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# PATTERN MATCHING: CLASSIFICATION OF AMMONITIC SUTURES USING GIS

**Lori L. Manship**

## ABSTRACT

Geographic Information Systems (GIS) is utilized to apply spatial analysis techniques to visually and quantitatively match ammonoid suture patterns for classification. The Turonian ammonite family Coilopoceratidae was chosen as the basis for this project, because the similar suture patterns within the family make species-level identification a challenge. A *Coilopoceras springeri* suture template was created by overlaying 10 different *Coilopoceras springeri* suture patterns, using the right holotype suture pattern as the basal or designation guide. Templates for *Coilopoceras colleti* and *Hoplitoides sandovalensis* sutures were constructed in the same manner. Sutures of known and unknown specimens were tested within the templates in order to identify species. The sutures of known specimens matched with the correct templates and did not compare well with other species' templates. Sutures of unknown specimens clearly fit within one template better than within others and, hence, could be reliably classified to the species level. In addition to species classification, the GIS method provides a mechanism for both visual and quantitative comparisons of individual sutures. This GIS method will aid professional and avocational paleontologists, biostratigraphers, and geologists in classifying ammonite species, and may help further our understanding of suture morphogenesis and function by providing a standard basis for morphological comparison of complex sutural patterns.

Department of Geosciences, Texas Tech University, Lubbock, Texas, 79409-1053, USA.
lori.l.manship@ttu.edu

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## INTRODUCTION

An important method for ammonoid identification is the recognition of suture patterns. These patterns mark the union between the septa and the shell wall of the ammonite phragmocone. Because of the complex structural components of suture patterns, it may be difficult to visually match patterns for species identification. However, the linear nature of the sutures makes them a prime candidate for evaluation using a Geographic Information System (GIS). GIS was developed to enable computers to perform spatial analysis for environmental problems and geological mapping. Using GIS is a novel and innovative way to apply spatial analysis techniques to paleontological problems. A GIS model has been developed that functions as a user-friendly template for matching ammonitic suture patterns for species identification. Unlike other methods, only a fragment of the ammonite that reveals the lateral sutural elements is required–it is not necessary to break the specimen to see the inner whorls. This model will aid paleontologists and geologists in identifying ammonites for systematics and biostratigraphy. One advantage of using the GIS sutural template is that GIS software is widely available, and GIS methods are taught in many universities. While developed specifically for species identification, this approach also permits quantification of variation in suture form and, hence, will be a valuable tool for morphometric analyses.

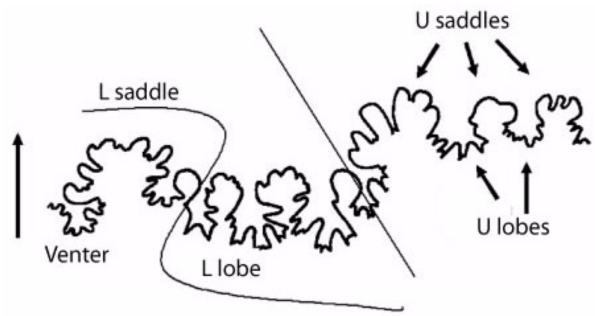



**Figure 1.** *Coilopoceras springeri* suture pattern using a modified version of Wedekind's terminology. Suture pattern nomenclature is expressed by the letters L = lateral and U = umbilical. Curved line separates the saddle from the lobe. Straight line is the division between the lateral and umbilical sutures. Arrow on venter points toward aperture.

## Suture Patterns

Sutures consist of groups of individual elements. These elements transform during the course of phylogeny, and hence offer a method to identify ammonoids. Two types of sutural terminologies used by paleontologists are morphogenetic and morphographic (Kullmann and Wiedmann 1970).

Noetling (1905, 1906) first used morphogenetic symbol terminology. This system was improved by Wedekind (1913, 1916). Noetling and Wedekind's system is based on ontogenetic development that provides information on homologies. Designated symbols are placed on the adult sutural elements, which record the ontogeny of the element, creating a sutural formula.

Wedekind's terminology uses five symbols in the order of their phylogenetic appearance. 'E' is the external lobe and external saddle. The 'E' saddle is located on the venter. The saddle on the venter is cut medially so that one half is on one side of the ammonoid, and one is on the other. The 'E' lobe is between the 'E' saddle and the 'L' saddle. 'L' is the lateral saddle and lateral lobe. Dorsal to the 'L' lobe is the 'U' saddle and 'U' lobe. 'U' denotes sutures close to the umbilical area of the ammonoid. 'A' signifies an adventitious lobe. 'I' is the internal saddle and lobe, the saddle and lobe dorsal to the 'U' lobe. 'I' elements are covered by the overlapping shell and so are not usually visible. Juveniles start out with one E, L, U, and I. As the ammonites grow and gain more umbilical lobes, the suture "formula" is denoted as E, L, $U_2$, U, and I. The 'U' subscript gives the order in which the umbilical elements appeared during ontogeny. Ruzhentsev (1949, 1957) and Popov (1965) use a modified version of Wedekind's terminology, using different names and symbols for sutural elements.

Morphographic sutural terminology is a descriptive system based on the position of individual elements. Schmidt (1921) developed this simpler morphographic method by adding symbols to Wedekind's terminology. This system works well for communication of morphological data.

Wedekind's terminology is the oldest practicable morphogenetic system of terminology and is the most popular today. The terminology used in this paper is a modified version of Wedekind's. For simplicity, only the L and U symbols will be used, because that is all that is necessary for this GIS model of identification (Figure 1).

## The *Coilopoceratidae*

The Upper Cretaceous Coilopoceratidae Hyatt 1903, which includes the genera *Coilopoceras* Hyatt 1903 and *Hoplitoides* von Koenen 1898, are mostly compressed, involute ammonites that can be either smooth or broadly ribbed, and show slender to somewhat more inflated whorl sections. They have a sharp venter that is narrowly rounded on early whorls and becomes well rounded on the later whorls. Cobban and Hook (1980) suggested that the *Coilopoceras* in the Western Interior of North America were dimorphic with one form being more compressed than the other form. Another dimorphic difference noted by Cobban and Hook (1980) is the occurrence of both smooth and ribbed shells. Some specimens even exhibit low, rounded ventrolateral tubercles.

*Coilopoceras* closely resembles *Hoplitoides* in appearance and suture pattern, making it difficult to

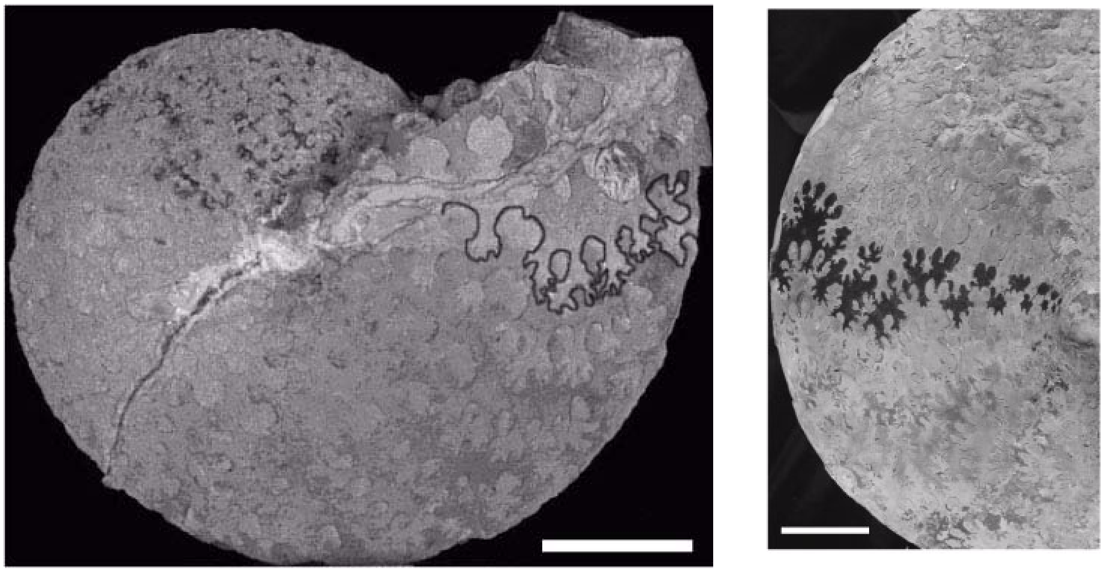


**Figure 2.** *Hoplitoides* and *Coilopoceras* specimens used in this analysis; 1, *Hoplitoides sandovalensis* USNM 275883; 2, *Coilopoceras chispaense* holotype (*Coilopoceras springeri*) BEG 34086. Scale bar in upper image is 5 cm, and in lower image is 10 cm.

distinguish between the two genera. Both *Coilopoceras* and *Hoplitoides* (Figure 2) have a characteristic suture in which the lateral lobe is broad and deeply bifid, and the dorsal branch of the lateral lobe is in a lower position than the ventral branch. Cobban and Hook (1980) stated that *Coilopoceras* was derived from *Hoplitoides* by the total loss of a truncated venter. *Hoplitoides* shows a progressive reduction in the extent of venter truncation (constant in each species, but more reduced in younger species), which disappears completely in *Coilopoceras.* The difference between *Coilopoceras springeri* (the oldest *Coilopoceras*) and *Hoplitoides sandovalensis* (the youngest *Hoplitoides*) is that *Coilopoceras springeri* completely lacks a truncated venter in the early whorls, whereas *Hoplitoides sandovalensis* retains a truncated venter in the early whorls.

The age relationships within the Coilopoceratidae in the Cretaceous Western Interior Seaway of North America are generally sequenced as: *Hoplitoides wohltmanni* von Koenen 1897 (the oldest species) followed by *Hoplitoides sandovalensis* Cobban and Hook 1980, *Coilopoceras springeri* Hyatt 1903, *Coilopoceras colleti* Hyatt 1903, and *Coilopoceras inflatum* Cobban and Hook 1980 (considered the youngest *Coilopoceras* species by Cobban and Hook (1980)).

## METHODS

The ammonite specimens used to make the *Coilopoceras springeri* template, as well those used to evaluate the model, are from the National Museum of Natural History in Washington, D.C., the University of Texas Memorial Museum in Austin, Texas, various literature sources (Table 1), and two field localities from the Chispa Summit Formation in Texas where over 80 unknown ammonite specimens were collected.

**Table 1.** *Coilopoceras springeri* template specimen's reference list.

| Specimen | Museum catalog # | Publication | Page # |
|---|---|---|---|
| 1 | Holotype | Hyatt 1903 | 276, Plate XII Fig. 1 |
| 2 | Holotype | " | 276, Plate XII Fig. 2 |
| 3 | USNM 420161 | Kennedy 1988 | 66-67 |
| 4 | USNM 420159 | " | " |
| 5 | USNM 275916 | Cobban/Hook 1980 | 18-19 |
| 6 | USNM 275907 | " | " |
| 7 | USNM 275917 | " | " |
| 8 | USNM 275918 | " | " |
| 9 | USNM 278123 | " | 20 |
| 10 | Drawing | K. Young's catalog of sutures TMM | copied |

ArcGIS Desktop® 8.2 by ESRI was chosen for this project because of its spatial and database capabilities (ArcGIS), and the easy point and click version (Desktop). Within the ArcGIS Desktop® software package, ArcInfo Workstation, ArcMap, and ArcToolbox were utilized. Arc handles the spatial features (locations and shapes of objects), and Info handles the object's descriptions and how they relate to each other. The spatial information is the suture pattern. The database has information on each specimen of ammonite, such as its species name, catalog number, the suture length, and area of the sutural template.

To create the *Coilopoceras springeri* templates, suture patterns available in the literature were used. Important factors in the choice of using published information rather than original specimens are their accessibility. Ten *Coilopoceras springeri* suture patterns (taken from 73 to 400 mm diameters) were scanned from publications and converted to a digital format. Table 1 lists the 10 specimens, museum catalog numbers, and publications from which the suture patterns were obtained.

To test the accuracy of the *Coilopoceras springeri* templates, the suture patterns from museum specimens were traced directly from the specimen onto a transparency film, including both left and right shell sides. Suture patterns closest to the aperture were chosen to get the most complex pattern. Using a transparency to trace the sutures was an accurate transfer method and provided the capability to visualize the suture pattern clearly while tracing. It was also an efficient way to obtain a suture pattern for entry into the GIS. (For complete, step-by-step instructions of how to build a sutural template, see Manship 2003).

The images were then scanned into Adobe Photoshop® 4 using a Hewlett-Packard Precision Scanner. In general, images are stored as raster datasets using binary or integer values and are positioned in some type of coordinate space. The suture images needed to be enlarged to be visible in ArcEdit, so a width of 5,000 pixels was set for each suture pattern in Adobe Photoshop® 4. The images were also changed in Adobe Photoshop® 4 to grayscale (not RGB color). This change prevents the images from becoming a band of three colors (RGB) when later converting from image to grid. Images were saved in the TIFF format, which is compatible with ArcInfo and ArcGIS Desktop®.

The suture images were next converted from the TIFF format to an ArcInfo grid (ArcScan's primary raster data format). The grid places coordinates on the suture patterns, which is important for controlling scale and orientation. Scanned images are in a non-real world coordinate system (image space) and must be converted into some type of

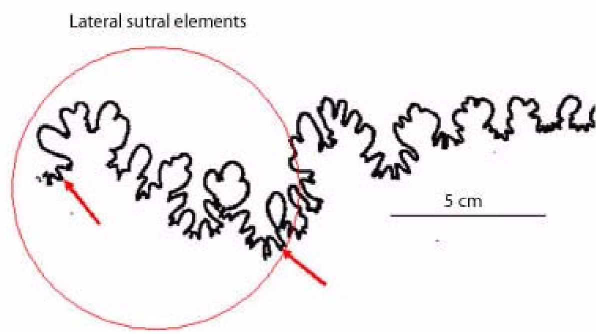



**Figure 3.** Placement of tics. Arrows denote the position where the tics (dots) are inserted on the *Coilopoceras springeri* holotype right suture. Placements of the tics are on the ventral edge of the lateral saddle and the major element in the lateral lobe closest to the umbilicus (circle around lateral suture). These positions were chosen as the baseline position for all tics. All right suture patterns have been adjusted to this pattern's orientation.

projection using x, y coordinates. The conversion is completed via ArcToolbox from ArcGIS Desktop®.

The grid-formatted suture patterns were opened using ArcTools through the ArcEdit environment. In order for ArcScan to capture the suture patterns, the grids must be converted into coverages for tracing. Coverages are file-based vector data storage formats used for storing attributes, projections, and shapes and are the primary vector format for ArcInfo and ArcGIS Desktop. The coverages store features such as arcs, polygons, tics, and links.

Each suture was digitized in ArcTools, using ArcEdit's editing environment. The process of digitizing converts features to a digital format using x, y coordinates. The coordinates were automatically recorded by the program and stored as spatial data. Manual adjustments were then performed, if necessary, to ensure an accurate tracing. Once the initial parameters were set correctly, automatic tracing proved efficient.

Once digitizing was complete, two tics (control points) were manually placed on predetermined positions on each suture pattern to allow the various sutures to be synchronized when aligning the patterns. The positions chosen for the tics were the beginning of the lateral saddle and the ending of the lateral lobe (Figure 3). These positions were chosen to bound the lateral sutural elements, the area of maximum variation within the suture pattern. Because of its variability, this region is most useful for species recognition.

In the attribute table of the suture pattern coverages, specimen identification columns were added. Attribute tables are tabular files containing

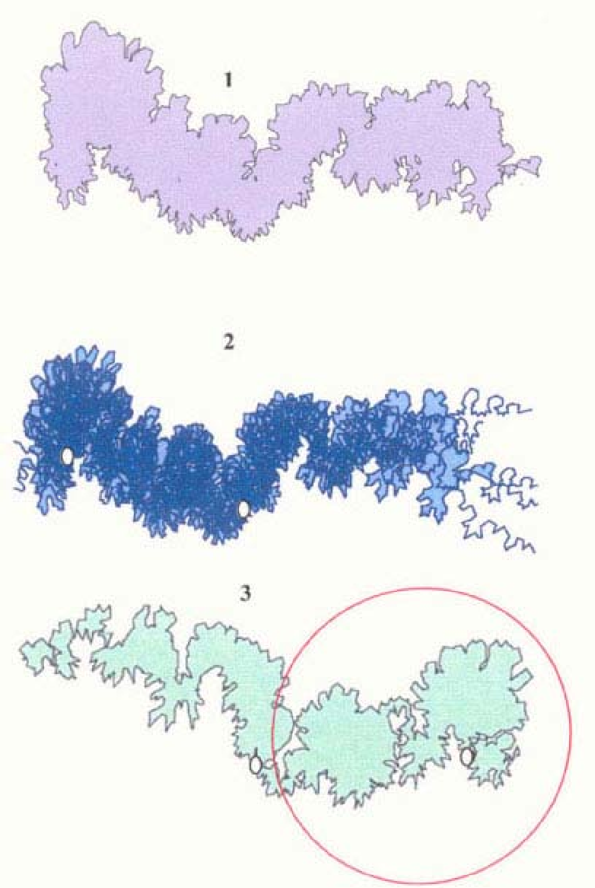



**Figure 4.** Completed polygons, with and without sutures, with white ovals representing the tics; 1, The right/left *Coilopoceras springeri* template. The polygon was made from the outer boundaries of 10 different *Coilopoceras springeri* suture patterns; 2, The polygon showing the 10 *Coilopoceras springeri* sutures that were used in the making of the *Coilopoceras springeri* right/left template. Note the increasing error in orientation dorsal of the tic marks; 3, The *Coilopoceras springeri* left template, large oval denotes the lateral sutural elements.

rows and columns. Columns represent one attribute of a feature (or information describing the feature), such as the area of the polygon, length of the suture, or specimen identification. The rows represent the actual values and sutural pattern identifications. The species name and museum catalog numbers were inserted into the appropriate attribute table columns.

The *Coilopoceras springeri* suture pattern coverages must be converted from their coordinate system to a predefined coordinate system, so they will all overlay in the same orientation. The *Coilopoceras springeri* holotype was chosen, combining opposing sutures from both left and right sides of the ammonite, for the basal suture pattern or destination. The left sutures were rotated in Adobe Photoshop® 4 to superimpose them with right sutures. The coverages of the other sutures (source) have been aligned or shifted to best fit the base pattern defined by the holotype (destination) using geometric transformations. The similarity transformation function compares and aligns the coordinates of the control points (the tics that were placed previously) and transforms the coverages to the new destination locations, keeping the aspect ratio of the suture patterns the same. This method scales all the sutures to the same size.

Once all the *Coilopoceras springeri* template sutures were transformed to the same destination locations or coordinates, they were merged together through the geoprocessing function. This process overlays coverage selections and performs analysis, topology processing, and data conversion. The output results from this operation created one layer of all 10 *Coilopoceras springeri* suture patterns merged, as well as their attribute tables, making the completed right/left template.

When the *Coilopoceras* suture patterns were merged together, they were changed into a shapefile. Shapefiles are vector data storage formats, but to get correct topology, shapefiles must be converted back into coverages. Topology in coverages refers to spatial relationships between connecting or adjacent features, arcs (sets of connected points), and areas (sets of connected arcs). Topology was created using the Clean and Build tools. Clean also corrected undershoots (an arc that does not extend far enough to intersect another arc) and overshoots (portion of an arc digitized past its intersection with another arc) within a specified tolerance, and placed nodes at each intersection. Manual editing was also used to correct small undershoots. Build was used to create a feature attribute table for the polygons. Dissolving the arcs within the polygon to make one polygon, based on specific attributes, was the last step.

The completed *Coilopoceras springeri* right/left template (Figure 4.1) is an outer boundary of all the suture patterns used (Figure 4.2) to make the polygon. To create the right/left template, the left *Coilopoceras springeri* template (Figure 4.3) was reversed, aligning the tics with the original right *Coilopoceras springeri* template. *Hoplitoides sandovalensis* and *Coilopoceras colleti* templates were also made and tested in the same manner as stated previously. Recall that most variation in the suture pattern occurs within the lateral sutural elements. With only two tie points or tics added to each specimen, accuracy in overlaying the sutures is lost in the polygon beyond the second tic (Figures 3 and 4.3).

One quantitative method to compare the sutures tested within a template was to calculate the percentage of suture pattern length that did not fit within the template. This method used x-tools, a script downloaded from the ESRI website (www.esri.com). The Erase command removes the portion of the suture that falls within the template, leaving the bits of suture that fall outside of the template. This outside length can then be divided by the total suture line length to determine the percentage of suture length that falls outside of a template.

In another effort to quantitatively compare sutures, two sutures were compared against each other. The sutures were overlain and the area (polygon) between the two sutures was calculated. The GIS software automatically calculates the area of a polygon, allowing an easy and quantitative comparison of two suture patterns.

## RESULTS

### Templates

To visualize the difference between the left and right sutural templates, the right *Coilopoceras springeri* template was overlaid on the *Coilopoceras springeri* right/left template. Figure 5.1 reveals the differences between right and left sutures. Notice that the horizontal sutural template length is much shorter for the right template.

The *Hoplitoides sandovalensis* and *Coilopoceras springeri* right templates were compared (Figure 5.2). Even with as few as three suture patterns combined to make the template, one can easily see that the templates are different. The *Hoplitoides sandovalensis* template has taller lateral saddles than the *Coilopoceras springeri* template, and the ventral most element of the *Hoplitoides sandovalensis* template is much narrower than the *Coilopoceras springeri* template.

### Individual Sutures

The area of mismatch or difference between individual sutures is documented in Table 2. The units are arbitrary quantitative units, but allow accurate comparisons of the sutures scaled to the same grid. The same *Hoplitoides sandovalensis* suture pattern drawn by two different authors shows a difference of 6.62 units (Figure 6.1). This difference demonstrates minimal error in tracing suture patterns. The area of mismatch or difference between the right and left opposing sutures of *Coilopoceras springeri* holotype is 10.48 units (Figure 6.2, Table 2). The closest sutural match of a second specimen to the *Coilopoceras springeri* holotype right suture is the *Coilopoceras springeri*

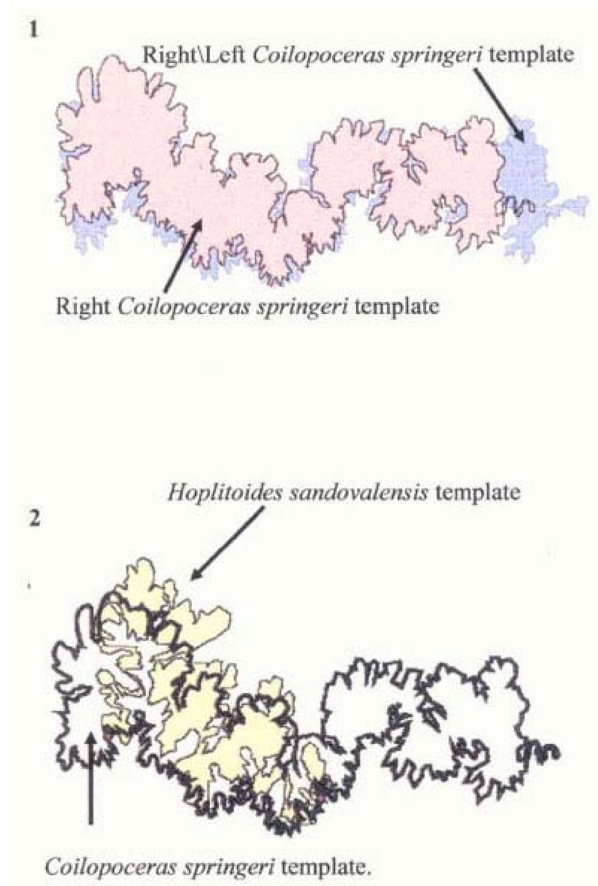



**Figure 5.** Templates tested against each other; **1.** *Coilopoceras springeri* right template tested against the *Coilopoceras springeri* right/left template. The difference between the right and left sutures is most noticeable by a shortening of the right suture template; **2.** The difference between *Hoplitoides sandovalensis* right template and *Coilopoceras springeri* right template. The *Coilopoceras springeri* right template has been faded to clarify the difference between the two templates.

paratype USNM 420161. Figure 6.3 shows the comparison of these two specimens. The difference in area between them is 14.45 units, indicating that the difference between individuals is larger than the difference between the right and left sides of the same individual (Table 2). In Figure 6.4, the *Coilopoceras springeri* USNM 420159 and *Coilopoceras colleti* USNM 278092 sutures have been compared to each other. The area of mismatch between these two different species is 21.87 units, which indicates that the difference between two different species is larger than the difference within the same species, as noted in Table 2. *Coilopoceras springeri* USNM 275907 and *Hoplitoides sandovalensis* USNM 420145 suture patterns (Figure 6.5) were also compared to each other. The area of mismatch between these two genera, as

**Table 2.** Quantitative comparisons between individual sutures.

| Sutures | Area | Relationship |
|---|---|---|
| *Hoplitoides sandovalensis* USNM 420145 vs. Itself (same suture) (Taken from Kennedy (1988) and Young's Suture Catalog) | 6.62 | Same suture |
| Right vs. left holotype (*Coilopoceras springeri*)l | 10.48 | R\L opposing |
| *C. springeri* holotype vs. *C. springeri* paratype USNM 420161 | 14.45 | Same species |
| *C. springeri* USNM 420159 vs. *C. colleti* USNM 278092 | 21.87 | Same genus |
| *C. springeri* USNM 275907 vs. *H. sandovalensis* USNM 420145 | 32.08 | Same family |

shown in Table 2, is 32.08 units, indicating that the largest area of difference is seen between genera.

### Identified Specimens

Several USNM specimens identified as *Coilopoceras springeri* were tested against the *Coilopoceras springeri* right/left template. First, consider USNM 278120, a rather unusual suture pattern compared with the other *Coilopoceras springeri* suture patterns, in that the first element in the lateral saddle seems too deeply split. The elements of USNM 278120 do not exactly line up with the template's elements (Figure 7.1) though the suture pattern mostly fits within the template. To get a better idea of just how much area is out of the template, the suture pattern of USNM 278120 was overlaid with the *Coilopoceras springeri* right/left template. As can be seen in Figure 7.2, little suture pattern lies outside of the polygon. The percentage of suture pattern length that does not fit within the template was also calculated. The percent of suture that falls outside of the sutural template is 4.85%, as seen in Table 3.

On the other hand, the specimen *Coilopoceras springeri* USNM 278121 falls satisfactorily in the *Coilopoceras springeri* left template (Figure 7.3). The elements all line up nicely, the exception being the second element from the venter, which is slightly taller than that of the template. The percentage of suture length that falls outside the boundaries of the left *Coilopoceras springeri* template is 17.48% (Table 3).

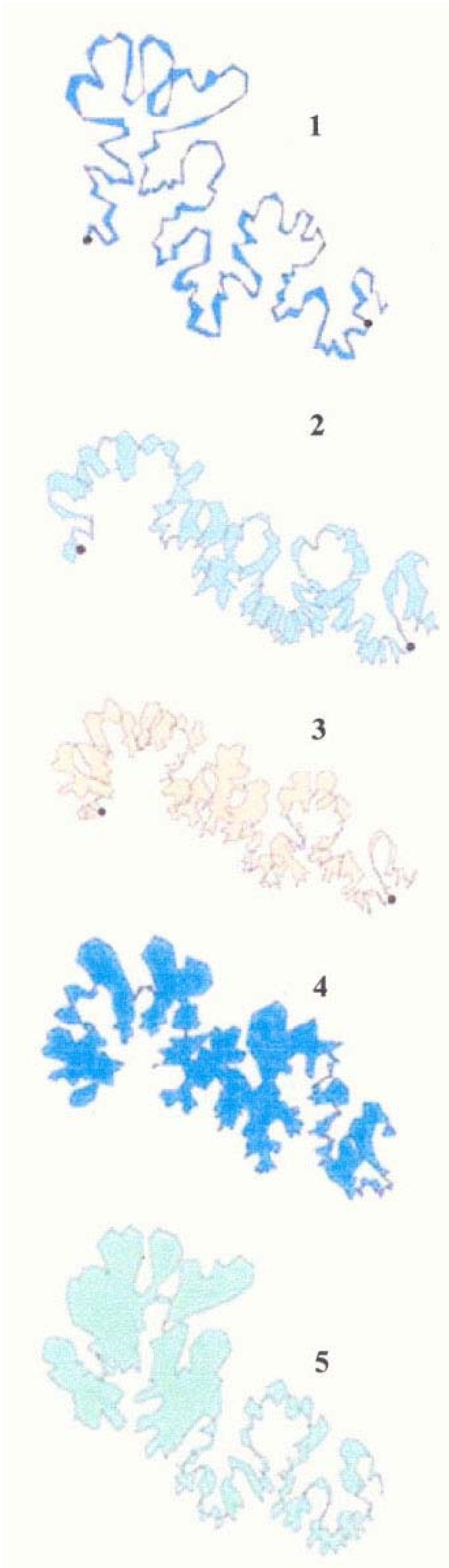
*Hoplitoides sandovalensis* is the ancestor of *Coilopoceras springeri*. The shell shape of *Hoplitoides sandovalensis* is virtually identical to *Coilopoceras springeri,* as Cobban and Hook (1980) pointed out. *Hoplitoides sandovalensis* USNM 275883 was tested against the *Coilopoceras springeri* left template. The *Hoplitoides sandovalensis* lateral saddle is significantly taller than the *Coilopoceras springeri* left template (Figure 7.4). Another interesting observation is that the lateral lobe element closest to the umbilicus is very deep. Hence, there is a large angle from the lateral saddle element closest to the venter to the lateral lobe element closest to the umbilicus. The percentage of *Hoplitoides sandovalensis* suture length outside of the *Coilopoceras springeri* left template is 47.24% (Table 3).

Two different sutures taken from the same specimen of *Hoplitoides sandovalensis*, USNM 420145, were tested against the *Coilopoceras springeri* right template (Figures 7.5 and 7.6). The specimen is described as a juvenile, and the two sutures were copied from sutural drawings taken from Cobban and Hook (1980). Like the previous *Hoplitoides sandovalensis* specimen, the first element (closest to the venter) is taller than the *Coilopoceras springeri* template. This specimen, however, does not seem to have the large angle from the saddle closest to the venter to the lobe closest to the umbilical sutures. The suture pattern in Figure 7.5 is denoted *Hoplitoides sandovalensis* USNM 420145 pattern 2. The percentage of suture length that falls outside of the boundary of the *Coilopoceras springeri* right template is 20.58%

(Table 3). The other suture pattern from the same specimen is shown in Figure 7.6 and labeled *Hoplitoides sandovalensis* USNM 420145 pattern 3. The first element (closest to the venter) is taller on the *Hoplitoides sandovalensis* suture than the *Coilopoceras springeri* template. The percent of suture length outside of the *Coilopoceras springeri* right template is 26.37% (Table 3).

*Coilopoceras inflatum* USNM 275937 was placed within the *Coilopoceras colleti* right template to compare the differences and similarities between these two species (Figure 8.1). The *Coilopoceras inflatum* sutural elements are similar to the *Coilopoceras colleti* right template elements. However, in the first element closest to the venter, the *Coilopoceras inflatum* suture is placed more ventrally. The percentage of suture length that falls outside of the *Coilopoceras colleti* right template is 22.35%. The calculated figure is listed in Table 3.

Suture patterns taken from various other museum specimens were tested using the *Coilopoceras springeri, Hoplitoides sandovalensis,* and the




*Coilopoceras colleti* templates. *Hoplitoides wohltmanni* USNM 307655 was tested against all three templates. *Hoplitoides wohltmanni* is the ancestor of *Hoplitoides sandovalensis* (Cobban and Hook 1980), which was tested in the *Hoplitoides sandovalensis* right template (Figure 8.2). The elements possess a similar alignment of sutural elements. The difference is that the *Hoplitoides wohltmanni* sutural elements are shorter than the *Hoplitoides sandovalensis* template elements, and the percentage of suture length that falls outside of the template is 38.50% (Table 3). When *Hoplitoides wohltmanni* USNM 307655 was placed into the *Coilopoceras springeri* right template (Figure 8.3), an even closer fit was noticed with 5.65% falling outside the template (Table 3). The only difference is in the lateral saddle closest to the venter, where it crosses the *Coilopoceras springeri* template slightly. Looking at the same specimen in the *Coilopoceras colleti* right template (Figure 8.4), several differences are clear. The basic shape of the pattern fits; however, the *Coilopoceras colleti* right template has only three lateral elements whereas *Hoplitoides wohltmanni* exhibits four lateral elements, similar to *Coilopoceras springeri* and *Hoplitoides sandovalensis.* The percentage of suture length that falls out of the sutural boundary is 22.75% (Table 3).

*Coilopoceras colleti* USNM 278093 is one of the sutures used in making the *Coilopoceras colleti* right template. This suture shows many differences from the *Coilopoceras springeri* right template (Figure 8.5). A primary difference is in the number of lateral sutural elements, with *Coilopoceras colleti* exhibiting only three lateral elements while the *Coilopoceras springeri* right template shows four lateral elements. There is 11.32% of the suture length outside of the template (Table 3).

**Figure 6 (left).** A comparison of sutures; 1. *Hoplitoides sandovalensis* USNM 420145 #1 and USNM 420145 #2 suture pattern tested against each other for comparison. The area of difference is 6.62 units. This result confirms that variations in how a suture pattern is captured are not an important source of error; 2. *Coilopoceras springeri* Holotype right and left opposing suture template. The polygon was edited so the overlaps did not show as differences. The area of difference is10.48 units; 3.*Coilopoceras springeri* Holotype right suture compared with *Coilopoceras springeri* paratype USNM 420161. The area of difference is 14.45 units; 4. *Coilopoceras springeri* USNM 420159 compared with *Coilopoceras colleti* USNM 278092, two different species within the genus *Coilopoceras.* The area of difference is 21.87 units; 5. A suture pattern comparison between two genera, using *Coilopoceras springeri* USNM 275907 and *Hoplitoides sandovalensis* USNM 420145. The area of difference is 32.08.

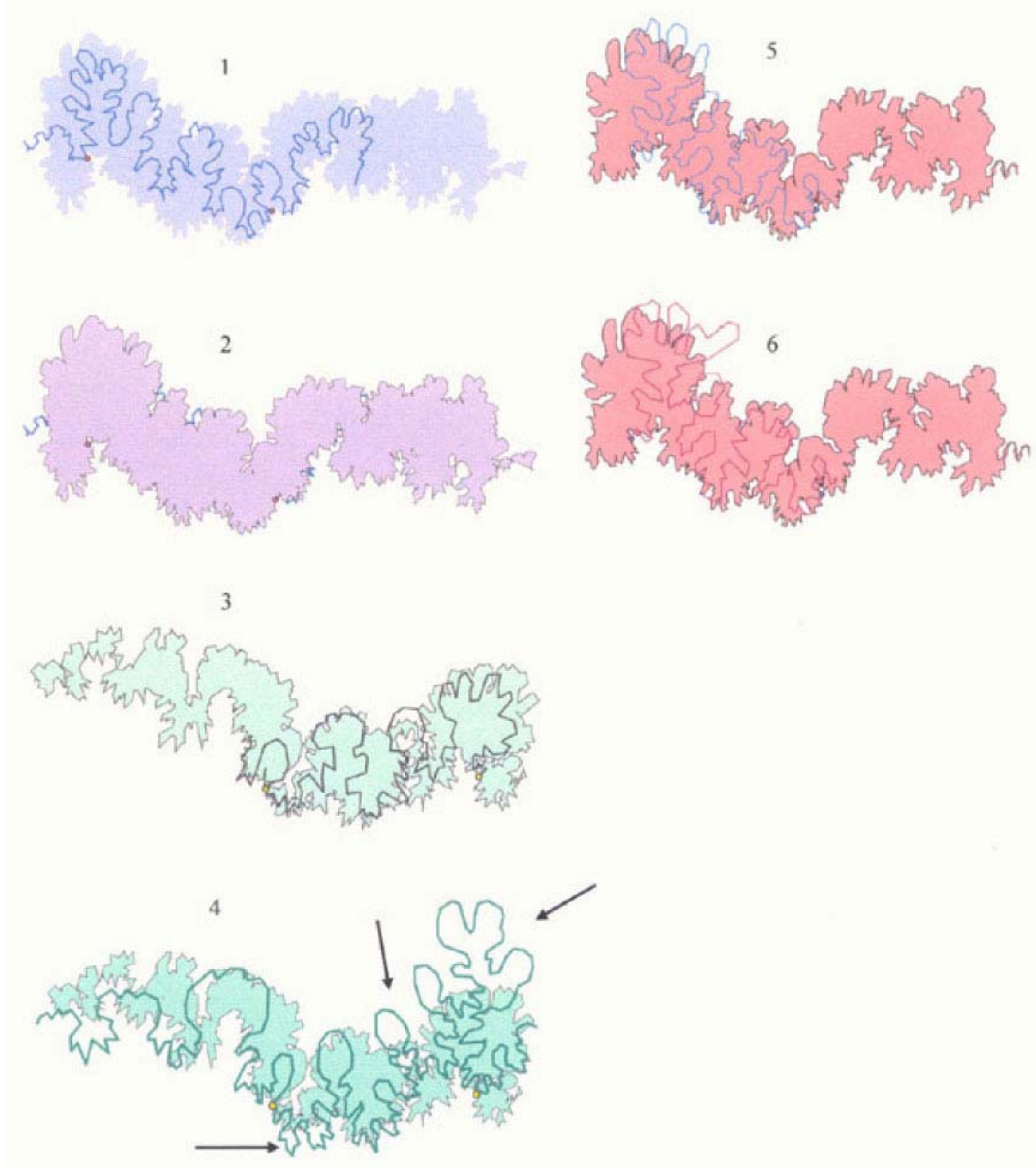



**Figure 7.** Testing the *Coilopoceras springeri* templates; **1.** *Coilopoceras springeri* USNM 278120 suture pattern tested in the *Coilopoceras springeri* right/left template. Elements are offset from the template's elements; however the area outside of the polygon is minimal; **2.** *Coilopoceras springeri* USNM 278120 suture pattern tested under the *Coilopoceras springeri* right/left template. The area outside of the polygon is minimal, indicating a good fit; **3.** *Coilopoceras springeri* USNM 278121 suture pattern tested in the *Coilopoceras springeri* left template. The elements line up with the template's elements. The second element from the venter is slightly taller, however; **4.** The two elements of *Hoplitoides sandovalensis* which are closest to the venter are twice as tall as the template's elements (upper arrows). The lobe closest to the umbilical sutures is also much deeper than the template's (lower arrow); (5 and 6), Two different sutures taken from the same specimen of *Hoplitoides sandovalensis*, USNM 420145; **5.** *Hoplitoides sandovalensis* USNM 420145 suture pattern tested in the *C. springeri* right template (USNM 420145 pattern 2). The lateral saddle closest to the venter is taller than the template's; **6.** *Hoplitoides sandovalensis* USNM 420145 suture pattern tested in the *Coilopoceras springeri* right template (USNM 420145 pattern 3). The lateral saddle closest to the venter is taller than the template's.

**Table 3.** Quantitative comparisons between sutures and templates.

| Suture | Template | Total Suture Length | Outside Suture Length | Percent Outside |
|---|---|---|---|---|
| *Coilopoceras springeri* USNM 278120 | *C. springeri* R\L | 80.043 | 3.884 | 4.85% |
| *Coilopoceras springeri* USNM 278121 | *C. springeri* left | 24.121 | 4.216 | 17.48% |
| *H. sandovalensis* USNM 275883 | *C. springeri* left | 41.134 | 19.43 | 47.24% |
| *H. sandovalensis* (Kennedy, 1988) USNM 420145 pattern 2 | *C. springeri* right | 77.194 | 15.89 | 20.58% |
| *H. sandovalensis* (Young's Suture Catalog) USNM 420145 pattern 3 | *C. springeri* right | 84.676 | 22.331 | 26.37% |
| *Coilopoceras inflatum* USNM 275937 | *C. colleti* right | 62.199 | 13.899 | 22.35% |
| *H. wohltmanni USNM 307655* | *C. springeri* R\L | 73.199 | 4.134 | 5.65% |
| | *C. colleti* right | 73.199 | 16.651 | 22.75% |
| | *H. sandovalensis* right | 73.199 | 28.181 | 38.50% |
| *Coilopoceras colleti* USNM 278093 | *C. springeri* R\L | 44.316 | 5.015 | 11.32% |
| *Coilopoceras colleti* USNM 278094 | *C. springeri* R\L | 91.61 | 24.137 | 26.35% |
| *Coilopoceras inflatum USNM 275939* | *C. springeri* R\L | 93.06 | 29.241 | 31.42% |
| | *C. colleti* right | 93.06 | 40.438 | 43.45% |
| | *H. sandovalensis* right | 93.06 | 44.599 | 47.92% |
| TMM NPL 1848-A | *C. springeri* left | 24.731 | 4.46 | 18.03% |
| TMM NPL 1848-AA | *C. springeri* R\L | 78.683 | 6.348 | 8.07% |
| | *C. colleti* right | 78.683 | 14.888 | 18.92% |
| | *H. sandovalensis* right | 78.683 | 35.141 | 44.66% |
| TMM NPL 1849 | *C. springeri* right | 88.586 | 0.923 | 1.04% |
| TMM NPL 1850-A | *C. springeri* right | 26.209 | 3.93 | 14.99% |
| TMM NPL 1851-R | *C. springeri* R\L | 69.703 | 2.406 | 3.45% |
| TMM NPL 1852 | *C. springeri* R\L | 66.434 | 1.503 | 2.26% |
| TMM NPL 1853 | *C. springeri* R\L | 104.813 | 8.987 | 8.57% |
| TMM NPL 1854 | *C. springeri* R\L | 75.717 | 2.716 | 3.59% |
| TMM NPL 1855 | *C. springeri* R\L | 56.839 | 6.354 | 11.18% |

becomes evident that the first and second lateral sutural elements are not completely split like most *Coilopoceras springeri.* However, the suture fits within the boundary of the template, and all the sutural elements are aligned with the template's elements, hence, this specimen can be identified as *Coilopoceras springeri.*

Specimens TMM NPL 1853 and TMM NPL 1854 were collected from measured section P (Figure 9). Specimen TMM NPL 1853 suture pattern was tested within the *Coilopoceras springeri* right/left template (Figure 10.8). The suture pattern fits relatively well within the template, and only 8.57% of the suture length is outside of the template (Table 3). The second, third, and fourth lateral sutural elements of TMM NPL 1853 are slightly offset toward the venter from the *Coilopoceras springeri* right/left template elements. TMM NPL 1854 was also tested within the *Coilopoceras springeri* right/left template (Figure 10.9). Like the other specimen from section P, the suture fits mostly within the boundaries of the template, with only 3.59% of its length being outside of the template (Table 3). The second and third lateral sutural elements of TMM NPL 1854 are slightly offset toward the venter from the *Coilopoceras springeri*

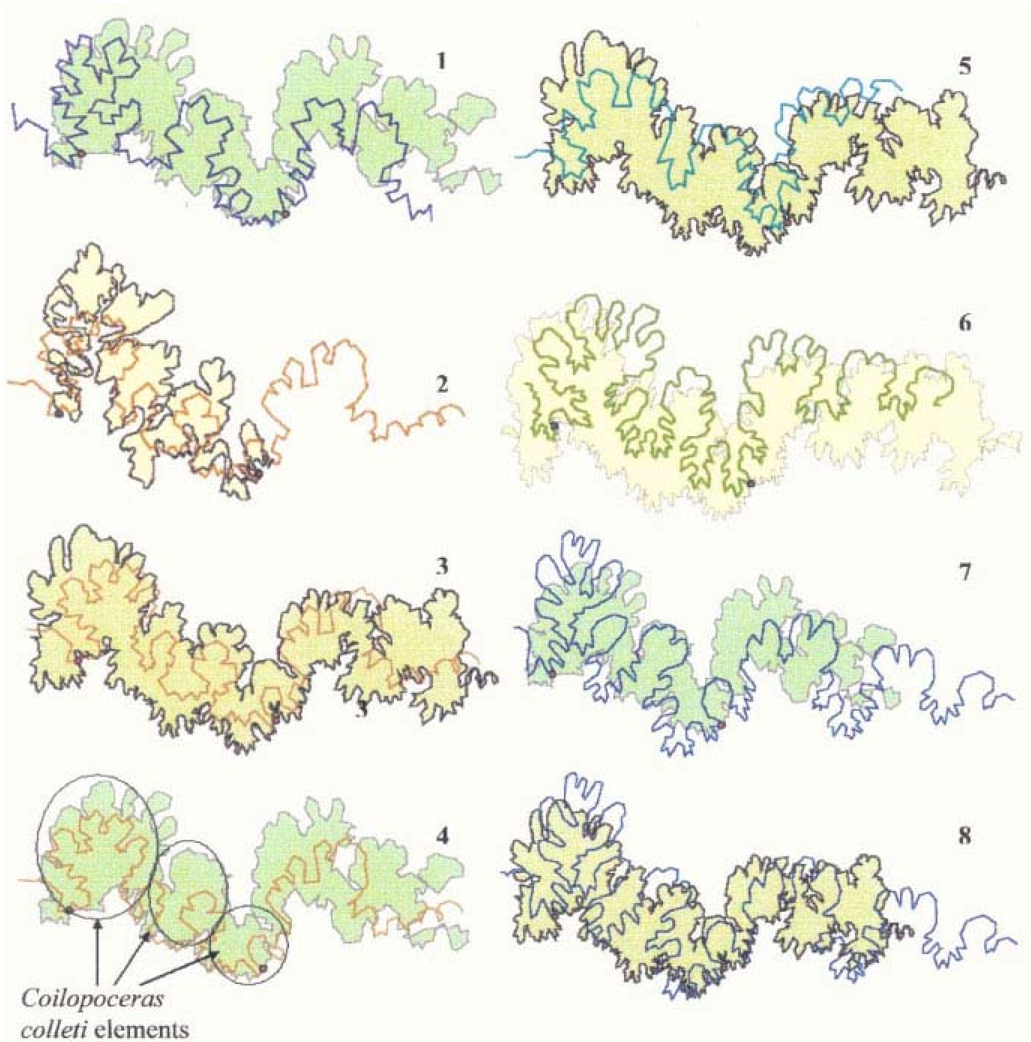



**Figure 8.** Comparison of various suture patterns within *Coilopoceras springeri, Hoplitoides sandovalensis,* and the *Coilopoceras colleti* templates; **1.** *Coilopoceras inflatum* suture pattern within the *Coilopoceras colleti* right template. Sutural elements of the *Coilopoceras inflatum* are similar to the *Coilopoceras colleti* right template elements, however, in the element closest to the venter, the *Coilopoceras inflatum* suture is placed more ventrally; **2.** *Hoplitoides wohltmanni* USNM 307655 tested against the *Hoplitoides sandovalensis* right template. Elements are similar in alignment. The difference is that the *Hoplitoides wohltmanni* sutural elements are shorter than the *Hoplitoides sandovalensis* template elements; **3.** *Hoplitoides wohltmanni* USNM 307655 tested against the *Coilopoceras springeri* right template. Elements are similar in alignment, except the lateral saddle nearest the venter is slightly over the top of the template; **4.** Elements are similar in alignment. *Hoplitoides wohltmanni* suture has four elements whereas *Coilopoceras colleti* right template shows three elements; **5.** *Coilopoceras colleti* USNM 278093 tested against the *Coilopoceras springeri* right template. The *Coilopoceras colleti* suture shows three elements, whereas the *Coilopoceras springeri* right template shows four; **6.** *Coilopoceras colleti* USNM 275894 tested against the *Coilopoceras springeri* right template. The *Coilopoceras colleti* suture shows three elements, whereas the *Coilopoceras springeri* right template shows four; **7.** *Coilopoceras inflatum* USNM 275939 tested against *Coilopoceras colleti* right template. Similar alignment in elements, however the height and depth vary; **8.** The *Coilopoceras inflatum* suture is much taller in the lateral-most saddle and has three lateral sutural elements versus the four lateral sutural elements in the *Coilopoceras springeri* right template.

right/left template elements. These two specimens are clearly *Coilopoceras springeri*, even though the elements of both are slightly offset from the templates. One possible explanation for the offset is that the large ribs on these specimens from this location forced a shift in septal position.

A specimen (TMM NPL 1855) from 20 miles northwest of the field location was examined. The unusual split in the lateral element closest to the

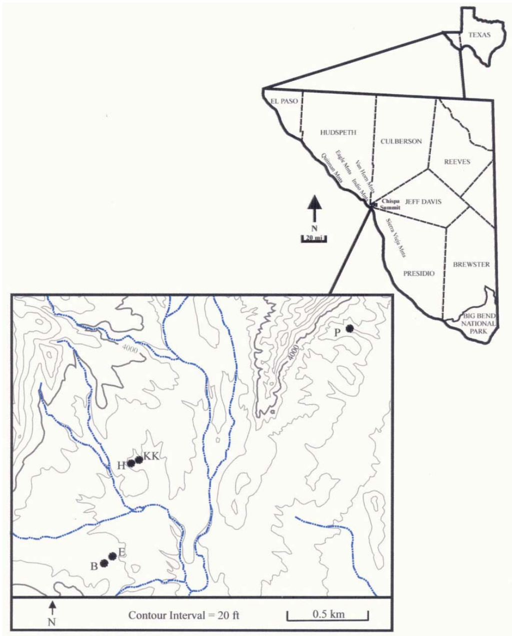



**Figure 9.** Collection localities (section B, E, H, KK, and P) in the Chispa Summit formation of Trans Pecos, Texas (Modified from Waggoner 2003).

venter and the shell's sharp keel resemble those in the *Coilopoceras springeri* specimen USNM 278120 (Figure 7.1). A suture taken from TMM NPL 1855 was tested against the suture pattern of *Coilopoceras springeri* USNM 278120 (Figure 10.10). Compared to USNM 278120, TMM NPL 1855 has basically the same alignment, and the match between the unusual split is nearly identical. The percentage of suture length that falls outside of the *Coilopoceras springeri* right/left template is 11.18% (Table 3). TMM NPL 1855 is visibly the same species as USNM 278120, a *Coilopoceras springeri.*

## DISCUSSION

The methods developed can be used to model and compare ammonitic suture patterns. Using the GIS system for visually and quantitatively matching ammonitic sutures has been demonstrated as an effective way to classify ammonites. A few suggestions are worth noting. The holotype should be used as the guide in making a template because the holotype is the specimen designated as the nomenclatural type in describing a new species and is the model against which other specimens are compared. By reversing the left template and overlaying it on the right, one produces the best-fit template (Figure 4.1). With the small number of actual published suture patterns, combining right and left patterns is the best method for attaining the most accurate template. The control points may be placed logically at the junction of the sutural elements, i.e., ventral, lateral, and umbilical beginnings and endings. Slight variation in the location of the tie points does not affect the results.

Investigating the differences between suture patterns is straightforward using GIS, as calculated suture lengths can be used for comparison. As seen in Figure 5.1, there is a definite difference between right and left suture patterns, with the right patterns being shorter in the ventral to dorsal length aspect. The difference when comparing the left and right sutural templates is 13.15 units. The shell measurement data shows that the right umbilical diameters are larger than the left umbilical diameters for all specimens (Manship 2003). A wider umbilicus on the right would support the fact that the sutures on the right would be shorter than those on the left; the opposite would be true for the left side. This right and left sutural difference is found in all Coilopoceratidae specimens from all localities and is not likely to be a result of compaction or other post-burial deformation.

With the GIS method, sutures can also be easily compared using the area of mismatch. Table 2 shows the comparisons between individual sutures. Quantitative measures of difference in area were seen and as expected, the difference is low for opposing sutures and continually increases from comparison of the same species, to the sutures of two different species, and the largest difference is between two different genera.

The fit of a suture pattern to a template can also be quantified by calculating the percentage of line that falls outside the template. Table 3 shows a quantitative comparison between the percent of suture length that lies outside of each template. As seen in Table 3, *Coilopoceras springeri* sutures fit best in the *Coilopoceras springeri* right/left template. The templates that were made with less than six sutures showed a higher percentage of suture length outside of the template's boundary. A much higher percentage of suture length outside of the template boundary is seen when comparing any suture to the *Hoplitoides sandovalensis* right template, made with only three sutures, in contrast to a much lower percentage of suture length outside of the *Coilopoceras springeri* right/left templates made using 10 suture patterns. This method, then, works best when all templates are made with a comparable number of sutures, ideally at least six. Otherwise, tested sutures may fit best in whatever template has the most sutures. With limited published sources of suture patterns, it may be difficult to acquire enough suture patterns to make an accurate sutural template. For the most complete

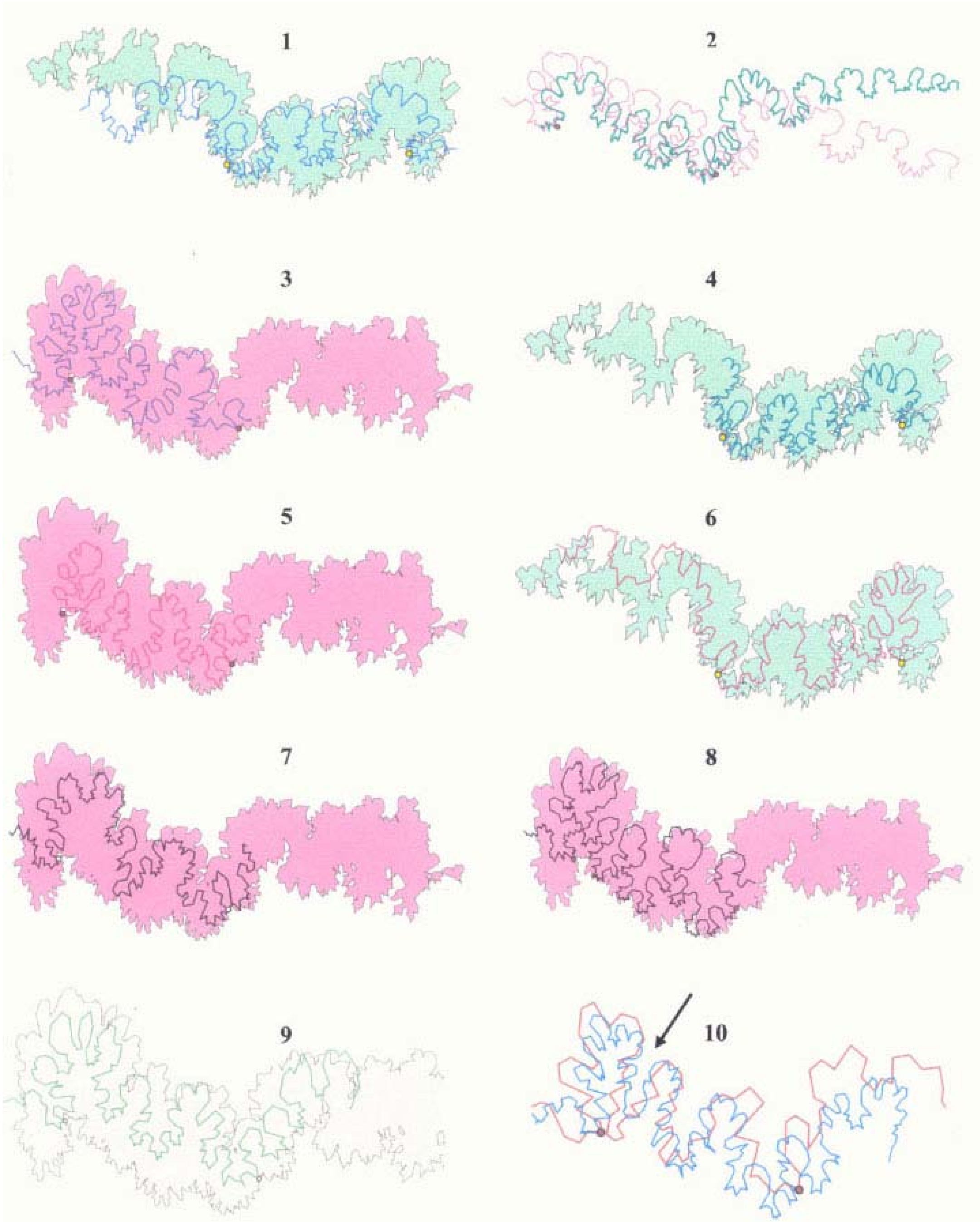



**Figure 10.** Unknown field specimens; 1, TMM NPL 1848-A suture tested in the *Coilopoceras springeri* left template. Similar alignment, with TMM NPL 1848-A being slightly taller in the second and third elements; 2, TMM NPL 1848-AA suture tested against the right holotype suture of *Coilopoceras springeri.* Similar alignment, with TMM NPL 1848-AA being slightly taller in the first, second. and third elements. The fourth element is not aligned; 3, TMM NPL 1849 suture tested against the *Coilopoceras springeri* right/left template. Very similar alignment; 4, TMM NPL 1850-A suture tested against the *Coilopoceras springeri* left template. Very similar alignment; 5, TMM NPL 1851 right suture tested against the *Coilopoceras springeri* right/left template. The suture fits within the boundaries of the template; 6, TMM NPL 1851 left suture tested against the *Coilopoceras springeri* left template. The suture fits closely within the boundaries of the template; 7, TMM NPL 1852 suture tested within the *Coilopoceras springeri* right/left template. This suture fits within the boundary of the template; 8, TMM NPL 1853 suture tested within the *Coilopoceras springeri* right/left template. This suture fits within the boundary of the template; 9, TMM NPL 1854 suture tested within the *Coilopoceras springeri* right/left template. This suture fits within the boundary of the template; 10, Differences between TMM NPL 1855 suture and *Coilopoceras springeri* USNM 278120. Elements are mostly aligned. An unusual split in the lateral element closest to the venter occurs in both the TMM and USNM specimens, as indicated by the arrow.

and precise template, museum collection resources should be thoroughly investigated.

Simpler sutures also are more likely to fit within multiple templates, which is why juvenile sutures are not a good choice. Even the relatively straight suture pattern of nautiloids could be made to fit within an ammonite template. For the best possible use of the template model for classification, only well-developed adult sutures should be used, and placement of the elements should be carefully noted.

The objective of this study was to assign ammonite specimens to species by use of a sutural template. The best approach is to combine visual examination of sutures and templates with these percentages to make the strongest case when classifying ammonites. The majority of all tested specimens correlated with their correct templates and do not fall within the templates of other species. All of the specimens from my field locality proved to be *Coilopoceras springeri.*

## SUMMARY

Using Geographical Information Systems (GIS) to quantitatively and visually identify and classify ammonoids by use of sutural templates will benefit the paleontological world, as well as biostratigraphers, geologists, and avocational paleontologists. Researchers will be able to use GIS software to match suture patterns within a set boundary and identify unknown suture patterns. Differences in suture patterns can be readily quantified. This method is user-friendly and easily accessible to most researchers. Other applications of this method could help us better understand suture formation and many other aspects of ammonoid paleobiology.

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