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Archaeocyatha, a computer-aided identification of genera

Adeline KERNER

CNRS (UMR 7207,Centre de recherche sur la paléobiodiversité et les paléoenvironnements), Laboratoire Informatique et Systématique, MNHN Département Histoire de la Terre, Bâtiment de Géologie, CP48, 57 rue Cuvier, 75005 Paris (France); kerner@mnhn.fr

ABSTRACT. An online service is proposed for recognition of the genera of a Cambrian fossil group, the Archaeocyatha, using Xper^2. It stores, edits and publishes the descriptive data compiled in the available documentation and provides a free access key. Why Archaeocyatha? They are well studied by an international cooperation, so avoiding most of the problems of an abundant and contradictory nomenclature as well as quarrels about the taxonomic rank of the taxa. Any geologist finding new Cambrian faunas may use this easy tool to help the identification of the collected material. The archaeocyath knowledge base comprises: 307 valid genera, their Cambrian stratigraphical and geographical distribution. Each genus is defined by figures of the type-specimen and 120 descriptors, each one comprising definition, pictures and character states. If an incomplete specimen cannot be identified at the genus level using traditional diagnosis, identification can be obtained with the free access key. Xper^2 offers tools to analyze geographic and systematic data of the knowledge base, to create lists of taxa for local faunal revisions, and to compare relationships between genera of the same taxonomic rank. The knowledge base is interactive and could be modified and improved at any moment. This work is permanently up to date and in progress.

KEYWORDS: Xper2, knowledge base, standardized characters, interactive identification key.

1. Foreword

Establishing a data base, generally extended to a knowledge base, is currently one of the necessary steps for systematic identification of recent or fossil specimens. It could be also applied to researches on biodiversity, ecology, and spatial and temporal distribution. Xper^2 is a management system for storage and editing descriptive data (knowledge base). Knowledge bases on various taxonomic groups are already available. Comparison of descriptions, export of data and interactive identification are operational (Ung et al., 2010). This system and associated tools is the software used for the present study devoted to the Archaeocyatha, a Cambrian fossil group. The resulting free interactive identification key offers specialists and non-specialists a tool that is easy to use (Kerner et al., 2011a, 2011b).

2. Why Archaeocyatha? Reasons for establishing a knowledge base on Archaeocyatha

2.1. First studies of a recently discovered group

The group seems an ideal candidate for establishing a knowledge base. Their range is limited in time, mainly early Cambrian to the end of late Cambrian (i.e. Cambrian stages two to nine according to the International Stratigraphic Chart), and in space, as components of reefs in inter-tropical zones (Debrenne & Courjault-Rade, 1994; Debrenne, 2007; Gandin & Debrenne, 2010). Archaeocyatha were discovered only in the mid-nineteenth century (Bayfield, 1845), whereas many other fossil groups were known for a longer period, in some cases since the eighteenth century, and consequently, were independently studied by numerous authors in different languages using their own descriptive terms, thus making further standardization very complex. On the contrary, the first studies on archaeocyaths concerned more their putative affinities with other known groups (corals, sponges, protozoans, even sphenophytes, Debrenne & Zhuravlev, 1992) than detailed descriptions of specimens. The first regional monograph was written by Bornemann on Sardinian fossils (Bornemann, 1884, 1886). He described and figured four new genera and 31 new species while only nine species were previously known from worldwide. He established a new subdivision “Archaeocyathinae” and named the group “Archaeocyatha” a class among Coelenterata. He was the first author to publish high-quality photographs rather than ink drawings. The second monograph, published by Taylor (1910), dealt with Australian faunas. He described 31 new species distributed among 12 genera (six of which were new). He established the first higher subdivision in archaeocyathan systematics by the allocation of the 15 known genera into five families, based on differences in intervallar structures. He was also the first to recognize their distinctiveness in considering Archaeocyatha as an independent group, intermediate between Porifera and Coelenterata and of the same taxonomic rank. Progressively, discoveries took place around the world (Debrenne & Zhuravlev, 1992). The real start of modern researches took place around 1930. Two schools were in competition, the Eastern school led by A.G. Vologdin and his team in Moscow, and the Western school led by V.J. Okulitch in Vancouver, and associated with the Bedfords in Australia. Okulitch’s systematics is based on ontogenetic stages (Okulitch, 1943). He proposed a new class of Porifera, the Pleospongea, divided into three subclasses according to the number of walls and the structure of the central cavity. This classification was not accepted by other specialists because parallel researches in the USSR by the Eastern school came to a more coherent pattern based on abundant and well preserved material. In the fifties about 400 species of archaeocyaths had been described, of which over 230 were due to the studies on material from the former USSR, (Siberian Platform, Altay-Sayan, Tuva, Urals, Kazakhstan) and Mongolia. For the Eastern school, archaeocyaths are divided into two classes Regularia and Irregularia on the basis of morphological differences of the secondary calcareous skeleton and ontogenetic stages, (Vologdin, 1937) and considered as an independent phylum, Archaeocyatha (Vologdin & Zhuravleva, 1947). Okulitch (1955) accepted the concept of an independent phylum and the name Archaeocyatha instead of Pleospongea (being too evocative of sponges), and slightly modified previous systematics by establishing seven orders including three classes (previously subclasses): (1) one wall, central cavity empty; (2) two walls; (3) central cavity full. He distinguished among others Metacyathida and Ajacicyathida equivalent to the Russian subdivisions.

2.2. Archaeocyatha: an international field of research

From the mid-1950s, I.T. Zhuravleva (Novosibirsk, USSR) began to exchange regular correspondence with F. Debrenne (Paris, France), despite the language barrier. From 1970 onwards, Debrenne was the guest of the All Soviet Union of Paleontologists periodic meetings and then became the link between the two research worlds even during this Cold War time. Since then, Russian and Western specialists have engaged in active cooperation that still continues today. Zhuravleva was at the origin of all modern researches. She proposed a firmer basis for the definition of Regulares and Irregulares, and emended the names Regularia and Irregularia to avoid confusion with the major subdivisions of Echinoidea and Cystoidea (Zhuravleva, 1955). She established the basis of modern systematics by applying the ontogenetic principle (Zhuravleva, 1960) (Fig. 1), studying the order of appearance and complication of skeletal structures. She

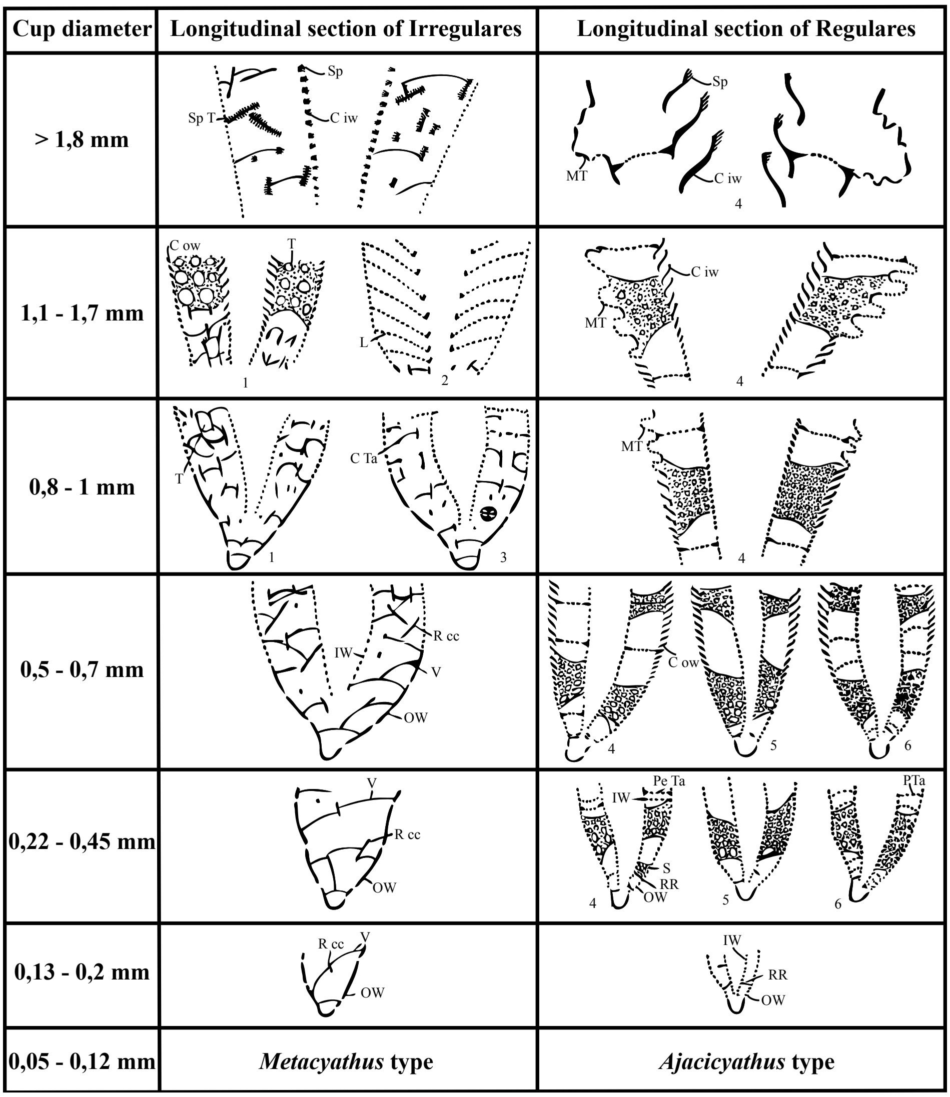

Figure 1. Ontogeny of archaeocyaths, stages of growth. 1: form with taeniae, 2: form with hexagonal radial tubes (syringes), 3: form with taeniae and tabulae, 4: form with pectinate tabulae, 5: form without tabulae, 6: form with tabulae. C iw: inner wall with canals, C ow: outer wall with canals, C Ta: convex tabulae, IW: inner wall, L: hexagonal loculi, MT: multiperforate tabulae, OW: outer wall, P Ta: porous tabulae, Pe Ta : pectinate tabulae, RR: radial rods, S: septa, Sp : spine, Sp T: spinose taeniae, T: taeniae, V: vesicular tissue. (Zhuravleva, 1960, modified).

demonstrated that the intervallar elements have hierarchic primacy over the outer wall structures, which in turn have primacy over the inner wall structures. Debrenne, working on North African-West European faunas (Debrenne, 1964), and Hill on Antarctic faunas (Hill, 1965, 1972) and in the new version of the Treatise on Invertebrate Paleontology, agreed with Zhuravleva's principle of classification. Nevertheless, they did not accept her view that Archaeocyatha were neither Metazoa nor Parazoa nor Protozoa but a superdivision of a new subkingdom, Archaeozoa (later emended to Archaeata). Debrenne, Hill and most other specialists,

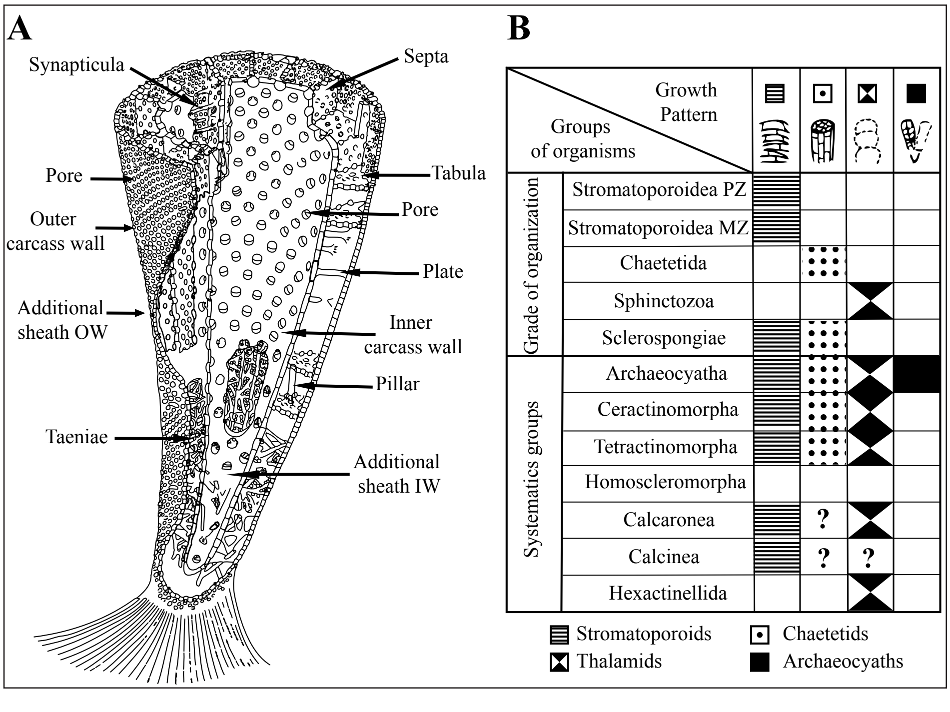

Figure 2. Archaeocyath growth patterns. A: Archaeocyath skeleton (Debrenne, 1964, modified) B: Growth patterns in various groups of Porifera and allied organisms (Debrenne & Zhuravlev, 1994, modified).

except some prescient zoologists who persisted in including them in Porifera, estimated that Archaeocyatha were a type of primitive organism convergent to many groups without dominant affinities. The position of archaeocyaths was definitively settled by the discovery of Recent calcified sponges in submarine caves. In this environment, Vacelet found a chambered demosponge with a massive calcareous skeleton devoid of spicules, described as *Neocoelia* (now *Vaceletia) crypta* (Vacelet, 1977; Picket, 1982). The absence of spicules is no longer a necessary character to define a sponge. Debrenne and Vacelet, (1984) demonstrated that the sponge model is consistent with the structural organization of archaeocyaths, a proposal accepted by Pickett (1985) and Kruse (1990) (Fig. 2). Immune reactions, asexual reproduction, cells interpreted as crypt cells suggest probable affinities with demosponges (Debrenne & Zhuravlev, 1994). In Systema Porifera , a Guide to the Classification of Sponges (Hooper et al., 2002), Debrenne, Zhuravlev & Kruse (2002) updated the diagnoses of genera published by Debrenne et al. (1990) and Debrenne & Zhuravlev (1992): every valid genus is defined by a short synonymy, its type species, its holotype, its definition, age, and stratigraphic and geographic distribution. A hierarchical set of keys is provided, based on the principles established by Zhuravleva (1960). This work was used to establish the present knowledge base on Archaeocyatha.

2.3. Sources for the knowledge base

Since 1960s, the genus has become a taxonomic category whose definition has achieved general consensus among specialists. It is based on variations of skeletal elements, particularly within designated categories of wall construction, and presence or absence of supplementary elements. Rozanov (1973), applying Vavilov's Principle (repetition of the same limited set of features = homologous series in variation, Vavilov, 1922), found homological series at the genus level in Archaeocyatha, permitting the establishment of classification based on homological variability. This is one of the first attempts at an identification key. The increasing number of genera between 1975 and 1990 reflects regional discoveries worldwide. Unfortunately, the splitting of taxa based on minor variations of the same morphological element led to inflation, and subsequent intensive revision was necessary to determine the systematic value of skeletal variations, and to list invalid names corresponding to incomplete or poorly preserved specimens, or to lost types, when no topotypes could be found. The different skeletal structures have been typified and their variations carefully defined to result in a clear systematization and the recognition of junior synonyms. Consequently, the number of genera in the whole group was drastically reduced from 587 before 1989 to 298 in 1992. This simplification allowed a better knowledge of the group and better application to paleogeographic reconstructions, biostratigraphic zonations and correlations (Debrenne et al., 1990; Debrenne & Zhuravlev, 1992). Debrenne, Zhuravlev and Kruse completed the research on genera: every valid genus is defined by a short synonymy, its type species, its holotype, its definition, age, stratigraphic and geographic distribution. This work, together with unpublished documents compiled for the Treatise of Invertebrate Paleontology (in press), are the sources used for the present computerization of Archaeocyatha.

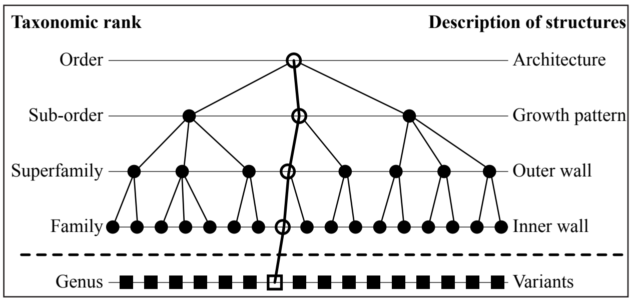

Figure 3. Archaeocyaths traditional key follow the classification: a natural identification keys.

3. Archaeocyatha, a free-access knowledge base: http://www.infosyslab.fr/archaeocyatha

When one opens this knowledge base for the first time the screens appear rather complex and inaccessible for the novice, but its use is more intuitive than it appears. We outline below how to work with and obtain an identification.

3.1. Identification tools

Traditionally, an identification paper key is used to identify a specimen. This type of key has a fixed sequence of questions. When the user has answered each question without doubt, an identification is obtained. In the case of archaeocyaths, the identification key is named a natural key, because the asked questions follow the classical systematic classification. In conventional determination, if one structure is missing, no complete identification can be obtained. In such cases a more flexible tool is required. The free access key offers several possibilities (Fig. 3 and Tab. 1). The archaeocyathan interactive key belongs to latter type. It is included in a three-part website: (1) introduction to Archaeocyatha, their role in the Cambrian system, their morphology and a list of references; (2) general remarks about the knowledge base and some exports: list of genera and their detail sheets, list of descriptors, list of groups of descriptors and knowledge base properties; (3) the interactive key and its tools: user guide, matching terminology and glossary.

3.2. Knowledge base construction

Standardization seems to be unnecessary after the important revisions quoted above. Nevertheless when definitions have been added to the knowledge base some difficulties appear. So a standardization step is required even for this group.

Firstly, terms already present in the base are examined and questioned: are they homogeneous and/or are they synonymous? A single term may correspond to different

	Natural key (single access keys)	Free access key
Information reduction	High	None (complete information is optimal)
Identification speed	Depends on the creators of the key	Depends on user's background knowledge; may exceed average
Complex statements (and, or...)	Yes but not recommended for polytomous keys	No
Question-answer style	Possible for simple statements	Implicit in character state or value choice
Difficulty of choosing next decision	None	Often high for beginners
Doubt managment	Difficult: all alternative paths must be followed to the end	Easy
Incomplete specimens managment	Identification is possible but taxonomic rank is higher	Easy
Resources required for construction	Low for first draft. Good keys require high expertise	High investment until first version can be tested

Table 1. Comparison of two identification methods: natural key and free access key (Hagedorn et al., 2010).

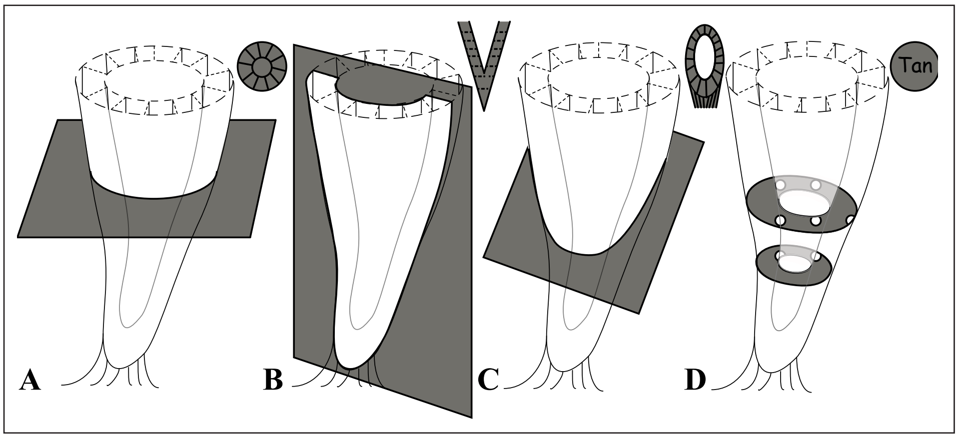

Figure 4. Different orientation of sections illustrated as in the knowledge base. A: Transverse section. B: Longitudinal section. C: Oblique section. D: Example of tangential section of tabulae.

structures, i.e. spine, a skeletal element close to bracts or tiny skeletal elements dividing pores to form an additional sheath. For a traditional determination there is no confusion but, for computer identification, the terms must be distinguished and standardized; the term *spine* is attributed to a structure equivalent to small bracts and protrusion leading to pore subdivision. Besides, some traditional terms included several concepts: *anthoid pore* contains information on pore shape and arrangement. Next, each character and its states have been reexamined and broken down into basic descriptors. Only terms corresponding to one concept are retained while similar concepts are regrouped. Only characters with taxonomic interest are present in previous diagnoses, but for computer-aided identification it is necessary to find other descriptive terms even without taxonomic importance, for instance external shape, solitary or colonial forms and so on. New terms are thus added.

Thin sections are absolutely necessary to study archaeocyathan skeletal structures. The resulting observations may correspond to primary morphological structures or to distorted observations because of the orientation of the sections. Descriptors have to be sorted by the type of section (Fig. 4).

3.3 Knowledge base conformation

When the standardization is complete, an adapted terminology is adopted. For specialists accustomed to the traditional terminology, a table explains the correspondence between ancient terms and computerized ones (Fig. 5). The taxonomic description module comprises 307 genera with systematics information and figures of type specimens. It is composed of 120 descriptors: 85 on morphology, 8 on stratigraphic and geographic distribution, 27 on traditional classification. Each descriptor has several states and descriptors and states are defined and illustrated (Fig. 6A).

4. User guide to the knowledge base

4.1. Successive steps of identification

To identify a specimen, it is necessary to follow several steps. The first is the choice of an adequate descriptor; the second, the choice of the states; the third, the confirmation of your choice. When this part is completed, the description is submitted and the process is repeated until the identification is obtained (Fig. 6B). At any time, it is possible to know how many states are different between the described specimen and each discarded genus and to check the differences (in red) on the detailed sheet of the discarded genus. At the end a detailed sheet appears with information on the classification, the genus type species, with figure of the type specimen and the complete description of the identified genus.

4.2. Tools

Moreover, other tools may help in the choice of the different steps described above. For example, it is possible to sort descriptors in alphabetical order, to display or conceal miniature pictures of descriptors, states and genera and eventually to reset the button and begin a new identification.

Descriptors may be sorted by special tools: the filter and the discrimination power. The filters reduce the list of descriptors to one special domain, for instance, by type of skeletal structure (outer or inner wall, intervallum), by other information (stratigraphy, geography, classification) or by orientation of the sections (transverse, longitudinal, oblique…). The second possibility is sorting descriptors by discrimination power. There are three possible sorting methods: Xper original sorting, Sokal and Michener sorting and Jaccard sorting.

The descriptors that discriminate more genera are placed at the top of the list. This order has to be examined with a

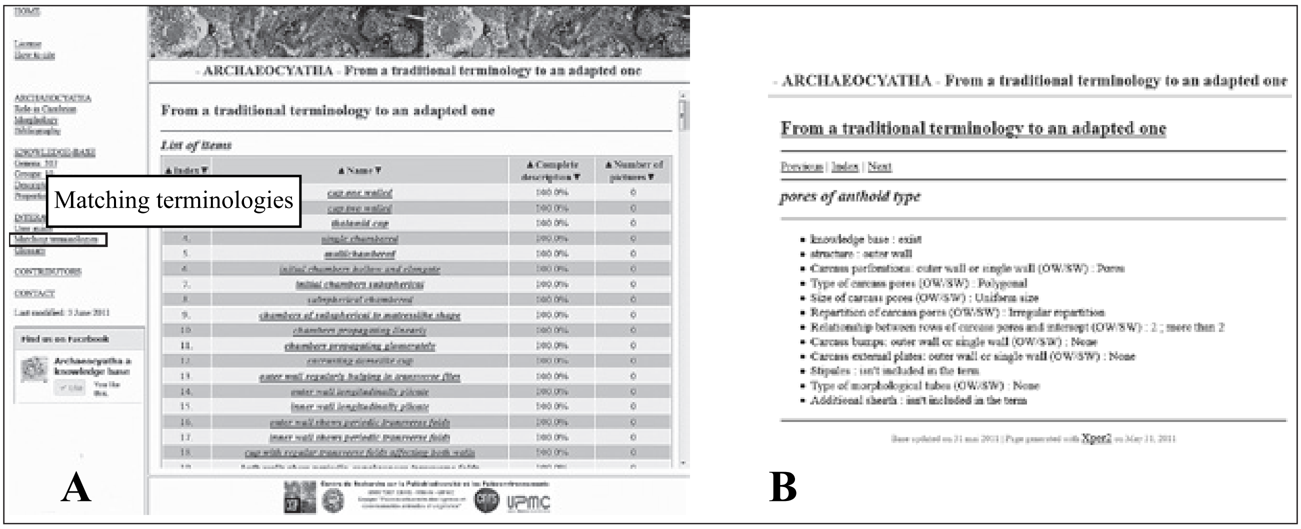

Figure 5. Comparison tool between traditional and adapted terminology. A: List of traditional terms in matching terminologies webpage. B: “Anthoid pores” example of computerization.

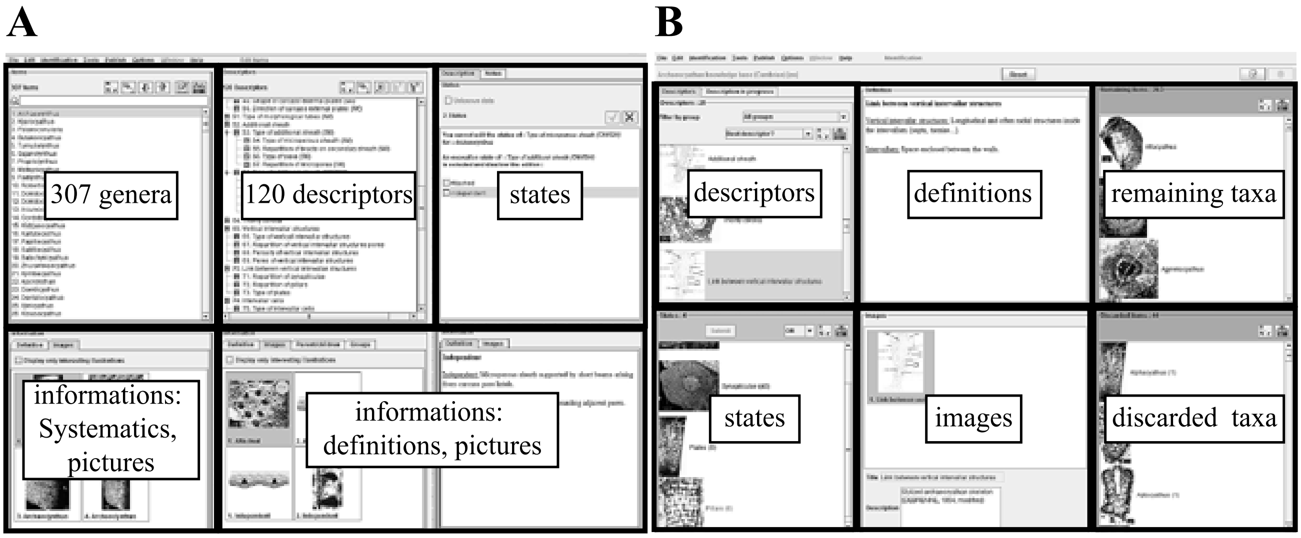

Figure 6. Knowledge base interfaces. A: Taxonomic description module with the 307 genera described with 120 descriptors. B: Interactive identification module: left: list of available descriptors and their states; middle: definitions above and images below, and right: list of remaining taxa above and list of discarded taxa below.

critical mind as the first descriptor could be difficult to define or might not be morphological data.

To be as precise as possible for the description of the studied specimen, logical operators (or, and, not, nor…) allow to improve the description or to raise doubt. For example, if external plates are observed they may be scales or annuli then OR is used (doubt); if these two structures are present in the same specimen then AND is used (qualification).

Several genera are compared by opening the window "comparison" on the data sheet. Descriptive data are represented in a table of taxa (row) and times descriptors (columns). This last tool permits to conclude an identification or to find the characteristics of different taxonomic ranks.

5. Conclusions

This knowledge base is either used as an identification genera key or as a special motor for different domains of archaeocyathan research, for instance, faunal geographic and stratigraphic distributions. The knowledge base is interactive and can be modified and sophisticated at any moment. This work is permanently up to date and in progress: a future stage is to include paleoecological data.

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