Columnar Display of Multiple Attributes of Linear Features Using ArcGIS

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Abstract.
Columnar display of linear referenced data portrays dozens of attributes of linear features simultaneously, visually, and interactively. In this genome-like display, each attribute is a layer of an ArcMap data frame. Location is in traditional geographic space and as distance along a measured route created with ArcINFO dynamic segmentation. The resulting display is familiar to investigators accustomed to stratigraphic columns, core logs, or correlation charts. Columnar display was used to visualize diverse data sets and suggest causal relationships among 20 mapped attributes of a shoreline of Antelope Island in Great Salt Lake. ArcGIS 3-D Analyst was used to communicate results.

Key words.
Linear referencing, columnar display, geomorphology, coastal zone management, visualization.

Introduction.
The purpose of this paper is to describe a GIS technique, columnar display, for visualizing dozens, even hundreds, of attributes of a linear feature interactively using ArcGIS. An example of its application to shoreline research is presented in order to show its utility. Shorelines are very complex features with many factors needed to describe them, such as morphology, materials, process, stratigraphy, and geographic setting. Columnar display is a technique for shoreline GIS analysis because it extends a researcher's or manager's capability to view abundant, diverse data simultaneously and interactively in a discipline where GIS is already a well-established management tool (Wright and Bartlett, 2000; Atwood and Cova, 2000). Columnar display allows an investigator to visualize and explore relationships among diverse data types if the data have been referenced to location along the route of a linear-referenced feature. Columnar display's applicability may not be limited to shorezones. The technique can be used to visualize diverse data along a variety of linear features, e.g., faultlines, core logs, political boundaries, highways, and streams. Columnar display may be an effective way to communicate to people who think about their world linearly, readily visualizing events along paths rather than in geographic or 3-dimensional space.

Many researchers and managers face the problem of organizing, viewing and analyzing

multiple variables and abundant data. For purposes of illustration, this paper will describe in detail why and how columnar display was used in research on shore processes of Great Salt Lake, explain the components of a columnar display, describe steps used to create a columnar display, and compare reactions to columnar displays versus five more traditional approaches to visualizing attribute data.

Example: Great Salt Lake shorelines on Antelope Island

Figure 1 presents data values for 20 attributes of a 64 km shoreline of Antelope Island, Great Salt Lake, Utah. The dataframes to the left and right of the map of Antelope Island are columnar displays. Figure 2 is a detail of Figure 1 shown as a computer-screen snapshot. It will be discussed later in detail. Figure 3 is a location map of Antelope Island in Great Salt Lake.

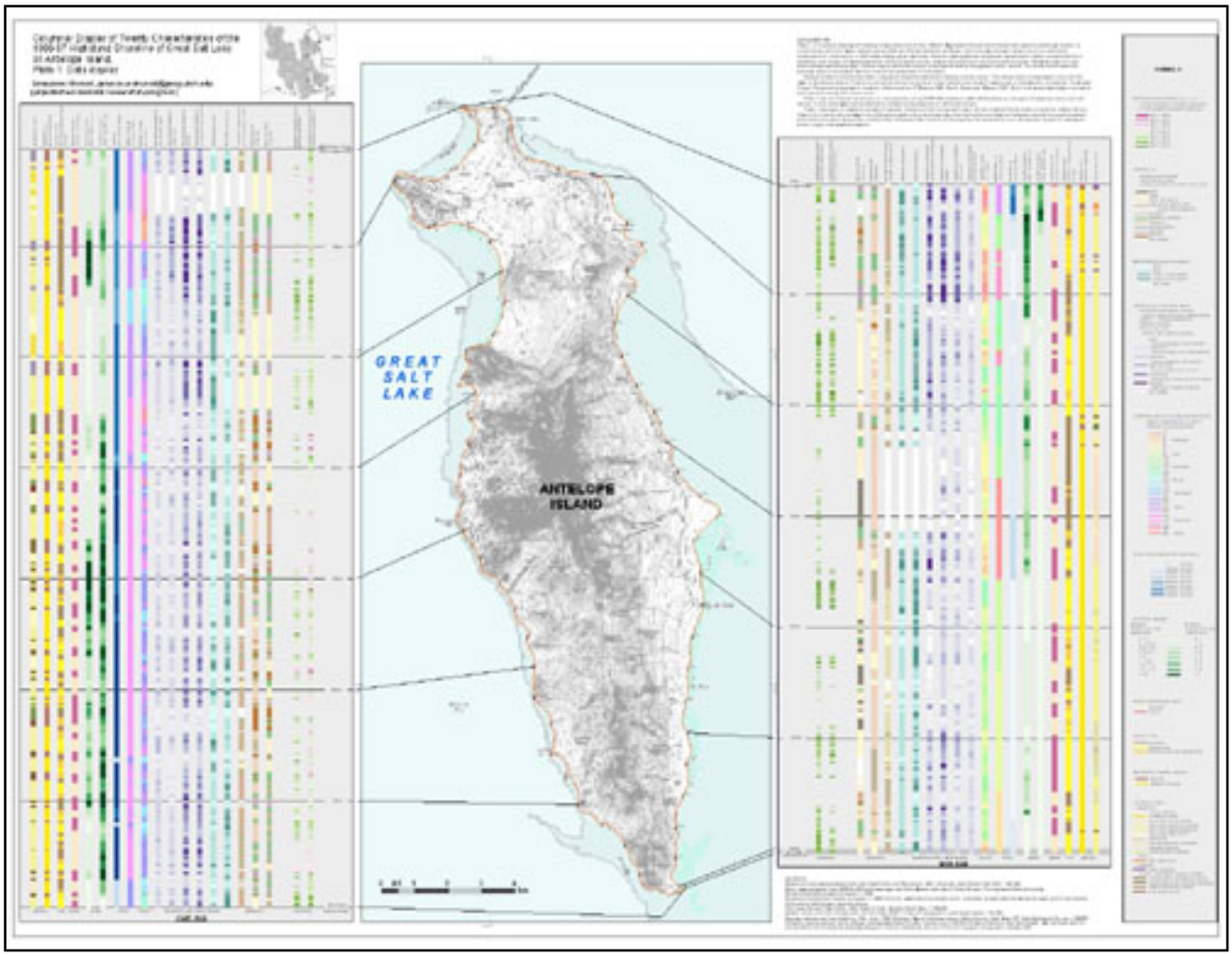


Figure 1. Presentation of data using columnar displays. Dataframes to the left and right of the map of Antelope Island show data collected for 20 attributes along the island's 1986-87 shoreline. The layout order of display columns for the east-side columnar display mirrors the layout order for columns of the west side. Location is referenced to distance

along the 64-km shore-route. The shore-route is shown in red on the map of Antelope Island. Any place along the shore-route is located in two spatial systems: geographic coordinates, and distance along the shore-route referenced clockwise from the northern tip of the island.

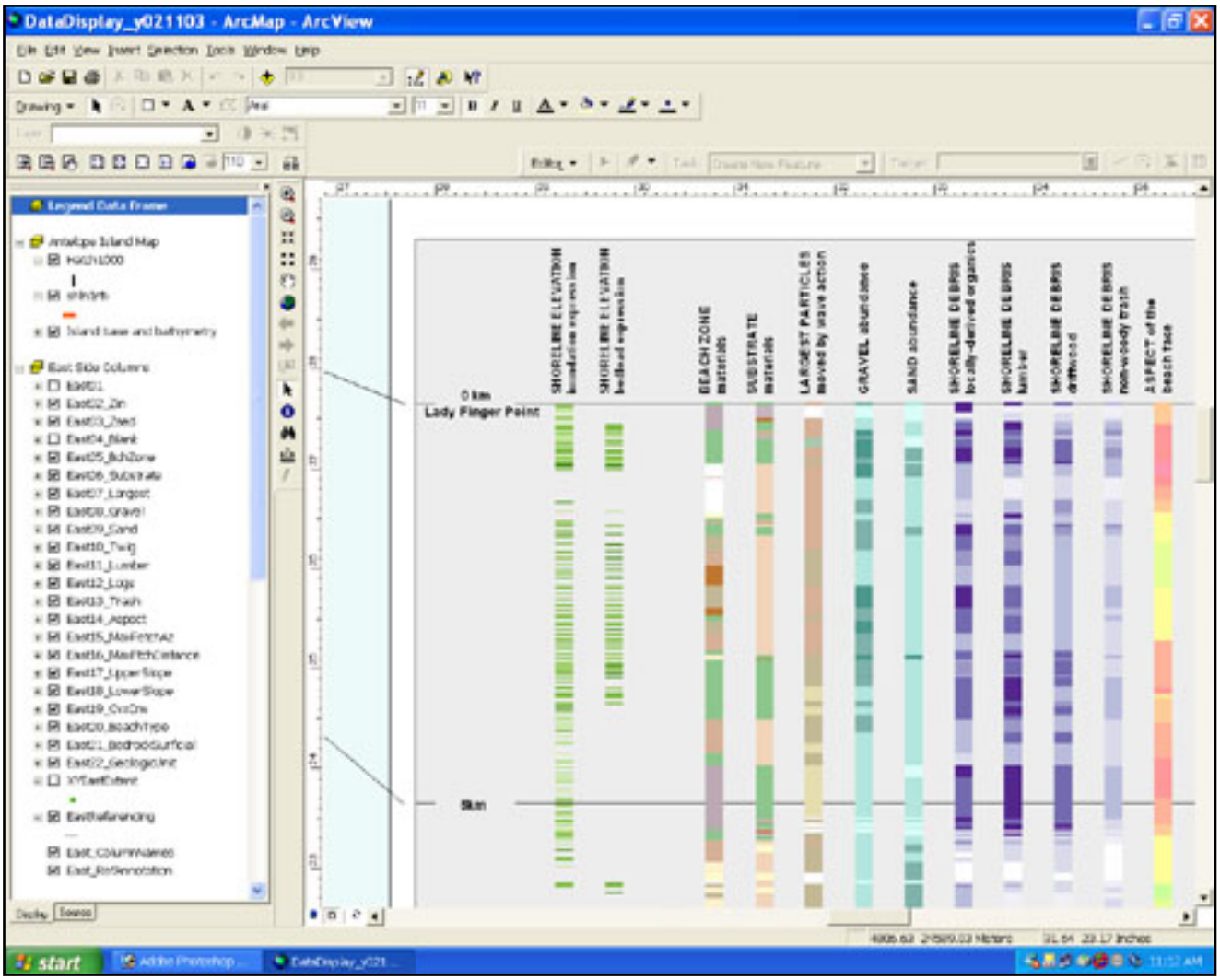


Figure 2. Detail of east-side columnar display. This snapshot shows a computer screen in ArcGIS. On the left is the table of contents of dataframes including a listing of map layers for the east-side columnar display. Each map layer is a display column that depicts one shoreline attribute. Colors denote attribute values. Horizontal grid lines show linear-referenced location along the shore-route at 5 km intervals. Horizontal grid lines tie to shore-route markers on the map of Antelope Island, see Figure 1.

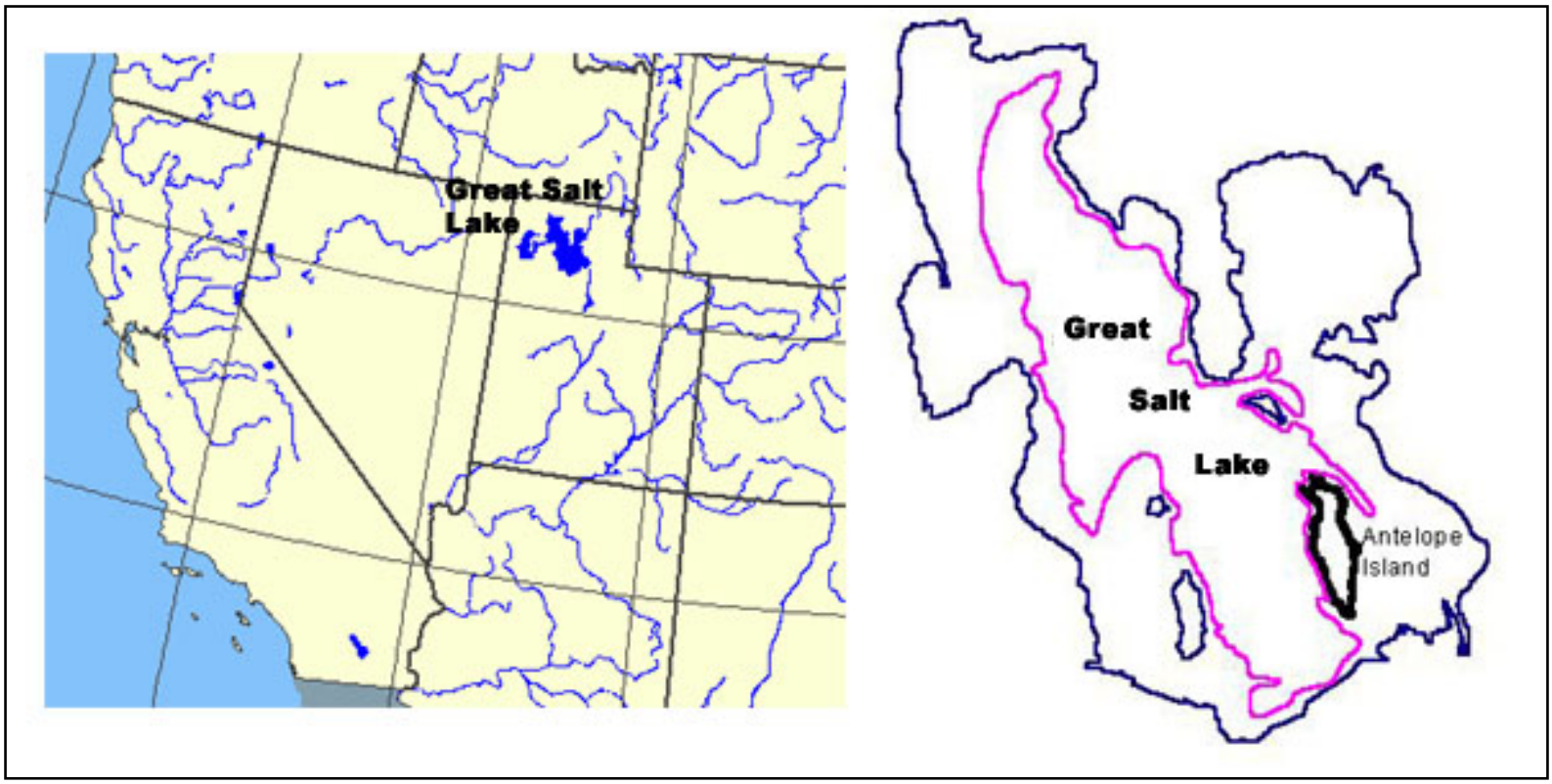


Figure 3. Location map. Map on left shows Great Salt Lake, largest lake of the western United States. Map on right shows Antelope Island, largest island in Great Salt Lake. The blue outline of Great Salt Lake indicates the lake's extent at its 1986-87 historic highstand. The pink outline indicates the lake's extent in 1963, its historic lowstand.

Great Salt Lake is a shallow closed-basin lake that fluctuates in response to climate. During the 1980s, the lake rose eleven feet in five years, nearly doubled its surface area, flooded public and private property, and cost the State of Utah hundreds of millions of dollars in public expenditures for flood control and damage mitigation (Alder, 2002). Great Salt Lake's rise to its historic highstand level in 1986 and 1987 not only caused damage, it left a shoreline record constructed by storm waves (Figure 4). The 1986-87 shoreline is distinctive because, unlike older, higher pre-historic shorelines, it incorporates anthropogenic trash such as tires, plastic, pottery, railroad ties, and lumber. The elevation of 1986-87 shoreline debris above the elevation of the 1986-87 stillwater lake level defines a storm-inundation hazard zone. This difference in elevation is called shoreline superelevation.

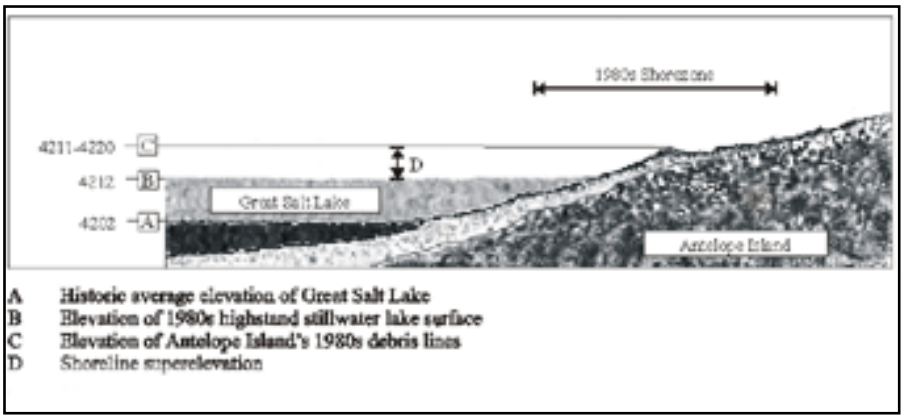


Figure 4. Shorezone features. Great Salt Lake's elevation has fluctuated approximately 20 vertical feet in historic time (1847 – present). Active, historic, and older shorezone features include: lakebed of Great Salt Lake; contemporary stillwater lake level, e.g. 4197.8 feet above sea level (ft a.s.l.) for 6/15/2003; average historic lake level (A); stillwater lake level of the 1986-87 highstand, approximately 4212 ft a.s.l. (B); shoreline evidence of the 1986-87 highstand (C); and evidence of older shorelines. Storm winds and waves construct shorelines above the stillwater level of the lake. The difference in elevation between the stillwater lake level and its shoreline evidence is called shoreline superelevation (D).

Many characteristics of the 1986-87 shoreline were mapped on Antelope Island as part of doctoral dissertation research at the University of Utah's Department of Geography. The amount of data and number of attributes were daunting and necessitated interactive visualization of multiple attributes of the shoreline. The subject matter of this paper is the GIS technique used to simultaneously portray spatial patterns and relationships of 20 shoreline attributes. Research findings are published elsewhere (Atwood, 2002).

The problem: how to visualize abundant data describing complex systems.

Geographers study the interrelatedness of people, places, and environments (Geography Education Standards Project, 1994). GIS provides powerful technology and scientific underpinnings for organizing, displaying, and analyzing spatial data. Linear referencing is a component of the GIS toolbox (ESRI, 2002). Linear referencing models location as one dimension (distance along a linear-referenced route) while maintaining geographic reference to geographic coordinates. Linear referencing makes it possible to associate multiple attributes with any portion of a linear-referenced route, and query for those values or subsets of those values. Linear referencing addresses the problem of managing hundreds, or even hundreds of thousands, of data classes defining characteristics of portions of a linear feature. Using linear referencing, highway managers, stream ecologists, and coastal geomorphologists can georeference their data using relative

distance along a linear feature and display the values on maps using dynamic segmentation. Linear referencing and dynamic segmentation have improved management of multiple attributes, query of multiple attributes, and visualization of individual attributes. This paper explores how linear referencing can be used to visualize multiple attributes, interactively, spatially, and simultaneously using ArcGIS.

Components of a columnar display of multiple attributes of a linear feature.

Figure 1 displays 20 attributes for a 64 km shoreline of Antelope Island. The display technique is not limited to 20 attributes. Columnar display has been affectionately dubbed a “genome-display” by co-workers because of its many brightly-striped columns. Figure 1 has five map components each of which is a dataframe in ArcGIS (Figure 5): title; legend; columnar display of data for the west side of the island; map of Antelope Island; columnar display columnar display of data for the east side of the island. The two columnar displays, one for the east side of the island and one for the west side of the island, are composed of 20 display columns, each representing a shoreline attribute, each a map layer in ArcGIS. The display columns are arranged as the mirror image of each other, thus the attribute, shoreline superelevation, is closest to the map of Antelope Island on both the east-side and west-side dataframes.

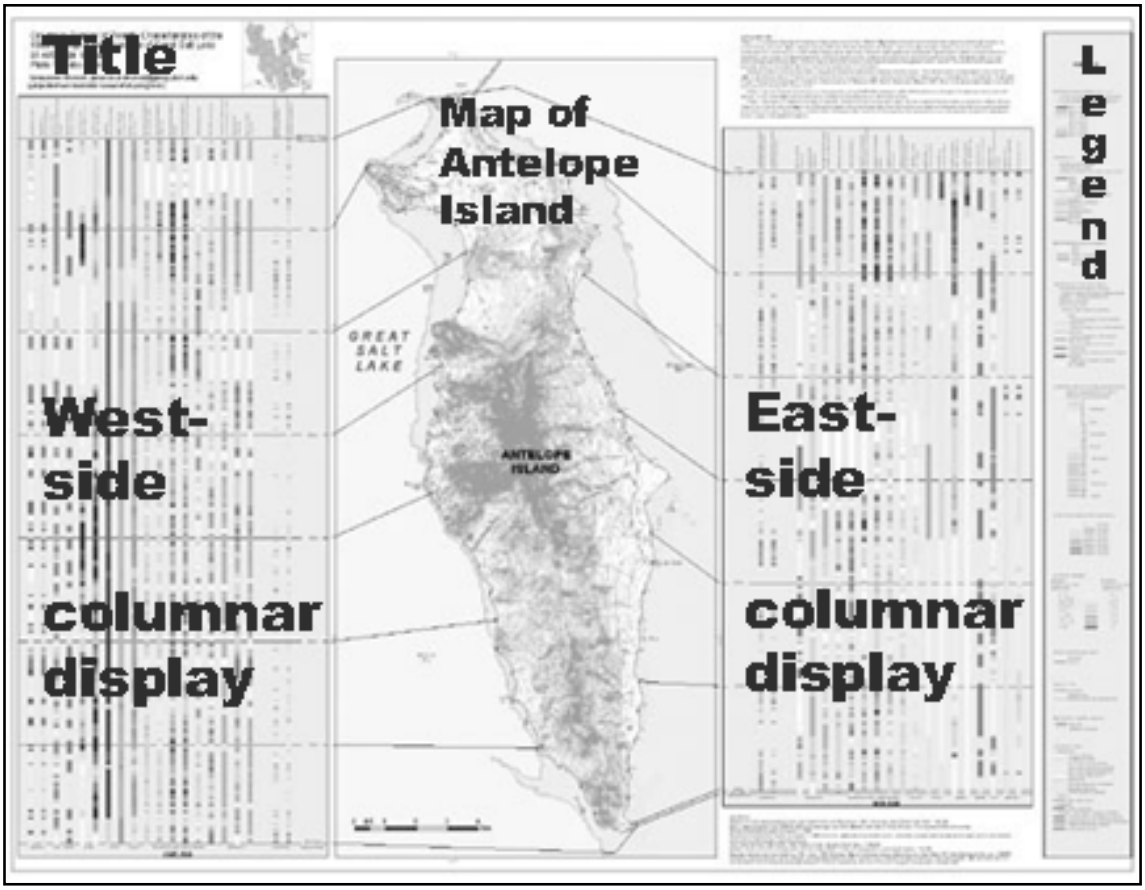


Figure 5. Components of a columnar display. Antelope Island is a north-south trending landform. For that reason, two columnar displays were used to present attribute values: one for the west side and one for the east side of the island. Figures 1 and 8 have the same layout, and the same map layers. Figure 1 displays data values for all 20 attributes. Figure 8 is an interpretive display showing data values for a subset of attributes and attribute values. The attribute tables of the columnar displays of Figure 1 and Figure 8 are the same.

Location is shown on the map of Antelope Island in traditional, two-dimensional, geographic, map coordinates. Location along the island's shore is shown on the Antelope Island map both as geographic coordinates and as relative distance along a linear-referenced shore-route. Hachures along the shore-route indicate distance along the shore-route from Ladyfinger Point, the northern tip of the island. The y-axes of the east-side and west-side columnar-displays show location along the shore-route. Horizontal gridlines cross columns at 5 km intervals. Reference lines link hachures on the map of Antelope Island to horizontal gridlines of the columnar displays. Places along Antelope Island's shoreline can be found on the columnar displays by first locating the place on the map of Antelope Island, interpolating its location along the shore-route, and then interpolating location on the columnar display using the horizontal gridlines. For example, a location on the east side of the island near Sea Gull Point has geographic coordinates of NAD1927, UTM Zone 12, easting 402,271 and northing 4,533,494. Its shore-route location is 18,204 m. The location can be found on the map of Antelope Island along the shore-route just south of kilometer marker 18, and found on the east-side columnar display about two thirds down the column between horizontal gridlines marking 15 km and 20 km.

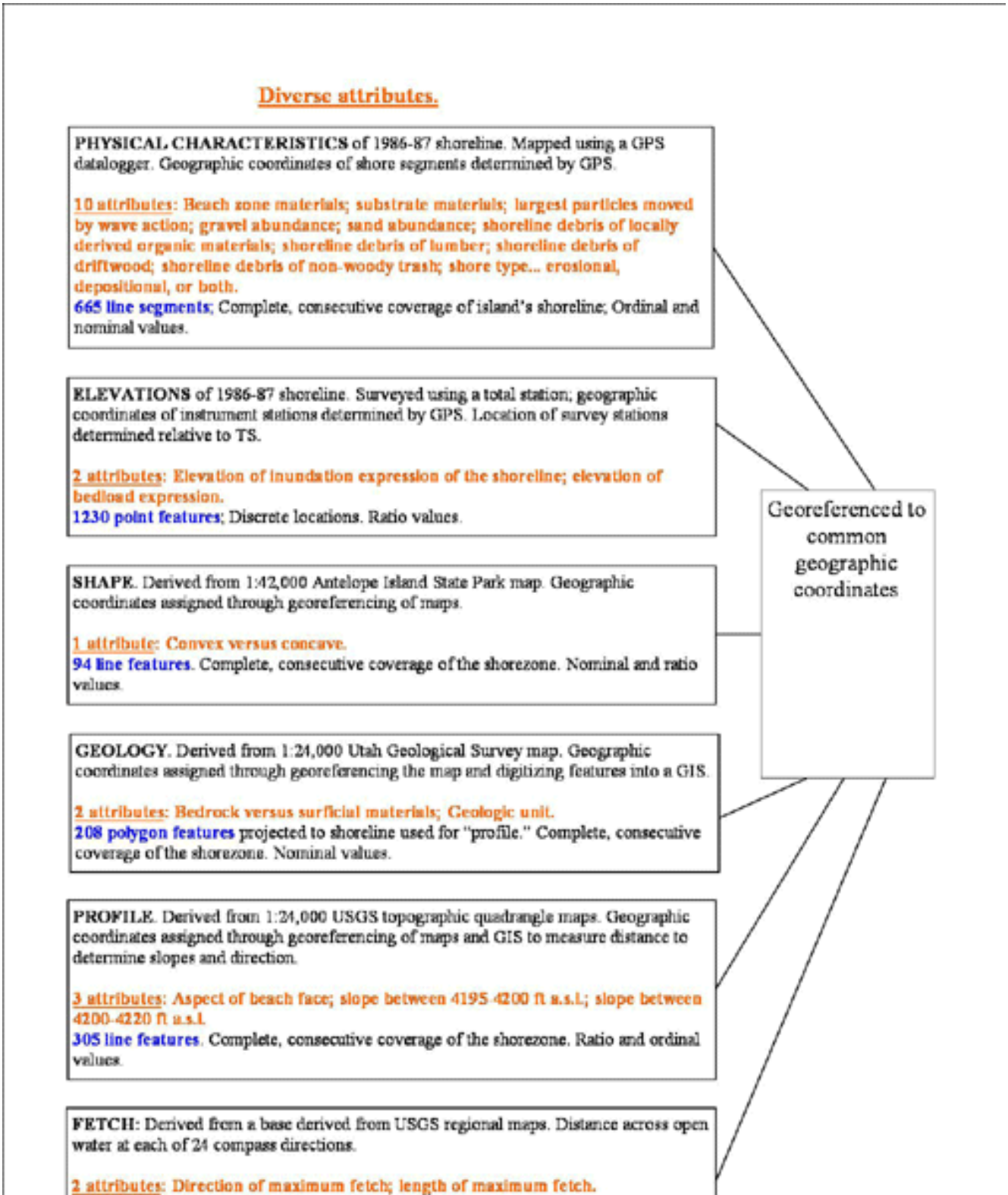
Colors of the display columns represent attribute values. Thus, for that particular location near Sea Gull Point, shoreline elevation of 4211.2 feet above sea level is depicted as green; beachzone materials are sand and gravel depicted as light tan; substrate is coarse beach deposits depicted as dark tan; maximum size of particles moved by wave action is coarse gravel depicted as dark tan; and so on for 20 shoreline characteristics.

Steps for making a columnar display.

Step 1. Determine that the subject matter will benefit from this relatively complex display. Is the feature linear? Is there a need to visualize more than 10 attributes simultaneously? Are the data in a GIS? Are the data types diverse, such as qualitative and quantitative, and interactions among attributes complex? Is the linear feature an appropriate scale for visualization at the level of detail required for analysis?

> *Antelope Island example: Figure 6 shows 20 attributes that emerged as having particular importance in the Great Salt Lake research project. Surveyed*

elevations are for point locations. Eighteen attributes describe characteristics along stretches of the shoreline and are line features. Data types are diverse, derived from different sources at different scales. Attribute values are assumed to be spatially autocorrelated. Analysis of attribute inter-relatedness requires visualizing various attribute sets in their spatial context. The data are managed in an attribute spreadsheet using S-Plus statistical software that can be imported into GIS attribute tables (Insightful, 2001).



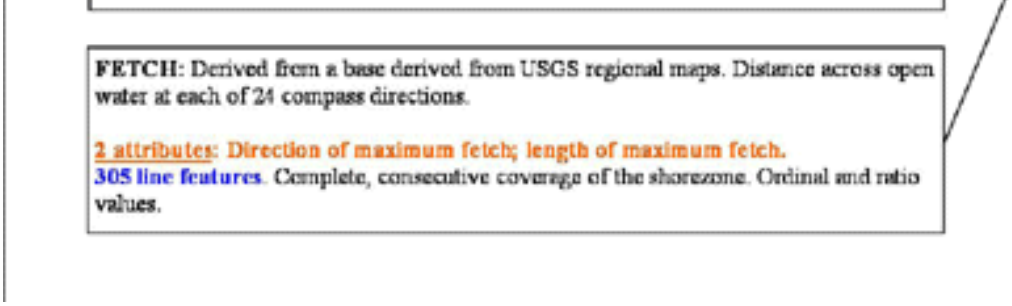


Figure 6. Diverse attributes. Columnar display can be used to visualize diverse data so long as they are in a GIS and are linear-referenced. Antelope Island example: red text highlights the 20 attributes displayed in display columns of Figures 1 and 8. Attribute data include quantitative and qualitative data for point and line features.

Step 2. Linear-reference the feature.
Represent the feature as a series of connected line segments in a GIS map layer with geographic coordinates. Use GIS software to transform the geographically referenced line into a linear-referenced route.

> *Antelope Island example: line segments were created by heads-up digitizing on a USGS 1:24,000 topographic base in NAD1927 coordinates using Cartalinx software (Hagan, Eastman, and Auble, 1998). The geographically-referenced line segments were imported into an ArcINFO coverage and transformed into a linear-referenced route using ArcINFO dynamic segmentation. The process was analogous to assigning virtual highway mileposts along a highway. Instead of highway mile markers, it was virtual shoreline meter markers. There are no physical shoreline posts on the island indicating distance along the shore-route. However, with a precise GPS unit, one could locate one's self in the field for any position along the route because shore-routes are located both in linear and geographic space.*

Step 3. Reference attribute data sets to the linear-referenced route.
Point, line, and polygon features can be referenced to the route. Examples of point data with attributes would be surveyed elevations of a shoreline, or car accidents on a highway. Examples of linear data with attributes would be abundance of gravel along a shoreline, or pavement material of a highway. Examples of polygon data attributed to a linear feature would be the geologic unit underlying a shoreline or the county within which a highway is located. Values for attributes can be qualitative or quantitative. Geographic location need not be coincident with the linear feature. However all data sets must share a common geographic reference system.

Technical tip: Check that linear-referencing makes sense. Algorithms assign location to the nearest portion of the linear-referenced route. For a shoreline with bays and narrow

headlands, a researcher should check that the nearest position on a shore-route accurately portrays position along the shore.

Antelope Island example: All data were georeferenced to NAD1927, UTM Zone 12 North. Data had been collected for four, different, geographically-referenced paths: one developed from field mapping using Pathfinder software and Trimble GeoExplorer datalogger (Trimble Navigation Limited, 2000); one developed from USGS 1:24,000 topographic maps used for attributes such as slope and aspect; one developed from a 1:42,000 Utah Department of Natural Resources map used to determine plan-view shoreline shape; and, of course, the shore-route to which all data would be referenced. Figure 7 shows how the data sets for shoreline attributes of a portion of the northern tip of Antelope Island were not coincident. This was not a problem. Linear-referencing was remarkably easy, almost too easy, as though a black box had instantly transformed geographic coordinates of point features and end points of line features and given them linear-referenced locations along the shore-route.

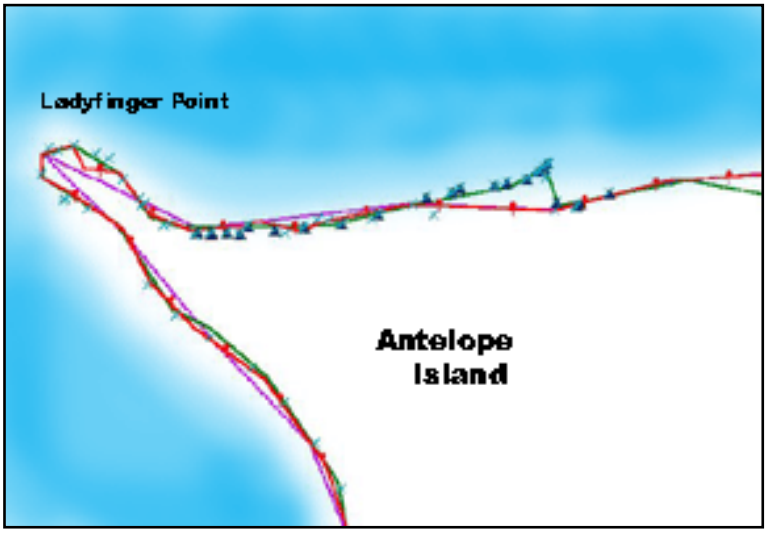


Figure 7. One shore-route, multiple shoreline paths. Detail of the northern portion of Antelope Island showing in red, the linear-referenced shore-route; in green, the GPS-tracked shoreline path of field mapping; in purple, the shoreline digitized from USGS 1:24,000 topographic maps; as light-blue crosses, locations of surveyed elevations of the flotsam-rich expression of the 1986-87 shoreline; and as dark blue triangles, locations of surveyed elevations of bedload-dominated expressions of the 1986-87 shoreline. As part of linear referencing, geographic locations of all points and paths were projected to the shore-route and assigned relative location along it. Linear referencing collapses two-dimensional geographic space into one-dimensional linear space. Locations along the

shore-route have x and y geographic coordinates and a shore-route location in route-meters measured from Ladyfinger Point.

Step 4. Create an attribute table.
Each map layer of a columnar display links to an attribute table. Rows of the attribute table are one-unit segments of the route. For a highway, this could be a route-mile. For a shoreline it could be a route-meter. Attribute-table columns are of two types: 1) those that locate the display columns in the columnar-display dataframe, and 2) feature attributes. An attribute table has as many rows as there are units along the linear-referenced route. One attribute-table column is for distance along the route. Another set of attribute-table columns provides an x-value for every display column of the columnar display. This x-value places the display column in the dataframe. The table has as many additional attribute columns as the investigator envisions for analysis. Cells value are attribute values for meter-segments of the shore-route.

Technical tip. It may be easier to populate the cells of the attribute table outside the GIS using statistical, spreadsheet, or data-base software.

> *Antelope Island example: The attribute table has 25 attribute columns for location in the dataframe. The first represents distance along the shore-route. Antelope Island's linear-referenced shore-route is 64,385 meters and, therefore the attribute table has 64,385 rows. The columnar display has 24 columns, two of which are blank. Therefore the attribute table has 24 attribute data-columns, one for each x-value that locates a display column on the columnar display. Shoreline attributes were numerous and included point locations for surveyed shoreline elevations. Most shorelines characteristics had been mapped in the field as shoreline stretches, not sampled as points along the shoreline. The beginning and end of each shoreline segment had a linear-referenced position. In order to have values for every cell describing a stretch of shoreline, blank cells between the "from" and "to" end locations of line features were populated using S-Plus statistical software (Insightful, 2001) and then imported into ArcCatalog.*

Step 5. Format the dataframe.
A columnar-display dataframe has an x-y coordinate system. The coordinate (0, 0) is at the lower left of the dataframe. The y-coordinate of the dataframe represents location along the linear-referenced route. The x-coordinate simply places a column in map units onto the dataframe. In formatting the presentation, the number of attributes to be displayed as columns determines the x-coordinate values. Display columns can be spaced in a meaningful way across the dataframe.

Technical tip: Leave the dataframe in unspecified coordinates. In ArcMap the coordinate system is “unknown.” Map extent is determined by route-units for the y-axis.

> *Antelope Island example: 20 attributes were displayed as columns. Two display columns were deliberately left blank for visual composition.*

Step 6. Create display columns in the dataframe.
Each display column is a map layer that displays an attribute in the dataframe. The coordinates of the map layer are: the y-axis for location along the linear-referenced route, and the x-axis for location on the dataframe. Each display column is then associated with values from attributes in the attribute table. In this way, display columns are constructed of a series of x-y located points colored to represent attribute values. The order of columns can be rearranged by changing the attribute values that populate the display column.

Technical tip: Note that this procedure does NOT have x1_y1 to x2_y2 commands to draw lines for the stripes of the column. Each column is constructed of a series of points symbolized as a hyphen. Because the marker symbol for a hyphen has more breadth than width, the resulting composite of points appears as a column. I thank Matthew A. Mabey of the Oregon Department of Transportation for this insightful idea.

Technical tip: The attribute table for each display column is the entire attribute table. Map layers can be interactively populated by another attribute from the attribute table and display columns can be interactively rearranged to investigate relationships.

Step 7. Analysis.
At the end of Step 6, the columnar-display dataframe is populated with display columns composed of a series of stacked, colored hyphens representing values of attributes along the linear-referenced route. The display can now be changed interactively. Colors for attribute values can be adjusted, attributes hidden or presented, and columns reordered.

Technical tip: Colors should be chosen with care. Too many colors result in a presentation that resembles fruit salad. The website of Cynthia Brewer, Pennsylvania State University, is most helpful in explaining the logic of color combinations as well as a source for color sets (http://www.personal.psu.edu/faculty/c/a/cab38/ColorBrewerBeta2.html).

> *Antelope Island example: Figure 1 shows all the values of 20 attributes selected to describe the island’s 64 km highstand shoreline. Shoreline superelevation is of particular research interest. Figure 8 shows a subset of the data presented in Figure 1. Figure 9 shows a detail of the east-side columnar*

display of Figure 8. Figure 10 shows a detail of the map of Antelope Island from Figure 8 and shows how values of an attribute can be displayed along the linear-referenced route. The columnar- display dataframes of Figure 1 and Figure 8 are the same including the order of display columns. The purposes of the presentations differs. In Figure 1, the purpose is to present data. In Figure 8, the purpose is to show an interpretation. Figure 8 displays those attributes and values whose island-wide patterns visually match those of shoreline superelevation. Values of shoreline superelevation were broken into three quantiles: high superelevation (red); moderate superelevation (orange); and low superelevation (green). Then, all other map layers were hidden. One by one, display columns were visually matched against shoreline superelevation. Red, orange and green were interactively assigned to values of the attributes of a display column until patterns of the attribute approximately matched those of shoreline superelevation. For example, Figure 11 shows the values of the attribute, shoreline aspect, and its match to shoreline superelevation. Figure 11 is a detail of the legend of Figure 8. Where patterns of a value of an attribute did not match patterns of high, medium, or low shoreline superelevation, no color was displayed.

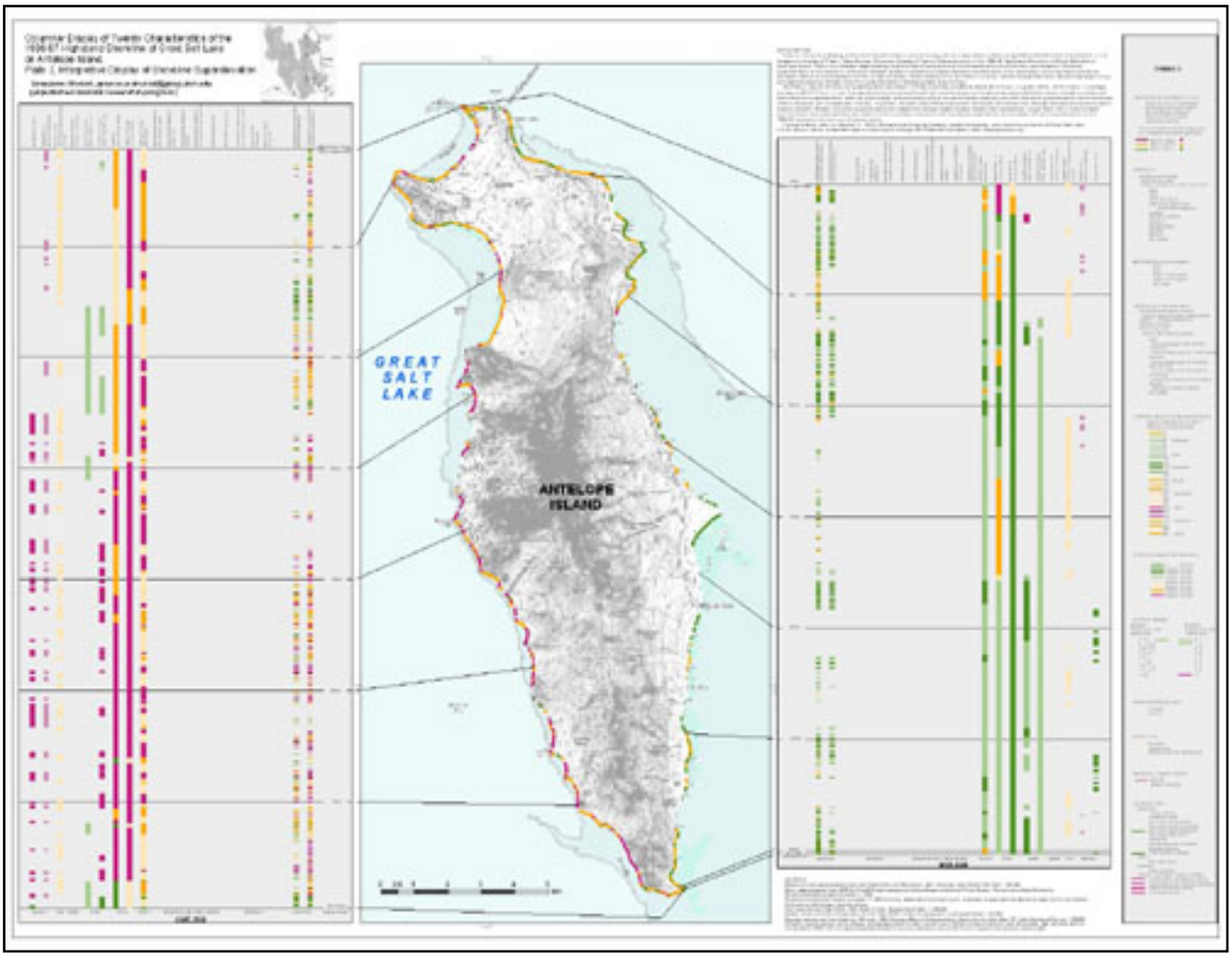


Figure 8. Interpretive presentation using columnar display of multiple shoreline attributes. Columnar displays are interactive in ArcGIS. Attribute columns can be hidden or put on view. Attribute values can be color-coded to highlight and explore relationships among attributes. The attribute, shoreline superelevation, was color-coded: red for high values, orange for moderate values, and green for low values. When patterns of values of other attributes visually matched those of shoreline superelevation, those values were color-coded. Strong visual matching is shown as bright red, orange, and green. Weaker visual matches are shown as subdued red, orange, and green. Poor correlations are left blank. Note extensive blank areas where patterns of attribute values do not match those of shoreline superelevation.

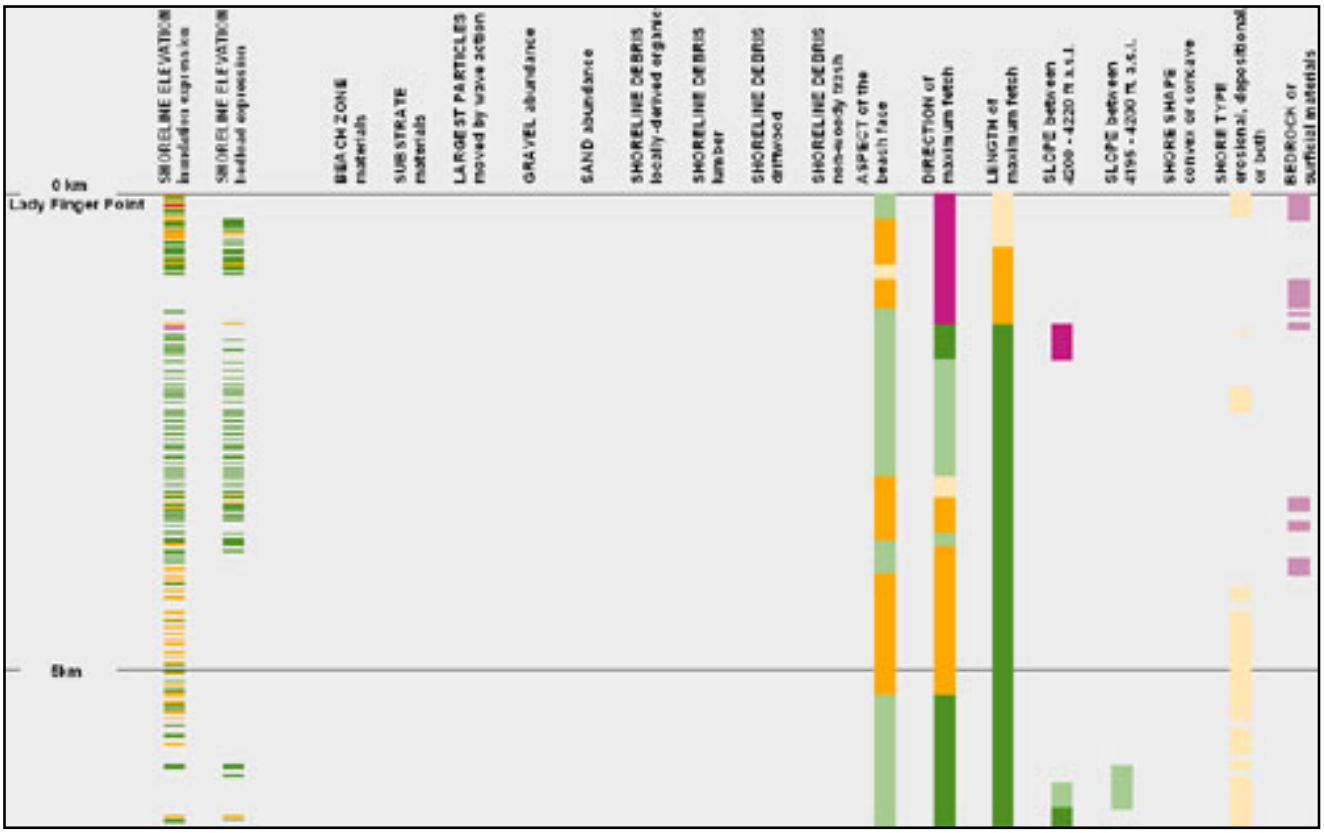


Figure 9. Detail of east-side columnar display of Figure 8. The two columns on the left show relative shoreline superelevation at point locations along the 1986-87 shoreline. To right of center, columns coded red, orange, and green show series of shoreline attributes with island-wide patterns that visually match those of shoreline superelevation. Those attributes are: aspect of the beach face; direction of maximum fetch; and length of maximum fetch. Very steep and very shallow slopes of Antelope Island's beachface match patterns of high and low shoreline superelevation and are coded red and green respectively. Patterns of bedrock exposure visually match patterns of high shoreline superelevation. Note how island-wide patterns of several attributes do not visually match shoreline superelevation and are blank: beachzone materials, substrate materials, gravel abundance, sand abundance, and four types of shoreline debris.

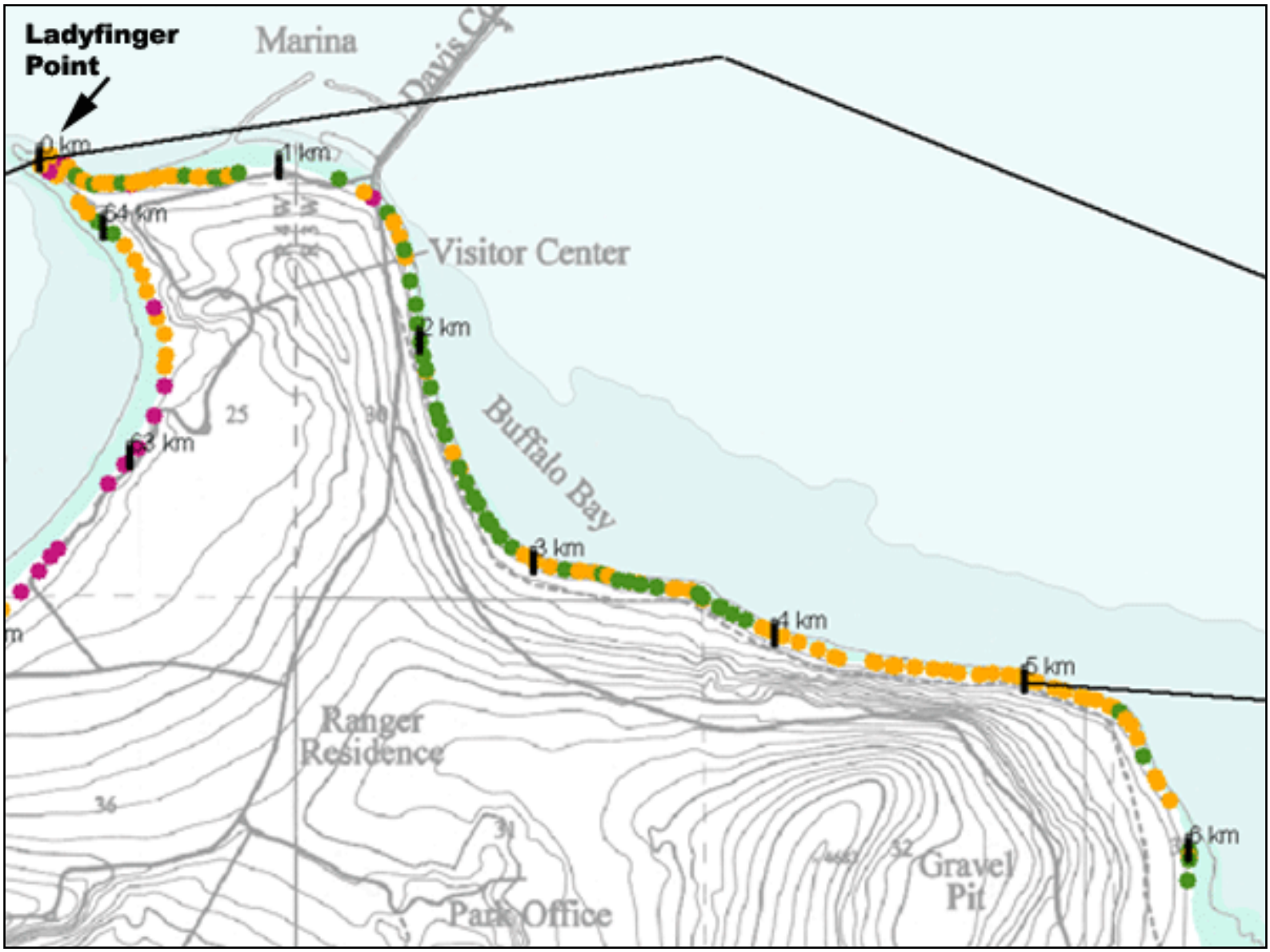


Figure 10. Detail of map of northern portion of Antelope Island shown in Figure 8. Ladyfinger Point is the northern tip of Antelope Island and the starting and ending point of the shore-route. Markers indicate 1 km distances along the route. Distance is measured clockwise around the island. Color of dots along the shore-route denotes magnitude of shoreline superelevation at surveyed locations. Geographic locations of surveyed point locations have been projected to the shore-route. Figure 9 shows approximately the same 6-km portion of the shore –route displayed in Figure 10. Shoreline superelevation data displayed in Figure 10 are the shoreline superelevation data displayed in Figure 9 on the two display columns farthest to the left.

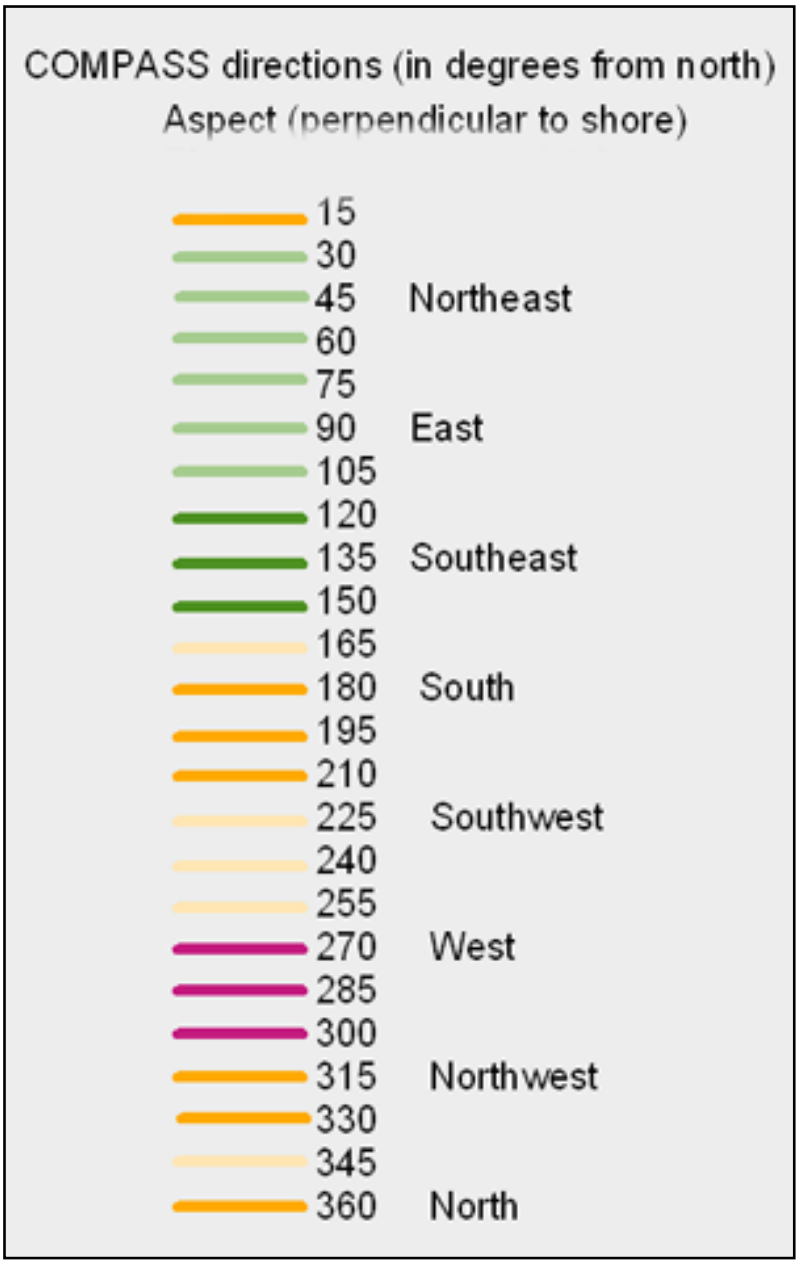


Figure 11. Detail of a legend shown in Figure 8. Shoreline aspect is the direction a shoreline faces. Colors for values of aspect were adjusted interactively so that the color patterns for aspect approximately matched those of shoreline superelevation. The legend shows the visual best-fit values for island-wide patterns of aspect compared to island-wide patterns of shoreline superelevation. For example, the pattern of spatial distribution of shorelines that face due west is generally similar to the pattern of spatial distribution for high shoreline superelevation. Western aspect is coded red. In general, western facing shorelines have high shoreline superelevation.

Discussion: applicability to Antelope Island research.

Columnar display of multiple shoreline attributes has aided an understanding of coastal processes of Great Salt Lake.

- It aided data display. Abundant, diverse, data were presented in a single view

(Figure 1). The presentation was printed hard-copy as an easily-examined 44 x 33 inch E sheet, and as 11 x 8.5 inch, page-size printouts that showed general patterns of shoreline characteristics.

- It aided in communicating results. Interpretive subsets of the research data set were presented in a single view, in the same format as the data set (e.g. Figure 8). The data could be explored interactively. Changes in color patterns exposed relationships. Once an interpretation had been analyzed, it could be printed hard-copy in the same format as the research data set display.
- It aided analysis. Expected relationships among attributes of the shoreline were tested by displaying three or four shoreline attributes simultaneously and examining patterns of variability. For example, it was expected that attributes associated with high-energy waves would have higher values on the windward side of the island. Indeed, Figure 8 shows that attributes of steep slopes of beach faces, exposed bedrock, and high shoreline superelevation tend to be on the windward, western side of Antelope Island. Very gentle slopes, unconsolidated surficial materials, and low shoreline superelevation tend to be on the eastern, leeward side of the island.
- Unexpected relationships among attributes became evident. Figure 8 displays the 20 attributes simultaneously, with colors matching patterns of shoreline superelevation. An absence of visual match for an entire block of attributes stands out. This block of attributes is represented by display columns next to those of shoreline superelevation and includes: size of largest particle moved; substrate materials, abundance of gravel, abundance of sand, and abundance of shoreline debris. For marine shorelines, size of beach materials generally indicates wave energy. For Antelope Island, provenance of beach materials in large measure determines particle size along the beaches and appears more important in determining beach-particle size than wave energy. In this way, columnar display revealed patterns and invited further research.
- Columnar displays communicate abundant information spatially. They are highly visual and, with a little practice, become intuitively related to geographic space. The linearity of the columns does not lead to a loss of sense of geographic relationships. Instead, it is possible to associate location on the y-axis of the dataframe with places on the island and visualize 20 shoreline attributes associated with that area of the island simply by looking left and right across the columns.

However, the technique has its problems.

- The files for Figures 1 and 8 are large, each approximately one megabyte. To refresh a view of a dataframe, an investigator must be patient and wait while, one by one, columns refresh on the screen. File size is a function of the number of segments chosen to represent the linear feature. If Antelope Island had been a smallerisland, or If the route-unit had been 10-m rather than 1-m, files would have been smaller and refreshed faster.
- Plotting problems arose as a result of the numerous layers of the display. Figures 1

and 8 are 12 mb files in .jpg format for hard-copy print outs with clarity on a 44 x 33 inch printout.

- Presenting all or portions of a dataframe as an html or hardcopy letter-page results in miniscule labels or lost information.

The technique is well-suited to the dynamic environment of a computer monitor, but not for executive summaries or overview presentations to clients.

Discussion: reactions to this display technique.

Hard-copy displays of Figures 1 and 8, along with several other displays discussed below, were presented at a poster session of the Geological Society of America (GSA) annual conference in Denver, 2002 (Atwood and Mabey, 2002). About 50 earth scientists filled out a questionnaire giving feedback on which types of display communicated information clearly, and which types looked useful for exploring data relationships.

Spatial display of a single attribute. Figure 12 shows the variability of one variable, shoreline superelevation, in geographic space. It displays variability of the attribute in a familiar, x and y coordinate, map context. Figures 13, 14, and 15 show location using linear referencing. Linear referencing collapses two-dimensional geographic space into a one-dimensional number line and therefore location can be displayed along a single axis of a graph. Figure 13 is a scatterplot where the y-axis is shoreline superelevation and the x-axis is location along the shore-route. Figure 14 shows box-and-whisker diagrams that indicate variability of shoreline superelevation on the y-axes and location as quantiles along the x-axes: two for east and west sides of the island, and 12 for 12 segments of the island ordered clockwise beginning at the island's northern tip. Figure 15 shows histograms where the x-axes depict shoreline superelevation, and the y-axes depict frequency of occurrence. Figure 16 shows the variability of shoreline superelevation in 3-D space using ArcGIS 3-D Analyst. These displays show contrasts in shoreline superelevation and invite exploration of causal relationships. GSA participants found one-variable displays easy to interpret and heuristic, meaning that the presentation of data invited further research.

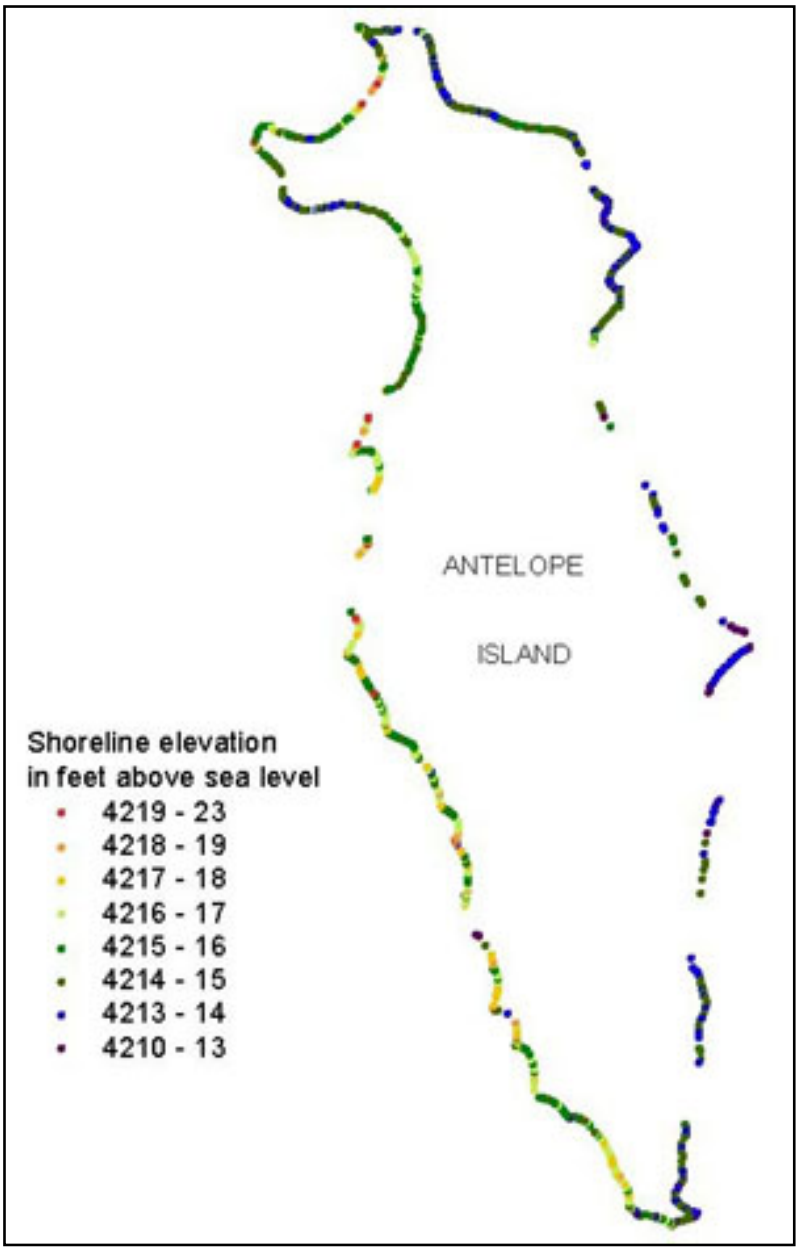


Figure 12. Map display of one attribute, shoreline elevation, with location referenced to 2-D geographic coordinates. Dots denote point locations along the shore-route. Color denotes the magnitude of shoreline superelevation. Surveyed elevations are for the flotsam-rich expression of the 1986-87 shoreline.

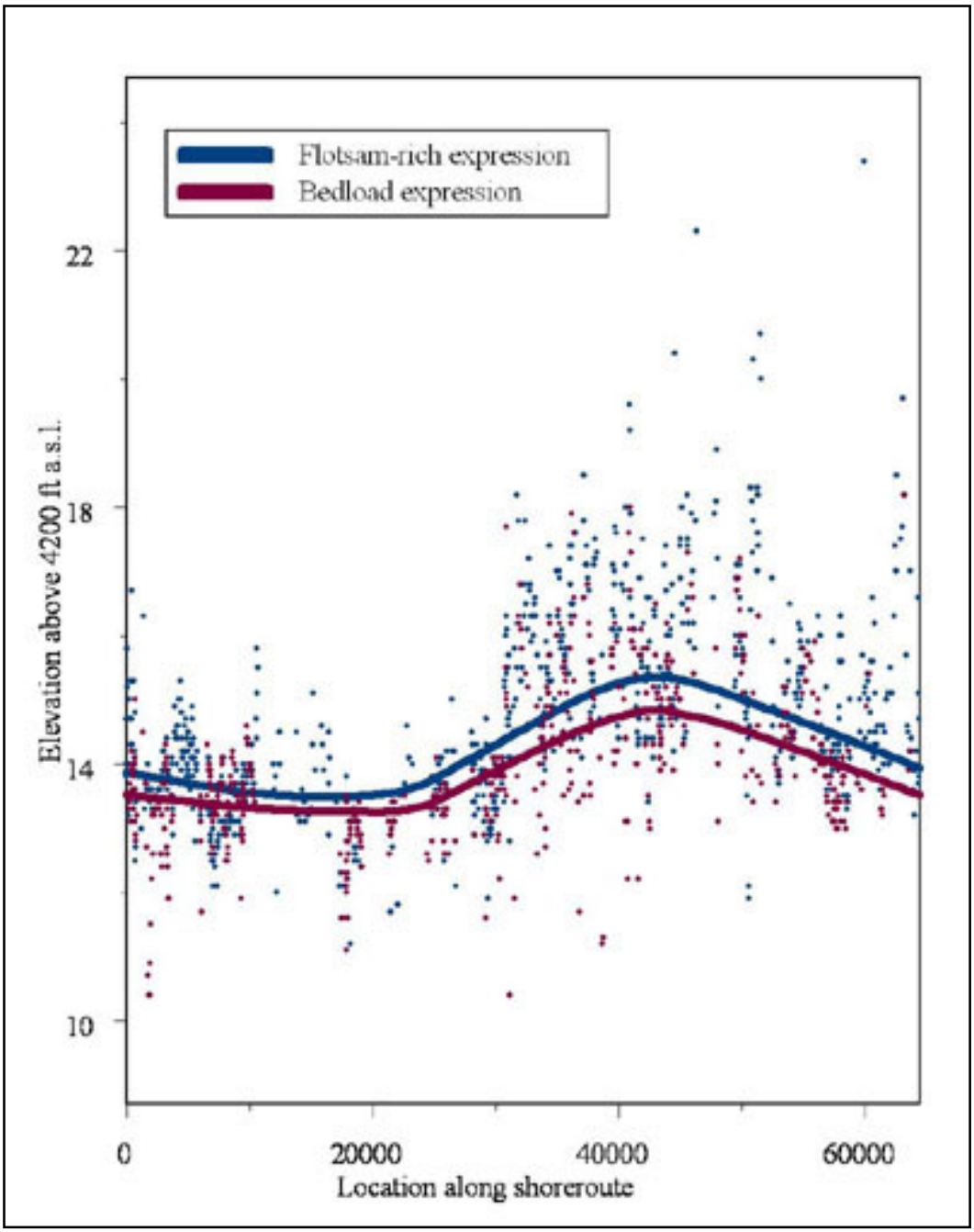


Figure 13. Scatterplot display of one attribute, shoreline elevation, with location referenced to distance along the shore-route. Color denotes type of expression of the 1986-87 shoreline: blue denotes shorelines with abundant flotsam incorporated into shoreline sediments; red denotes shorelines with debris consisting dominantly of bedload sediments. The x-axis represents location along the shore-route. The y-axis represents elevation above 4200 ft a.s.l. Loess regression lines show general trends of superelevation for the two shoreline expressions. This scatterplot effectively communicates the extent of scatter among data points and the contrast between west and east sides of the island.

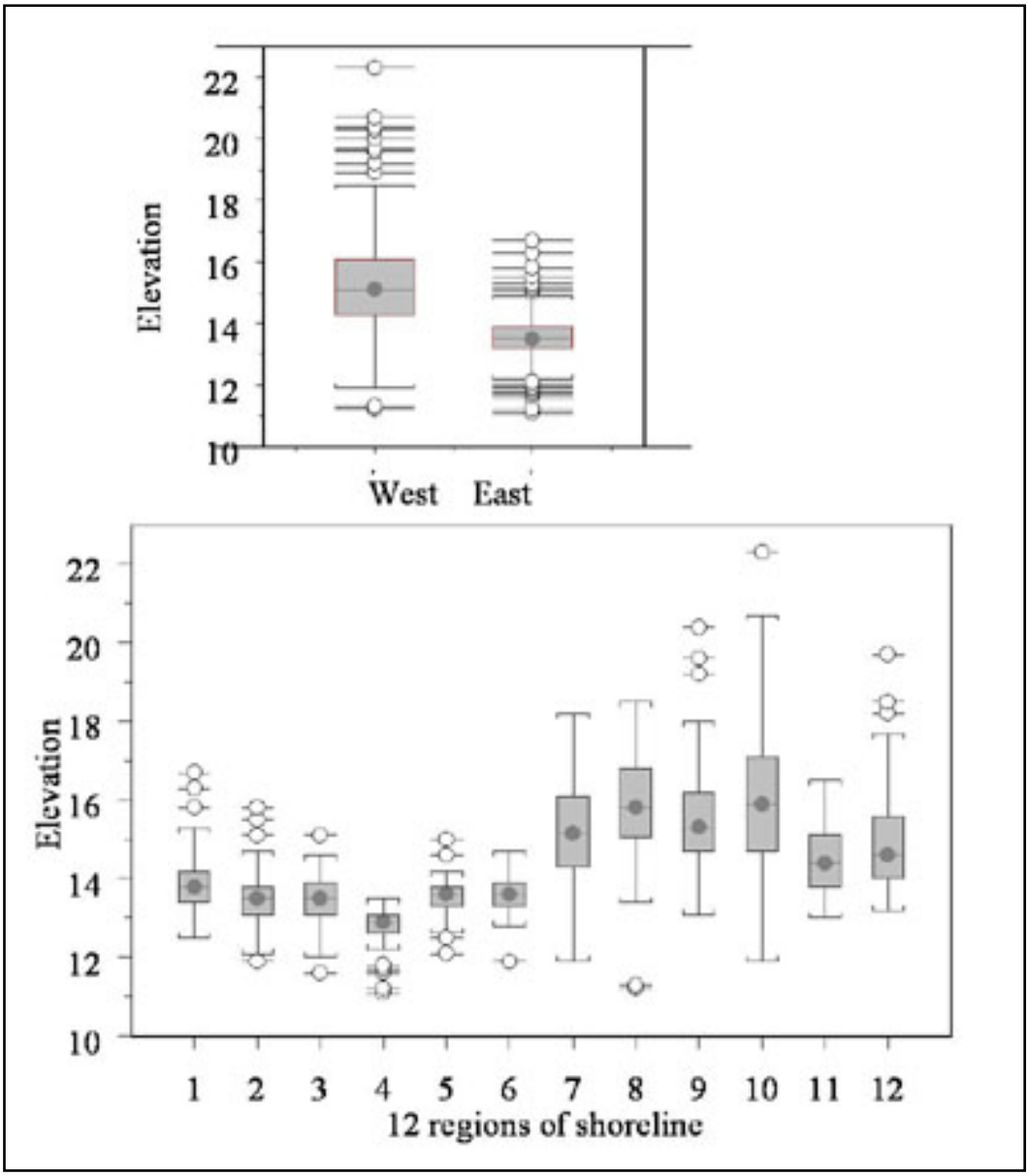


Figure 14. Box-and-whisker displays of one attribute, shoreline elevation, with location generalized as segments of the shore-route. Lower diagram divides location along the shore-route into 12 segments. Upper diagram divides location along the shore-route into two segments: the west and east sides of the island. Box-and-whisker displays effectively communicate that shoreline superelevation is greater and more variable on the west side than the east side of Antelope Island.

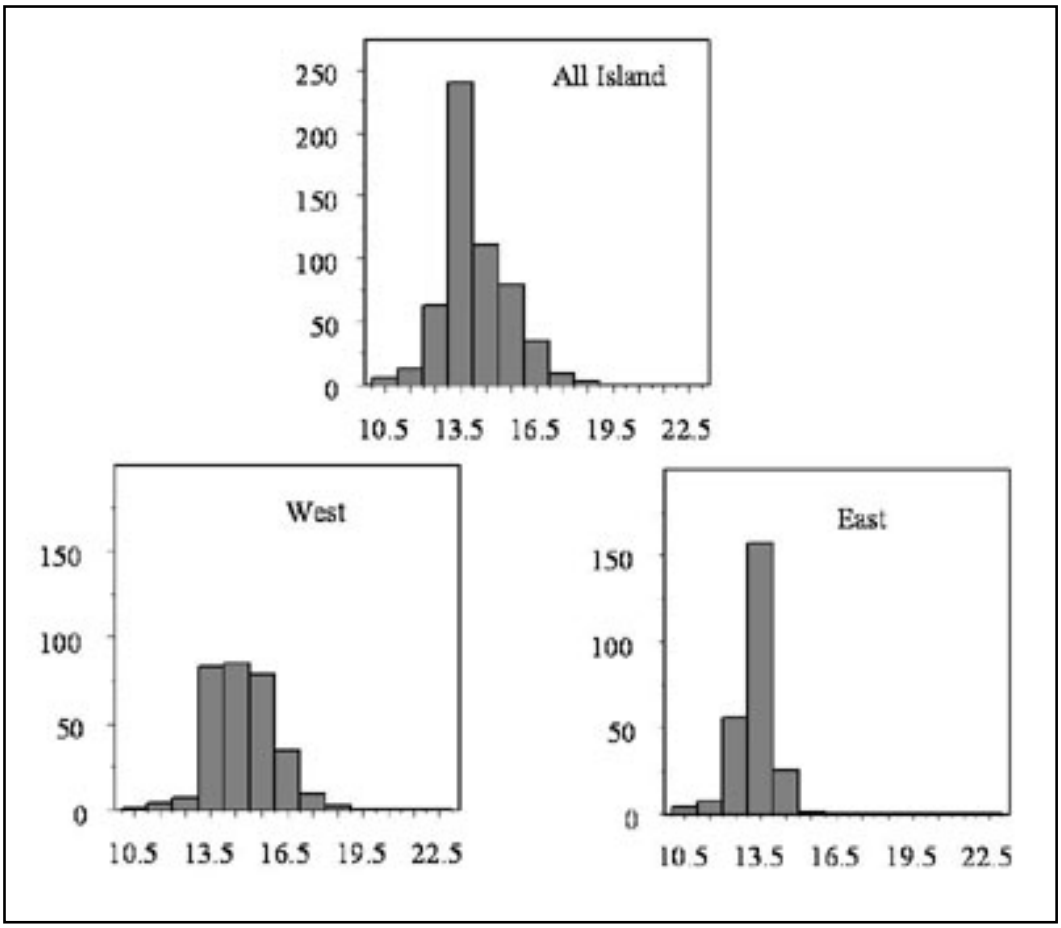


Figure 15. Histogram displays of one attribute, shoreline elevation, with location generalized as segments of the shore-route. The x-axis breaks elevation into 1-ft categories of elevation change. The y-axis shows frequency of occurrence. The lower histograms divide location along the shore-route into two segments: the west and east sides of the island. The upper histogram shows distribution for the island as a whole. Histograms effectively communicate that shoreline superelevation is more variable on the west side than on the east side of the island.

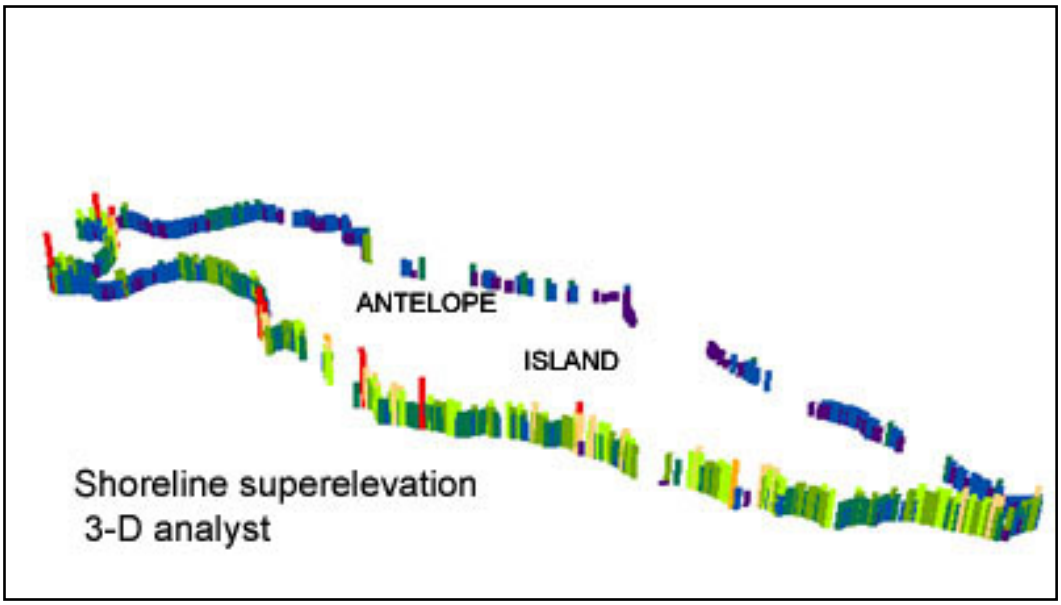


Figure 16. ArcGIS 3-D Analyst display of one attribute, shoreline elevation, with location referenced in 3-D space. Both color and height of vertical lines represent magnitude of shoreline superelevation. This display effectively communicates that shoreline superelevation is greater on the west side than on the east side of the island.

Spatial display of two-attributes. The next level of complexity was to display two attributes spatially. Figure 17 is a 3-D plot displaying length of maximum fetch, location, and slope of the shorezone. This display is complex and difficult to interpret. With close examination, a change in pattern is evident for the lower left part of the graph (east side of the island) versus the upper right part of the graph (west side of the island). GSA participants found this display not helpful, confusing, and counter-productive. It did not explain relationships and discouraged further inquiry.

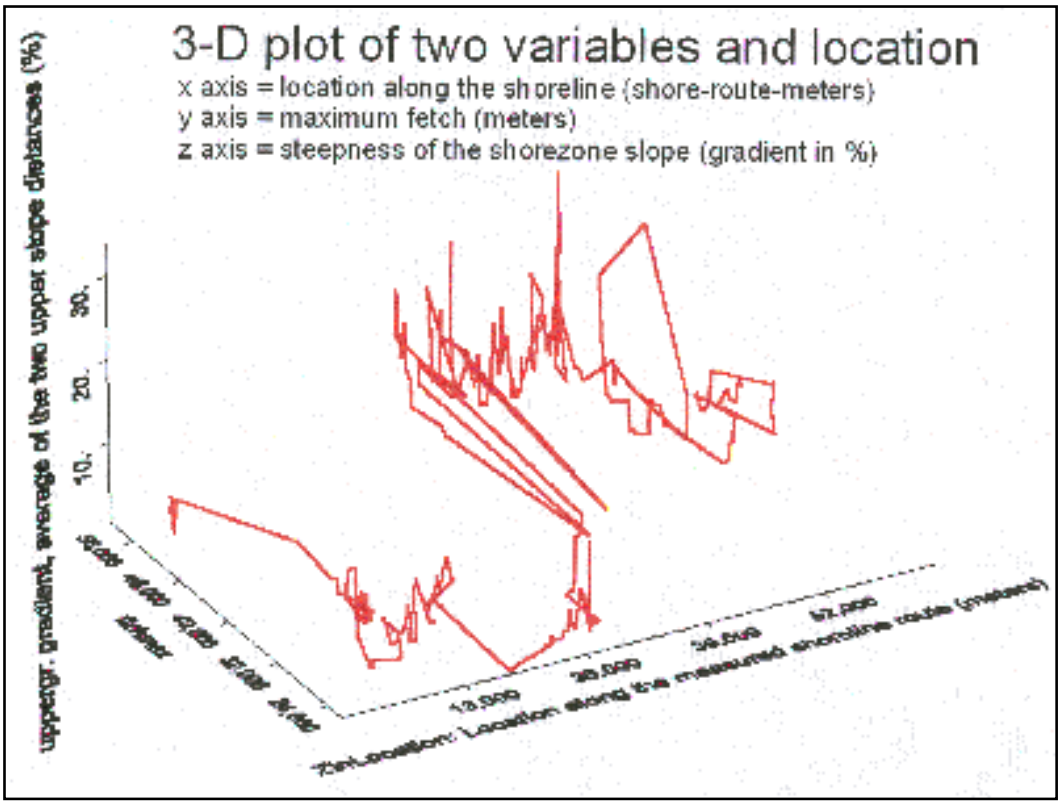


Figure 17. Tri-axial plot of two attributes with location referenced in 3-D space. The x-axis represents location along the shore-route. The y-axis represents length of maximum fetch. The z-axis represents slope of the shorezone. Contrasting line patterns of the lower left and upper right parts of the graph indicate contrasts between the east and west sides of the island. The display is messy and does not invite further inquiry.

Spatial display of more than two attributes. ArcMap 3-DAnalyst also was used to display more than one attribute spatially. Figure 18 shows four attributes as stacked layers from bottom to top: slope of the beach face, length of maximum fetch, shoreline superelevation, and shoreline aspect. GSA participants found this display effective in communicating relationships although they found the overlap of east and west side data distracting. They saw potential for communication of up-to-4 or 5 attributes as stacked layers. They saw the display as better for communication than for exploring relationships among variables.

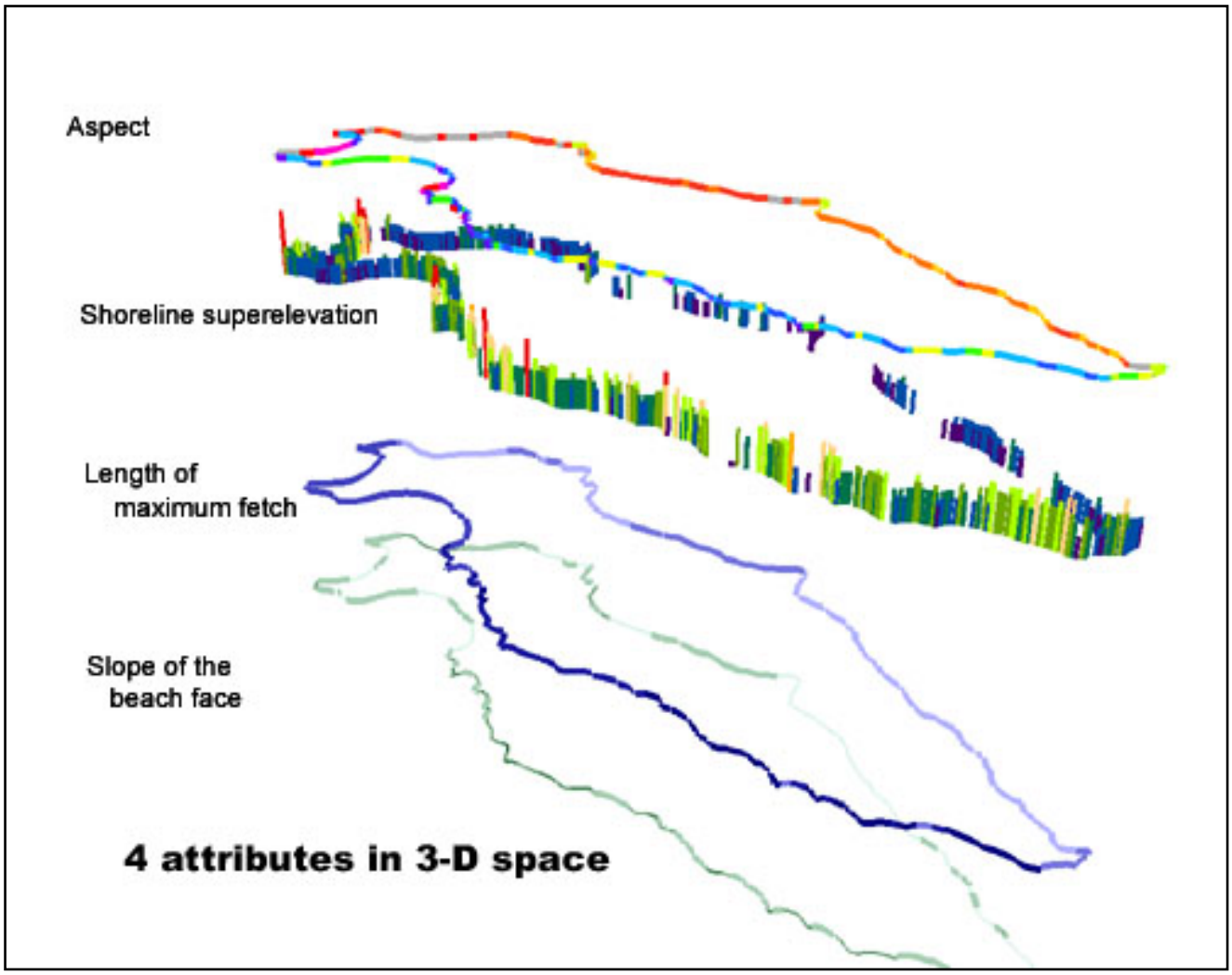


Figure 18. Stacked-attribute display of four attributes with location referenced in 3-D geographic space. From high to low the four attributes are: aspect, shoreline superelevation, length of maximum fetch, and slope of the beach face. Color hue, color intensity, and line thickness denote greater values of fetch and slope. For aspect, colors from a color-rose indicate 24 compass directions. Magnitude of shoreline superelevation is shown by color hue and by rod height as in Figure 16. Stacked-attribute displays communicate general patterns of four attributes effectively.

Traditional maps and graphs display one attribute in space effectively and lead to data insights. Stacked 3-D visualization effectively communicates relationships among up to 5 attributes. But these approaches do not meet the need to visualize many attributes, spatially, simultaneously, in a format where they can be manipulated, rearranged, and their colors changed to explore relationships.

Columnar displays of multiple attributes. GSA participants' initial reactions to columnar displays included wonder, confusion, amusement, and genuine interest. Most earth scientists work with columnar depictions of core logs, correlation charts, and stratigraphic columns. In their own work they face challenges of displaying information on maps and

frustration that pre-GIS, hard-copy maps rarely can show more than five attributes for a location simultaneously. At least two researchers saw the potential for viewing their data as columnar displays. One, a researcher working on reservoirs of the Tennessee Valley Authority, saw immediate use for the technique to display shorezone attributes similar to those of Great Salt Lake shoreline research. Another, working on climate change and the Great Lakes, saw the potential to display stratigraphic information, in color, using columnar displays. Another researcher working on coastal processes of Chesapeake Bay saw the potential for visualizing relationships but was concerned about the GIS sophistication it would take for him to get his data ready for display.

Discussion: applicability beyond shoreline research.

As former State Geologist of Utah, and a present member of the board of the Metropolitan Water District of Salt Lake and Sandy, I identify several applications for this type of display. Examples include: columnar display of multiple attributes of faultlines, pipelines, streams, core logs, and stratigraphic columns. GIS has expanded opportunities to manage diverse data types associated with these features. Columnar display of multiple attributes is one more tool in the toolbox of GIS display alternatives. Perhaps because I have invested so much time with it, I perceive many situations where an array of attributes associated with linear features could be presented simultaneously and interactively using columnar display.

I displayed my data in this format because I did not find a relatively easy way to present multiple attributes simultaneously and interactively in a GIS. I hope this approach is attractive enough for a product developer to collaborate to make it user-friendly. Columnar displays helped me visualize relationships among shoreline attributes. It may help others visualize relationships among multiple attributes of other linear features.

Conclusions.

GIS offers an array of tools for visualizing spatial data for analysis and for presentation. In general, the more attributes to be displayed, the more complex the display. Displays of spatial variability of one attribute of a linear feature are effective for visualizing spatial relationships and communicating information. Presentations of up-to-four or five attributes, stacked in 3-D space are effective for communicating relationships. The stacked-attribute approach has limitations for analysis and communications beyond four or five attributes for a complex linear feature such as a shoreline.

Columnar displays can present dozens, if not hundreds, of multiple attributes of a linear feature. They can be constructed using commercially available software, specifically ArcGIS. They have flexibility and can present diverse data types. They show spatial

coordinates both in geographic location and location along a linear-referenced route. Because display columns represent attributes as map layers, they can be displayed or hidden interactively. Attribute values and subsets of attribute values can be highlighted interactively using color. Problems with the technique in its present state of development include its large files, complex sets of map layers and resulting slow display. Large-format hardcopy display is required for hard-copy analysis and presentation. Construction of columnar displays requires familiarity with several components of GIS including measured routes, linear referencing, cartographic display, and plotting of large files. Earth scientists familiar with stratigraphic columns found columnar display of linear-referenced attributes a familiar format. The technique helped in explorations of patterns of relationships among 20 attributes of the 1986-87 shoreline of Great Salt Lake on Antelope Island because all 20 attributes could be viewed at once, spatially, and interactively.

Acknowledgements.

I thank Matthew A. Mabey for his collaboration in the development of the first successful columnar display of the Antelope Island research data. Past and present colleagues in the Department of Geography, University of Utah have encouraged and provided constructive criticism of this technique. I thank Barry Beidiger, Thomas J. Cova, George F. Hepner, Matthew A. Mabey, and Tamara J. Wambeam for reading earlier drafts of this paper. Reference to equipment and software in no way represents an endorsement of a product.

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