45161	9.48100	18.93261	-0.0294
538	10.13714	8.74282	18.87996	1.3943
539	10.37687	10.21318	20.59005	0.1637

540	9.21829	10.15018	19.36847	-0.9319
541	9.40403	9.37361	18.77763	0.0304
542	9.51714	9.42752	18.94466	0.0896
545	8.91388	8.27048	17.18436	0.6434
546	8.79480	9.29124	18.08604	-0.4964
547	7.65440	7.84406	15.49846	-0.1897
548	11.09742	10.73629	21.83372	0.3611
549	10.54090	9.55471	20.09561	0.9862
550	8.31474	7.27963	15.59437	1.0351
551	9.03466	9.46457	18.49922	-0.4299
552	6.86003	6.51227	13.37229	0.3478
553	6.50748	5.95457	12.46205	0.5529
554	7.80008	8.30858	16.10866	-0.5085
555	8.55164	7.99078	16.54242	0.5609
556	10.04203	9.84000	19.88203	0.2020
557	9.51086	8.95288	18.46374	0.5580
562	8.23622	8.14249	16.37871	0.0937
563	7.75393	8.33115	16.08507	-0.5772
564	6.91052	5.56227	12.47280	1.3482
566	7.48835	6.73287	14.22123	0.7555
568	8.45044	7.75903	16.20948	0.6914
569	9.44696	8.73930	18.18626	0.7077
572	4.01294	3.96308	7.97602	0.0499
573	4.86129	4.16173	9.02302	0.6996
574	4.51976	4.97229	9.49205	-0.4525
576	6.32181	6.48390	12.80571	-0.1621
577	7.66452	7.57525	15.23977	0.0893
578	13.24734	14.37816	27.62550	-1.1308
579	7.77340	7.91397	15.68737	-0.1406
580	8.29002	7.80139	16.09142	0.4886
581	4.63366	4.77554	9.40920	-0.1419
582	4.78732	4.57031	9.35762	0.2170
583	4.68175	4.58852	9.27027	0.0932
584	4.43416	4.29010	8.72427	0.1441
585	5.20634	5.54149	10.74783	-0.3351
587	5.38257	5.67684	11.05941	-0.2943
588	6.87128	5.86408	12.73536	1.0072
589	6.95829	6.82706	13.78535	0.1312
590	7.80426	6.18903	13.99329	1.6152
591	7.03346	7.09330	14.12676	-0.0598
593	6.75433	6.84895	13.60328	-0.0946
594	7.42647	7.57737	15.00384	-0.1509
595	5.70148	5.51287	11.21435	0.1886
596	5.95063	5.76407	11.71470	0.1866
597	6.09803	5.55706	11.65509	0.5410
598	7.02181	6.93542	13.95723	0.0864
599	8.30586	6.72536	15.03121	1.5805
600	1.79000	1.56000	3.35000	0.2300
602	5.93556	5.42441	11.35997	0.5112
603	4.57223	4.97213	9.54436	-0.3999

604	4.66190	5.48056	10.14246	-0.8187
605	4.46593	4.66435	9.13028	-0.1984
609	6.92558	7.57884	14.50442	-0.6533
610	7.16955	8.13099	15.30054	-0.9614
611	6.15969	6.15059	12.31029	0.0091
612	3.69385	4.42821	8.12205	-0.7344
614	7.34927	7.79808	15.14735	-0.4488
617	3.76001	3.58108	7.34109	0.1789
618	7.89137	7.99088	15.88224	-0.0995
619	6.22403	6.86214	13.08617	-0.6381
621	8.31195	6.72625	15.03820	1.5857
623	3.61889	3.18573	6.80463	0.4332
624	7.17610	8.04174	15.21784	-0.8656
625	5.67567	7.00940	12.68507	-1.3337
626	4.77436	6.10627	10.88063	-1.3319
627	6.24254	6.60721	12.84975	-0.3647
629	6.62097	6.84085	13.46182	-0.2199
630	15.39490	13.50736	28.90226	1.8875
631	17.26331	19.17518	36.43848	-1.9119
632	19.77659	20.55006	40.32666	-0.7735
633	16.46415	15.50288	31.96702	0.9613
634	24.16886	18.66492	42.83378	5.5039
635	16.98190	16.46326	33.44516	0.5186
636	12.97487	14.20572	27.18059	-1.2308
638	9.94771	11.78189	21.72960	-1.8342
641	17.23973	17.93586	35.17559	-0.6961
642	12.41369	11.86076	24.27445	0.5529
643	18.64001	18.84638	37.48639	-0.2064
644	15.87331	12.79463	28.66794	3.0787
645	15.37488	16.44912	31.82400	-1.0742
646	14.39337	13.14498	27.53835	1.2484
647	12.44695	13.74236	26.18931	-1.2954
648	16.49648	16.72872	33.22520	-0.2322
650	17.38358	21.53520	38.91879	-4.1516
651	13.39335	11.31655	24.70990	2.0768
656	13.64472	15.14443	28.78916	-1.4997
657	20.32942	19.64549	39.97491	0.6839
658	16.86150	16.65585	33.51735	0.2056
660	20.23274	21.50878	41.74152	-1.2760
662	14.98944	16.11003	31.09947	-1.1206
663	13.50556	14.51807	28.02364	-1.0125
666	10.48817	9.72634	20.21451	0.7618
668	5.99388	6.30635	12.30023	-0.3125
669	9.49866	8.38005	17.87871	1.1186
672	13.57470	15.81082	29.38552	-2.2361
677	10.78501	11.28796	22.07297	-0.5029
679	17.59310	16.30989	33.90299	1.2832
682	14.08908	14.87940	28.96848	-0.7903
683	12.93957	16.01521	28.95478	-3.0756
684	9.81772	10.77999	20.59771	-0.9623

687	12.69540	11.41078	24.10618	1.2846
688	15.49671	15.70465	31.20136	-0.2079
690	14.99319	15.31707	30.31025	-0.3239
692	13.39524	13.97364	27.36888	-0.5784
693	9.32153	9.13396	18.45549	0.1876
695	7.30507	8.64650	15.95158	-1.3414
697	7.98777	7.64807	15.63584	0.3397
698	9.44528	12.42221	21.86749	-2.9769
701	7.86787	6.44811	14.31597	1.4198
702	6.84947	8.56245	15.41193	-1.7130
703	10.39478	9.86676	20.26153	0.5280
704	10.14271	9.51912	19.66183	0.6236
706	23.84581	21.07653	44.92235	2.7693
709	12.26570	12.72697	24.99267	-0.4613
711	13.70380	13.35100	27.05480	0.3528
713	15.10783	15.32439	30.43222	-0.2166
714	13.16346	14.26288	27.42634	-1.0994
715	14.59022	13.71166	28.30188	0.8786
718	9.15880	10.20896	19.36777	-1.0502
719	8.35180	8.85506	17.20686	-0.5033
720	7.70934	7.43307	15.14241	0.2763
723	9.18616	8.81681	18.00297	0.3694
724	12.86524	10.63222	23.49746	2.2330
727	9.44505	8.49947	17.94452	0.9456
728	5.45396	4.56856	10.02252	0.8854
729	5.50244	4.19237	9.69482	1.3101
732	16.07299	14.55893	30.63192	1.5141
733	10.89196	9.70469	20.59665	1.1873
734	13.76012	15.01799	28.77812	-1.2579
735	13.76172	14.68675	28.44847	-0.9250
738	12.38164	11.85038	24.23202	0.5313
740	12.21549	13.43933	25.65482	-1.2238
741	9.26258	8.93309	18.19567	0.3295
742	11.46222	11.24619	22.70841	0.2160
745	12.33501	14.02500	26.36000	-1.6900
746	14.90584	14.22471	29.13055	0.6811
747	11.70310	12.03898	23.74208	-0.3359
750	13.95986	11.87275	25.83261	2.0871
755	18.63069	19.65268	38.28337	-1.0220
756	20.15576	21.11199	41.26775	-0.9562
758	13.28068	12.07641	25.35709	1.2043
759	18.87963	18.91933	37.79896	-0.0397
760	11.39151	10.64029	22.03179	0.7512
761	14.87925	15.57235	30.45159	-0.6931
762	13.13798	14.28394	27.42192	-1.1460
763	12.07942	12.21980	24.29923	-0.1404
764	15.15024	16.51601	31.66625	-1.3658
767	11.62515	10.24407	21.86922	1.3811
769	15.39104	14.61069	30.00173	0.7803
770	15.00595	16.22581	31.23176	-1.2199

771	12.07450	12.28284	24.35734	-0.2083
773	15.44307	16.63226	32.07534	-1.1892
775	13.54696	13.73175	27.27871	-0.1848
778	13.24037	12.73101	25.97138	0.5094
779	13.25688	10.86249	24.11937	2.3944
780	9.56871	9.20377	18.77247	0.3649
781	11.87015	11.90628	23.77643	-0.0361
783	12.01674	14.81177	26.82851	-2.7950
784	12.08323	12.70562	24.78886	-0.6224
785	10.38511	8.87362	19.25873	1.5115
788	7.78214	6.20791	13.99005	1.5742
790	18.97007	18.44310	37.41317	0.5270
791	11.25574	12.80248	24.05822	-1.5467
793	12.07537	13.16607	25.24143	-1.0907
794	13.73994	12.74057	26.48051	0.9994
795	13.77013	14.57258	28.34271	-0.8024
796	12.56486	12.56411	25.12897	0.0007
797	11.03393	13.29683	24.33076	-2.2629
798	22.48067	23.04576	45.52643	-0.5651
799	15.74411	19.20788	34.95198	-3.4638
801	15.22070	14.59914	29.81984	0.6216
802	10.63222	11.65299	22.28521	-1.0208
805	13.44795	14.19774	27.64568	-0.7498
806	17.41604	17.32680	34.74284	0.0892
807	11.44361	11.28417	22.72778	0.1594
808	11.77867	13.13156	24.91022	-1.3529
810	12.16788	12.11618	24.28406	0.0517
811	15.56099	15.08060	30.64159	0.4804
812	13.20924	12.56008	25.76932	0.6492
813	14.97865	14.05820	29.03686	0.9205
815	13.33664	12.69754	26.03418	0.6391
816	12.80476	12.03975	24.84452	0.7650
817	13.74557	13.91379	27.65937	-0.1682
818	13.36082	11.97502	25.33583	1.3858
819	13.86001	12.08020	25.94022	1.7798
820	10.72243	11.54291	22.26534	-0.8205
821	11.28495	12.52149	23.80644	-1.2365
822	12.31195	13.20849	25.52044	-0.8965
823	15.30782	14.22993	29.53775	1.0779
826	11.75010	14.92816	26.67826	-3.1781
828	13.59521	15.54831	29.14352	-1.9531
831	9.89952	10.10069	20.00021	-0.2012
833	11.28683	12.87171	24.15853	-1.5849
834	13.75855	12.21840	25.97695	1.5402
835	12.96446	13.29475	26.25922	-0.3303
837	5.19879	8.42461	13.62340	-3.2258
839	5.75196	5.19528	10.94723	0.5567
840	14.80580	15.32556	30.13136	-0.5198
841	12.58730	12.20502	24.79231	0.3823
842	9.19462	8.95198	18.14660	0.2426

843	12.17503	12.42654	24.60157	-0.2515
845	10.86876	10.84663	21.71539	0.0221
846	12.86745	12.66670	25.53415	0.2008
848	14.47357	13.56234	28.03591	0.9112
849	8.02325	7.59055	15.61379	0.4327
850	13.77045	11.96274	25.73319	1.8077
854	12.37268	14.98742	27.36011	-2.6147
855	13.72401	13.08268	26.80669	0.6413
857	10.42905	10.94081	21.36985	-0.5118
858	8.20577	10.93885	19.14462	-2.7331
859	9.34230	10.29200	19.63430	-0.9497
860	8.51184	7.78807	16.29991	0.7238
861	6.17554	7.78297	13.95851	-1.6074
863	11.64441	14.27641	25.92082	-2.6320
864	10.61008	12.12193	22.73201	-1.5119
865	12.02299	13.41315	25.43614	-1.3902
866	16.44238	17.46022	33.90260	-1.0178
867	13.49099	12.45324	25.94423	1.0377
868	8.63725	7.81463	16.45188	0.8226
869	12.66376	12.21818	24.88195	0.4456
871	8.46291	7.70976	16.17267	0.7532
872	17.85910	18.21578	36.07488	-0.3567
873	13.26566	12.21494	25.48060	1.0507
874	7.13320	7.33676	14.46996	-0.2036
875	12.13439	13.52512	25.65951	-1.3907
876	14.57865	13.10042	27.67907	1.4782
877	22.70185	20.44137	43.14322	2.2605
879	15.41945	14.75206	30.17151	0.6674
880	18.68027	18.58544	37.26571	0.0948
881	10.54217	11.67104	22.21321	-1.1289
883	15.93424	15.92435	31.85860	0.0099
886	12.97690	11.42991	24.40682	1.5470
889	15.99553	15.64390	31.63943	0.3516
890	12.57981	12.53000	25.10982	0.0498
891	12.87287	13.80961	26.68248	-0.9367
892	13.19459	15.67666	28.87126	-2.4821
893	18.90884	19.97705	38.88589	-1.0682
894	20.01780	19.76898	39.78678	0.2488
895	14.79265	16.58959	31.38224	-1.7969
896	18.99316	19.64922	38.64237	-0.6561
897	21.19270	21.10276	42.29545	0.0899
900	15.72466	14.22495	29.94962	1.4997
901	15.55751	17.64732	33.20483	-2.0898
903	15.28024	15.96318	31.24342	-0.6829
904	14.02414	11.22293	25.24707	2.8012
905	14.94122	9.35836	24.29958	5.5829
907	15.23126	15.18022	30.41148	0.0510
908	14.91905	15.50836	30.42741	-0.5893
910	10.22663	7.27585	17.50248	2.9508
912	19.00054	18.94204	37.94258	0.0585

913	11.23356	12.04678	23.28034	-0.8132
915	14.39215	15.12024	29.51239	-0.7281
916	14.63716	14.82930	29.46646	-0.1921
917	14.16037	14.06025	28.22061	0.1001
919	14.18353	11.77771	25.96124	2.4058
920	11.20673	10.34538	21.55212	0.8614
922	11.62484	15.07141	26.69625	-3.4466
923	11.33787	11.77905	23.11692	-0.4412
924	10.48727	11.11786	21.60513	-0.6306
925	12.91928	11.54536	24.46463	1.3739
926	13.12662	13.25341	26.38003	-0.1268
927	12.88624	12.61525	25.50149	0.2710
928	15.21258	17.22269	32.43527	-2.0101
929	15.32877	12.95596	28.28473	2.3728
932	13.54341	15.78100	29.32442	-2.2376
933	17.73756	12.76972	30.50729	4.9678
934	16.09578	17.12234	33.21812	-1.0266
935	19.88770	18.51348	38.40118	1.3742
937	14.80927	13.70881	28.51809	1.1005
938	17.23932	14.27035	31.50967	2.9690
940	13.84025	12.27945	26.11970	1.5608
941	11.40739	9.29088	20.69827	2.1165
942	8.42407	8.25545	16.67952	0.1686
943	17.14563	21.73543	38.88105	-4.5898
944	14.20199	16.63840	30.84039	-2.4364
945	14.72257	15.81189	30.53446	-1.0893
946	14.21974	14.53047	28.75021	-0.3107
947	12.06444	12.41151	24.47595	-0.3471
948	14.91332	16.24107	31.15440	-1.3278
949	15.12897	15.98320	31.11217	-0.8542
950	14.72232	14.01815	28.74047	0.7042
951	12.39646	12.89989	25.29635	-0.5034
952	11.28523	9.69013	20.97536	1.5951
953	14.79110	16.16716	30.95825	-1.3761
954	11.87708	13.27253	25.14961	-1.3955
955	15.69831	14.09048	29.78879	1.6078
956	10.70311	10.52107	21.22418	0.1820
957	14.18402	11.12621	25.31023	3.0578
958	12.61205	11.98310	24.59514	0.6289
959	14.79885	13.40577	28.20462	1.3931
960	15.12033	15.24257	30.36291	-0.1222
961	11.73583	11.05573	22.79157	0.6801
962	17.77618	18.29471	36.07089	-0.5185
963	14.43435	15.30246	29.73681	-0.8681
964	12.80558	10.77169	23.57727	2.0339
965	16.74191	15.57776	32.31966	1.1641
967	14.97370	14.98763	29.96133	-0.0139
968	12.30722	11.55185	23.85907	0.7554
969	14.66632	15.26780	29.93412	-0.6015
970	15.97561	15.83948	31.81509	0.1361

971	15.42005	16.01031	31.43036	-0.5903
972	11.82108	11.65386	23.47494	0.1672
973	13.07817	10.63226	23.71043	2.4459
974	11.90745	12.71134	24.61879	-0.8039
975	14.86045	18.97807	33.83852	-4.1176
977	12.43634	12.00079	24.43713	0.4356
978	13.41517	14.07588	27.49105	-0.6607
979	10.10842	10.96809	21.07651	-0.8597
981	17.37226	16.45483	33.82709	0.9174
982	18.60583	20.03540	38.64123	-1.4296
983	19.91125	20.31268	40.22393	-0.4014
986	13.86407	14.04325	27.90733	-0.1792
989	9.33542	11.13744	20.47286	-1.8020
991	8.81865	10.88857	19.70722	-2.0699
992	10.37082	10.29696	20.66779	0.0739
994	9.07233	9.09921	18.17155	-0.0269
996	8.64454	8.39806	17.04260	0.2465
997	8.14033	8.21005	16.35039	-0.0697
999	6.26230	6.96322	13.22552	-0.7009
1000	6.94873	8.41836	15.36709	-1.4696
1003	6.28590	6.46579	12.75168	-0.1799
1004	5.72466	5.51902	11.24368	0.2056
1006	10.51096	9.18391	19.69487	1.3270
1007	8.79778	9.72922	18.52700	-0.9314
1009	10.99967	11.86895	22.86862	-0.8693
1010	5.20200	6.06869	11.27069	-0.8667
1011	14.36096	11.62582	25.98678	2.7351
1012	11.23844	13.48322	24.72166	-2.2448
1013	4.55390	5.10154	9.65544	-0.5476
1014	15.07719	12.29654	27.37374	2.7807
1016	13.27697	13.59812	26.87509	-0.3212
1017	10.50454	11.42512	21.92965	-0.9206
1019	11.70269	11.29436	22.99705	0.4083
1021	9.70487	11.94359	21.64846	-2.2387
1022	13.50858	14.22877	27.73735	-0.7202
1023	9.89875	8.75825	18.65700	1.1405
1026	12.02712	12.24562	24.27275	-0.2185
1027	10.77343	13.48885	24.26229	-2.7154
1028	6.40739	6.09978	12.50717	0.3076
1030	18.38535	19.68851	38.07385	-1.3032
1031	10.84994	9.79678	20.64672	1.0532
1033	13.98375	15.18068	29.16443	-1.1969
1034	13.25753	15.53348	28.79101	-2.2760
1036	12.64285	14.05692	26.69977	-1.4141
1037	16.15909	15.89160	32.05069	0.2675
1038	14.66884	14.82876	29.49760	-0.1599
1039	14.64843	15.24286	29.89129	-0.5944
1040	8.64419	8.12150	16.76569	0.5227
1041	12.65622	13.85935	26.51558	-1.2031
1042	13.39543	14.64467	28.04011	-1.2492

1043	14.73073	14.83950	29.57024	-0.1088
1048	9.62481	9.24018	18.86499	0.3846
1049	12.39258	12.88600	25.27858	-0.4934
1051	10.53613	11.05425	21.59038	-0.5181
1053	5.12864	5.59604	10.72468	-0.4674
1054	12.59446	12.80094	25.39540	-0.2065
1055	9.45762	9.59713	19.05476	-0.1395
1056	8.31856	8.49021	16.80877	-0.1717
1057	8.41407	8.23214	16.64620	0.1819
1058	8.60403	8.68247	17.28650	-0.0784
1059	9.68174	10.87624	20.55798	-1.1945
1060	8.08115	8.09588	16.17703	-0.0147
1061	10.92437	10.84813	21.77250	0.0762
1062	11.53262	10.79356	22.32618	0.7391
1064	11.58849	11.55917	23.14766	0.0293
1065	11.44330	10.56871	22.01202	0.8746
1067	8.90933	9.33922	18.24855	-0.4299
1068	10.75167	11.18915	21.94082	-0.4375
1069	8.95670	10.09812	19.05482	-1.1414
1071	10.01312	11.13476	21.14788	-1.1216
1072	12.40267	14.36485	26.76751	-1.9622
1075	9.15631	8.96046	18.11677	0.1959
1076	8.23253	8.46450	16.69702	-0.2320
1078	8.26562	8.10247	16.36808	0.1631
1080	10.41470	11.57904	21.99374	-1.1643
1081	8.54942	8.63612	17.18553	-0.0867
1082	12.66006	14.80092	27.46099	-2.1409
1084	10.17657	9.38233	19.55890	0.7942
1087	9.04419	8.29002	17.33421	0.7542
1088	11.39440	11.04082	22.43522	0.3536
1089	9.40226	8.47245	17.87471	0.9298
1090	10.19765	9.40691	19.60456	0.7907
1094	13.32524	12.97149	26.29673	0.3538
1095	11.81153	13.53728	25.34881	-1.7258

APPENDIX B

Raw data -- shell morphology

SPEC NO	WIDTH	THICK	SULC W	SULC H	LENGTH	ALAE W	LAT RIB	SULC RIB
KS								
188	24.92	26.6457	8.6545	25.5521	10.0861	6.3742	7	3
190	30.21	24.0019	5.9944	22.1349	9.1942	6.2709	7	3
191	30.2101	14.459	14.1023	8.5156	15.0123	11.7345	7	3
192	28.79	35.6974	12.203	27.6091	15.4122	13.8674	8	3
193	29.1874	16.61	16.1175	6.906	19.3306	13.3645	8	3
194	8.57	29.4571	12.402	26.2938	20.5106	15.1277	8	4
FI								
481	19.5016	8.6362	10.9707	7.6521	12.1201	7.2253	8	3
482	20.44	26.7718	12.1826	24.2039	11.0096	10.6435	5	4
483	21.5356	8.6362	10.6137	7.4757	12.3105	9.8039	6	3
484	16.94	26.3513	9.3209	25.9046	11.9702	7.7514	8	3
485	17.2396	9.09	8.8108	9.7423	9.3708	7.3156	7	3
486	13.81	24.3787	9.533	22.54	12.1934	8.7689	6	2
487	15.4629	9.09	7.6164	6.12	8.818	6.4687	6	3
488	17.16	24.3787	9.2452	22.8961	9.3865	7.2956	6	3
490	15.46	25.4254	7.2802	24.4782	10.176	6.6974	7	3
491	15.4631	7.9102	5.9609	5.6521	10.2307	6.6885	6	3
492	16.65	21.5302	10.3458	24.6983	8.2445	5.6834	6	3
493	16.6856	6.9203	8.4109	4.8626	9.5682	4.7974	9	3
494	16.09	23.5014	10.2407	20.1455	12.1226	8.055	5	3
495	14.2034	6.9203	6.18	4.9033	10.6432	6.2993	7	3
496	19.57	25.2373	6.0012	23.0388	10.4279	8.6823	7	3
497	19.5719	9.89	8.162	7.8538	11.2281	8.0313	7	4
500	16.49	24.664	9.3202	25.5508	10.06	8.0313	6	3
502	8.07	23.132	6.5636	21.3845	8.6471	5.8181	8	3
503	12.3327	6.7724	5.9814	4.5636	7.2858	5.1779	7	3
504	20.57	22.3583	7.3361	24.2362	8.7048	6.6029	7	3
505	21.2721	6.9353	7.9626	12.0936	9.1094	6.3569	6	3
509	17.39	10.3106	8.9558	7.2085	10.1024	5.5517	6	3
510	20.8	25.4823	8.2697	23.7474	9.2159	7.0408	7	3
511	20.8003	8.1153	10.4907	7.3491	13.636	9.2314	7	3
512	22.8	25.2234	8.2534	23.4148	10.8933	6.5569	8	3
514	20.82	23.9825	9.4045	24.2663	13.301	8.2664	7	3
515	21.5127	9.4045	9.8101	8.2051	12.9368	9.7195	7	3
516	21.81	22.6761	7.4542	23.1061	10.0301	7.3552	7	3
517	21.8137	10.7947	9.7502	8.4357	11.4497	8.1706	6	3
518	26.44	27.7423	7.3663	24.1641	8.743	6.2816	8	3
520	6.72	23.5487	8.6436	22.681	10.5607	7.441	6	3

SPEC NO	WIDTH	THICK	SULC W	SULC H	LENGTH	ALAE W	LAT RIB	SULC RIB
521	11.0565	4.8473	8.4804	8.3389	11.0441	9.0006	7	3
522	11.94	19.4866	7.1286	21.4897	10.901	7.4137	7	3
523	9.7301	4.8473	4.7122	2.5965	6.4405	4.2126	6	3
524	16.99	19.542	8.313	18.7121	10.6408	7.2721	6	3
525	17.0002	7.9365	8.7045	6.2043	11.1215	6.79	6	3
526	12.64	19.5754	7.3036	17.0226	8.1904	5.2899	6	3
527	14.4406	7.9365	6.3358	5.6532	9.7278	6.5178	6	3
528	13.82	19.5754	8.3781	18.6726	12.6207	8.341	8	3
529	13.8309	5.8	6.7776	4.2802	8.7539	6.0976	7	3
530	21.08	30.0067	12.3503	28.9897	14.2002	9.8496	8	3
F1s3								
535	19.8042	9.8515	10.3503	7.76	17.7643	8.7428	8	3
536	20.84	34.6484	13.7473	30.5357	18.2627	10.2132	8	3
537	21.6267	11.3151	11.7072	14.7557	18.9447	10.1502	9	3
539	24.7012	11.3151	10.2422	8.8342	16.6684	10.2132	9	4
540	22.29	34.6111	10.9413	30.0284	13.1337	10.1502	8	3
541	22.4331	9.0504	12.0138	9.5059	15.7489	9.3736	8	3
542	23.37	32.5773	10.7254	34.3166	16.9027	9.4275	7	3
543	22.9559	9.0504	12.2228	6.1802	14.9702	9.596	7	4
544	21.52	34.1901	11.3624	31.9235	16.7568	10.0317	7	3
545	21.6534	11.0356	11.6229	11.2004	10.9403	8.2705	8	3
546	17.38	33.1476	13.1042	31.3565	15.823	9.2912	9	3
548	24.44	33.1476	10.2133	31.1327	13.3602	10.7363	8	3
550	23.59	32.3449	9.2191	30.8365	13.0802	7.2796	8	3
551	23.6016	10.0934	12.7	7.7137	14.86	9.4646	7	4
552	21.65	27.4498	8.2945	29.6479	9.8142	6.5123	9	2
553	21.6992	11.1945	9.3473	7.3335	11.9012	5.9546	8	3
556	23.53	25.5936	11.8138	22.8606	14.7301	9.84	7	3
557	23.614	9.3111	10.9702	9.8111	13.831	8.9529	9	3
558	21.2927	11.2028	11.7915	7.5646	14.3598	9.8726	9	3
559	24.2101	9.3111	12.2806	7.3278	14.9289	10.0354	7	3
560	17.94	24.1704	10.3867	23.5558	14.09	8.5912	8	3
FRM								
561	17.9565	7.1584	9.6629	6.0302	11.6021	8.6554	7	2
563	17.6086	7.1584	8.6119	5.7336	11.9999	8.3311	7	3
564	15.8	23.8506	7.2003	23.6037	9.12	5.5623	6	3
566	21.98	22.4582	7.9191	23.4539	10.03	6.7329	6	3
568	20.75	22.4582	7.1	21.1914	11.8078	7.759	7	3
569	20.751	9.2439	10.1208	7.3046	14.7566	8.7393	7	2
573	29.5326	10.7431	5.5603	18.4427	18.0667	6.4839	6	3
576	27.37	34.2503	6.7015	32.7257	14.9103	7.914	5	3
577	27.6097	10.1157	7.8102	15.3679	13.9	7.8014	7	1
578	1.63	32.1854	12.2552	28.0549	17.3844	14.3782	7	3
579	17.06	10.1157	9.7452	8.062	10.0229	7.914	6	3
580	13.75	24.3424	8.4804	31.4485	10.5979	7.8014	6	3
581	13.8294	4.5236	6.8838	2.772	6.8109	4.7755	5	3

583	11.4106	4.5236	4.4016	2.95	7.428	4.5885	7	3
SPEC NO	WIDTH	THICK	SULC W	SULC H	LENGTH	ALAE W	LAT RIB	SULC RIB
584	15.19	17.4939	5.5001	13.9933	7.7205	4.2901	7	3
585	15.3109	6.9246	5.4443	8.1555	7.5102	5.5415	6	3
587	13.4572	6.9246	7.2151	5.4586	8.9747	5.6768	6	3
588	16.07	18.6581	6.7901	17.2665	9.3615	5.8641	7	4
589	16.0706	6.9835	8.3305	5.4245	11.5712	6.8271	8	3
591	16.3673	9.4026	7.9464	6.3013	10.8303	7.0933	6	3
593	19.9942	7.2266	8.4036	9.2278	9.5308	6.8489	6	3
B69r								
594	12.26	23.8715	8.7956	22.2828	10.87	7.5774	5	3
596	15.09	23.0329	6.648	23.3563	10.6895	5.7641	7	3
597	15.1684	10.0288	6.4245	6.3303	6.4085	5.5571	6	3
598	10.84	22.6867	7.2843	21.2672	9.3702	6.9354	6	3
603	12.2914	6.4937	6.27	4.1189	7.9753	4.9721	6	3
605	11.0535	8.6636	5.8133	4.8271	7.1418	4.6644	5	3
609	16.038	9.6023	7.1481	6.1373	7.4417	7.5788	6	3
613	5.621	4.4703	6.8136	12.1847	9.3252	4.5286	5	3
614	12.71	14.6465	7.0246	20.5837	7.4387	3.5811	7	3
616	22.33	25.2344	6.7024	20.8551	14.6399	6.8621	6	3
619	14.0152	7.7723	6.8849	5.4303	9.2607	6.8621	5	3
622	15.7	20.0983	7.0048	20.1015	8.7526	6.1351	5	3
624	16.89	21.2071	10.6434	18.9563	10.9718	8.0417	7	3
625	16.9178	8.4894	7.4276	5.8439	9.8159	7.0094	6	3
626	15.42	18.441	7.9719	19.8625	7.7854	6.1063	6	3
629	14.6811	6.6555	6.5606	5.0902	8.7128	6.8408	6	1
BMV								
630	36.92	35.1745	14.7309	32.5406	18.0844	13.5074	6	3
631	36.9205	21.4399	20.0402	14.2266	23.2502	19.1752	8	4
632	42.09	52.1948	17.8763	45.9021	24.3113	20.5501	8	4
633	42.2223	25.8603	17.9703	18.6717	21.1519	15.5029	9	4
636	16.61	29.8028	16.3327	40.5493	21.9906	14.2057	6	3
637	23.6462	12.0777	18.2907	11.0693	26.5802	19.0163	10	3
641	40.7575	27.5622	18.635	24.593	24.6402	17.9359	7	3
642	37.27	43.647	15.3603	40.3297	20.8096	11.8608	7	3
644	28.93	38.9796	17.4361	39.3315	23.2102	12.7946	7	3
646	37.31	45.2135	16.0714	35.1771	22.0541	13.145	8	3
648	34.35	45.2135	20.3735	41.9202	27.668	16.7287	9	3
650	27.06	37.6319	23.856	37.0385	28.4808	21.5352	8	3
651	27.1302	11.5814	13.7125	7.5105	18.6413	11.3166	6	2
654	41.56	43.7962	16.9078	43.4955	27.8587	19.6455	7	3
655	36.5194	18.6053	16.2003	12.3407	24.7021	16.6558	7	2
656	39.96	46.5625	19.7111	39.9907	21.6503	19.7821	8	4
657	40.6782	21.4934	20.4104	19.2962	33.0819	21.5088	8	4
659	39.5974	21.4934	22.5077	15.9566	25.8721	19.7821	8	3

SPEC NO	WIDTH	THICK	SULC W	SULC H	LENGTH	ALAE W	LAT RIB	SULC RIB
BK20								
662	26.06	34.1232	14.5215	33.2229	16.3916	16.11	7	3
663	28.371	11.8178	12.2657	10.1503	17.2691	14.5181	7	3
669	21.5213	11.1441	11.2102	7.63	10.2845	8.3801	5	3
675	24.197	13.0704	13.0432	9.6375	13.268	9.8828	6	3
677	43.0706	28.1708	15.5116	29.3697	15.2326	11.288	7	3
BG								
682	17.47	30.9471	14.2777	34.8979	18.2662	14.8794	6	2
683	31.9269	18.2213	16.8103	12.9269	25.4502	16.0152	8	4
688	32.38	41.2496	14.3166	38.8276	16.141	15.7047	6	3
690	29	38.8081	15.2074	37.5178	18.8154	15.3171	7	3
692	31.49	32.3198	13.2641	33.8291	8.4455	8.6465	7	3
695	20.1627	8.9835	8.7532	5.0225	25.6704	12.4222	8	3
697	31.944	18.59	9.6069	18.099	20.5379	16.4291	5	3
700	26.69	24.5657	12.4211	28.4841	14.1981	16.4291	6	1
701	27.0263	11.9906	9.8103	13.9513	11.4723	6.4481	7	4
702	43.63	35.9854	7.8523	32.5061	10.8602	8.5625	6	2
704	47.63	51.4562	11.7307	39.7188	19.7171	9.5191	8	3
706	9.07	39.1787	20.1129	41.8306	29.4302	21.0765	9	3
707	34.4788	20.4539	16.5736	13.8	19.1514	16.8366	9	3
709	24.6634	13.6684	11.7082	11.7521	13.4631	12.727	8	3
711	26.6905	12.981	11.3803	10.7412	13.2107	13.351	7	3
713	29.2561	17.0776	19.0095	10.4419	25.77	15.3244	9	3
718	29.48	27.5526	11.4581	26.2661	12.371	10.209	5	3
719	17.6016	8.5178	9.6502	6.3246	10.9136	8.8551	6	3
720	26.18	31.1685	8.072	26.4792	11.7033	7.4331	7	3
723	19.9076	13.3848	9.9903	9.9976	13.1249	8.8168	7	1
725	24.1372	11.0337	12.0565	10.8194	14.3062	12.1665	7	1
727	18.7727	11.0337	8.0763	9.3518	11.0159	8.4995	5	2
729	11.2613	4.242	4.6641	2.6103	7.1682	4.1924	7	3
732	25.28	34.8441	11.9446	30.5634	14.0907	14.6867	7	1
735	28.4548	16.8309	14.9562	12.76	18.2304	11.8504	8	3
738	26.02	34.6355	14.0512	32.945	15.1562	11.8504	7	3
740	21.58	32.4455	14.8511	33.6906	16.2608	13.4393	6	3
741	21.6415	14.93	9.1667	9.5595	10.8347	8.9331	7	3
742	24.9	30.2005	13.2502	28.9443	14.6309	11.2462	6	3
BRS								
745	27.4593	15.2289	14.7991	8.8015	17.6645	14.025	8	3
746	28.87	33.1018	16.2178	35.0941	18.8542	14.2247	6	3
747	26.7665	15.2289	14.0241	10.8431	15.2408	12.039	8	3
750	23.97	35.798	15.9638	33.7614	16.9661	11.8727	8	3
752	36.89	37.5039	13.6003	35.2121	15.82	12.4165	8	3
753	37.4793	28.4362	13.3744	27.4475	13.4253	11.7082	7	4
755	41.0169	28.4362	21.1581	16.578	27.8388	19.6527	11	3
757	40.8741	16.786	14.1459	19.7836	14.9205	13.6511	7	3

758	28.92	29.5032	15.562	24.5126	15.8008	12.0764	7	3
SPEC NO	WIDTH	THICK	SULC W	SULC H	LENGTH	ALAE W	LAT RIB	SULC RIB
759	36.8752	16.786	17.3311	13.8539	19.5586	18.9193	10	3
760	29.82	32.8612	12.2601	29.355	15.4724	10.6403	8	3
761	30.0611	15.9521	15.4547	8.9538	15.7376	15.5723	6	3
762	23.72	30.1271	13.8708	27.9569	13.9777	14.2839	5	3
764	27.27	29.1258	13.8409	29.7427	16.4256	16.516	8	3
765	27.271	13.021	12.4958	10.5313	14.8562	13.697	7	3
767	25.0458	13.021	13.4002	10.2503	15.4281	10.2441	7	3
768	30.28	28.582	15.5186	27.6428	13.1443	16.0101	7	3
769	30.3119	17.2989	13.6402	12.0615	16.8793	14.6107	7	3
770	25.24	32.9047	16.1123	30.5994	15.7748	16.2258	9	3
771	25.2913	16.3465	11.8659	13.7406	14.7312	12.2828	8	3
772	28.06	32.7899	14.4508	29.913	12.2576	13.7318	7	2
774	28.9	31.8588	15.7367	30.8143	11.6829	14.7717	7	3
775	27.1339	14.7489	13.188	10.384	16.9555	12.731	7	3
776	28.28	29.13	14.59	30.1981	15.4891	10.8625	8	3
777	28.2934	15.4931	14.0437	10.3863	14.69	9.2038	7	3
778	27.02	31.3156	12.7918	26.806	16.6472	12.731	7	3
779	27.9171	15.4931	13.8213	12.1859	15.6706	10.8625	8	3
781	25.052	15.1657	14.2759	8.8361	14.2843	11.9063	6	3
783	26.9614	15.1657	12.8521	10.2889	15.9207	14.8118	7	3
785	21.6192	8.4413	10.4535	7.6594	13.1932	8.8736	6	3
787	18.3541	8.4413	9.763	5.8146	11.7836	7.6633	6	3
788	24.9	29.5392	8.2903	28.8774	11.3914	6.2079	7	3
789	24.9059	14.3977	14.9474	10.0448	15.2106	12.0316	6	3
790	23.9	33.7019	18.8684	32.0043	19.6947	18.4431	6	3
791	23.9068	11.6295	12.29	6.576	12.7327	12.8025	7	3
794	28.7	33.9726	14.349	33.0649	14.7203	12.7406	7	3
795	28.8606	16.0523	13.0021	12.2524	14.2166	14.5726	8	3
801	25.6601	11.49	15.3104	7.4678	17.0659	14.5991	9	3
802	28.96	30.6737	12.2203	27.7355	17	11.653	7	3
804	15.47	34.276	14.546	25.9789	14.55	9.455	6	3
807	22.451	8.9689	11.4401	5.7806	14.9612	11.2842	7	4
808	26.66	23.6317	10.9292	20.2964	12.0222	13.1316	9	3
809	26.6627	12.6063	13.8801	9.4572	15.4929	13.1616	6	3
BS								
1	37.6282	26.2981	21.9274	18.5095	29.0247	17.8355	9	3
2	37.5307	26.1054	19.383	16.6615	35.1931	17.8479	11	3
3	31.6182	22.5288	17.5879	14.5011	20.7645	12.864	8	5
4	33.328	20.7928	16.7003	14.5683	12.7035	16.1238	10	3
5	32.5342	14.4494	14.7092	9.5568	16.9312	13.3566	10	3
6	26.5897	16.38	14.5258	12.8868	31.8164	33.6062	9	3
7	41.6802	27.613	23.8013	17.8873	45.4099	18.5714	7	3
8	29.6292	11.6198	9.0341	7.2661	19.382	19.6764	6	3
9	30.2047	18.1708	17.6955	10.9793	13.1013	32.8642	7	3
10	27.7	14.26	14.3505	8.2044	26.9556	13.4438	9	7
11	41.7019	28.9707	23.6306	19.8224	50.1966	16.6602	6	4

12	25.1155	12.1925	10.961	9.4185	32.9142	29.748	7	2
SPEC NO	WIDTH	THICK	SULC W	SULC H	LENGTH	ALAE W	LAT RIB	SULC RIB
13	37.6808	21.11	19.79	13.0047	59.1176	22.7321	8	4
14	36.7843	27.0702	18.0554	20.1908	24.0953	14.0701	9	3
15	37.9761	25.8171	21.6417	18.0911	10.2784	16.5349	9	3
17	31.7339	21.4612	17.184	12.9786	37.827	13.289	8	3
18	17.5739	6.95	9.242	4.0291	7.3715	8.3214	8	3
19	42.9876	23.9481	28.2222	9.8486	28.4125	15.6329	8	6
20	24.2656	14.0604	11.5676	9.2724	18.1054	22.9193	6	3
21	29.2027	15.8711	16.7005	9.654	11.0724	9.2118	7	3
22	40.4926	24.7401	19.5914	14.1419	43.062	13.1886	7	3
23	28.2722	19.6397	13.5581	13.2393	13.0062	12.1563	7	3
24	25.7044	17.5974	13.4503	11.6414	15.9626	26.1458	7	3
25	25.5404	14.9137	12.2921	10.29	2.7785	12.2809	6	1
26	36.1228	23.0636	19.8107	14.2622	53.3465	16.4582	7	3
28	40.0402	27.4925	17.7219	17.5813	29.0616	18.7112	9	3
29	42.9736	24.877	25.7804	15.0409	14.6601	56.5016	8	5
31	34.93	23.8063	16.9074	16.6719	20.2713	13.759	5	2
32	24.9488	15.0718	15.9382	10.7422	18.2022	10.3005	5	3
33	25.8493	14.4993	12.814	9.77	12.9608	12.2724	6	3
41	26.0132	17.8647	13.5823	12.4203	15.7344	11.1336	7	3
43	25.38	15.8809	14.7137	11.5147	15.1307	11.1177	7	3
45	26.2114	17.6808	15.9223	11.6103	13.6125	12.7968	6	1
47	18.4417	9.162	8.982	6.0603	11.7901	9.047	7	3
49	22.2148	11.9033	10.8454	8.5302	16.2004	11.6518	7	3
50	22.7906	15.9869	10.9938	10.8139	13.3672	10.4767	6	3
52	24.3709	14.5729	13.3629	10.1722	15.9767	9.3703	6	3
54	21.1509	14.3775	13.1141	10.8932	15.5512	9.3007	7	3
57	23.2178	16.8106	11.9967	12.8508	15.2601	11.4203	7	3
58	14.3148	6.5163	8.0033	4.3345	10.32	5.043	6	3
59	23.4349	13.4416	11.7207	10.131	13.2128	11.0434	6	1
60	19.7677	10.2431	10.3859	7.476	12.7246	10.4441	7	3
63	44.6016	31.7523	22.5614	20.1616	31.3207	20.9154	8	3
64	39.1164	25.2144	20.5004	17.1832	29.0002	18.2428	10	3
65	46.6681	32.7903	25.2805	22.2405	33.9088	19.3813	8	3
66	40.7679	28.195	22.1196	16.1938	30.1429	18.4439	7	3
67	37.8524	26.4121	22.3544	17.3577	26.2719	15.5644	7	3
68	36.4663	24.5214	19.5702	16.7405	25.3602	16.5916	7	3
70	23.1191	17.1152	11.2886	12.3825	15.6607	8.946	6	3
73	22.1203	12.4806	13.1539	7.261	15.6005	10.9809	6	3
76	23.1	7.3089	11.7022	5.8649	15.4313	10.7783	8	3
77	11.8908	4.7677	6.0333	2.8888	9.2645	5.722	7	3
82	29.4015	18.0406	16.8095	16.1307	19.8423	13.7301	6	3
84	24.3127	15.5416	11.1557	9.8769	15.6604	12.912	7	1
92	30.0973	15.5909	15.332	11.5229	22.0944	15.4402	9	3
93	12.6113	5.141	5.9804	3.4601	8.86	5.9376	7	3
96	36.2198	24.2823	19.2194	13.9163	25.6675	16.377	9	3
97	18.4379	10.2161	9.3417	6.2402	13.3625	8.2295	9	3
100	22.1646	10.5455	11.2271	6.6522	16.0069	11.18	9	5

101	16.5401	8.3127	8.2787	5.2039	12.8401	8.342	8	3
SPEC NO	WIDTH	THICK	SULC W	SULC H	LENGTH	ALAE W	LAT RIB	SULC RIB
103	18.9002	8.4155	8.441	5.4706	12.45	7.6745	8	3
105	30.5901	15.3716	15.0007	10.7409	21.5101	12.89	9	3
106	31.8703	16.5679	17.9594	11.3653	17.9934	10.0793	9	5
109	30.1911	19.6506	19.3254	13.1724	23.1091	14.9459	8	3
112	20.8109	10.2227	10.8502	6.4249	14.5299	9.9107	7	3
118	28.4604	14.3318	13.2119	8.2649	20.2438	12.1243	7	3
119	15.9307	6.1607	7.4548	4.3126	9.6762	8.3942	5	3
123	22.1101	11.4705	9.96	8.0016	14.8001	9.7525	9	3
124	22.0803	10.7626	11.5673	7.5472	16.948	11.1861	8	3
125	13.6207	6.3113	6.9206	4.6702	9.5915	5.9422	6	3
126	33.4504	20.9011	20.7002	13.3603	26.3613	14.1552	8	3
136	10.6761	6.6731	5.743	4.7611	13.3572	11.6419	5	3
139	34.6968	22.9691	18.4388	17.0711	25.9031	14.7881	9	3
140	36.3792	23.8573	19.8913	14.1673	25.9402	16.0423	8	3
143	39.4309	25.8003	21.8437	18.5243	26.8722	17.192	6	3
144	40.3536	26.7503	19.9247	15.9455	25.9116	22.3569	10	4
145	27.0733	14.9456	12.44	9.3606	19.5703	13.7213	9	3
149	18.2716	8.9503	8.4314	5.8705	13.4501	7.9021	9	3
152	35.1337	21.9733	20.0665	13.0355	25.9348	16.8129	10	5
155	39.79	22.7502	23.3636	14.1983	26.5906	19.6238	9	5
156	20.2795	9.4965	10.41	6.3508	15.0034	9.9059	9	4
157	24.7303	11.57	12.8117	7.1255	17.5468	11.5053	7	3
159	36.605	17.43	15.3509	11.0363	32.76	17.4071	10	3
160	18.24	8.975	8.6822	5.2916	13.6744	7.7512	9	3
161	29.9935	16.9284	17.2859	11.3024	25.7775	11.8199	9	3
162	29.9935	16.9284	17.2859	11.3024	25.7775	11.8199	9	3
163	34.9502	27.1384	17.2664	18.6938	27.0164	13.7722	8	4
169	27.9335	14.9359	14.4211	9.2366	20.1892	13.9765	8	3
172	36.2934	27.7037	19.6093	18.9701	26.4738	16.6757	7	3
173	28.7593	17.4211	16.1514	10.2	19.7883	14.8375	7	3
175	20.3834	13.289	11.3902	8.6333	14.3443	9.8828	6	3
177	14.7512	5.9202	6.4579	3.871	10.1254	6.6754	7	3
183	19.6343	9.8259	10.231	6.5933	14.0628	9.1472	8	3
185	17.9912	8.9602	9.1959	6.2023	12.2306	8.7673	6	3
CR								
810	31	28.6037	12.2428	27.527	13.755	12.1162	6	2
816	24.99	35.7201	13.9324	34.2736	11.3158	12.0802	5	2
817	25.2409	16.9457	13.4225	11.4655	23.3239	11.5429	5	2
819	26.8819	16.9457	13.4803	12.245	15.8313	12.0802	8	3
822	24.33	32.2608	13.5429	30.7016	15.5908	13.2085	7	3
CO42								
831	19.8916	8.4513	9.3833	6.5422	11.8946	10.1007	8	2
832	23.82	29.9373	10.2163	23.4374	14.5105	11.8883	7	3
834	9.55	25.0851	18.0634	26.7064	19.6384	12.2184	7	5
835	26.4829	13.5242	13.5919	10.8777	15.6804	13.2948	8	3

836	14.93	18.5747	12.9017	25.1122	11.8935	12.1454	7	3
SPEC NO	WIDTH	THICK	SULC W	SULC H	LENGTH	ALAE W	LAT RIB	SULC RIB
837	15.2225	6.2035	8.351	7.454	9.9411	8.4246	6	3
839	13.0862	6.2035	7.1407	3.6515	8.7327	5.1953	6	3
840	23.51	30.3896	14.6	28.1073	14.7588	15.3256	8	3
841	23.5112	11.996	13.4198	10.2682	15.5614	12.205	7	3
842	27	29.9751	9.4077	28.993	13.3716	8.952	6	3
843	25.4688	11.996	11.8838	9.7936	15.0716	12.4265	7	3
844	37.49	31.7816	13.9208	30.8429	16.5173	13.9498	7	3
846	15.18	29.3536	12.3022	24.8065	15.793	12.6667	6	3
848	16.57	29.3536	11.3404	28.9356	17.252	13.5623	7	3
849	16.5824	9.69	10.9153	7.1105	12.3885	7.5905	5	3
850	19.12	24.6011	12.5181	24.0325	14.4892	11.9627	6	3
851	19.124	7.0114	9.5612	4.9985	12.7276	9.2321	6	3
852	22.95	34.2217	14.7118	34.3694	14.1736	13.0827	6	3
854	14.52	27.7548	13.2133	31.5232	13.056	10.9408	8	3
855	26.6653	14.6716	14.4517	11.253	11.5622	10.9389	7	3
856	19.61	25.6294	9.636	25.5735	10.7607	10.292	9	3
857	19.6116	11.9231	9.3665	10.833	13.48	7.7881	7	3
858	7.98	23.8401	10.5871	22.1803	13.7215	10.9389	6	2
859	21.6717	11.9231	10.6354	7.7774	12.6627	10.292	7	3
860	29.06	20.8779	8.131	25.2761	10.2905	7.7881	6	3
861	29.3259	16.0044	6.4385	20.4752	10.6045	7.783	7	3
863	27.3628	16.0044	15.6402	11.7465	15.5921	14.2764	7	3
864	39.86	37.4579	14.0713	30.6605	14.6701	12.1219	7	3
865	41.0855	13.3504	11.6651	22.5291	13.9032	13.4131	7	2
866	29.88	36.5895	17.6725	36.2263	21.263	17.4602	9	3
867	28.3766	13.3504	15.4003	11.6936	18.0581	12.4532	11	3
868	29.13	36.5895	8.0622	34.0278	12.6744	7.8146	5	3
869	29.2431	16.0195	16.8574	9.9842	15.2799	12.2182	6	5
870	19.33	32.8869	11.9017	32.4495	15.262	14.0946	6	3
871	19.3303	7.5281	9.5142	6.0184	12.4018	7.7098	5	3
CTM								
872	16.21	23.7513	16.2362	34.3402	23.7408	18.2158	9	3
873	17.4946	16.3377	13.6577	12.1777	12.9143	12.2149	5	3
875	25.6315	16.3377	14.4409	12.8725	16.3677	13.5251	7	3
877	38.5632	15.3117	18.713	13.102	27.3015	20.4414	10	4
878	14.46	36.4083	14.8962	36.3365	18.5423	15.3586	8	3
879	29.8318	15.3117	14.5143	11.2713	19.8061	14.7521	10	3
881	41.9191	18.9012	11.7353	23.6729	15.6704	11.671	6	3
883	32.8871	18.9012	16.1255	13.32	17.66	15.9244	8	3
886	26.7	28.8186	14.2317	25.9423	16.1171	11.4299	7	3
887	22.0544	10.6322	10.9019	7.4683	14.2507	11.1294	6	3
889	32.8007	15.5416	15.9781	11.1587	16.0734	15.6439	7	3
890	27.49	27.4641	14.9342	25.7324	14.5473	12.53	7	3
891	27.4909	12.1802	13.2594	7.3925	14.3701	13.8096	8	3
894	56.32	48.1461	20.998	42.9229	26.2007	21.1028	10	5
896	28.47	35.0232	19.8976	36.8284	26.9752	17.1269	7	3

897	28.7427	18.2592	28.2048	11.5108	26.4021	14.225	9	3
SPEC NO	WIDTH	THICK	SULC W	SULC H	LENGTH	ALAE W	LAT RIB	SULC RIB
MABR								
910	23.06	46.7043	14.5025	45.7773	20.7156	7.2759	8	4
912	36.19	46.4276	18.6729	38.8358	28.1607	18.942	8	4
913	37.5515	24.8703	14.5588	22.315	18.6755	12.0468	10	3
915	35.9909	24.8703	18.8205	15.4129	22.6563	15.1202	9	4
916	33.14	46.2311	17.3942	44.165	23.1865	14.8293	8	3
917	33.2719	20.0462	16.57	16.2141	23.4945	14.0602	10	5
920	44.91	39.5331	16.0919	41.5194	17.9015	10.3454	7	4
922	24.55	44.4927	18.2848	33.1073	23.3129	15.0714	7	3
923	29.4102	20.3646	15.1504	10.3276	19.9002	11.779	9	3
924	19.07	27.7828	15.4945	39.3045	18.3571	11.1179	8	3
925	20.8704	22.5894	14.6853	12.1643	20.5254	11.5454	8	4
926	48.91	41.2659	14.7007	29.7086	19.501	13.2534	11	3
927	31.3721	22.5894	14.2857	15.4709	24.959	12.6152	9	5
928	42.83	41.2659	20.3604	35.0394	28.8372	17.2227	9	3
929	42.8419	34.7617	24.671	22.09	31.084	12.956	7	3
930	38.66	43.335	19.5307	39.9683	26.3473	15.1416	9	5
934	37.21	44.5501	20.0414	41.0939	25.4914	13.7088	8	4
935	36.7434	24.8972	17.7248	16.4967	23.8115	14.2704	10	3
937	41.1637	21.9233	18.697	15.8197	17.5285	12.2795	10	5
940	45.65	34.6117	14.6549	43.3178	20.933	12.2795	9	3
941	46.205	28.9006	14.2407	30.6004	19.68	9.2909	10	4
942	41.62	40.8569	10.4827	32.1117	16.031	8.2555	11	3
943	39.27	28.9006	17.7231	20.8912	26.475	21.7354	10	3
MARL								
944	35.95	41.9401	16.5558	36.0724	23.5849	16.6384	9	3
945	35.9902	21.4285	20.7493	17.4575	30.5221	15.8119	8	3
946	35.32	45.7521	21.2243	39.5215	24.5161	14.5305	9	5
947	31.073	21.4285	17.0851	13.3418	23.3196	12.4115	9	3
948	36.1	45.7521	17.7239	44.6198	24.2183	16.2411	8	3
949	36.1141	26.4112	19.6204	17.4871	25.4517	15.9832	7	3
950	31.32	50.33	19.0452	46.2611	23.7941	14.0181	9	4
951	31.3404	19.92	14.5644	13.15	22.5006	12.8999	9	3
952	42.32	33.9067	13.7435	31.7782	20.2025	9.6901	8	3
953	42.3469	26.3668	16.8463	20.2516	22.9501	16.1672	9	4
954	34.34	38.0137	17.2007	29.085	21.5798	13.2725	8	3
955	35.2855	26.3668	18.1034	18.2529	25.8458	14.0905	8	5
956	42.55	45.0578	13.5941	39.6589	19.9009	10.5211	9	3
957	43.3596	29.2673	19.9426	27.6578	23.2863	11.1262	5	3
MAG								
958	41.85	49.7884	22.7103	43.1709	27.5122	11.9831	7	4
962	41.75	45.4779	18.2016	36.5384	24.0707	18.2947	9	3
963	39.2277	32.5814	19.7957	22.66	30.1907	15.3025	8	3
964	39.62	47.2636	19.6045	39.7311	23.366	10.7717	8	4
965	39.62	28.98	22.9314	17.8627	27.2502	15.5778	8	3

SPEC NO	WIDTH	THICK	SULC W	SULC H	LENGTH	ALAE W	LAT RIB	SULC RIB
967	38.523	28.98	19.4581	18.8496	27.8655	14.9876	8	3
968	39.14	38.8208	21.297	34.1436	25.4635	11.5519	7	3
969	39.1402	27.3198	21.8285	16.5912	26.5663	15.2678	7	3
970	35.89	43.6232	18.4697	38.7931	26.3702	15.8395	10	3
972	24.83	32.3078	20.2021	42.2974	21.5951	18.9781	6	3
973	25.9525	20.6976	16.321	14.045	19.1184	11.3188	6	3
974	21.47	31.5801	13.3901	24.2391	18.1696	26.4847	9	4
ABa								
975	38.5239	20.6976	20.3603	13.0884	16.4476	14.0759	8	5
979	27.317	14.8509	14.7404	9.59	19.4333	10.9681	7	4
ASp								
981	40.9303	22.6355	20.4882	16.0458	27.116	16.4548	8	3
983	40.2111	22.6355	19.6721	13.9386	23.898	20.3127	9	4
FACA								
986	29.22	24.9365	12.6416	24.2022	14.7699	14.0433	10	3
989	22.86	17.0567	11.5602	26.1933	11.9102	11.1374	8	3
991	21.52	17.2311	10.7509	17.1544	12.3057	10.8886	5	3
993	18.3	21.1574	11.1062	16.3873	11.6544	12.1282	6	3
996	20.65	18.4463	10.9601	18.4098	12.5141	8.3981	5	3
997	18.5	19.5484	7.2101	16.0795	10.4846	8.2101	7	2
999	12.88	17.7874	8.246	17.8623	10.41	6.9632	7	3
1000	13.64	17.2988	6.7087	18.0497	9.2301	8.4184	5	1
1004	23.47	29.0388	5.5307	22.2143	8.2305	5.519	5	3
LR								
1006	19.06	25.6487	10.8766	26.6862	10.2787	9.1839	6	3
1007	10.75	22.6094	8.1214	24.897	9.7209	9.7292	7	3
1009	27.73	22.547	14.5224	25.0775	15.6487	11.869	6	4
1010	10.98	20.4431	5.1305	13.0793	8.1924	6.0687	8	3
1011	26.43	21.9718	10.4543	23.2112	13.7136	11.6258	11	3
1013	27.24	27.2894	5.2433	19.9322	6.8619	5.1015	7	3
1016	22.15	29.0747	11.3509	25.8015	15.1207	13.5981	6	3
1019	20.97	20.318	11.1488	24.6187	12.2886	11.2944	10	3
1020	24.68	22.7509	11.3537	26.9468	16.9789	8.8881	8	3
1023	27.71	23.1445	10.5804	21.7021	12.4929	8.7582	7	3
1026	29.08	22.3417	12.6045	25.1898	17.9374	12.2456	8	3
1027	37.91	30.2067	10.4743	25.7763	15.1062	13.4889	7	3
1029	37.69	30.8658	10.8435	29.4254	14.5137	14.358	8	3
LGH								
1030	28.84	32.5565	13.034	31.3918	16.4462	19.6885	14	3
1031	33.04	34.2651	9.21	30.6617	12.0024	9.7968	9	3
1032	17.04	30.8039	13.8398	28.3702	13.8402	17.5368	9	3
1033	20.26	26.4358	13.2998	30.9083	14.7621	15.1807	7	3
1034	35.6	31.0066	10.9215	32.1957	13.8022	15.5335	10	3

1035	34.2	33.832	11.0965	28.2371	13.3686	12.2403	8	4
SPEC NO	WIDTH	THICK	SULC W	SULC H	LENGTH	ALAE W	LAT RIB	SULC RIB
1037	11.98	29.6323	15.7239	30.0121	15.3127	15.8916	13	4
1038	19.63	21.5587	13.1226	28.5852	14.4427	14.8288	9	3
1039	27.29	26.4304	11.0004	30.1256	14.1215	15.2429	9	3
1040	28.31	25.6901	7.3633	21.0673	9.661	8.1215	8	3
1041	24.2	23.8395	12.8379	23.4584	16.3737	13.8594	9	3
1042	24.79	22.4211	11.8294	22.9524	12.8066	14.6447	11	3
1043	25.94	21.2554	11.0108	21.9337	13.6119	14.8395	9	3
1047	18.31	22.1725	8.8021	21.8928	11.39	8.116	9	3
1048	23.45	21.2082	10.0488	22.7513	14.0146	9.2402	10	3
1049	24.36	22.0141	11.8282	22.2712	13.6124	12.886	11	3
1050	7.69	21.9313	8.6412	19.5943	10.3418	8.4482	7	3
1051	25.33	14.8698	10.522	21.0135	13.1684	11.0543	11	3
1053	15.37	21.4741	4.7588	10.9984	6.2406	5.596	7	3
1054	13.53	16.3857	10.0408	21.2357	12.8119	12.8009	10	3
1057	18.82	21.173	7.5118	19.0156	8.464	8.2321	9	3
1058	19.25	22.4823	5.6779	17.8305	9.7911	8.6825	10	2
WWCL								
197	25.4617	14.1782	9.5808	12.6451	11.3201	6.8308	7	3
199	23.7049	14.1782	11.3478	10.0145	13.1307	11.4154	6	3
200	17.81	25.4543	9.8311	24.9716	13.2618	10.3517	7	3
201	18.0414	9.2129	8.8411	5.0277	12.54	11.0027	9	3
202	12.24	15.7402	9.1005	21.9254	12.67	10.1965	8	3
204	26.02	24.4711	7.7843	17.3313	10.7106	8.3488	8	3
205	26.2917	11.4311	5.5118	11.5113	8.2618	8.421	7	3
207	21.8512	11.4311	9.9142	7.3737	11.1	11.7632	9	3
208	14.21	22.3799	11.8893	21.1202	13.1634	11.9855	9	3
209	14.2101	6.6751	7.4817	5.1493	9.2439	7.1436	7	3
210	26.94	27.8268	11.9384	26.181	13.7205	13.2265	9	3
211	26.954	14.3848	11.8382	10.3394	12.7169	13.1924	7	3
213	20.6754	9.1514	7.8728	8.755	19.2586	13.3397	6	3
215	22.39	9.1514	10.6912	6.92	13.4401	10.0746	7	3
216	16.34	21.0044	12.3003	30.3984	11.6842	8.1599	8	3
217	16.3403	7.9802	8.8935	6.2219	9.0726	7.0135	8	3
219	17.0936	7.9802	7.1754	5.0529	10.2599	8.1599	8	3
220	18.58	18.6397	7.7902	17.5646	8.1824	7.0135	7	3
221	18.6381	9.3216	6.9357	6.3891	9.0743	6.5712	8	3
222	16.46	21.078	6.8305	17.5722	9.7944	7.895	7	3
223	15.3501	9.3216	7.7839	5.6528	10.5421	6.6799	7	3
225	20.6079	8.4819	8.4719	5.4923	10.0473	7.0457	9	3
227	20.3904	8.4819	8.3017	6.1112	11.7133	7.7022	8	3
228	25.65	25.0227	11.1866	22.7693	13.8402	12.5892	9	4
229	25.6595	15.068	11.7733	10.5214	13.9637	12.8851	7	3
232	16.25	25.9888	11.2151	21.1128	11.5311	10.3995	10	4
234	17.39	26.1648	11.1735	25.2659	11.75	12.0593	9	3
237	19.7783	6.8114	8.929	4.4069	11.4204	9.3673	8	3
238	16.41	19.2872	9.7702	18.3621	13.4779	9.6308	8	3

239	19.49	6.8114	8.6805	4.6239	10.0508	8.8411	9	3
SPEC NO	WIDTH	THICK	SULC W	SULC H	LENGTH	ALAE W	LAT RIB	SULC RIB
240	23.23	21.9772	7.3604	19.7101	9.4905	7.8782	7	3
242	19.82	27.5173	8.2847	19.0677	10.5667	8.0376	7	3
243	19.9487	8.7802	9.5328	6.9809	11.7203	8.7152	6	3
246	24.13	24.7356	11.0765	24.9846	14.9759	11.7539	10	3
247	23.5081	13.0306	10.6308	9.4331	12.6125	12.1304	6	3
248	24	24.7356	9.7246	23.3872	12.9745	11.0766	8	3
249	24.0007	11.1317	10.7683	8.9255	12.5723	12.3692	9	3
251	18.0804	9.1001	9.2291	6.0729	11.3592	8.2044	7	3
252	22.87	23.1272	9.7178	21.7795	14.1181	9.5875	9	3
256	23.76	22.7318	12.1215	20.3974	11.7903	13.0623	9	3
257	23.7823	12.3789	11.2551	7.8969	10.3632	8.7378	9	3
259	25.2506	12.3789	11.3113	9.7943	12.5121	13.0623	8	3
260	22.12	18.9298	8.4406	19.5525	9.6957	8.7378	9	4
261	22.1261	10.7607	9.8264	7.9259	9.9845	7.8208	7	3
262	25.61	20.2082	8.6856	18.7226	10.1754	9.7522	8	3
268	17.15	22.8035	9.0708	21.1869	11.9248	9.8218	7	3
269	17.1731	10.6907	8.8	5.9403	12.2801	7.4508	8	3
273	11.7713	10.2681	6.4041	4.9719	8.4253	5.7873	7	3
275	18.2046	10.2681	9.635	7.352	11.0302	6.9445	7	3
284	8.27	19.1178	8.4743	15.5469	8.5249	7.9283	7	3
289	21.7016	10.9753	8.3673	8.0338	12.6246	10.3711	9	1
290	26.42	27.4986	10.0016	25.6814	10.83	7.8606	6	3
291	26.4482	15.955	11.7902	11.6269	12.9613	13.074	7	3
299	21.0723	9.6375	8.6011	8.4009	11.0796	10.3922	7	3
301	23.7218	13.0001	10.5972	11.4056	11.3054	10.5865	7	3
303	23.7615	13.0001	11.0612	8.84	11.7315	12.0306	7	3
305	16.5493	5.638	7.3702	0.9276	11.3357	10.0452	6	2
306	5.47	18.1222	10.1502	22.1205	11.8026	12.9912	7	3
308	11.14	18.1222	5.4687	17.3465	7.6801	6.2886	7	3
311	16.5544	8.5429	8.933	5.6634	9.7259	8.3536	7	3
314	16.73	22.1544	8.6631	19.0253	10.4912	7.7554	9	3
315	17.8008	7.9972	7.4856	5.281	9.2123	8.1999	7	3
317	17.8492	7.0403	6.9003	4.6751	9.1991	8.1597	7	2
324	24.02	27.1475	7.0616	19.7932	8.5518	9.7129	7	3
331	18.7084	8.5221	9.8598	6.3009	11.255	8.2564	6	3
334	10.49	17.853	6.1514	15.6293	9.1243	5.0676	10	5
345	20.6948	6.5652	11.5066	3.1456	13.4554	9.1676	9	3
346	26.69	31.144	8.6515	28.4676	10.9702	10.7369	7	3
347	17.9137	6.5652	7.181	4.6039	10.3263	8.4445	8	3
348	17.95	31.144	8.0019	29.3334	9.7909	9.7517	8	3
353	21.9712	9.8685	7.9157	9.9957	11.0802	8.9918	7	3
355	24.1517	9.8685	10.5176	8	12.7438	11.7623	10	3
356	27.69	28.3358	11.3503	31.1667	14.3034	14.702	8	1
363	12.1535	5.9655	6.2212	3.7044	8.0479	6.0929	8	3
364	13.88	20.487	10.2811	24.8345	12.2307	11.2554	8	2
365	14.7839	8.0439	11.2956	7.8227	14.2208	13.2599	10	3
368	20.26	23.5033	7.9218	21.2836	9.6559	5.7048	8	3

369	20.2625	9.9734	9.3381	5.7215	12.779	7.6061	9	4
SPEC NO	WIDTH	THICK	SULC W	SULC H	LENGTH	ALAE W	LAT RIB	SULC RIB
371	22.9189	9.6834	8.7031	6.1312	11.9412	11.1348	8	3
374	13.16	26.1362	11.5684	26.3698	8.1749	10.0245	8	3
378	22.05	30.4033	10.8704	29.1766	12.4667	14.7529	9	3
382	7.24	28.1774	10.3604	29.1519	12.814	8.2073	8	1
383	29.4505	15.0636	12.0923	9.9027	14.5002	15.5722	10	3
385	21.9452	9.4938	4.4928	13.6188	7.0996	4.7432	5	3
386	25.84	26.2331	10.0208	27.4522	14.5212	9.6942	10	3
387	20.5074	9.4938	10.4602	7.5049	10.867	9.2886	7	3
388	20.5074	9.4938	10.4602	7.5049	10.867	9.2886	7	3
389	13.61	25.2645	10.7536	25.0619	11.5929	11.5206	7	3
391	24.14	27.578	10.3601	24.8198	14.5479	10.9963	7	3
392	24.1433	15.6218	12.0343	10.6875	14.2132	12.3812	9	3
393	12.67	26.0088	7.7209	21.315	10.6707	9.426	9	3
394	13.8242	6.1301	7.8653	3.2354	11.3201	8.6676	9	1
395	19.96	20.4064	10.8442	25.9607	13.5148	13.1971	11	3
396	12.6703	6.1301	5.3563	4.4909	8.6409	6.5166	7	3
397	25.46	25.1067	6.6724	18.9037	9.5743	7.1994	9	3
398	25.7091	9.3708	10.3885	4.3873	12.8179	11.3865	7	3
399	11.72	20.0853	11.1995	20.6551	12.7	9.8476	8	3
400	22.344	9.3708	10.2202	6.6324	10.9624	11.3896	9	3
401	14.13	17.84	9.7332	19.3532	11.0575	8.7431	7	3
402	32.89	29.1269	4.6531	25.4103	7.8201	6.8684	8	3
403	12.1503	5.8841	6.6845	3.8687	7.6701	6.1757	7	3
404	23.62	32.8189	6.9102	26.6594	10.2203	6.7604	8	3
405	23.6202	8.655	12.2729	9.4512	16.4585	13.1601	10	3
407	21.854	8.655	8.3969	7.372	11.98	10.2782	9	3
409	22.5114	10.9603	9.18	7.6405	12.25	11.9267	9	3
410	8.64	30.0226	11.062	29.7313	13.5909	12.2055	8	3
411	8.6404	4.9985	4.5502	3.1022	6.4801	3.6672	7	3
412	20.58	25.7484	8.4716	25.1353	15.0601	9.8172	8	3
413	20.6063	9.6714	9.4123	6.7328	12.9297	9.0197	9	3
414	7.2	20.9346	9.3318	20.7327	9.7372	5.397	7	3
415	20.0954	9.6714	9.661	7.7147	16.3583	12.7625	7	3
416	15.14	26.5626	9.9687	20.8268	8.7873	8.0321	9	3
418	46.0143	13.7074	11.5841	19.2468	14.0934	12.7625	7	3
419	42.552	11.5758	9.4802	18.5628	10.5572	10.1078	7	3
420	16.911	6.8742	7.11	4.84	10.8836	8.0321	9	3
422	17.7	25.3104	11.2735	30.6619	13.9129	13.4186	8	3
423	21.1909	11.6403	10.011	8.5988	12.0108	10.4636	9	3
424	24.57	32.1732	9.92	27.7766	11.0048	11.1016	10	3
425	24.5974	8.2851	10.2083	10.0146	12.5601	9.657	10	3
426	2.56	19.7659	7.9391	27.6305	10.8926	8.8512	9	3
427	16.4554	8.2851	7.4278	5.5127	9.82	7.9723	8	3
428	13.71	19.7659	6.1402	19.3512	8.1602	6.0465	7	3
430	21.6	16.7928	4.9836	15.62	7.6232	5.0406	9	3
431	21.6	10.0039	9.7899	7.2433	11.4039	10.921	8	3
432	20.59	27.439	9.1026	22.1139	9.7219	7.7881	8	3

433	20.6703	13.9014	7.9663	8.3122	10.716	8.7587	9	3
SPEC NO	WIDTH	THICK	SULC W	SULC H	LENGTH	ALAE W	LAT RIB	SULC RIB
434	10.78	17.3413	10.1822	24.706	13.2449	9.5187	8	3
436	17.34	20.4784	5.8849	17.1485	8.2212	6.1289	8	3
438	20.43	22.1221	6.83	20.1147	7.9106	8.8037	8	3
440	14.24	21.7657	6.9697	19.4446	9.6123	9.2413	9	3
441	14.5485	4.9233	9.1783	3.4868	10.6207	9.7966	9	3
442	6.06	14.0482	8.7563	19.172	11.34	8.9978	9	4
443	14.3411	4.9233	6.5469	3.9673	8.8716	7.1787	7	3
444	14.9	15.66	5.3528	15.0927	7.2347	4.1054	7	4
445	15.2191	5.0293	4.0004	7.1408	5.5865	5.0658	9	2
447	12.9324	5.0293	4.8708	3.7916	7.9704	7.1985	9	3
449	11.6001	5.2716	5.2972	3.3793	7.8103	5.7573	8	3
450	12.7	13.6686	5.3136	12.9119	7.7041	4.5195	8	3
451	12.7013	6.2406	6.9167	4.5067	9.1875	5.8753	7	4
453	11.1301	5.2005	6.8614	2.8685	7.5813	5.8815	7	3
454	11.77	16.4453	4.2812	16.903	7.7212	6.5676	8	3
456	13.34	17.5963	6.1314	16.5014	7.5054	4.3482	8	4
457	13.3405	4.4323	5.8115	3.4931	11.1926	9.6738	7	3
459	9.7703	4.4323	4.91	2.9883	7.181	4.3482	7	4
460	1.89	14.6219	8.337	18.099	9.7728	9.6738	11	3
461	3.166	2.4702	7.1974	8.351	9.5933	5.4597	8	3
463	6.7343	2.4702	2.5928	1.4612	4.2709	3.7961	7	3
464	2.7	11.4107	5.7885	17.9468	9.8916	5.9579	9	3
465	8.9471	5.5101	6.5803	10.5029	8.8011	6.3804	6	2
466	8.19	13.6311	4.8401	11.1336	7.0303	4.1777	7	3
467	10.0922	5.5101	3.8501	3.8358	7.0937	4.4894	8	1
468	5.47	13.6311	5.1965	12.9484	9.3426	6.06	7	3
469	5.4723	1.8134	2.1502	1.3185	3.9329	2.2945	6	1
470	16.71	16.2352	5.9801	15.3254	8.2474	5.7822	8	3
471	16.7101	7.37	8.4215	5.7502	10.2326	7.7401	8	3
472	6.52	25.0033	7.5441	16.9293	9.371	7.9863	8	3
474	8.43	13.1452	7.8102	24.8999	8.9969	5.5713	5	3
475	9.1205	3.9201	4.2801	2.7002	6.2872	3.5731	6	3
WW101								
476	28.53	27.6638	4.31	20.2264	6.4815	4.2035	7	3
1064	22.23	19.5819	9.9246	17.0958	13.43	11.5592	9	3
1067	21.43	24.0858	7.0419	21.0179	11.0501	9.3392	9	2
1069	23.38	22.6318	9.9129	22.4759	11.6123	10.0981	10	3
1072	18.9	24.2852	12.4081	20.5619	15.1705	14.3648	9	3
1075	11.59	15.4871	9.5875	21.1452	11.8457	8.9605	10	3
1076	23.52	20.0367	9.23	23.2213	11.2405	8.4645	8	3
1078	17.45	19.9758	11.2904	15.5275	13.7308	8.1025	10	2
1081	24.42	25.3081	8.1747	19.7576	10.9401	8.6361	8	3
1082	24.72	27.3053	10.832	25.3776	15.7311	14.8009	10	3
1084	12.22	23.8218	8.9469	23.135	11.5144	9.3823	10	3
1085	17.18	19.928	9.6541	24.5909	12.42	9.2864	10	4
1088	21.63	26.2068	10.368	20.4539	12.0901	11.0408	9	3

SPEC NO	WIDTH	THICK	SULC W	SULC H	LENGTH	ALAE W	LAT RIB	SULC RIB
1090	28.28	27.2558	12.4013	27.44	13.989	9.4069	8	3
1091	30.84	32.2876	9.08	27.5803	10.8602	10.2684	9	3

APPENDIX C

Platystrophia Collection Sites

Locality	*Code*	*Description*
Bardstown, Kentucky	ABa	NE of Bardstown, 4 miles on south side of Blue Grass Parkway near 55. Bardstown quadrangle. 37° 50' 29" N, 85° 23' 44" W
Brookville, Indiana, Garr Hill	LGH	Intersection of Indiana S.R. 101 and Brookville Dam Rd., approximately 9.5 km (5.7 miles) northeast of the intersection of Rts. 101 and 52 in Brookville, Indiana. Road cut on both sides of Rt. 101. Whitcomb quadrangle, Indiana. 39° 29' 15" N, 85° 56' 55" W
Brookville, Indiana, Route 101 (Bon Well Hill)	WW101	Intersection of Indiana S.R. 101 and Brookville Dam Rd., approximately 1.6 km (1.0 miles) north of Brookville, Indiana. Road cut on both sides of Rt. 101; W side, 3 m from top; Whitcomb quadrangle, Indiana. 39° 26' 13" N ,84° 58' 41" W
Cincinnati, Ohio	FAC	Immediately north of intersection of S.R. 27 and I-275. Open field on east side of 27. 39° 16' 03" N ,84° 35' 52" W
Cincinnati, Ohio, Blue Rock Road	MABR	.5 km (.3 miles) SE of I-275 on Blue Rock Rd., Cincinnati West quadrangle, Cincinnati, Ohio. 39° 13' 47" N; 84° 37' 16" W, 2 m above road.
Cincinnati, Ohio, Rumpke landfill	MARL	Collections of D. L. Meyer
Corinth, Kentucky	FC	I-75 northbound through Corinth near underpass for Keefer Rd; W side of road, 3 m up. Sadieville quadrangle, Kentucky. 38° 29' 47" N ,84° 53' 09" W
Covington, Kentucky, Riedlin (Mason) Road	BRM	.6 km (.4 miles) north of I-275 on Kentucky S.R. 16 at intersection of Reidlin Rd. 3 m up "island" off Rt. 16 near stop light on exit ramp. Covington quadrangle, Kentucky-Ohio. 39° 01' 40" N, 84° 30' 38" W
Covington, Kentucky, Reidlin (Mason) Road	FRM	.6 km (.4 miles) north of I-275 on Kentucky S.R. 16 at intersection of Reidlin Rd. Covington quadrangle, Kentucky-Ohio. 39° 01' 40" N, 84° 30' 38" W
Covington, Kentucky, Thomas More Parkway	CTM	Turkeyfoot Rd. exit near 275 E. in Covington, creekside exposure down Kentucky. Covington quadrangle, Kentucky-Ohio. 42. 39°01'20"N, 84°33'57"W

Cowan Lake, Ohio	WWCL	Exposures in spillway of Cowan Lake and on north bank of Cowan Lake adjacent to spillway, near top. Clarksville, Ohio quadrangle. 39°33'22"N, 83°55'38"W
Florence, Kentucky, Old 42	CO42	South of Florence on Old U.S. 42 (semi-circular road enclosing Natorp's Nursery); specimens in field on top of rise. Union quadrangle. 38° 58' 59" N, 84° 37' 38" W
Georgetown, Ohio	BG	Roadcuts along Ohio S.R. 125 on both sides of the Whiteoak Creek valley, 0.8 miles west of intersection with U.S. Route 68 in Georgetown, Ohio. Higginsport Ohio-Kentucky quadrangle. 38°52'20"N, 83°55'00"W
Goshen, Ohio	MAG	Collections of D. L. Meyer
Idlewild, Kentucky	FI	Extreme west end of exposure where I-275 crosses Ohio River, just above Fairview/Kope contact, Lawrenceberg quadrangle. 39° 05' 34" N, 84° 49' 06" W
Maysville, Kentucky	BMV	Exposures on both sides of road cut for AA-62/68, 1 mile south of Ohio River, Maysville West quadrangle. 38° 35' 35" N, 83° 45' 49" W
Petersburg, Kentucky, Exit 20	BK20	South of I-275, exit ramp for Kentucky 20, northwest side of road, bottom 7 m of section, Lawrenceberg West KY-OH quadrangle. 39° 04' 00" N, 84° 38' 23" W
Richwood, Kentucky	CR	2 exposures off I-75 northbound along exit ramp 175, 1-2 m up; Union quadrangle. 38° 55' 13" N, 84° 37' 40" W
Rising Sun, Indiana	BRS	Road cut on both sides of 262 outside of Rising Sun. 38° 55' 20" N, 84° 53' 00" W
Sadieville, Kentucky	KS	Northbound I-75 outside of Sadieville, under 141 overpass near concrete barrier on east side of road, Sadieville quadrangle. 38° 22' 57" N, 84° 34' 18" W
South Gate, Indiana, Route 1	LR	Road cut on both sides of Rt. 1, approximately 1.0 mile north of South Gate, Indiana. Cedar Grove, Indiana quadrangle. . 39° 21' 30" N, 84° 57' 17" W
Springdale, Ohio	ASp	Beacon Park in Springdale, 1 m above *Retrospirifera carlyii* zone (lower Arnheim) in shale-rich interval, 39° 17' 14" N, 84° 29' 08" W
Sulphur, Kentucky	BS	Road cut, railroad tracks 2.2 miles west of intersection of 157 and S. R. 1606, Smithfield, KY quadrangle. 38° 27' 57" N, 84° 34' 18" W

APPENDIX D
Cartesian coordinates derived from landmarks

LAND MARK	ANTERIOR 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
31 x	-0.5417	0.5699	1.5234	0.4763	0.5035	-0.1771	-0.0699	0.0000	0.4194	0.5165	0.7224	0.7796	1.0000	1.0994	1.1763
y	0.2308	0.9837	0.1697	-0.4212	-0.0001	0.0348	0.1577	0.0000	0.6545	0.4368	0.3786	0.5698	0.0000	0.1012	-0.0419
angle															
32 x	-0.2113	0.6179	1.3471	0.5369	0.5531	-0.1005	-0.0588	0.0000	0.1883	0.2067	0.7641	0.8337	1.0000	1.1347	-0.8220
y	0.2823	0.7323	0.1345	-0.2099	0.0614	0.0585	0.1243	0.0000	0.3524	0.3010	0.3773	0.4542	0.0000	0.1489	-0.8318
angle															
33 x	-0.4447	0.5293	1.5672	0.4605	0.5102	-0.1463	-0.0626	0.0000	0.2841	0.3238	0.7167	0.7476	1.0000	1.0887	1.1515
y	0.1977	0.7495	0.0514	-0.3800	-0.0127	0.0185	0.1179	0.0000	0.6549	0.6180	0.5980	0.6129	0.0000	0.1141	0.0017
angle															
34 x	-0.5117	0.4514	1.4682	0.4745	0.4585	-0.1397	-0.0594	0.0000	0.1603	0.2428	0.7925	0.8113	1.0000	1.0364	1.1188
y	0.0184	0.7889	0.0605	-0.5390	-0.0200	-0.0605	0.0941	0.0000	0.4959	0.4024	0.3960	0.4080	0.0000	0.0772	-0.0123
angle															
35 x	-0.5118	0.4647	1.5372	0.5203	0.4936	-0.1491	-0.0818	0.0000	0.2290	0.2774	0.7058	0.7408	1.0000	1.0405	1.1036
y	0.0967	0.7970	0.1580	-0.3948	-0.0069	-0.0078	0.0670	0.0000	0.4666	0.4044	0.4072	0.4867	0.0000	0.1000	0.0054
angle															
36 x	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
y	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
angle															
37 x	-0.4951	0.4197	1.4952	-------	0.4974	-0.1391	-0.0578	0.0000	0.1688	0.2112	0.6872	0.7321	1.0000	1.0430	1.1367
y	-0.0574	0.7060	0.1265	-------	0.0284	-0.0573	0.0756	0.0000	0.3983	0.3040	0.3829	0.4668	0.0000	0.1068	-0.0580
angle															
38 x	-0.5128	0.4055	1.4809	0.5642	0.5177	-0.1147	-0.0462	0.0000	0.1422	0.2057	0.7274	0.7458	1.0000	1.0461	1.1252

APPENDIX E
Principal Components: Axis Scores

Spec No	1	2	3	4	5	6
1	1.509	0.767	1.64	0.71	-1.001	-2.4
2	0.59	0.699	4.474	-2.031	0.098	-1.909
3	1.534	-0.401	0.218	1.115	0.651	-0.14
5	-0.711	0.936	-0.074	0.997	0.08	2.856
10	-1.873	0.345	4.087	-1.029	0.399	-1.314
14	3.376	-0.475	0.285	-0.578	-1.837	1.275
17	-0.654	-1.109	7.019	-2.323	-0.479	-1.812
18	-1.183	-0.057	-1.334	1.378	1.123	0.089
19	-2.12	-0.02	2.195	7.062	4.364	0.87
21	0.391	-0.9	-2.033	4.284	0.955	2.764
22	-0.794	-1.674	8.354	-2.054	-0.407	2.273
23	1.975	0.201	-1.975	0.331	0.918	0.89
28	1.633	1.561	1.917	-2.406	1.06	0.475
31	2.321	0.001	-0.419	0.151	-0.366	1.644
32	0.09	-0.91	0.648	2.045	-0.961	-1.277
33	0.249	0.67	-1.206	0.646	0.64	0.171
41	1.378	-0.371	-0.568	0.265	0.027	-0.139
43	0.758	-0.312	-0.672	1.454	-0.548	-0.745
45	0.888	0.388	-1.677	2.121	1.013	-1.682
47	-0.68	-0.164	-0.072	-0.261	0.442	-0.469
49	-0.449	0.437	0.643	-0.887	-0.226	-1.153
50	1.229	-0.222	-0.823	-0.598	0.661	-0.307
52	0.397	-0.949	0.227	0.969	-0.5	0.308
54	0.778	-1.04	0.08	0.815	-1.099	-1.735
57	1.622	-0.125	-0.591	-0.794	-0.782	-1.446
58	-0.863	-1.713	0.345	0.585	-0.138	0.051
59	0.491	0.151	-0.812	0.106	-0.514	-0.247
60	-0.472	0.21	-0.252	-0.013	-0.119	-1.302
63	2.045	1.818	1.488	-0.555	1.308	-0.58
64	0.974	1.224	1.893	-0.118	-0.447	-0.832
65	2.437	0.628	2.081	0.797	-0.748	0.066
66	0.775	1.075	2.108	0.677	2.359	-0.789
67	1.582	-0.072	0.939	2.16	0.015	-0.673
68	1.402	0.763	0.907	0.393	-0.228	-0.761
70	1.798	-1.214	-0.041	-0.83	-0.556	0.246
73	-0.865	0.021	0.421	1.129	1.173	-1.665
76	-1.949	0.381	0.917	0.74	-1.245	0.271
77	-1.279	-1.081	0.344	-0.403	0.45	-0.806
82	1.52	0.172	-0.101	0.677	-3.713	-1.526
84	0.351	0.841	-0.132	-1.269	1.311	-0.945
92	-0.559	1.303	1.37	-0.344	-1.045	-1.138
93	-1.047	-0.983	0.063	-0.512	0.235	-0.454
96	0.509	0.83	1.445	0.535	2.212	-0.436
97	-0.56	-0.721	0.524	-0.252	0.694	-0.4
100	-1.221	0.361	0.892	-0.128	0.461	-0.785

101	-0.969	-0.457	0.663	-0.637	0.534	-1.022
103	-0.869	-0.714	0.49	-0.362	0.147	0.932
105	-0.523	0.263	1.569	0.174	-0.868	1.018
106	0.113	-1.097	0.125	3.343	-0.977	2.573
109	0.143	0.426	1.066	1.854	-0.126	-3.027
112	-1	-0.102	0.575	0.211	0.47	-0.578
118	-1.026	0.265	1.725	-0.263	0.936	1.207
119	-1.196	-0.042	-0.261	-0.328	0.253	-0.533
123	-0.28	-0.227	0.491	-0.749	-0.165	0.525
124	-1.02	0.218	1.105	-0.213	-0.343	-1.183
125	-0.68	-1.194	0.035	-0.247	-0.247	-0.436
126	-0.073	-0.237	2.141	2.219	-0.16	-1.381
139	1.571	0.005	1.498	-0.077	-1.88	-0.369
140	0.461	0.614	1.519	1.019	1.522	-0.428
143	1.639	0.678	0.879	1.233	-1.344	-0.475
144	0.706	3.372	0.319	-0.69	2.888	-1.901
145	-0.556	0.981	1.207	-1.189	0.843	-0.436
149	-0.75	-0.731	0.787	-0.703	0.125	0.187
152	-0.231	1.066	1.671	1.283	1.406	-1.576
155	-0.564	2.056	1.034	2.684	0.84	-1.717
156	-1.114	-0.075	0.853	-0.128	0.018	-0.74
157	-1.331	0.276	1.148	0.476	0.406	-0.19
159	-1.818	1.634	5.083	-2.907	-0.414	0.83
160	-0.958	-0.805	0.94	-0.462	0.618	0.171
161	-0.591	-0.79	3.008	0.975	-1.055	-0.346
162	-0.591	-0.79	3.008	0.975	-1.055	-0.346
163	2.821	-0.697	1.732	-1.442	-0.608	0.334
169	-0.901	0.926	1.244	0.051	0.747	-0.899
172	2.484	0.467	0.891	-0.351	-0.107	-1.497
173	-0.465	1.063	0.579	0.863	1.685	-1.814
175	0.146	-0.409	0.043	0.111	0.628	-1.478
177	-1.106	-0.768	0.29	-0.691	0.265	0.125
183	-0.789	-0.391	0.561	0.029	0.043	-0.589
185	-0.683	-0.347	0.114	-0.144	0.072	-0.742
187	-0.832	1.031	0.654	-0.608	-0.918	0.412
188	-0.399	-0.669	-0.526	0.144	0.477	0.886
190	-1.363	-0.872	0.263	-0.487	0.54	-0.326
191	-0.624	0.637	-0.466	1.302	1.254	2.441
192	0.287	1.052	-0.567	-0.699	1.056	1.805
193	0.144	0.616	0.247	0.861	0.637	0.483
194	-0.752	1.585	1.316	-1.724	0.189	0.507
197	0.136	-1.785	-0.034	0.715	-0.547	-0.795
199	0.601	0.164	-0.839	-0.178	0.151	0.059
201	0.07	0.603	-0.503	-1.45	0.466	0.152
202	-0.261	0.083	-0.135	-0.828	-0.229	0
204	-0.805	-0.165	-0.134	-0.594	0.769	-0.442
205	-0.82	0.673	-0.825	-1.726	1.412	-0.411
207	-0.163	0.155	-0.877	-0.016	0.866	0.672
208	-0.152	0.685	-0.772	0.266	0.813	-0.329
209	-0.623	-0.75	-0.364	-0.095	-0.269	-0.954
210	0.859	0.823	-1.133	-0.505	-0.9	-0.439

211	0.381	1.274	-1.433	-0.293	0.261	0.655
213	-0.111	-1.06	-0.243	-0.292	0.118	-0.48
215	-0.79	0.528	-0.935	0.669	-0.313	0.568
216	0.902	0.959	-0.871	-0.782	1.285	-0.72
217	0.475	-0.474	-0.869	-0.445	0.885	-0.445
219	-0.748	-0.168	-0.214	-0.867	0.768	0.139
220	-0.666	-0.669	-0.839	0.34	0.061	0.868
221	-0.175	-1.052	-0.415	-0.477	0.95	-0.677
222	-0.795	-0.423	-0.123	-0.736	0.194	-1.026
223	-0.231	-1.055	-0.086	-0.363	0.926	-0.583
224	-1.453	1.035	-0.161	0.43	-0.109	-0.729
225	-0.484	-0.213	-0.571	-0.127	-0.309	-1.114
227	-0.926	0.737	-0.252	-1.029	0.157	0.193
228	-0.993	1.202	-0.268	-0.173	1.318	0.15
229	0.509	1.004	-0.945	-0.598	0.471	-0.236
232	0.268	0.047	-1.085	0.484	-0.426	-0.61
233	1.103	-0.741	-1.172	-0.09	0.347	0.043
234	-0.351	1.395	-1.323	-0.056	0.316	0.708
237	-0.269	-0.654	-0.216	-0.146	-0.327	0.678
238	-0.008	0.881	-0.407	-1.267	0.561	-1.037
239	-1.434	0.605	-0.554	0.041	0.409	0.294
240	-0.785	0.096	-0.553	-0.671	1.789	-0.503
242	-0.635	-0.028	-0.395	-0.437	1.347	-0.727
243	-0.518	-0.338	-0.236	0.098	-0.862	0.467
246	0.289	0.579	-0.211	-0.923	0.34	-0.557
247	0.303	0.631	-0.921	-0.551	0.097	0.027
248	-0.483	0.672	-0.297	-0.767	0.265	0.186
249	-0.192	0.832	-0.823	-0.279	-0.804	0.382
251	-0.667	-0.119	-0.262	-0.018	0.452	-0.828
255	0.348	-0.897	-0.171	0.178	-0.231	1.357
256	-0.298	1.568	-0.914	-0.234	0.275	0.447
258	-0.219	-0.146	-1.059	0.885	0.704	-0.214
263	-0.445	0.616	-0.33	0.066	-1.173	-0.054
266	0.281	-0.739	-0.268	-0.523	-0.05	-1.547
267	-0.631	-0.109	-0.254	0.186	0.746	-0.37
269	-0.343	-0.851	0.245	-0.32	1.462	-0.654
274	0.177	-0.783	0.167	-1.704	0.461	-0.81
275	-0.021	-0.617	-0.548	0.235	-0.043	-0.587
278	-1.081	-0.631	-0.341	-0.489	0.181	-0.861
280	-0.952	0.221	-0.229	-0.3	0.616	0.072
289	-0.113	0.675	-0.342	-1.689	0.064	0.37
296	-0.32	-0.507	-0.263	0.323	0.458	0.005
300	-0.312	-0.109	-0.792	-0.916	0.923	-0.027
304	-0.44	-0.401	-0.572	0.088	0.203	0.353
305	0.255	-0.104	-0.439	-1.686	0.421	0.873
317	-0.768	0.293	-0.658	-0.977	1.031	-0.272
322	0.376	-0.701	-0.133	-0.485	-0.8	-0.729
324	-1.748	0.323	-0.53	-0.163	0.082	1.91
331	-0.516	-1.267	-0.078	0.955	-0.693	0.861
332	-0.5	0.167	-0.558	-0.584	0.316	-0.455
334	-1.018	-0.194	-0.203	-0.997	0.838	-0.252

345	0.028	-1.22	0.031	0.949	-0.267	0.987
354	0.101	-0.545	-0.503	-0.921	1.048	0.516
360	-0.217	0.302	-0.473	0.602	-0.205	-0.105
362	-0.759	-0.097	-0.003	-0.685	-0.435	-0.33
364	0.772	0.179	-1.008	-0.685	2.031	-0.089
365	0.692	0.611	-0.728	-0.817	-1.441	0.396
368	-0.512	-0.873	-0.327	0.04	0.458	-0.695
378	0.806	1.522	-1.699	-1.209	0.176	2.194
379	-0.333	0.557	-0.564	-0.751	1.04	-0.164
382	0.754	-0.211	-0.595	-0.509	-0.179	-1.973
383	0.02	1.442	-0.863	-0.569	0.916	1.711
385	-0.611	-0.778	-0.483	-1.263	1.091	-1.028
386	0.966	-0.25	-0.129	-1.317	-0.464	-0.8
389	-0.856	1.302	-1.023	0.084	0.373	0.758
391	-0.236	0.357	0.143	-0.781	0.087	-1.061
392	0.725	0.553	-0.8	-0.369	0.615	-1.009
393	-0.464	0.269	-0.506	-1.076	0.391	0.388
394	0.678	-0.5	-0.53	-1.399	1.236	-0.126
395	-0.061	0.377	-0.434	-0.325	-0.8	0.824
397	-0.251	-0.545	-0.392	-1.031	0.921	-0.438
398	-0.755	1.009	-0.496	-0.367	-0.046	0.668
399	0.462	-0.003	-0.771	0.052	0.136	-0.994
400	-0.814	0.607	-0.855	0.331	0.16	0.684
401	-0.142	-0.965	-0.353	0.569	-0.709	-0.702
402	-0.632	-0.65	-0.385	-1.446	0.187	0.369
403	-0.771	-0.929	-0.56	0.066	0.538	-1.16
404	-0.157	-0.861	-0.135	-0.938	0.606	-0.76
405	1.664	0.478	-0.574	-1.351	-1.728	-0.395
407	-0.633	0.891	-0.407	-1.301	-0.926	0.716
409	-0.288	0.555	-0.494	-0.937	0.318	0.807
410	-0.551	0.118	-0.114	0.217	-0.825	0.812
411	-0.479	-1.762	-0.349	-0.552	0.652	-0.968
412	-0.034	-1.013	-0.198	-0.217	0.254	-0.197
413	-0.575	0.368	-0.323	-0.453	0.847	-0.743
414	-0.591	0.224	-0.269	-0.375	0.419	-0.775
415	-0.333	0.362	-0.596	-0.318	-0.608	-0.645
416	-1.477	0.036	-0.218	0.915	0.276	-0.537
417	-0.567	-1.544	-0.294	-0.363	-0.309	-0.702
418	-0.306	0.698	-0.394	-0.086	-1.259	0.564
419	-0.4	0.582	-1.012	-0.208	0.037	0.201
420	-1.077	0.09	0.057	-1.03	0.202	-0.234
423	0.152	0.171	-0.726	-0.384	-0.136	-0.26
424	-0.654	0.786	-0.923	-0.044	-0.294	0.373
425	-0.432	-0.597	-0.028	0.347	-0.059	0.395
426	-0.79	-0.445	-0.019	-0.401	0.183	0.101
427	-0.169	-1.852	-0.044	0.037	-0.024	1.742
428	-0.907	-1.204	-0.205	-0.181	-0.067	0.668
430	-0.67	-1.346	-0.214	-0.773	0.306	0.611
431	-0.451	0.324	-0.686	-0.093	-0.016	0.491
432	-0.294	-1.163	-0.535	0.746	0.961	0.037
433	-1.334	0.734	-0.303	-0.7	0.213	0.007

434	-0.381	-0.581	0.188	0.111	-0.441	-0.281
437	0.082	-0.847	-0.827	-0.038	0.153	-1.312
438	-0.944	-0.092	-0.848	-0.334	0.782	0.694
440	-0.857	0.17	-0.488	-0.936	0.288	0.674
441	0.084	0.18	-1.004	-0.444	-0.76	0.311
442	-0.838	-0.299	-0.029	-0.085	0.086	-0.8
443	-1.145	-0.495	-0.199	-0.399	-0.329	-0.213
444	-0.858	-1.326	-0.241	-0.31	0.109	-1.413
445	-0.816	-1.1	-0.681	-0.824	0.622	0.007
446	-1.018	-0.382	-0.418	0.371	0.648	-1.155
447	-0.742	-1.027	-0.179	-1.077	-0.071	0.558
448	-0.886	-0.932	-0.226	-0.891	0.177	0.033
449	-0.844	-0.94	-0.245	-0.759	0.601	-0.672
450	-0.758	-1.225	-0.193	-0.594	0.244	-0.956
451	-0.659	-1.245	-0.061	-0.111	-0.079	-0.91
453	-0.512	-0.491	-0.206	-0.905	0.11	-0.301
454	-0.815	-1.707	-0.38	-0.355	0.372	-0.799
455	-0.584	-1.366	-0.595	-0.34	0.493	-0.358
456	-0.884	-1.141	-0.088	-0.351	-0.111	0.206
457	-0.626	-0.688	-0.379	-0.894	0.512	-0.349
459	-0.826	-1.37	-0.195	-0.562	0.347	-0.911
460	-0.292	0.135	-0.924	-0.459	-0.588	0.359
461	-0.886	-0.847	-0.065	-0.173	0.221	-0.327
463	-0.816	-1.82	-0.533	-0.861	0.634	-0.197
464	-0.563	-0.26	-0.106	-1.63	0.7	-0.343
465	-0.746	-0.516	-0.395	-0.578	-0.056	-0.479
466	-0.862	-1.66	-0.096	-0.369	0.116	-0.851
467	-0.279	-1.437	-0.283	-1.455	0.373	-0.289
468	-0.456	-1.23	0.183	-1.312	0.028	-0.501
469	-0.843	-1.756	-0.549	-1.037	0.424	-0.771
470	-0.766	-0.71	-0.373	-0.655	0.106	-0.443
471	-0.595	-0.897	-0.222	0.236	-0.635	0.148
474	-0.586	-0.685	-0.535	0.106	0.419	-1.214
475	-0.736	-1.682	-0.297	-0.558	0.247	-0.344
476	-0.744	-1.55	-0.282	-0.665	0.287	-0.587
478	0.33	0.236	-1.058	1.826	-0.164	-2.791
479	-0.04	0.617	-0.166	-1.473	0.579	0.25
480	-0.197	-0.703	-0.72	-0.568	0.824	0.206
481	0.168	-0.842	-0.431	0.75	-0.634	-0.958
482	0.697	-0.148	-1.568	1.067	-0.509	-0.054
483	-0.652	-0.193	-0.252	0.571	-1.556	0.665
484	-0.354	-0.679	-0.066	-0.005	-0.62	0.7
485	0.315	-0.558	-1.115	-0.014	0.126	-0.192
486	0.432	-0.656	-0.45	-0.434	-0.046	1.622
487	0.07	-1.04	-0.761	-0.149	0.478	-0.142
488	-0.16	-1.004	-0.807	0.763	0.248	0.367
489	-0.767	-1.254	0.324	0.127	-0.267	0.909
490	-0.719	-1.025	0.052	-0.298	-0.09	0.8
491	-0.26	-0.744	-0.001	-1.522	0.088	0.304
492	-0.121	-0.987	0.284	0.228	-1.59	-0.15
493	-0.191	-0.979	-0.284	-0.061	-0.023	0.342

494	-0.698	-0.741	0.28	0.451	-1.845	1.53
495	-0.282	-1.248	-0.525	-0.459	0.096	0.624
496	-0.182	-1.558	-0.491	-0.326	0.037	-0.225
497	-0.434	-0.411	0.134	-0.872	-0.407	0.895
500	0.274	-0.583	-0.962	0.128	0.156	-0.215
501	-0.527	-0.835	0.393	-0.132	-1.059	-0.021
502	-0.107	-0.989	-0.594	-0.664	0.358	0.675
503	-0.155	-1.694	-0.584	-0.173	0.309	0.199
504	-0.288	-0.836	-0.645	-0.182	0.078	-0.529
505	-0.506	-1.033	-0.451	0.309	0.379	-0.483
506	-0.92	-1.141	0.082	-0.113	-0.377	0.4
509	0.255	-1.158	-0.651	0.24	0.063	0.1
510	-0.35	-1.033	-0.568	0.361	0.48	0.043
511	-0.824	-0.389	0.361	0.34	-1.968	0.299
512	-0.238	-1.428	0.062	0.046	-0.67	0.21
514	-0.39	-1.087	0.524	-0.06	-1.986	0.585
515	-0.325	-0.037	-0.122	-0.364	-1.613	0.535
516	-0.119	-0.718	-0.385	-0.659	-0.185	-0.387
517	-0.636	-0.649	-0.189	0.546	-0.62	0.726
518	-0.453	-0.953	-0.543	-0.022	0.002	0.191
519	-0.412	0.332	0.206	-0.552	-1.484	1.14
521	-0.356	-0.236	-0.356	-0.485	-0.457	0.011
522	-0.02	-0.617	-0.191	-1.245	0.243	0.838
523	-0.73	-1.634	-0.351	-0.387	0.984	-0.341
525	-0.927	-0.975	0.165	0.373	-0.435	0.819
526	-0.308	-1.415	-0.546	0.291	0.513	-0.731
527	-0.119	-1.201	-0.097	-0.967	0.018	0.072
528	-0.065	-0.702	0.157	-0.911	-1.06	1.343
529	-0.77	-1.219	-0.171	-0.033	-0.216	0.111
530	-0.515	-0.508	0.081	1.146	-0.678	0.817
531	-0.254	-1.006	0.555	-0.063	-0.131	1.01
536	-0.776	-0.733	0.854	1.52	-2.064	1.062
537	-0.655	-1.033	1.141	0.501	-1.416	1.791
539	-0.389	-0.057	0.966	-1.154	-1.307	1.534
540	0.471	-0.519	-0.522	0.035	-1.284	2.497
541	-0.823	-0.489	0.721	0.662	-1.396	1.911
542	0.319	-0.661	0.884	-0.983	-1.673	1.094
545	-0.289	-0.462	-0.91	1.491	0.309	0.278
546	-0.494	-0.971	0.622	1.378	-0.61	1.071
548	-0.345	0.493	-0.284	-0.571	0.045	0.87
550	-0.155	-0.667	0.166	-0.521	-0.638	1.58
551	-0.836	-0.67	0.437	1.452	-1.302	0.937
552	0.326	-1.097	-0.724	-0.164	0.054	1.223
553	-0.174	-1.437	0.151	0.366	-0.176	0.241
556	-0.494	-0.206	0.213	0.487	-0.552	0.781
557	0.513	-0.486	-0.3	-0.185	-0.703	1.457
563	-0.914	-0.653	0.35	-0.111	-0.895	0.058
564	-0.511	-0.79	-0.404	-0.284	0.418	-0.542
566	0.089	-0.772	-0.544	-0.464	-0.654	-0.396
567	0.071	-0.222	-0.922	0.179	0.011	0.098
568	-0.486	-0.264	0.176	-1.449	-0.24	0.764

569	-0.773	-0.274	0.722	-0.305	-1.121	-0.052
570	0.047	0.07	0.399	0.577	-1.745	0.191
572	-0.898	-1.602	0.03	-0.771	0.637	-0.171
573	-0.368	-1.517	-0.189	-0.606	0.106	-0.952
576	-0.138	-1.08	-0.298	-0.699	-0.98	-0.083
577	0.787	-0.747	-1.242	-0.657	1.098	0.223
578	0.68	0.791	-0.025	-1.265	-1.994	1.552
579	0.356	-0.879	-0.936	0.541	-0.758	-1.009
580	-0.101	-0.488	-0.476	-0.35	-0.013	-0.899
581	0.212	-1.752	-1.018	0.334	0.132	-0.466
583	-0.854	-1.313	-0.088	-0.973	0.37	0.399
584	-0.858	-1.549	-0.086	-0.254	-0.14	0.123
585	-0.987	-1.157	-0.249	-0.391	0.593	0.285
586	-0.127	-1.177	-0.805	-0.675	0.659	-0.125
587	-0.25	-1.508	-0.287	0.043	-0.586	-0.38
588	0.215	-0.94	-0.526	-0.926	0.179	-0.723
589	-0.841	-0.979	0.381	-0.005	-0.728	-0.306
591	-0.11	-1.013	-0.116	-0.442	0.315	-0.165
593	-0.333	-1.032	-0.498	0.341	0.489	-0.068
594	0.714	-1.079	-0.619	-0.381	-0.167	-0.142
596	0.195	-1.436	0.121	-1.091	-0.282	-0.55
597	-0.063	-0.965	-1.242	-0.118	0.29	-0.753
598	-0.299	-0.809	-0.429	-0.413	0.098	-0.64
601	-0.538	-1.97	-0.66	0.257	0.08	-0.867
603	-0.437	-1.677	-0.286	-0.045	0.449	-0.034
605	-0.629	-1.585	-0.402	-0.019	0.705	-0.251
607	0.404	-1.245	-0.194	-1.776	0.156	-0.857
609	0.274	-0.794	-1.325	-0.308	1.041	0.384
614	-0.045	-0.725	-0.302	-1.056	-0.125	0.93
617	-0.833	-1.646	-0.202	-0.642	0.301	-0.561
618	-0.477	-1.039	0.355	0.837	-0.028	-1.26
619	-0.226	-1.137	-0.298	-0.475	0.171	-0.461
624	-0.404	-1.149	-0.364	1.375	0.111	-0.301
625	0.057	-1.501	-0.258	-0.277	-0.385	0.828
626	0.375	-1.895	-0.953	0.671	0.719	0.128
628	-1.019	-1.043	-0.382	-0.581	0.57	-0.277
629	-0.484	-0.812	-0.443	-0.551	-0.202	0.065
630	-1.183	1.764	0.325	0.524	0.652	-1.091
631	0.202	1.443	0.429	1.57	0.187	-0.379
632	1.092	2.473	0.343	-1.15	2.043	-1.032
636	0.724	-0.141	1.041	0.3	1.438	1.416
641	-1.17	1.731	1.671	0.982	-0.523	-0.975
642	-1.194	0.2	1.643	1.023	-0.955	0.579
644	0.727	0.923	0.895	0.04	0.541	-1.305
646	-0.092	0.648	1.237	0.166	1.557	-0.299
648	1.553	0.456	1.521	0.305	-1.331	-0.322
649	1.259	1.984	0.949	-1.614	0.308	-2.418
650	1.686	0.545	0.897	1.975	-2.568	3.298
651	-1.663	1.033	1.174	0.454	0.084	-0.225
652	-0.998	-0.066	1.859	-0.054	-0.078	1.369
654	0.688	0.545	0.58	0.415	1.008	0.286

655	-0.66	3.064	0.833	-1.139	0.623	-0.08
656	1.026	-0.423	1.354	1.553	-2.237	-0.151
657	-1.351	2.779	1.795	0.812	0.687	-1.399
662	1.57	1.219	-1.279	-0.383	-1.172	-0.02
663	-0.582	1.166	0.394	-0.703	-2.012	1.082
665	-0.853	1.047	0.256	-0.397	-1.447	0.213
666	-0.242	-0.047	-0.115	0.422	0.61	-0.618
669	-0.117	-0.142	-1.253	1.148	0.341	0.299
671	-0.928	2.131	0.047	0.849	-1.683	-0.161
672	0.113	0.864	-1.021	1.612	-0.129	0.638
674	-1.291	-0.227	0.144	0.072	0.015	0.283
676	-1.08	-0.105	-0.326	-0.498	-0.362	-0.113
677	0.181	-0.403	-0.478	2.308	-2.072	-0.718
682	3.21	0.324	-0.987	-1.461	-2.254	-1.594
683	0.017	-0.316	2.487	0.156	-1.469	0.302
686	0.409	-0.509	-0.024	1.215	-0.504	-1.072
688	0.857	1.633	-1.173	-0.278	-0.322	0.433
690	-0.844	1.458	0.408	0.601	-1.682	-0.452
692	2.284	0.537	-1.57	-0.727	1.478	-0.658
693	-0.571	-0.193	-0.575	0.887	0.423	-0.573
695	-1.05	-0.939	0.879	-0.24	0.719	1.77
697	-0.555	-0.721	0.068	0.3	-1.344	-0.284
701	-1.045	-0.685	0.06	0.824	1.237	-0.422
702	-0.668	-0.957	0.135	-0.21	-0.397	0.184
704	-1.069	-0.454	2.184	-0.523	0.042	0.238
705	0.356	1.052	2.124	0.531	1.295	0.441
708	0.999	-0.088	1.417	-0.985	1.37	1.452
709	0.854	0.628	-1.094	-0.442	-1.741	-0.318
711	0.273	1.459	-1.214	-0.731	-1.088	0.5
713	1.177	0.197	1.394	0.365	0.085	1.225
714	1.072	0.875	-1.926	0.689	-1.507	0.613
718	-0.018	-0.517	-0.491	0.888	-0.752	-0.858
719	-0.583	-0.487	-0.369	0.535	-0.306	-0.781
720	-0.758	-0.651	0.279	-0.459	0.492	0.105
723	0.923	-0.626	-0.388	-0.69	-0.45	-0.775
727	0.753	-0.11	-0.846	-1.417	-1.081	-0.428
729	-1.081	-0.916	-0.247	-0.835	0.649	-0.23
732	2.189	1.7	-0.925	-2.911	0.463	-0.165
733	0.568	0.081	-0.393	-0.721	0.442	-0.902
735	0.894	0.833	-1.213	0.816	-0.742	-0.535
736	0.5	0.226	-1.157	1.743	-1.133	-1.195
738	0.985	0.252	-0.836	0.615	-0.793	-1.856
739	0.931	1.143	-0.319	0.563	0.097	-2.291
740	1.765	-0.122	-0.853	0.557	-2.324	-1.735
741	-0.427	-0.053	-0.562	-0.075	-0.234	-0.625
742	-0.019	0.162	-0.392	0.886	0.66	-0.739
744	-0.682	0.562	-0.714	1.265	1.034	-0.617
745	0.126	0.15	0.196	0.848	0.776	-0.312
746	-0.064	1.153	0.016	0.927	-1.943	-0.965
747	0.398	0.102	-0.552	0.963	-0.323	0.232
748	-0.549	1.319	0.55	0.067	0.808	-0.98

749	0.283	1.539	-1.048	1.343	-0.693	-0.995
750	0.853	0.677	-0.745	1.051	-0.491	-1.461
755	1.208	1.357	1.216	0.342	2.516	-0.122
758	0.267	0.687	-0.882	1.437	-0.46	1.431
759	-0.181	2.855	-0.669	0.445	-1.957	0.559
760	0.073	0.187	-0.038	0.004	-1.437	0.17
761	0.759	1.293	-1.306	0.776	-0.465	0.051
762	0.763	0.752	-1.324	0.639	1.191	-0.589
764	-0.385	1.769	-0.49	-0.004	-0.674	0.918
767	-0.012	0.192	-0.197	0.747	-1.273	-0.431
769	0.503	1.645	-0.646	-0.7	0.365	0.15
770	1.614	1.097	-1.728	0.768	0.156	-0.126
771	1.757	0.24	-0.989	-1.009	-1.877	-0.351
773	-1.533	2.384	0.223	-1.181	-0.786	1.998
775	0.253	1.194	-1.407	0.498	0.355	0.024
776	-0.315	1.831	-0.927	0.585	-0.145	0.833
778	-1.068	1.088	0.4	0.092	0.591	0.165
779	0.652	0.746	-0.753	0.215	-1.204	-0.011
781	0.261	0.193	-0.827	1.392	2.481	-0.853
783	0.229	0.335	-0.158	0.02	0.205	0.647
785	0.011	0.051	-0.288	-0.294	-0.445	-1.058
788	-0.943	-0.572	0.211	-0.161	-0.26	-0.254
790	-0.749	2.811	-0.566	1.678	-0.761	-0.816
791	-0.958	0.512	-0.552	1.178	1.53	0.189
792	-0.933	-0.496	-0.001	1.957	-0.793	1.021
794	-0.461	1.173	-0.736	1.212	-0.371	-1.591
795	0.886	1.132	-1.359	-0.233	-0.599	0.78
796	0.211	0.746	-1.094	0.608	0.788	-0.622
800	-1.048	0.624	-0.803	0.997	0.771	-0.359
801	0.408	1.4	-0.689	0.473	-0.743	-1.298
802	-1.236	-0.007	1.146	0.414	-1.534	0.064
807	-1.698	0.652	0.62	0.407	0.265	-0.53
808	-0.924	0.959	-0.772	0.285	1.007	1.339
810	-0.48	0.77	-0.521	0.478	-1.086	-0.592
812	0.219	1.096	-1.114	0.042	0.109	-0.584
813	-0.249	1.343	-0.557	1.517	-1.159	-1.77
817	0.566	0.949	-0.418	-0.337	-1.892	-0.445
819	0.888	0.948	-0.791	-0.288	-0.034	-1.07
821	-0.254	0.329	0.148	-0.44	-0.997	-0.287
822	2.054	0.023	-1.026	-0.299	-1.131	-1.581
825	2.201	0.621	-1.117	-1.889	-0.101	-0.956
826	1.143	-0.123	-0.615	0.602	-0.039	-0.105
828	0.309	0.541	-0.323	1.623	-2.426	-1.152
831	-0.818	0.226	-0.219	-0.19	-0.488	-0.16
834	0.159	0.3	0.247	2.182	-1.302	-2.857
835	0.04	0.752	-0.405	0.436	-1.371	-0.457
837	-1.229	-1.551	0.241	1.01	-0.283	0.733
838	-0.859	-0.247	-0.521	0.956	0.15	-0.555
839	-0.925	-1.199	-0.151	0.265	0.703	-0.593
841	0.571	0.467	-0.504	0.233	-0.844	-1.441
842	-0.819	-0.221	0.425	-0.346	-0.063	-0.214

843	-0.2	0.668	-0.169	-0.228	-1.368	0.324
846	1.027	0.622	-0.541	-0.849	-2.03	-0.558
847	0.398	3.099	3.065	-1.813	-2.45	-2.613
848	0.231	1.487	0.087	-1.903	-1.103	0.035
849	-0.344	-0.95	-0.005	1.015	-0.448	-2.13
850	-0.321	1.328	-0.624	-0.016	1.647	-1.103
853	1.566	0.58	-1.481	-0.099	-0.696	0.036
854	0.487	0.381	-0.16	-0.093	-1.525	0.457
855	0.065	0.892	-0.233	0.529	-0.948	-1.399
856	-0.982	0.343	-0.282	0.029	0.379	-0.382
857	-0.21	0.104	0.489	-1.351	-0.591	-0.055
858	0.142	-0.974	0.157	0.144	-1.421	0.286
859	-0.1	-0.354	-0.329	0.23	0.511	0.405
860	-0.927	-0.137	-0.303	-0.208	-0.104	0.069
861	-0.464	-1.154	0.301	-0.979	-0.479	0.093
863	0.597	-0.146	-0.711	1.864	-0.8	-0.183
864	-0.25	-0.217	-0.288	1.733	-1.06	-0.174
865	0.676	0.506	-0.841	-0.461	0.477	0.327
866	0.954	1.327	-0.045	0.419	-2.871	-0.909
867	-0.237	0.706	0.164	1.033	-2.655	-0.563
868	-0.518	-0.369	0.378	-1.039	0.476	-0.427
869	-0.214	0.379	-0.878	2.815	0.899	0.147
871	-1.022	-0.418	0.256	0.233	-0.963	0.326
872	-1.062	2.286	1.507	-0.605	0.916	0.045
873	0.757	0.912	-1.705	0.704	2.368	-0.003
874	-0.703	-0.58	-0.681	-0.07	1.042	-0.211
875	1.064	0.011	-0.486	0.593	-1.437	-1.353
877	-0.75	3.882	1.426	-1.233	0.245	-1.299
879	-0.383	1.522	0.611	-0.411	-0.692	-0.667
880	0.504	1.795	1.057	0.333	0.271	-0.49
881	0.07	-0.128	0.199	-0.194	-1.909	1.46
883	0.688	1.566	-0.911	0.494	0.053	0.214
884	0.405	0.303	-1.234	0.737	-1.48	0.482
885	-0.691	0.85	-0.515	2.309	-0.753	-1.688
886	0.465	0.554	-0.483	0.557	-0.705	-0.97
888	-0.296	0.563	0.123	0.226	-0.769	0.226
889	-0.351	1.966	-1.08	1.229	-0.162	0.791
890	-0.313	0.618	-0.795	1.834	-1.027	-0.192
891	-1.142	1.088	-0.395	1.051	1.02	0.958
892	0.764	0.564	-0.572	0.349	-0.756	0.505
894	-3.179	2.882	3.052	1.657	-2.707	-0.448
895	1.243	-0.22	2.115	0.402	-0.473	1.839
896	0.741	1.73	1.469	-0.267	2.756	-1.053
897	-3.385	2.804	1.778	6.045	-0.197	1.641
900	-0.552	1.27	1.65	-0.361	0.14	-1.605
902	3.962	-0.711	0.178	0.062	0.425	0.888
903	-0.233	0.7	1.29	1.29	2.557	1.092
904	2.169	-0.329	0.073	1.284	2.182	0.574
907	4.048	-0.86	-0.108	1.785	2.458	0.249
908	0.682	0.669	0.23	0.882	2.472	1.793
909	1.056	0.565	-0.548	2.037	0.4	0.967

910	0.394	-1.081	1.563	0.329	1.707	0.179
911	-0.105	-0.636	0.5	-0.157	1.995	0.819
912	0.212	1.919	2.07	-0.932	1.079	-1.691
913	0.663	-0.469	0.451	0.41	1.521	2.324
915	1.583	0.032	0.342	0.998	1.25	0.935
916	0.516	0.448	1.157	0.425	-0.731	-0.514
917	1.01	0.147	1.318	-0.277	0.733	-1.107
918	0.618	0.036	0.16	1.178	2.173	-0.804
920	0.758	-0.595	0.009	1.616	-0.324	0.538
921	0.282	0.257	0.896	0.166	0.577	-2.078
922	2.925	-1.48	0.614	0.591	0.518	1.434
923	0.428	-0.582	0.94	0.61	3.098	0.909
924	0.98	-0.969	0.3	1.189	1.43	0.753
925	-0.527	0.323	1.342	0.22	1.603	-0.145
926	-0.21	0.455	0.754	0.229	2.422	1.372
927	1.8	-0.445	1.998	-2.181	-0.429	0.532
928	1.488	-0.174	2.06	0.284	1.121	2.578
929	3.533	-1.167	1.517	1.63	0.651	0.327
934	1.077	0.734	0.195	1.565	1.953	-0.588
935	1.253	2.437	0.593	-1.521	1.009	-1.758
937	1.837	0.072	0.578	0.456	1.964	0.302
940	0.837	0.442	0.789	-0.76	0.601	-0.22
941	0.419	-0.438	1.055	0.13	-0.303	-0.866
942	0.023	-1.01	0.904	-0.539	0.038	1.897
943	3.306	0.75	0.641	-2.136	-0.978	0.797
944	1.945	0.073	0.745	-0.89	1.121	3.741
945	3.017	-0.902	2.167	-0.389	-0.282	0.87
946	2.606	-0.627	0.318	1.721	-0.521	-0.102
947	0.916	-0.788	1.549	0.66	0.576	0.082
949	2.067	-0.046	0.929	0.468	0.187	-0.359
950	2.351	-0.099	0.391	0.462	0.425	-0.063
951	0.904	-0.298	1.505	-0.891	-0.028	1.354
952	0.404	-0.469	1.271	-0.327	0.794	0.556
953	0.225	0.601	1.258	0.204	2.417	-0.561
954	0.831	-0.716	1.013	1.266	-0.929	-0.406
955	2.389	0.254	1.07	-0.895	-0.355	-0.727
956	0.557	-0.729	1.273	-0.237	-0.408	-0.3
957	1.656	-0.261	0.486	1.644	0.705	-0.676
958	3.907	-1.988	0.949	1.803	-2.041	-0.476
960	2.685	-0.125	0.512	0.139	2.065	0.7
961	3.16	-1.864	1.36	0.712	-0.302	1.742
962	0.081	1.766	0.954	0.093	2.544	-0.589
963	4.153	-1.146	1.811	-1.365	-1.002	0.686
964	2.559	-1.018	0.367	1.278	2.239	1.58
965	3.183	-0.003	0.298	1.192	2.628	0.861
966	2.458	-1.645	1.288	1.268	-0.177	3.519
967	2.616	-0.382	1.545	-0.469	0.368	0.869
968	2.63	-1.61	1.01	2.034	0.818	-0.508
969	1.544	-0.426	1.225	1.949	1.169	0.927
970	2.151	0.339	1.234	-0.762	0.975	-0.495
972	1.133	-1.407	1.931	1.865	0.932	2.77

973	2.278	-0.564	1.049	-0.834	1.111	0.599
974	1.112	-0.133	0.133	-0.491	2.141	0.597
975	-0.178	0.413	1.061	2.367	0.109	2.108
977	0.922	-0.005	0.026	0.507	-1.415	-2.33
979	-0.367	-0.85	1.352	1.164	-0.25	0.935
981	-1.335	1.534	2.173	1.569	-2.247	1.364
982	-1.882	2.227	1.129	2.953	0.701	3.46
983	-0.104	2.684	0.308	0.593	1.586	0.284
984	0.681	-0.302	-0.531	-0.589	-1.472	-0.095
986	0.66	1.196	-1.026	-0.513	-0.227	0.414
989	0.186	-0.445	-0.796	0.912	-0.592	-0.44
991	-0.933	-0.377	-0.052	0.93	-1.478	0.19
992	0.113	0.23	-0.421	-0.987	-2.074	-0.273
996	-0.573	-0.584	-0.08	0.916	-1.423	-0.534
997	-0.43	-0.345	-0.199	-0.963	-0.584	-0.529
999	-0.023	-1.372	-0.187	0.027	-0.256	-0.402
1000	-0.763	-0.623	-0.314	-0.578	-0.519	1.527
1001	-0.706	-0.878	0.116	-0.373	-1.054	-1.003
1004	-0.866	-1.005	-0.149	-0.691	-0.205	0.089
1005	0.358	-0.821	0.117	0.829	-1.215	0.274
1006	0.166	0.267	-1.452	0.568	0.245	-0.756
1007	-0.451	-0.043	-0.769	-0.389	-0.165	0.736
1008	-0.304	2.412	-0.801	-1.807	-0.532	3.76
1009	-0.269	-0.167	-0.049	1.716	-1.416	-0.827
1010	-0.457	-1.288	-0.176	-1.003	0.355	0.371
1011	-0.766	2.044	-0.698	-1.191	-0.616	1.954
1012	0.223	0.841	-1.189	-1.465	-0.724	2.479
1013	-1.069	-1.374	-0.271	-0.144	0.571	-0.126
1016	0.835	1.024	-0.728	-1.378	-1.516	1.289
1017	0.218	-0.022	-0.064	-0.608	-0.611	-0.524
1019	0.45	0.585	-1.181	-0.219	0.481	0.374
1021	-1.158	0.303	-0.493	0.309	-0.004	1.321
1022	-0.278	1.027	-0.009	-0.088	-0.67	0.054
1023	-0.231	-0.063	-0.408	0.167	0.113	-0.145
1026	0.388	0.156	0.552	-0.676	-0.345	-0.225
1027	-0.344	0.212	0.307	-0.749	-1.109	1.446
1028	-0.552	-0.849	-0.243	-0.911	0.155	-0.23
1030	0.414	3.207	-1.397	-1.816	-1.132	3.334
1031	0.125	0.463	-0.725	-1.043	1.16	0.598
1033	0.05	1.338	-0.944	0.151	-0.819	1.02
1034	-0.39	1.424	-0.713	-0.822	0.184	2.817
1037	0.492	1.922	-1.62	0.834	0.6	0.046
1038	0.272	1.64	-1.251	-0.181	-0.015	1.298
1039	-0.219	1.971	-0.915	-1.282	0.547	2.401
1040	-0.688	0.001	-0.528	-0.695	-0.523	0.039
1041	-0.054	0.648	0.011	-0.118	-0.528	0.161
1042	0.169	1.336	-1.363	-0.249	0.212	1.501
1043	0.282	1.922	-1.254	-1.378	0.63	1.453
1044	-0.797	1.38	-1.367	0.201	1.083	1.171
1048	0.475	-0.406	0.009	-0.766	-1.177	-0.993
1049	-0.308	0.915	-0.678	0.073	-1.221	0.592

1051	-0.408	0.229	-0.224	-0.116	-0.801	-0.091
1053	-0.943	-1.036	-0.582	-0.519	0.178	0.037
1054	-0.885	1.373	-0.57	-0.72	-0.484	1.837
1057	-0.214	-0.14	-1.098	-0.478	0.986	0.102
1058	-1.182	0.252	-0.113	-1.63	0.391	1.567
1059	-0.155	0.187	-0.744	-0.761	-0.772	0.957
1060	-0.179	-0.658	-0.219	-0.24	0.856	-0.724
1061	-1.488	0.975	-0.795	0.297	-0.449	0.822
1062	0.936	-0.062	0.595	-1.588	-0.252	-1.124
1064	-0.411	0.743	-0.274	-0.87	0.27	0.682
1065	0.433	0.52	-0.622	-1.262	1.342	-0.069
1067	-0.086	-0.106	-0.294	-1.612	1.65	0.512
1069	-0.477	-0.321	-0.317	0.325	0.138	-0.742
1072	-0.307	0.74	-0.254	0.04	0.025	1.322
1075	-0.235	-0.27	-0.316	-0.104	0.109	-0.819
1076	-0.129	-0.617	-0.376	-0.016	0.322	-0.137
1077	-0.579	-1.089	-0.182	0.027	0.814	0.169
1078	0.12	-1.04	0.104	0.613	-0.613	-0.589
1079	-0.744	1.041	0.093	-0.669	-0.46	0.046
1081	-1.234	-0.105	0.021	-0.204	-0.506	0.124
1082	-0.493	1.007	0.176	-1.104	-0.351	1.592
1084	-0.83	0.386	-0.305	-0.45	1.625	-0.523
1088	-0.562	0.71	-0.638	-0.106	1.131	-0.604
1090	0.525	-0.379	-0.479	0.572	-0.03	-0.557
1094	-0.219	1.127	-0.362	-0.377	0.951	-1.043
1095	-0.764	1.062	-0.469	-0.939	0.436	2.535

APPENDIX F

Code for Bootstrapping Program (written in VBA for Microsoft Excel)

```
'Begin procedures

Sub Bootstrap()

  Counter = N
  For N = 1 To 10,000

      Sample
      Average (N)


  Next

End Sub

Sub Sample()

'Sample first population

   Application.Run "ATPVBAEN.XLA!Sample", ActiveSheet.Range("$A$1:$A$17"), _
   ActiveSheet.Range("$B$1"), "R", 15, False

'Sample second population

   Application.Run "ATPVBAEN.XLA!Sample", ActiveSheet.Range("$A$1:$A$17"), _
   ActiveSheet.Range("$C$1"), "R", 2, False


End Sub



Sub Average(N)

 'Average the population of samples

      Cells(N, 4).Select
      ActiveCell.Value = "=AVERAGE(R1C2:R15C2)"

      ActiveCell.Copy
      Selection.PasteSpecial Paste:=xlValues, Operation:=xlNone, SkipBlanks:= _
```

```
        False, Transpose:=False

    'Average second population

        Cells(N, 5).Select
        ActiveCell.Value = "=AVERAGE(R1C3:R2C3)"
        ActiveCell.Copy
        Selection.PasteSpecial Paste:=xlValues, Operation:=xlNone, SkipBlanks:= _
        False, Transpose:=False
        Range("$C$1").Select

        ClearDown
        ActiveCell.Offset(0, -1).Range("A1").Select
        Selection.End(xlUp).Select

        ClearDown


End Sub


Sub Move()

Counter = K
For K = 1 To 5
Application.Run "ATPVBAEN.XLA!Sample", ActiveSheet.Range("$A$1:$A$17"), _
ActiveSheet.Range(1, 2), "R", 15, False
Range(Cells(20, 2)).Formula = Range(Cells(1, 2)).Formula
Next

End Sub

Sub ClearDown()

    Do Until ActiveCell = ""
        ActiveCell = ""
        ActiveCell.Offset(1, 0).Range("A1").Select

    Loop
        Selection.End(xlUp).Select

End Sub
```

APPENDIX G

Bootstrapping Results and Bonferroni Inequality

The results (below) were generated by the computer code given in Appendix F. The procedure was conducted on the first four principal components of all 17 specimens. Principal component four yield significant results at the $\alpha = .05$ level (see discussion below.)

Additional bootstrapping tests (not shown) using Hotelling's T^2 statistic (Johnson and Wichern, 1988) yielded significant differences for 3 principal components tested simultaneously (2, 3, and 4).

<u>Bonferroni Inequality</u>

Since an increasing possibility exists that a *true* null hypothesis will be rejected as more null hypotheses are tested, the Bonferroni Inequality in probability (Dunn, 1964) was employed. Formally stated, "if we test each of "c" null hypotheses at level α/c, then assuming all the null hypotheses are true, the probability of falsely rejecting at least one hypothesis will be at most α." In other words, to maintain our overall rejection level at $\alpha = .05$, the rejection level of each individual test must be lowered in proportion to the number of tests employed. Since 4 null hypotheses were tested, dividing the rejection level $\alpha = .05$ by 4 yields $\alpha = .0125$ for each of the tests. The actual *p*-value of .0068 falls within this adjusted rejection region.

<u>Results</u>

Bin	Frequency
0.0259	339
0.0517	301
0.0775	328
0.1033	309
0.1291	327
0.1549	310
0.1807	309
0.2065	288
0.2323	335
0.2581	310
0.2839	312
0.3097	261
0.3355	289
0.3613	260
0.3871	280
0.4129	261
0.4389	278
0.4645	232
0.4903	232
0.5161	246
0.5419	220
0.5677	205
0.5935	210
0.6193	197
0.6451	211
0.6709	184
0.6967	173
0.7225	164
0.7483	176
0.7741	135
0.7999	145
0.8257	133
0.8515	111
0.8773	114
0.9031	116
0.9289	115
0.9547	100
0.9805	86
1.006	89
1.032	68
0.0579	83
1.0838	89
1.1096	72
1.1353	70
1.1612	71
1.187	70
1.2128	51
1.2386	59
1.2644	62

1.2902	61
1.316	40
1.3418	58
1.3676	41
1.3934	43
1.4192	33
1.445	31
1.4708	31
1.4966	39
1.5224	29
1.5482	20
1.574	19
1.5998	18
1.6256	19
1.6514	17
1.6772	16
1.703	12
1.7288	8
1.7546	9
1.7804	7
1.8062	8
1.832	5
1.8578	4
1.8836	4
1.9094	2
1.9352	4
10961	6
1.9868	1
2.0126	0
2.0384	1
2.0642	7
2.09	1
2.1158	2
2.1416	2
2.1674	1
2.1932	1
2.219	2
2.2448	3
2.2706	1
2.2964	1
2.322	0
2.348	0
2.3738	1
2.3997	1
2.4255	1
2.4512	0
2.4771	1
2.5029	0
2.5287	1
2.5545	0