THE JURASSIC AMMONITE IMAGE DATABASE 'AMMON'

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ABSTRACT. 'Ammon' is an interactive database that incorporates taxonomic, morphological, stratigraphical and locality information as well as digitized images. When necessary, a user can measure morphological features directly from an image using the mouse to mark points on which are based the measurement of distances, the calculation of ratios and derivation of logarithmic spiral parameters. Features such as ribs can be counted using the mouse, and counts extrapolated automatically to a standardized unit of measurement such as a half whorl. 'Ammon' is also provided with a module that can measure features automatically once the image has been processed using edge detection, line thinning and tracing algorithms. The characterization of whorl shapes is a difficult problem best addressed by the use of elliptic Fourier analysis which not only faithfully mimics whorl cross sections but can also be animated to show, for example, the transition from one shape to another during ontogenetic development. 'Ammon' is a useful aid in fossil identification both as a retriever of species based on specified morphological, stratigraphical, and/or geographical information and as a way of assembling image collages of specified families, genera or species.

Several general issues are raised by advances in computer technology and the growth in use of 'Ammon' and its kind. Paramount are: the universality of database design; completeness of taxonomic, stratigraphical and geographical coverage; efficiency of data entry; and the question of accessibility.

WHILE palaeontologists are quick to acknowledge the imperfections of the fossil record, they point less readily to the almost overwhelming wealth of still accumulating data. The collective database is so large and complex that in the past it could only be dealt with by specialists operating within spheres of taxonomic, temporal and spatial competence. Evolving technology is softening and perhaps even breaking down the boundaries of these spheres, allowing us to undertake research of a style and content that was not previously possible. Witness the impact, so to speak, of taxonomic databases in the area of extinction studies (Raup and Sepkoski 1982; Sepkoski 1993). Certainly palaeontological databases are proving of considerable service to those engaged in geological mapping, museum management, and exploration for minerals and fuels, although educational applications have barely been considered (Huber 1990; Price 1984; Rich 1989). Databases built so far often deal with fairly coarse taxonomic and temporal units where morphology is usually not emphasized, images are rarely incorporated directly, and the computer is used as a sophisticated filing cabinet rather than as a means of generating new data. An important question in considering the application of computers to palaeontology is whether fossil identification can be done entirely by expert systems or whether, as we suggest below, a marriage of human and machine capabilities is the best approach.

At a fundamental level, the description of morphology and the documentation of variation may be approached in two ways: (1) the use of geometric models to describe morphology quantitatively, an approach that is theoretically capable of producing a universal set (or morphospace) of all possible morphologies; (2) the use of specimens and their images to obtain quantitative and qualitative data, thereby determining which parts of the universal set are actually occupied. Computers and computerized image databases readily unite these approaches allowing us to chart the boundaries of occupied morphospace through evolutionary time, document the evenness of occupation and wonder about the functional or adaptational significance of unoccupied morphospace volumes (Gould 1991). Questions of function as well as genetic linkage are also raised

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when covariation amongst morphological features is detected, an area where the sheer capacity of computers to manipulate and analyse data comes into its own.

The prototype 'Ammon' was initiated to handle systematically data accruing from stratigraphical studies of Jurassic sedimentary basins in western North America (Smith 1986). It has been growing steadily in content and scope, and there is now an independent sister database called Goniat dealing with Palaeozoic ammonoids (Kullmann *et al.* 1993; Korn *et al.* 1994). The purpose of the present paper is to document recent changes to 'Ammon' that demonstrate: (1) the incorporation of digitized images into a database; (2) an interactive module that helps a user measure morphological parameters directly from an image; (3) an automatic module where the computer measures and derives morphological parameters independently using edge detection techniques; (4) the potential of elliptic Fourier analysis for characterizing whorl shapes and ontogenetic change; (5) the use of an interactive database as an aid to fossil identification.

Copies of the new computer programs and interfaces (modules) mentioned in this paper (*ImagEdit*, *Caliper*, *Imagic* and *Animator*) have been deposited at the British Library, Boston Spa, Yorkshire, U.K., as Supplementary Publication No. Sup 00000. In a subsequent paper, 'Ammon' and its new modules will be used to reveal hitherto undetected patterns of covariation and morphological diversity in Lower Jurassic ammonites.

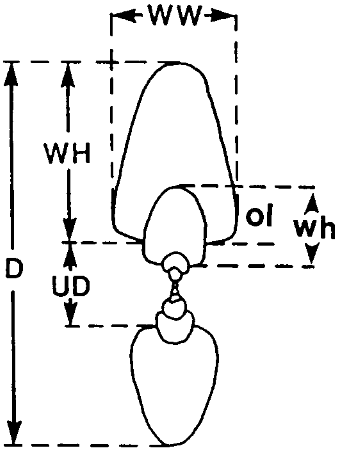
'AMMON'

The database 'Ammon' was originally designed for a mainframe computer using Taxir as the database management program (Smith 1986). Subsequently, it was transferred to a workstation (SparcStation) and converted to work under Oracle Relational Database Management System at which time several image related descriptors were added. The present greatly expanded version of 'Ammon' contains 7790 specimens representing 15 families, 179 genera and 1319 species. Each specimen has 102 descriptors covering taxonomy, quantitative morphology, qualitative morphology, stratigraphy, locality information and general comments (Table 1). These descriptors and their states have been described in detail by Smith (1986) except for the following new descriptors (Table 1): 13 SYNSPECIES is the valid species name as judged by the person operating the database; 21 WHMAX is the maximum measurable whorl height for incomplete specimens; 27 RIBWIDTH is the ratio of maximum rib width to whorl height; 31 FURCPOS0 (the quantitative equivalent of FURCPOS) is the distance between the rib furcation point and the umbilical seam expressed as a ratio of the whorl height; 32 UNITUBPOS0 (the quantitative equivalent of UNITUBPOS) is the distance between a tubercle and the umbilical seam in unituberculate ammonites expressed as a ratio of the whorl height; 35 VOLUTION0 (the quantitative equivalent of VOLUTION) is the ratio of whorl overlap to inner whorl height (ol/wh in Text-fig. 1); 36 AH is the ratio of whorl overlap to outer whorl height (ol/WH in Text-fig. 1); 82 AREA divides the world into a few broad geographical regions such as the Western Pacific, Western Tethyan, North America, South America, Northwest Europe so that rapid scans for biogeographical data can be made; 99 IMAGE and 100 SCALE give the relative path of image files in the file system and the scale of the illustration; 101 SPECFEATURE is added because some taxonomic groups have unusual features that are important for identification but not common enough to warrant a separate descriptor in the database, e.g. the mid-flank spiral groove in *Hildoceras*.

As shown by Raup (1967), the basic geometry of planispiral ammonites can be described by just three parameters (Text-fig. 1): the whorl expansion rate (W), the umbilical ratio (U), and whorl compression (WWWH). The list of descriptors shown in Table 1, which includes the Raup parameters, is not rigidly fixed but expansion to accommodate new categories of data obviously requires all existing entries to be updated. In our unpublished study using 'Ammon' to examine covariation and recovery from the end-Triassic mass extinction, for example, we did not have to deal with heteromorph ammonites and consequently the Raup parameters were adequate for our needs. Some descriptors are derived from others and it is a matter of judgment as to whether they should be stored separately or simply calculated when needed thereby trading computer storage

TABLE 1. The 102 descriptors of the database 'Ammon' arranged in six categories as shown on the left. The descriptors have been defined (Smith 1986), with the exception of the 10 additions described in the text that either augment existing descriptors, quantify qualitative descriptors, or incorporate information related to images.

Taxonomy	1 SUBORDER		2 SUPERFAMILY		3 FAMILY	
	4 SUBFAMILY		5 GENUS		6 SUBGENUS	
	7 QUALIFIER		8 SPECIES		9 SUBSPECIES	
	10 TAXAUTHYEAR		11 REFAUTHYEAR		12 SYNGENUS	
	13 SYNSPECIES					
Quantiative morphology	14 DMAX	15 DPHRAG	16 D	17 UD	18 U	19 W
	20 WH	21 WHMAX	22 WHD	23 WW	24 WWD	25 WWWH
	26 PRHW	27 RIBWIDTH	28 SRHW	29 THW	30 BISPACE	31 FURCPOS0
	32 UNITUBPOS0	33 CHW	34 SF	35 VOLUTION0	36 AH	37 APPROX
Qualitative morphology	38 VOLUTION	39 WHORL SHAPE	40 EXPANSION	41 UWALL	42 UWALLHT	43 UWALLANG
	44 USHOULD	45 FLANKS	46 VENTER	47 VENTPROF	48 KEEL	49 SULCI
	50 PRIBD	51 PTREND	52 PFORM	53 PPROF	54 FURC	55 FURCPOS
	56 SRIBD	57 STREND	58 SFORM	59 SPROF	60 TUBERC	61 UNITUBPOS
	62 CONSTRD	63 CTREND	64 CFORM	65 APERTURE	66 SUTURE	67 ONTOGENY
Stratigraphy	68 STAGE	69 SUBSTAGE	70 EURZONE	71 EURSUBZONE	72 ZONE	73 SUBZONE
	74 HORIZON	75 FORMATION	76 MEMBER	77 LITHOLOGY	78 DATUM	79 RELDATUM
	80 SITU	81 ASSOCSPEC				
Locality and catalogue information	82 AREA	83 COUNTRY	84 PROVINCE	85 LONG	86 LAT	87 Q
	88 SECTNAME	89 SECTNO	90 LOCNO	91 OTHERNO	92 SUBLOCNO	93 SUPERLOCNO
	94 REPOSITORY	95 TYPE	96 COLLECTORYR		97 GENERALOC	98 SPECNO
	99 IMAGE	100 SCALE				
Others	101 SPECFEATURE		102 REMARKS			



TEXT-FIG. 1. Ammonite cross section showing the basic geometric parameters (modified from Smith 1986). $W = (WH/wh)^{2\pi/r}$ where r is the angular distance between WH and wh (in this case $r = 2\pi$ because WH and wh are separated by one whorl); $U = UD/D$; $WWWH = WW/WH$.

capacity for increased retrieval time. An important example is the length of the body chamber, a parameter that is necessary for understanding hydrostatics but difficult to use in systematics because the peristome is rarely preserved and often the body chamber itself is completely missing. When data are available, the angular length of the body chamber in radians (r) can be calculated from the expansion rate (W), the maximum shell diameter (DMAX), and the diameter of the phragmocone (DPHRAG), by rearranging the expression $W = (DMAX/DPHRAG)^{2\pi/r}$ (Smith 1986).

Ammonite illustrations are scanned into a Sun SparcStation using a MicroTek image scanner with 256 grey shades. Fossil plates in journal articles normally have multiple specimens figured on each plate. To speed up the digitization process, a whole plate is scanned into the computer and a program (*ImagEdit*) is used to extract individual specimens, clear irrelevant components such as figure numbers, and save the selected part of the image as a separate file.

INTERACTIVE IMAGE MEASUREMENT MODULE

When a specimen is entered into the database for the first time, morphological data are sometimes not available and have to be measured from images of the specimen. This is facilitated by a front-end user interface called *Caliper* built on top of the 'Ammon' database. *Caliper* is a module implemented in C, embedded SQL, Sunview and a graphics library called Pixrect. Its function is to derive morphological characters by combining the human ability to locate features visually with the computer's ability to memorize and compute. With the lateral image of the ammonoid on the screen, the operator uses the mouse to position five control points: O on the coiling axis, P_1 and P_2 on the inner coiling curve, and P_3 and P_4 on the outer coiling curve (Text-fig. 2). From these points, the shell expansion rate (W) and the umbilical ratio (U) are calculated and the inner and outer coiling curves simulated. By definition (Text-fig. 1)

$$W = (OP_3/OP_4)^{2\pi/r},$$

where OP_3 and OP_4 are separated by an angular distance of r radians which must be less than π to make coiling direction unequivocal to the program.

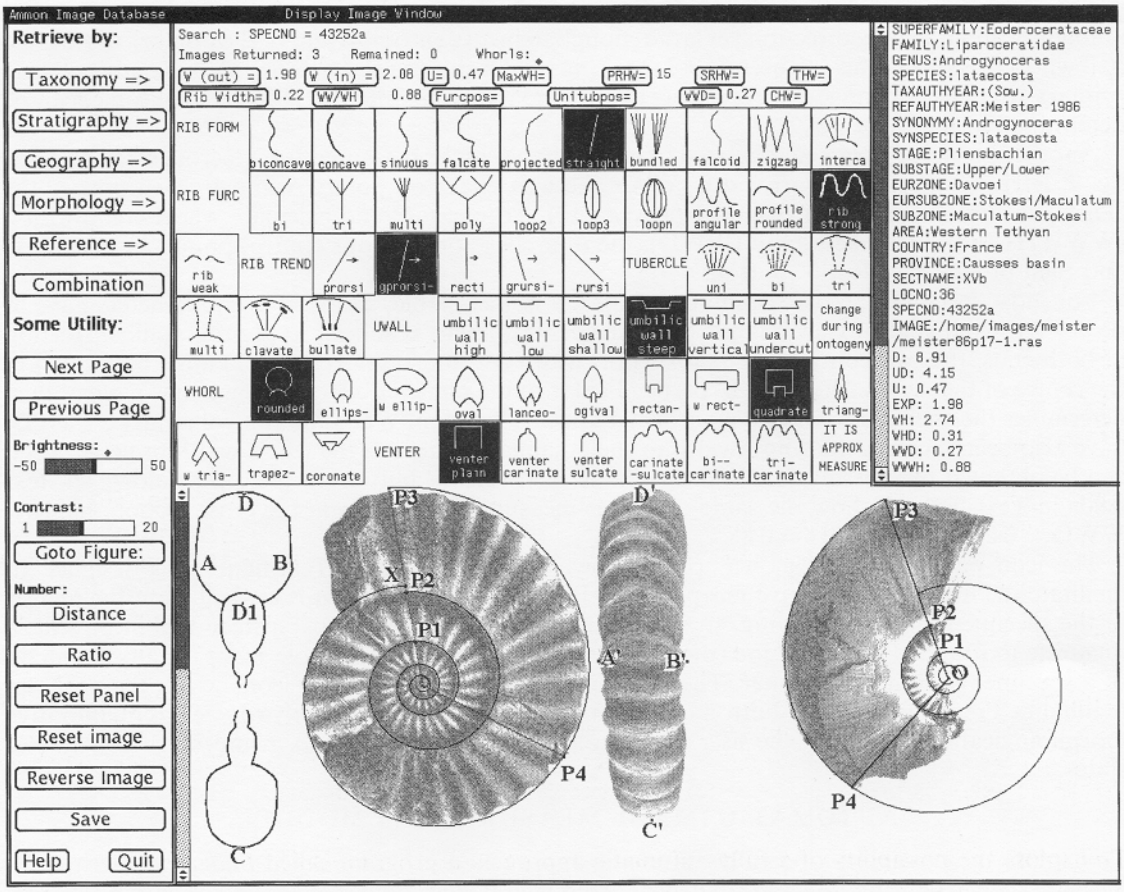
$$U = OP_2/OP_3.$$

An equivalent measurement of W for the inner whorl is

$$WI = OP_2/OP_1,$$

where OP_2 and OP_1 are separated by one whorl. WI can be used to simulate the inner whorl spiral. The diameter of the shell and the whorl height at point P_3 are:

$$D = OP_3 + OP_3/\sqrt{W}, \quad WH = P_2P_3.$$



Search : SPECNO = 43252a
Images Returned: 3 Remained: 0 Whorls:
W (out) = 1.98 W (in) = 2.08 U= 0.47 MaxWH= PRHW= 15 SRHW= THW=
Rib Width= 0.22 WW/WH 0.88 Furcpos= Unitubpos= WVD= 0.27 CHW=

```
SUPERFAMILY:Eoderocerataceae
FAMILY:Liparoceratidae
GENUS:Androgynoceras
SPECIES:lataecosta
TAXAUTHYEAR:(Sow.)
REFAUTHYEAR:Meister 1986
SYNONYMY:Androgynoceras
SYNSPECIES:lataecosta
STAGE:Pliensbachian
SUBSTAGE:Upper/Lower
EURZONE:Davoei
EURSUBZONE:Stokesi/Maculatum
SUBZONE:Maculatum-Stokesi
AREA:Western Tethyan
COUNTRY:France
PROVINCE:Causses basin
SECTNAME:XVb
LOCNO:36
SPECNO:43252a
IMAGE:/home/images/meister
/meister86p17-1.ras
D: 8.91
UD: 4.15
U: 0.47
EXP: 1.98
WH: 2.74
WHD: 0.31
WWD: 0.27
WWWH: 0.88
```

TEXT-FIG. 2. Data entry and interactive image measurement screen for 'Ammon' (colour suppressed). Descriptor states can be entered automatically by clicking on the relevant buttons in the top middle panel (those relevant to the left figured specimen are highlighted). The control points marked O, P and A–D, which are placed on the images by the user, are used to simulate whorl spirals, calculate quantitative parameters, and reconstruct specimen fragments. The top right panel shows all the data sorted for the left image. The left panel is the command window housing buttons for retrieving and manipulating data.

The whorl overlap ratios with respect to the inner whorl and the outer whorl are (Text-fig. 2):

$$\text{VOLUTION0} = P_2X/P_1P_2, \quad \text{AH} = P_2X/P_2P_3$$

To calculate the above parameters, all the user needs to do is to mark the five control points with the mouse then press one of the 'W(out) =', the 'W(in) =' or the 'U =' command buttons in the top window. The program will superimpose the simulated inner and outer coiling curves on the image and show the parameter values in the text fields following the command buttons (Text-fig. 2). If a specimen is incomplete or damaged and the control points cannot be located with confidence, a 'try and see' approach can be used; the 'Reset image' button in the left window will dispose of unsuccessful attempts. Once the location of the coiling axis is settled, the primary rib density (PRHW) can be counted by clicking on a number of consecutive ribs with the middle mouse button. If N ribs are marked then

$$\text{PRHW} = N^*\pi/r,$$

where r is the angular distance between the first and last ribs which must be less than π to avoid ambiguity about coiling direction yet large enough to justify extrapolation of the number of ribs to a half whorl (PRHW). This is a useful tool for using rib densities to characterize species and exploring primary rib density change during ontogeny. Secondary rib density (SRHW), if applicable, can be determined in the same way.

Another group of parameters related to whorl shape can be measured from a cross section (Text-fig. 2, left). To measure whorl width (WW), the user clicks on points A and B, then presses the 'Distance' button in the left window (Text-fig. 2). To measure and calculate whorl compression (WWWH) and the fineness ratio (WWD), the user clicks on the four control points A through D and then presses the 'Ratio' button.

For most specimens, cross section drawings are not available, so the above parameters have to be derived from ventral view images. Since the ventral image is subject to photographic distortion at both ends, the two control points for whorl width (A' and B' in Text-fig. 2) must be located in the centre of the view with line $A'B'$ perpendicular to the plane of bilateral symmetry. *Caliper* then determines the shell diameter and whorl height at this location. When the control points C' and D' have also been located, the whorl width to shell diameter ratio and the whorl width to height ratio can be obtained by pressing the 'WWD =' and 'WWWH =' buttons in the top window. The text fields in Text-figure 2 show the same results as measured directly from the cross section, namely, WWD = 0·27 and WWWH = 0·88.

The icon panel which is shown 'pulled down', in the centre of Text-figure 2 is designed to facilitate the input of qualitative morphological data into 'Ammon'. It is evident from the images of the specimen that it has strong, straight and gently prorsiradiate ribs; a steep umbilical wall; a quadrate to rounded whorl section (the database 'Ammon' allows multiple states for any character of a specimen) and a plain venter. The user clicks on the corresponding icons which the program highlights. Pressing the 'Save' button in the left window stores all qualitative as well as quantitative morphological data without the user typing a single word or having to memorize any character states.

AUTOMATIC IMAGE MEASUREMENT MODULE

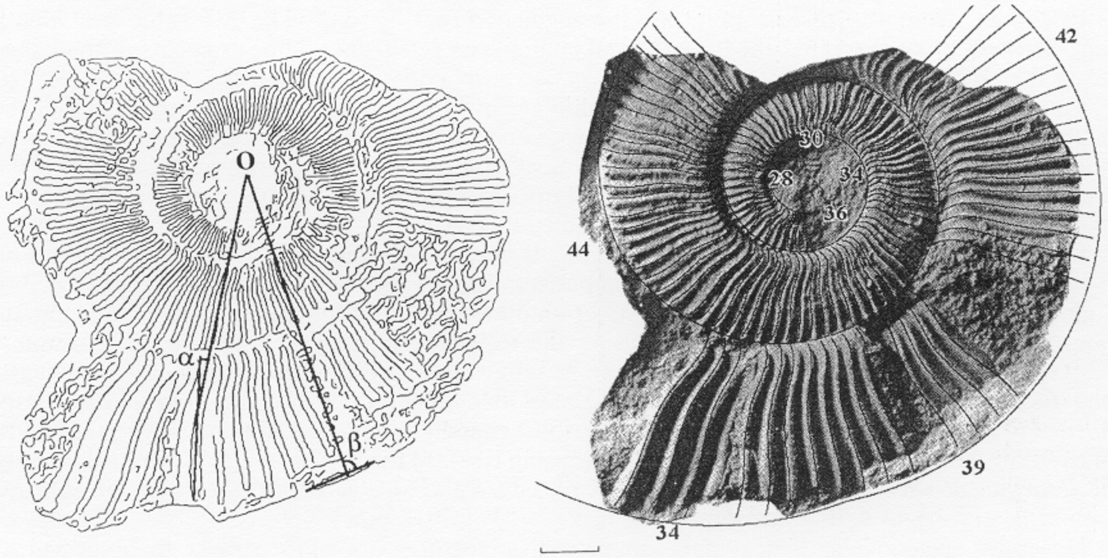
To explore the possibility of a fully automatic approach, a program called *Imagic* was written to measure shell expansion rate and rib density from lateral view images of specimens without human intervention. The program applies to specimens with simple ribs; other morphological features such as tuberculation and rib furcation are ignored to make the task tractable. The geometry and ornamentation of ammonites have a high degree of regularity and this is the basis of image interpretation since it allows the computer to ignore noisy elements of the image that reflect the state of preservation rather than shell morphology. Analysis first involves an image preparation stage after which the computer locates the coiling axis and measures several parameters.

Image preprocessing

Images are cleared of irrelevant components such as text labels using the program *ImagEdit*. To focus the subsequent analyses on the ammonite image, the average (X) and standard deviation (S) of the background brightness intensity are estimated from a three-pixel wide sample of the entire margin of the background. The program reassigns brightness intensity value (256 grey shades) to each pixel in the image as follows:

$$\begin{aligned} &Z = 0 \text{ when } Z < X+S \text{ and } X < 128 \text{ (black background)},\\ &Z = 256 \text{ when } Z > X-S \text{ and } X > 128 \text{ (white background)},\\ &Z = Z \text{ otherwise}, \end{aligned}$$

where Z is the brightness intensity of the pixel. The major elements in an ammonite image are coiling curve and ribs; both are edges where brightness shows significant changes. Edge detection serves to simplify the analysis of images by drastically reducing the amount of data to be processed, while at



A B

TEXT-FIG. 3A. Edge detection output from the Canny operator used to locate the coiling axis from possible rib and coiling curve segments. The hypothetical coiling axis is marked O; α is the angle between the radius vector and the midpoint of a radially arranged line segment (rib) and β is the angle between radius vector and the tangent to the spiral. The ammonite is a poorly preserved specimen of *Dubariceras freboldi* (from Smith *et al.* 1988). 3B. An example of automatic image measurement, where a matching coiling curve and rib pattern simulated by the computer is superimposed over the original specimen (*Dubariceras freboldi*, as used in A). The numbers represent calculated rib densities per half whorl at various stages of ontogeny. Scale bar represents 10 mm.

the same time preserving useful structural information about object boundaries. The Canny operator (Canny 1986) was chosen for this purpose. The output of the Canny operator consists of separate pixels which are then linked into line segments according to 2-D spatial proximity and collinearity. Each line segment has three components: orientation, length in terms of number of edge points in the segment and co-ordinates of these points. Before the tracing of line segments, a thinning algorithm (Pavlidis 1982) is used to skeletonize edge segments potentially wider than one pixel into one-pixel wide segments. Text-figure 3A is an example of an ammonite image that has undergone edge detection, thinning and line tracing; the original image is shown in Text-figure 3B.

Locating the coiling axis, coiling curve and ribs

The most important feature of ammonite morphology is that ribs distribute around the coiling axis radially and coiling curves follow a logarithmic spiral starting from the coiling axis. The angle β, which describes how rapidly the coiling curves move away from coiling axis, is made by the radius vector intersecting the tangent to the spiral. Lower Jurassic ammonites, for example, typically have β values between 75° and 90° even when there are changes during ontogeny. A statistical parameter (SC) based on this observation is used to locate the coiling axis:

$$\mathrm{SC} = \sum_{i=1}^{m} \mathit{CoilingLen}[i] + \sum_{i=1}^{n} \mathit{RibLen}[i],$$

where *CoilingLen*[*i*] is the length of the *ith* line segment which has a β value between 75° and 90° with respect to the hypothetical coiling axis O (Text-fig. 3A). *RibLen*[*i*] is the length of the *ith* segment with $\alpha < 15°$ so the line segment is in a radial position to the hypothetical coiling axis, α

is calculated from the middle point of the segment (Text-fig. 3A). The SC value provides a measurement of support that the hypothetical coiling axis gets from all line segments in the image using the underlying geometric pattern.

The coiling axis is nearly always located within a central region in the image which is half of the image size in terms of width and height. The program samples this region from left to right, top to bottom computing the SC values with an increment of 4 pixels which corresponds to 1 mm if the image scale is 1 and the monitor resolution is 100 dpi (dots per inch). The pixel which has the highest SC value is considered to be the location of the coiling axis.

Distinguishing coiling curves and ribs is difficult because of noise, and line segments resulting from local brightness changes related to imperfections in specimen preservation (Text-fig. 3B). Again, the underlying geometric constraints of ammonite shell morphology are used to eliminate non-rib and non-coiling-curve elements using the following criteria: (1) empirically reasonable limits for the range of shell expansion rate can be set at 1·2–5, and possible coiling curve segments, and geometric relations among them, should meet this constraint; (2) coiling curves are nearly normal to radius vectors ($\beta > 75°$); (3) ribs distribute radially around the coiling axis; (4) the length of each rib should be consistent with its neighbouring ribs; (5) the 'white to black' rib edges should be sandwiched between two 'black to white' rib edges and *vice versa*; (6) the width of each rib should be consistent with its neighbouring ribs.

Generally speaking, statistical data on geometric features are more robust than individual measurements. The image is therefore divided into 12 equiangular sectors around the coiling axis. Rib and coiling curve segments are verified in each sector and then rechecked during the final assembling stage according to the above constraints.

Deriving morphological parameters

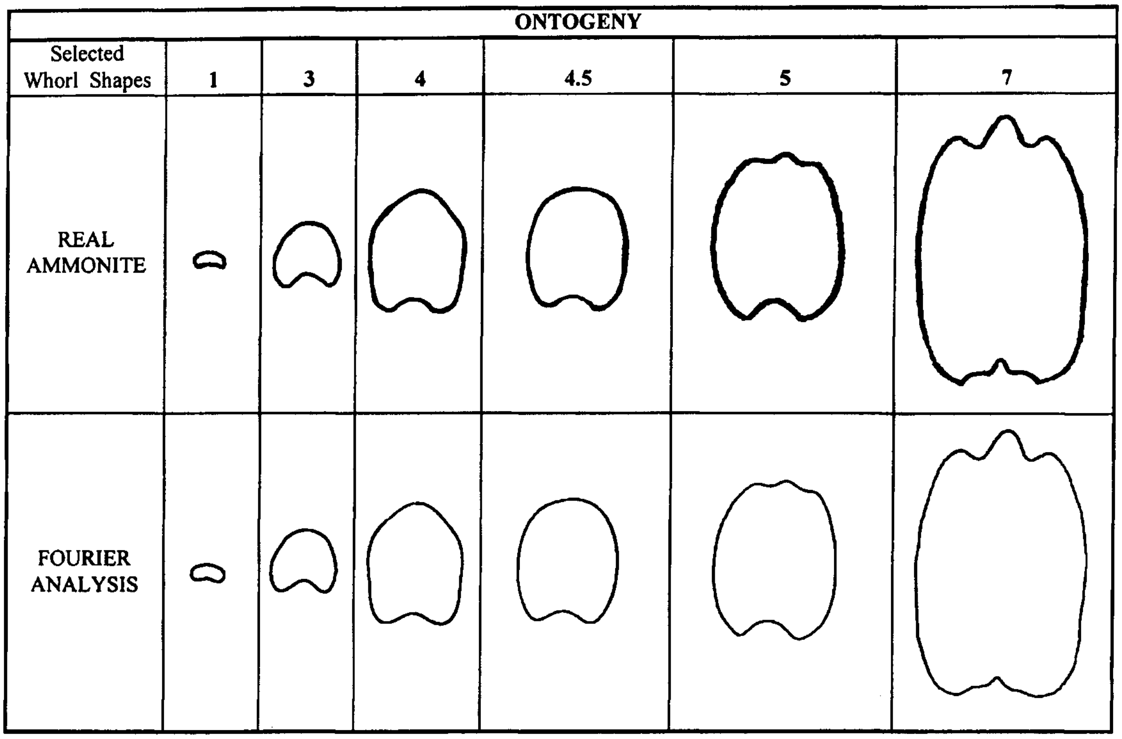
Once the coiling axis, coiling curves and ribs are determined, shell expansion rate (W), rib density (PRHW), volution (VOLUTION0), whorl overlap (AH) and their changes during ontogeny can be computed easily. Nonlinear regression can be used to formulate rib forms.

Text-figure 3B shows ribs and coiling curves simulated by the program superimposed on the original image; ribs were matched using the least squares technique. This program can be a useful tool for exploring ontogenetic changes. A user may determine the shell expansion rate between any two points by clicking on them with the mouse. Similarly, rib density between any two points may be determined by clicking on each rib. The program will display how many ribs there are between the two points and how many ribs there would be for half a whorl. By working from the inner to the outer whorl, the user can get a clear picture of how the shell expansion rate and rib density change during growth. In this example (Text-fig. 3B), the rib density gradually increases from 28 to 44 from the visible innermost whorl to the outer whorl, then starts to decrease to 34 on the last half whorl where, in this case, maturity is probably reached.

ELLIPTIC FOURIER ANALYSIS OF WHORL SHAPE

Whorl shape is an important aspect of ammonite shell morphology. A simple descriptor in the 'Ammon' database is the ratio of whorl width to whorl height (WWWH) which does not define the shape uniquely since a circle and a square would give the same ratio. Another descriptor WHORL_SHAPE uses descriptive terminology such as 'quadrate', 'rounded', 'subrounded', etc., but workers do not necessarily agree on the exact meaning of a given descriptive phrase such as 'subrounded', and it is difficult to compare variations across different taxonomic groups. These considerations create a need for a method like Fourier analysis which has been used in many palaeontological studies for the characterization of closed curves (Kaesler and Waters 1972; Anstey and Delmet 1973; Christopher and Waters 1974; Younker and Ehrlich 1977; Canfield and Anstey 1981; Foote 1989).

One common Fourier method is polar Fourier analysis (Kaesler and Waters 1972) which we did not use because it is limited to simple curves without multiple re-entrants. We compared the more

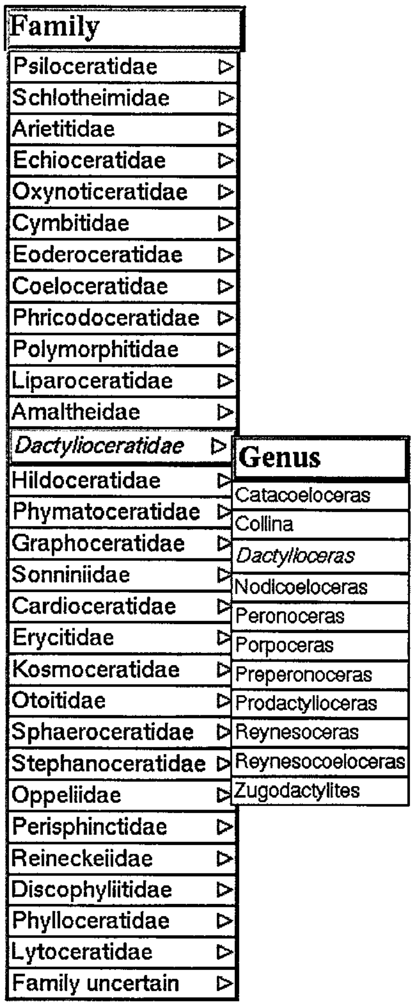


TEXT-FIG. 4. Ontogenetic change in whorl shape for *Arnioceras ceratitoides*, by whorl number. The upper sequence is taken from a real specimen (Blind 1963, fig. 25) whereas the matching sequence below is computer generated using elliptic Fourier analysis. From left to right, the number of harmonics used in the Fourier series are: 4, 5, 6, 8, 15, 23 (root mean square error < 0·01) reflecting the increase in morphological complexity during growth.

sophisticated elliptic Fourier analysis (Kuhl and Giardina 1982) and perimeter-based Fourier analysis (Foote 1989) and found that elliptic Fourier analysis gave better results. There is also the advantage that there is no need to determine an artificial centroid for the shape. Furthermore, Elliptical Fourier descriptors are invariant with rotation, dilation and translation of the contour.

Whorl shape drawings are scanned into the computer from published work. The previously mentioned thinning algorithm (Pavlidis 1982) is used to skeletonize lines potentially wider than one pixel and the line tracing program links separate pixels into a continuous outline ready for analysis.

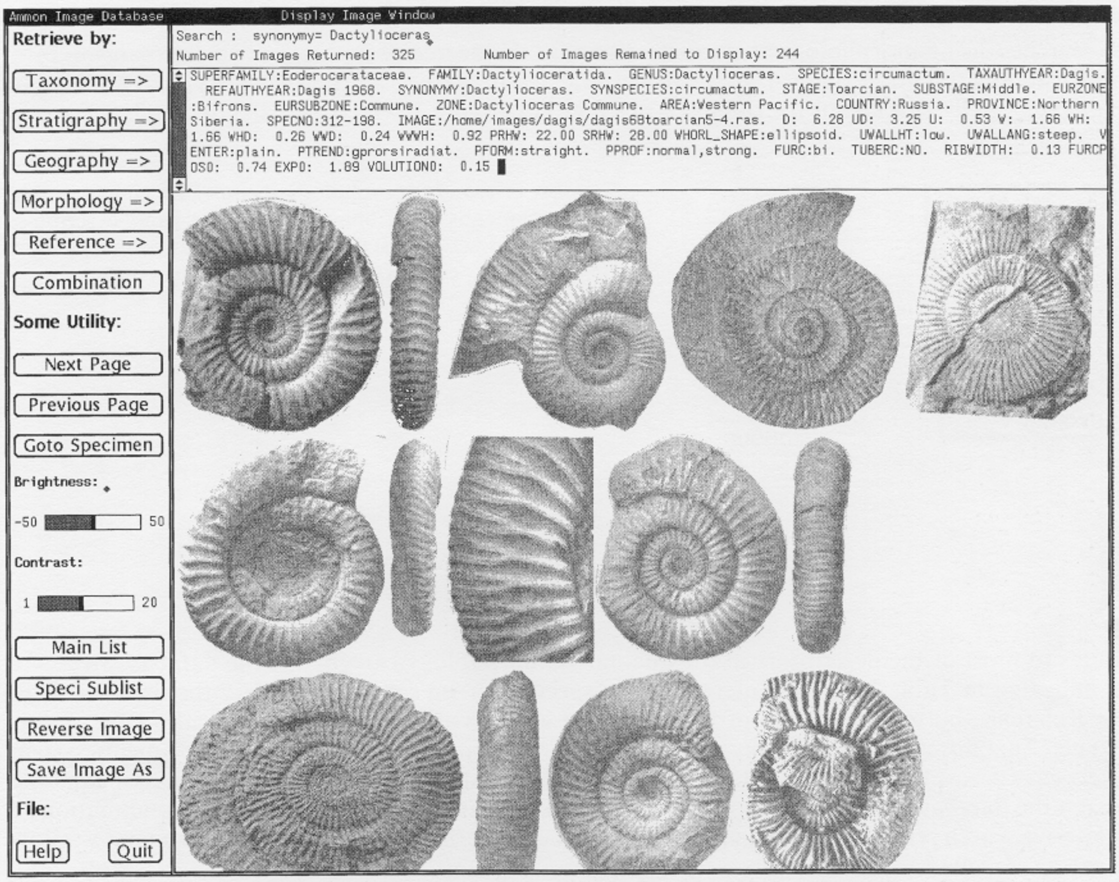
Text-figure 4 shows the ontogenetic variations of *Arnioceras ceratitoides* (from Blind 1963). The number of harmonics required to reduce root mean square error to 0·01 or less increases with ontogeny. This is consistent with the visual observation of the general increase in whorl shape complexity. The most significant change occurs from whorl 4·5 to 5 where the number of harmonics increases from 8 to 15, corresponding to the development of a keel. A program called *Animator* has been written to visualize and animate the detail of how one whorl shape can evolve into another. All whorl shapes in the sequence are produced at the same size and superimposed in sequence so that subtle changes in shape can be detected. In addition, Fourier analysis can detect and quantify whorl shape variations within and among taxa. It would be interesting to map the whorl shape distribution of naturally occurring ammonites with respect to their Fourier representations so that the relative density of occurrence can be evaluated. Current models of 3D simulation of ammonite shells assume a circular or elliptical whorl section (e.g. Raup 1967; Chamberlain 1981). Fourier representation of whorl sections make it possible to model real ammonites.



TEXT-FIG. 5. Family menu (left) and genus submenu for the family Dactylioceratidae.

AN AID TO IDENTIFICATION

Identifying ammonites involves an evaluation of shell morphology and stratigraphical occurrence as well as an appreciation of geographical distribution. Once a list of potential candidate species has been formulated, it becomes necessary to compare numerous illustrations. This can be a difficult task if the list of candidates is long but, in addition, all species normally show variation which must also be evaluated before a species can be identified with confidence. Traditionally, intraspecific variation is assessed by examining the illustrations and descriptions of specimens in the synonymy of the species which may mean scouring a voluminous literature that is in several different languages and often reaches back well into the last century (Smith 1986). In order to utilize the literature effectively, the attributes of a large number of specimens have to memorized and evaluated in an objective manner. To a large extent, the image database 'Ammon' can overcome these problems. Given morphological information supplied by the user, a search of 'Ammon' is made and closely matching species displayed on the screen for comparison with the specimen in question. Other constraints such as the approximate stratigraphical range can be added to shorten the list of candidate species. Searches can also be restricted to a specified shell diameter range to circumvent the problem of ontogenetic change. 'Ammon' has an easy-to-use, menu-driven user interface which is written in Sunview and the embedded SQL query language of the Oracle Database Management System. Users can retrieve Jurassic ammonite data and images by using the 'Taxonomy', 'Stratigraphy', 'Geography', 'Morphology', or 'Reference' buttons in the command window or any combination of these by using the 'Combination' button (Text-fig. 2, left). When the 'Taxonomy' button is pressed using the mouse, a pull-right menu appears which shows the available ammonoid families in the database. If, for example, the user selects the ammonite family Dactylioceratidae by highlighting it and releasing the mouse button, all specimens of the family in the database will be retrieved. Each item in the family menu has a pull-right menu producing a genus list for the family (Text-fig. 5). Suppose that the genus *Dactylioceras* is selected, then the screen shown in Text-figure 6 would be the query result. Image quality can be adjusted using the 'Brightness' and 'Contrast' sliders in the command window. The top-right window records the query text, gives the number of images retrieved and the number remaining for display. Images are displayed in order of decreasing size for efficient utilization of screen space; the user can go to next or previous screen of images by clicking the 'Next Page' or 'Previous Page' buttons in the command window. By clicking on an image, all information related to that specimen will be displayed in the middle-right text window (Text-fig. 6). A user interested in the species to which the specimen belongs and wanting to examine intraspecific variation can mark an image with the middle mouse button



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Search :  synonymy= Dactylioceras
Number of Images Returned:  325          Number of Images Remained to Display: 244
```

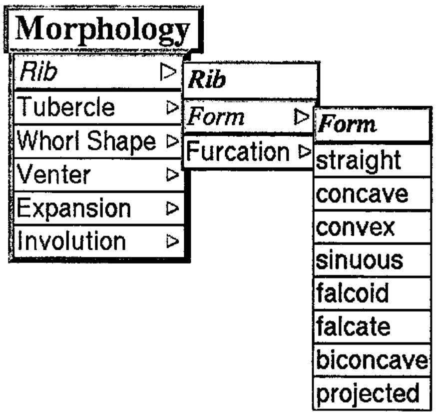
```
SUPERFAMILY:Eoderocerataceae.  FAMILY:Dactylioceratida.  GENUS:Dactylioceras.  SPECIES:circumactum.  TAXAUTHYEAR:Dagis.
  REFAUTHYEAR:Dagis 1968.  SYNONYMY:Dactylioceras.  SYNSPECIES:circumactum.  STAGE:Toarcian.  SUBSTAGE:Middle.  EURZONE
:Bifrons.  EURSUBZONE:Commune.  ZONE:Dactylioceras Commune.  AREA:Western Pacific.  COUNTRY:Russia.  PROVINCE:Northern
Siberia.  SPECNO:312-198.  IMAGE:/home/images/dagis/dagis68toarcian5-4.ras.  D:  6.28 UD:  3.25 U:  0.53 V:  1.66 WH:
1.66 WHD:  0.26 WWD:  0.24 WWH:  0.92 PRHW: 22.00 SRHW: 28.00 WHORL_SHAPE:ellipsoid.  UWALLHT:low.  UWALLANG:steep.  V
ENTER:plain.  PTREND:gprorsiradiat.  PFORM:straight.  PPROF:normal,strong.  FURC:bi.  TUBERC:NO.  RIBWIDTH:  0.13 FURCP
OSO:  0.74 EXPO:  1.89 VOLUTIONO:  0.15
```

TEXT-FIG. 6. Retrieval results from 'Ammon' for the genus *Dactylioceras*.

and click on 'Speci Sublist' which will display all the images for that species. Clicking on the 'Main List' button will return the display to the genus level. Exercises such as this enable anyone to familiarize themselves very quickly with a particular taxonomic group.

The 'Stratigraphy' panel has a two-level menu. The top level is the Jurassic stage menu and each stage has a pull-right menu which shows the zones (north-west European scheme) in the stage. The user can scan the database by zone and get some idea of how ammonite morphology or ammonite communities changed through time. Exploring morphological and temporal changes of ammonite taxa in different parts of the world is possible by using 'Geography' as a query criterion, retrieving by geographical region or country. There are five geographical regions: Northwest Europe, Western Tethyan, Western Pacific, North America and South America, each of which has thousands of specimens in the database and could easily overwhelm the user. Geographical regions are most commonly used with other criteria to narrow a search.

If the user has no idea as to which taxonomic group a specimen belongs, then the database can be searched using morphological characters such as the degree of involution, shell expansion rate, rib form and furcation pattern, tubercle pattern, whorl shape, ventral geometry, and so on. An example of pull-right menus for ribbing is given in Text-figure 7, which also demonstrates the access routes to most of the descriptors in the qualitative morphology category of the database structure as indicated in Table 1. A user interested in a specific person's work can query the database with the Reference button which will produce a list of authors arranged in alphabetical order.



TEXT-FIG. 7. Morphology menu (left) and pull-right submenus for ribbing showing selected descriptors and descriptor states in the qualitative morphology category of the database structure.

The 'Taxonomy', 'Stratigraphy', 'Geography', 'Morphology' and 'Reference' menu system offers easy access to the database but, at the same time, reduces flexibility because the user can only search the database in one area of inquiry at a time. For any serious application, a combination of the above search criteria is needed as provided by the 'Combination' panel in the command window (Text-fig. 6, left).

DISCUSSION

'Ammon' can be useful in assisting with the identification of ammonites. The user only needs to know a few morphological descriptors and database operators. A new user of 'Ammon' may need to measure a few quantitative morphological parameters but after some practice they should be able to build up a sense of relationship between quantitative and qualitative parameters at which point identification becomes fun. The computer can even help by tabulating stored qualitative descriptors against their quantitative counterparts. Because of problems of poor preservation and the complex rules underlying taxonomy, it seems unlikely that computers will replace the human expert, but databases will alleviate the burden of memorizing many species and associated data allowing the user to focus on more important questions. Continuing advances in computer hardware and software technologies have made it feasible to store and manipulate fossil images digitally with ease, and access speeds and storage capacities are progressively increasing while costs decrease. As this trend continues, image databases will proliferate and make a significant impact on the way that palaeontologists work, particularly if databases become networked through the 'Information Superhighway'. It is not clear at this point whether these systems will simply continue to be created on an *ad hoc* basis and allowed to grow, compete and evolve, or whether palaeontological organizations will take a more proactive role and encourage efficient growth by avoiding duplication of effort, ensuring universal coverage, and guarding against restricted accessibility. We hope the latter because we cannot help but wonder whether the journal that you are holding in your hand is on the verge of extinction.

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