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论四射珊瑚的内生长线
——以新疆早二叠世 *Kepingophyllum aksuense* Wu et Zhou 为例

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内容提要

新疆早二叠世 *Kepingophyllum aksuense* Wu et Zhou 的内生长线发育良好，它们是由年季节温度的变化而形成的。据内生长线，可推算出 *K. aksuense* Wu et Zhou 的平均生长率为 5mm/年。运用珊瑚的生长率及年龄可计算出沉积事件发生的频率。

关键词　早二叠世 *Kepingophyllum* 内生长线　生长率　幕式沉积

前言

生长线是增生组织包括外壳和内部骨骼特征的突然的或重复的变化（Clark, 1979），这些变化通常与环境变化有关。生长线的表现形式多种多样，人们最早注意到的生长线是树木的年轮和水生贝类的外壳年线。年轮的区别在于颜色、明暗度及结构组份。壳上的生长线是以颜色、厚度或凸起方面的不同而表现出来。因此，生长线的定义不仅包括象贝壳、珊瑚等的外部表现的颜色变化和凹凸情况等的外生长线，而且也包括象树木的年轮、珍珠的内部堆积面、复体珊瑚内部骨骼排列的致密度变化的内生长线(插图 1)。不论是内生长线或外生长线，最显著的特征是它的周期性。颜色从明到暗的逐渐变化，骨骼组份的致密和疏松的交替，都反映了诸如温度、光照、潮汐、产卵、蜕壳甚至太阳周期活动的变化情况。

Whitfield 对采自印度的现代六射珊瑚 *Madrepora palmata* 进行了外生长线研究，从而开创了珊瑚生长线研究的历史。Wells (1963) 详细研究中泥盆世的 *Heliophyllum halli* Edward et Haime 的外生长线后发现，每年有平均 400 条细生长线，他认为大致代表 400 天，并进行了生长率计算和环境讨论。Scrutton (1965) 进一步研究中泥盆世的标本后指出，保存完好的标本可分出年、月、日生长线；一年有 13 个生长带对应 13 个阴历月，每个阴历月的平均天数为 30.59，一年共有 399 天。并认为，这 13 个生长带的形成极有可能与每月一次的排卵相一致。

Wells (1963) 根据泥盆纪一年的天数与现代的相比较，得出一个重要结论：从地质历史时期到现代，地球的旋转速度逐渐减慢。从此，有关古生代珊瑚作为地质年代计 (geochronometers) 的工作引起了越来越多的地质学家、地球物理学家甚至天文学家的重视。Johnson 和 Nudds (1975) 在研究石炭纪维宪期的 *Lithostrotion martini* 后，提出了地球旋转速率

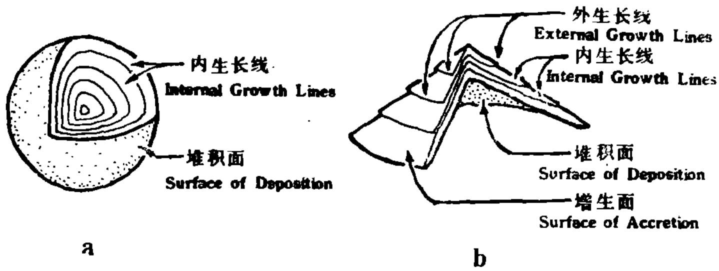

插图 1　两个生长线的例子(据 Clark, 1974)
Two examples of growth lines (from Clark, 1974)
a. 珍珠 (peal); b. 蝛 (limpet)

随地质年代的演变而改变的经验公式。

珊瑚内生长线的研究以往主要着重在现代六射珊瑚，通过X光透射照片而得出的暗层和亮层的分带性，Knutson 等(1972)、Weber 等(1975)认为是季节温度变化的结果。Scrutton 等(1981)对古生代蜂巢珊瑚类和 Ezaki 等(1989)对早二叠世 *Wentzellella irregularis* Wu et Zhao 的研究也发现有内生长线，前者表现为横板疏密相间，后者表现为纵切面上鳞板大小交替出现等。

本文研究的 *Kepingophyllum aksuense* Wu et Zhou 主要采自新疆阿克苏地区开派兹雷克剖面(插图 2)的下二叠统康克林组上部 K27层。本层厚 2.8m，岩性为灰黑色泥粒岩，具藻类和结壳状有孔虫包裹生物屑组成的长形核形石。与其共生的化石有：牙形刺 *Sweetognathus whitei* (Rhods), *Ligondina* sp.; 海参骨片 *Eocaudina marginata* Langenheim

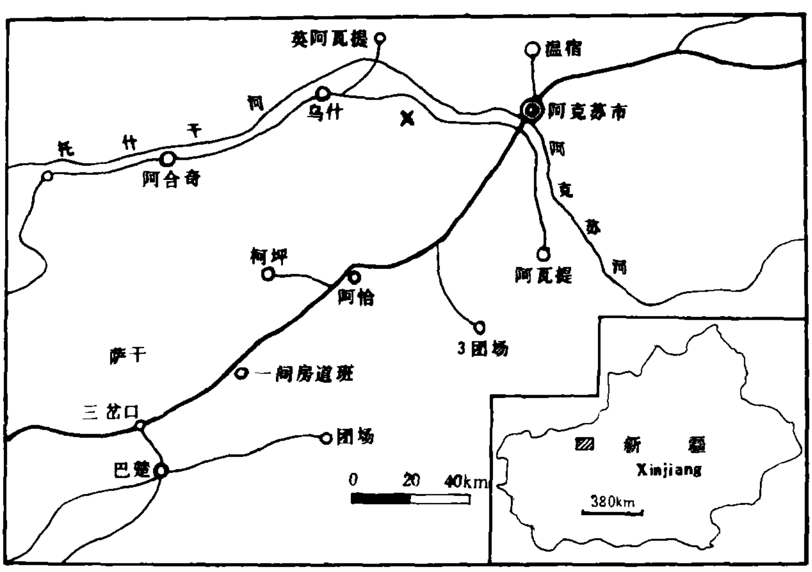

插图 2　化石产地图
Map showing lacation of fossils
×. 剖面位置

et Epis, *Eocaudina gutschicki* Frizzell et Exline, *Mortensenites* sp.; 䗴 *Rugosofusulina complicata* (Schellwien)。

Kepingophyllum aksuense 的内生长线

Kepingophyllum aksuense Wu et Zhou 是我国特有的具三级隔壁和鱼钩状间壁的复体块状四射珊瑚,它常为上下扁平的盘状,并有较特殊的生长型式(王向东,1992)。在开派兹雷克的标本中,有一块样品发育有较清晰的外生长线。

在 *K. aksuense* 的纵切面上,各种骨骼构造,如泡沫板、隔壁、横板、中柱等十分明显地表现出周期性的生长,可分为亮带和暗带两部分。亮带(在薄片上透光性好,而在光面上则相反)的骨骼堆积疏松,泡沫板大而薄,隔壁细且略弯曲,子代个体(offset)的生长常发生在亮带,中柱中的斜板间隔大。暗带(在薄片上透光性差)的骨骼堆积致密,泡沫板小且厚,隔壁厚且直,横向上相互之间常连结成条带状,在中柱上有较致密的灰质带(图版 I, 图 2c)。

研究现代和古代珊瑚生长线的学者们一致认为,亮层和暗层的形成原因是由于一年中季节温度变化造成的。亮层代表夏季生长的产物,温度高,生长快,骨骼排列疏松;冬季温度低,生长慢,骨骼排列紧密。因此,一个亮带和一个暗带构成了一个年生长线。

不论是古生代的四射珊瑚(Ezaki *et al.*, 1989)和横板珊瑚(Scrutton *et al.*, 1980; Philcox, 1971)还是现代六射珊瑚(Weber *et al.*, 1975),都有一些共同的内生长线特征,即亮层和暗层的交替,生长线之间宽度不均匀以及亮层中有某些“加速带”(stress band)存在。对于后两种特征的解释是年与年之间的平均温度差或温度的突然变化。现代珊瑚内部年生长线的确定毋庸置疑,但古生代珊瑚的内生长线是否确实是年生长的结果却仅靠推论。在阿克苏开派兹雷克剖面,有一块外壁保存十分完好的标本(图版 II, 图 1a—d),外生长线和内生长线均清晰可辨。据 Wells (1963), Scrutton (1965) 及 Johnson 等(1975)的报道,外生长线可分为年、月、日三级。采自阿克苏的标本可识别出 4 个外部年生长线,每一外部年生长线内可有多于 10 条的月生长线,而每一月生长线内有 30 条左右的日生长线。由于标本保存不全,并有些磨损,不能详细地辨认出具体的月、日生长线数目,因而不能确定早二叠世每年的天数。对照同一标本纵向光面上的内生长线,恰好与外部年生长线相对应。外部年生长线之间的收缩部位大致与内生长线中的暗层一致。因此,可以断定,早二叠世 *Kepingophyllum aksuense* 的亮、暗交替的内生长线与现代六射珊瑚相同,是年生长的产物。

珊瑚中生长线越明显,表明其环境变化越显著。在赤道附近,由温度变化造成的内生长线不明显;离开赤道越远,内生长线就越显著(Ma, T.Y.H., 1937; Weber *et al.*, 1975; Johnson *et al.*, 1975)。据浙江大学古地磁实验室陈汉林提供的古地磁资料,早二叠世新疆阿克苏开派兹雷克位于北纬 28.6°(±4.3°),已处于温带,气候变化分明,因此,内生长线明显。

Kepingophyllum aksuense 的生长率

珊瑚生长率是单位时间内珊瑚生长的大小。常常以年为时间单位,并取平均值。以往,对古生代四射珊瑚生长率的计算是根据外生长线(Johnson *et al.*, 1975),而横板珊瑚(Philcox, 1971)与现代六射珊瑚相同,常据内生长线来测量。在此,*Kepingophyllum aksuense* 的生长率计算运用内生长线,即只要数出某一垂直距离内的生长线数目,就可计算其生长率。

通过对现代六射珊瑚的研究发现,生长率的大小取决于两个因素:水的温度和珊瑚骨骼

排列的紧密程度 (Wells,1956)。海水的年平均温度越大,珊瑚生长越快;骨骼排列越疏松,生长率也越大。在同等条件下,单体和丛状体的生长率较块状体的大。据 Wells (1963) 报道,同一珊瑚礁中的不同珊瑚生长率不等,一般在 5—82mm/年。Johnson 等(1975)对北部英格兰维宪期 *Lithostrotion martini* 的研究,其生长率为 36—69mm/年,当时处于南纬 10°,这比泥盆纪处于北纬 40° 的纽约的珊瑚生长率 20mm/年高得多。另外,沉积类型的不同也可影响珊瑚的生长率, *Lithostrotion martini* 在薄层状灰岩中为 54mm/年, 在灰质页岩中为 33mm/年 (Johnson *et al.*, 1975)。

据中国科学院南海海洋研究所聂宝符介绍,产于中国南海的现代珊瑚 *Porites lutea* 的生长率为 5—10mm/年,而 *Acropora* 达 70—80mm/年。前者为骨骼生长致密的复体块状珊瑚,后者是骨骼生长疏松的复体枝状珊瑚。

对采自开派兹雷克剖面的复体块状 *Kepingophyllum aksuense* 的 8 块标本进行生长率统计(插图 3),其平均生长率为 5mm/年。如此低的生长率可能为多个原因所致,一是其骨骼排列成致密的块状;二是开派兹雷克当时处于北纬 28.6° 的温带。另外,由于 *Kepingophyllum aksuense* 成扁平状,造成了同一单位时间内由内生长线所计算出来的生长率较低。

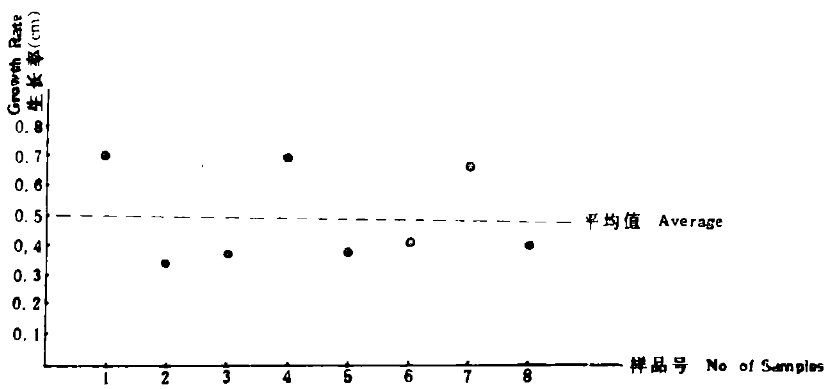

插图 3 *Kepingophyllum aksuense* 的生长率

The growth rates of *Kepingophyllum aksuense*

从插图 3 可看出,同一产地、同一层位所产的同种珊瑚的生长率可有较大幅度的变化, 从 3.4—7.0mm/年不等。因此, 影响珊瑚生长率的因素是多方面的, 除了水温、骨骼疏松程度以外,尚有某些次要的原因。

生长线的应用

有关生物生活时环境变化的信息必然保存在生物骨骼的结构、形态及化学变化上。同样,沉积物的变化,每一次大的沉积的发生在珊瑚的形态,内部结构上均有表现 (Hubbard, 1970; Philcox, 1971)。采自开派兹雷克剖面 K27 层的样品 3, 可明显地看出两期生长(插图 4)。第一期生长延续时间较长。据样品 3 的生长率 3.7mm/年可知,本期生长延续了 16 年,随后,发生了一次较大的沉积事件,这从完整的珊瑚群体中间包有一团灰泥, 边缘的生长呈指状(图版 II, 图 1c) 可以看出;沉积事件发生后,并没有完全使珊瑚致死,而仅使部份珊瑚个体死亡,另外个体又继续生长(返青生长 rejuvenescence)。第二期生长延续了 13 年,然后被更大的一次

沉积事件打断，导致珊瑚完全死亡。其整个生长过程可由插图 4 及插图 5 表示。

样品4(采自 K23 层)呈指状生长(图版 III，图 2a,b)，与样品 3 相似，可识别出 3 次沉积事件，其规模和间隔均较 K27-层的小(插图 5)。

插图 4　间歇性沉积(幕式沉积)对珊瑚生长的影响
Episodic sedimentation influencing on coral growth

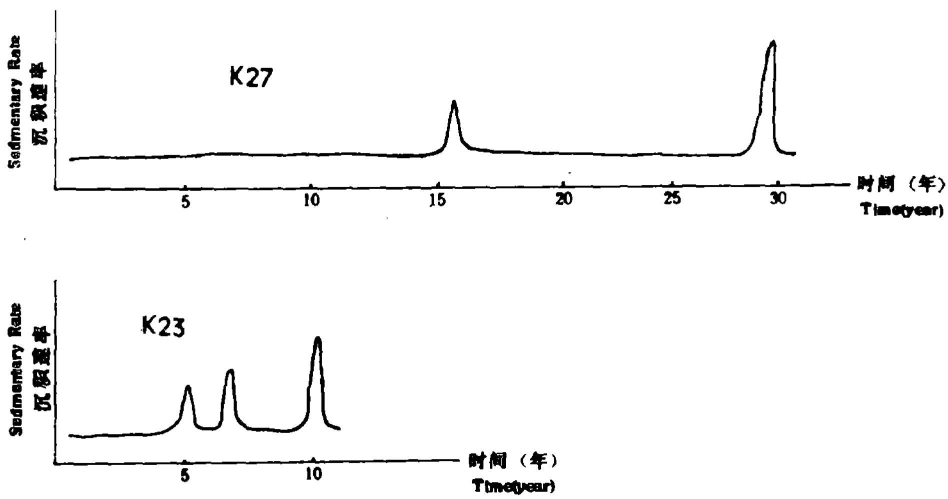

插图 5　不同地质时期幕式沉积发生的频率不同
Frequency of occuring episodic sedimentation varing with different geological periods

从上所述，可得出以下认识：(1) 地质历史中沉积物的沉积不均一，而是呈间隙性，可分出相对静止和相对活动两种沉积时期(插图 5)。(2) 珊瑚化石既作为生物又作为沉积物本身对沉积作用有着特殊的指示作用。据珊瑚的生长率而计算出的珊瑚年龄可有效地说明沉积事件发生的频率。(3) 四射珊瑚对地质历史中的沉积十分敏感，对一般较少量的沉积不至于导致死亡，可发生返青生长。

此外，研究珊瑚的生长线，还可用来推测古纬度和古温度，进行居群分析，甚至可用来识别灾难性死亡事件的发生及频率。

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ON INTERNAL GROWTH LINES IN RUGOSE CORALS —WITH AN EXAMPLE OF *Kepingophyllum aksuense* Wu et Zhou FROM EARLY PERMIAN IN XINJIANG

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Key words Early Permian, *Kepingophyllum,* internal growth lines, growth rates, sedimentation events

Summary

Growth lines are abrupt or repetitive changes in the character of an accreting tissue including shells and skeletons, and these changes are usually related to changes in the environment (Clark, 1979).

There are various expressions of growth lines. Those annual lines of trees and shellfish were first noticed, which can be seen as differences in color, thickness, relief, or shading. For this reason, they can be recognized in two categories: external growth lines visible on the surface of organisms such as shells, corals; and internal growth lines visilb in thee section of pears, some corals and so on (Text-fig. 1).

The periodicity of both external and internal growth lines is the most noticeable character. The colors of shells grading gradually from light to dark and the arrangements of skeletons alternating between coarse and dense reflect all changes of surroundings such as temperature, light, tidal current, spawning, moulting, and even periodical solar action.

Growth lines on the epitheca of corals were irst recognized by Whitefield in 1898. More detailed studies were made in 1963 by Wells who recognized epithecal banding of 2 orders, annual banding and daily growth lines. He postulated that daily lines of every annual increment are results of daily growth. Therefore, he obtained the result that there are roughly 400 days in the Middle Devonian year based on fine daily line on the epitheca of the rugose coral *Heliophyllum halli.* In addition, he came to an important conclusion that he earth's rotation has been slowing down. From then on more and more geologists, geophysicists and even astronomers are interested in research on well-preserved corals as geochronometers. Scrutton (1965) worked again on Middle Devonian corals and recognized synodic month growth ridges betw en daily lines and annual banding. Johnson and Nudds (1975) studied the Carboniferous coral *Lithostrotion,* providing an equation which makes it possible to compare the deceleration rates of earth rotation in different periods of geological time.

Research on internal growth lines in corals is mainly based on living scleractinians. Annual alternating bandings of higher and lower density calcification by X-ray examination are the result of changes in seasonal temperature (Knutson *et al.*, 1972, Weber *et al.*, 1975). Paleozoic favositids and Early Permian *Wentzellella irregularis* also have similar alternating bandings (Scrutton and Powell, 1981; Ezaki and Kato, 1989).

The specimens are collected from Bed 27 of the Lower Permian Kangkelin Formation at Kaipaizileike Section of Aksu, Xinjiang (Text-fig. 2). This bed is about 2.8 meters in thickness, consisting of black-grey packstone with long-shaped oncolite composed of algae and crusted foraminifers and bioclasts. Other fossils from Bed 27 are he conodonts *Sweetognathus whitei* (Rhods), *Li-*

gondina sp.; the holothurian sclerites *Eocaudina narginata* Langenheim et Epis, *Eocaudina gutschicki* Frizzell et Exline; and the fusulinid *Rugosofusulina complicata* (Schellwien).

INTERNAL GROWTH LINES IN *KEPINGOPHYLLUM AKSUENSE* WU ET ZHOU

Kepingophyllum aksuense established by Wu and Zhou in 1982 is characterized by tertiary septa and brambly theca, usually discoid with a spec al increase pattern.

In longitudinal section, skeletal elements can be distinguished into two parts: (1) The part with lighter band: skeletal elements coarser in arrangement, lonsdaleoid dissepiments large and thin, septa vertically thin and sinuous and discontinuous t some places, interval between two tabellae large (offsets originating from this banding); and (2) The part with darker band; skeletal elements denser in arrangement, lonsdaleoid dissepiments small and thick, septa vertically thick and straight, with calcareous thickened banding in syncolumela. Alternation from lighter band to darker band must be the result from periodical changes of environmental factors. Most authors consider that growth lines are controlled by seasonal temperature. In summer, because of high temperature and fast growth of corals, skeletal elements are coarser in arrangement. In winter, skeletal elements are denser in arrangement. Therefore, an annual growth band is composed of a lighter part and a darker part (Knutson *et al.*, 1972; Johnson and Nudds, 1975; Weber *et al.*, 1975; Scrutton and Powell, 1980; Ezaki and Kato, 1989). However, except for living scleractinians, whether internal growth lines of Paleozoic corals are the result from changes of annual seasonal temperature is mere conjecture. In a specimen from Kaipaizileike Section pr served with both external and internal growth lines, the external growth lines can be recognized as in 3 orders problable repressening the annual, synodic month and daily growth lines. The contracted line between two external annual bands corresponds to the darker band in internal growth lines. Therefore, it can be concluded that the internal growth lines in *K. aksuense* are similar to those in living scleractinians, which are the result from changes in annual seaconal temperature.

GROWTH RATE IN *KEPINGOPHYLLUM AKSUENSE*

Growth rate in corals varies with the average water temperature throughout the year and the structure of skeleton. The higher the average water temperature, the greater the growth rate, and the more porous the arrangement of skeletal elements, the faster the growth of corals. Annual increments in an overall height ranging from 5 to 82 mm are given by Wells for warm-water reef corals with different skeletal elements in morphology. Corals from the Visean of Northern England, living across the equator, show greater rates of growth (up to 69mm per year) than those from the Devonian of New York living at 40° north of the equ tor (20mm per year) (Johnson and Nudds, 1975). The dendroid *Acropora* has a greater growth rate of 70—80mm per year than the massive *Porites lute* from the same area in the South China Sea with a growth rate of 5—10 mm per year (Nien Baofu, personal communication).

The calculated growth rates from 8 specimen of *K. aksuense* give an average value of 5 mm per year (Text-fig. 3). The reason for the lower growth rate lies in its discoid-shape and location in the temperate zone at 28°36′ north of the equator.

From Text-figure 3 it is known that the growth rate in the same species at a locality and horizon varies between 3.4 and 7.0mm per year. Therefore, besides seawater temperature and skeletal morphology, microenvironment is also a factor influencing the growth rate of corals.

SIGNIFICANCES

Information about changes of environments must be reserved in skeletal morphology, texture and chemical components. Similarly, skeletal structure in corals varies with changes of sedimentation. Two periods of growth can be recognized in Specimen 3 from Bed 27. The first period continued for 16 years known by its growth rate of 3.7 mm per year, with a subsequent sedimentation event resulting in the death of some but not all polyps (Pl. III, figs. 1a—c). The second (rejuvenescence) period continued for 13 years and was broken by a larger-scale sedimentation resulting in the death of all polyps (Text-figs. 4, 5). Based on Specimen 4 from Bed 23, three sedimentation events can be recognized (Text-figs. 4, 5; Pl. III, fig. 2a).

From the above statement, it can be summarized that (1) Sedimentation processes in geological times are intermittent and can be distinguished into the relatively active and silent periods (Text-fig. 5); (2) Frequency in the occurrence of sedimentation events can be reckoned by growth rates obtained from internal growth lines; and (3) Rugose corals are very sensitive to sedimentation, and can not be killed by a small amount of sediment instead of their rejuvenescence.

图 版 说 明

所有标本和薄片均保存在南京大学地球科学系。

图 版 I

1—3. ***Kepingophyllum aksuense*** Wu et Zhou

1a,b. 纵向光面，示内生长线，1a，×1，1b. ×2.5，1b.为1a的局部放大；登记号：K002，野外号：K27-2。2a. 横切面，×2；2b. 纵向光面，×1；2c. 纵切面，示中柱内的生长线，×3；登记号：K006，野外号：K27-6。3.纵向光面，×2；登记号：K008，野外号：K27-8。新疆阿克苏县开派兹雷克剖面，下二叠统康克林组。

4. ***Kepingophyllum aksuense*?** Wu et Zhou

纵切面，×3；登记号：035，野外号：Q53-3。新疆柯坪县丘达依沙依剖面，下二叠统康克林组。

图 版 II

1. ***Kepingophyllum aksuense*** Wu et Zhou

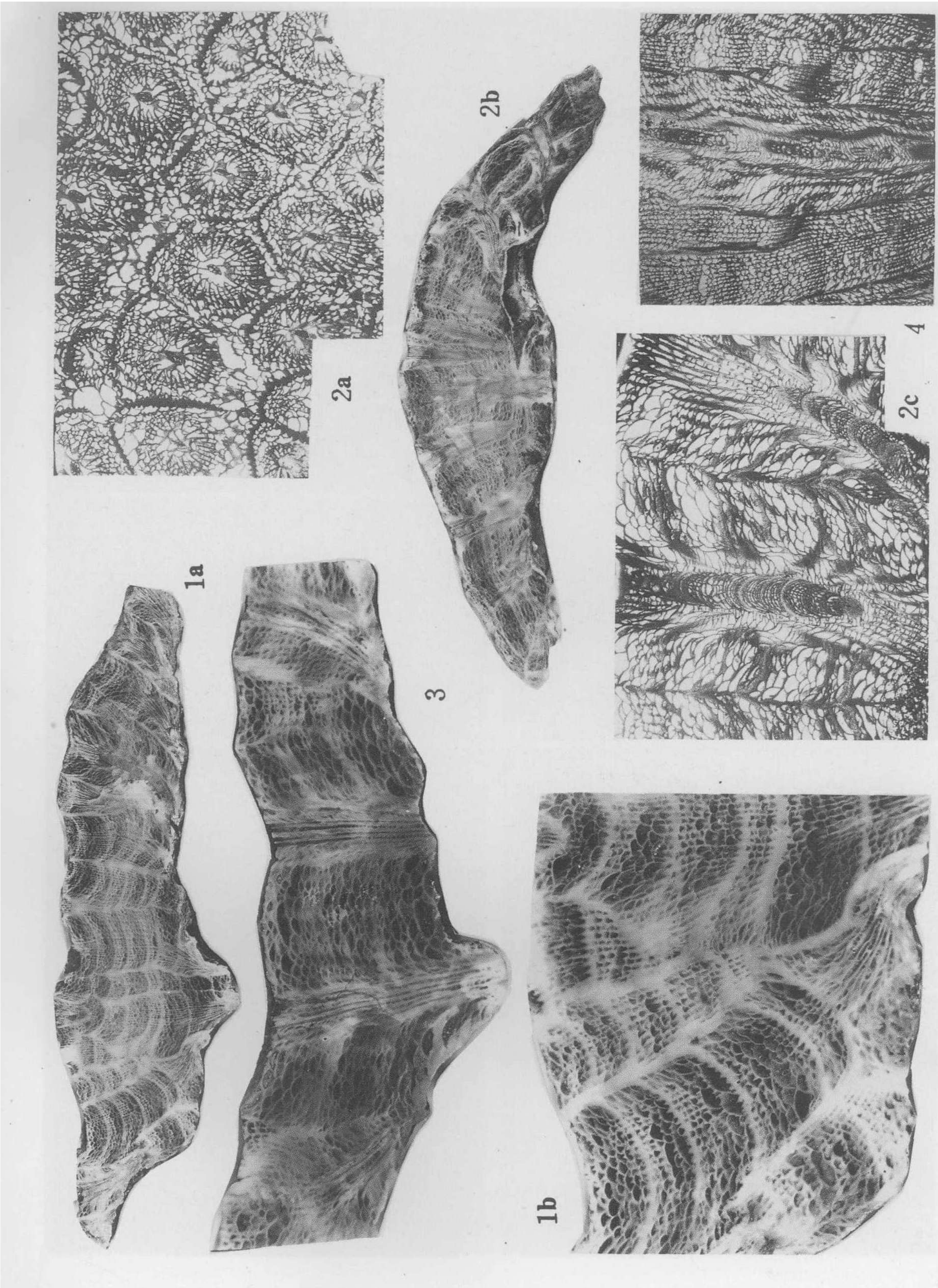
1a. 底面观，示一个月生长带中的日生长线，为 1b 的放大，×15；1b. 底面观，示一个年生长带中的月生长带，为 1c 的放大，×5；1c. 纵向光面，示内生长线，与 1d 中的外生长线的年带大致对应(箭头所示)，×1；1d. 底面观(局部)，示年生长带，×1；登记号：K009，野外号：K27-9。新疆阿克苏县开派兹雷克剖面，下二叠统康克林组。

图 版 III

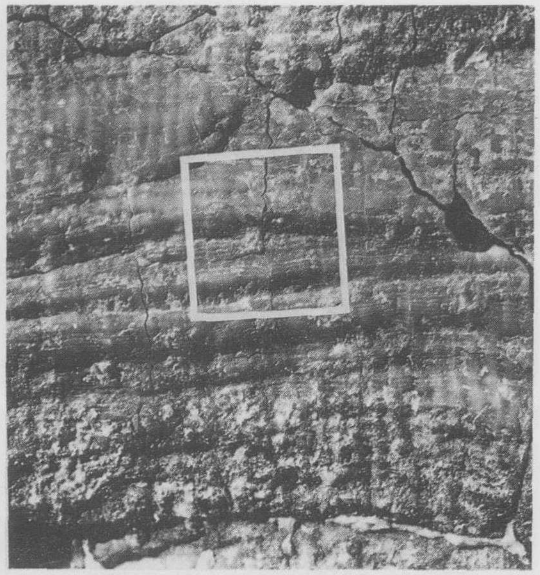
1,2. ***Kepingophyllum aksuense*** Wu et Zhou

1a. 纵向光面，为 1b 的局部放大，示包在群体中的灰泥，×2.5；1b. 纵向光面，示返青生长，×1/3；1c. 侧面观，×1/4；登记号：K003，野外号：K27-3。2a,b. 纵向光面，示内生长线和指状生长，×1；登记号：K004，野外号：K23-1。新疆阿克苏县开派兹雷克剖面，下二叠统康克林组。

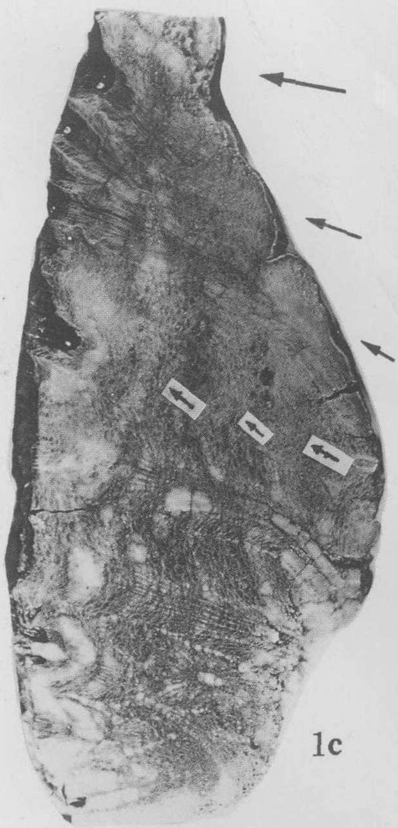
3,4. K27 层的泥粒岩，示藻类和结壳状有孔虫包裹生物屑组成的长形粒形石；薄片，×3；新疆阿克苏县开派兹雷克剖面，下二叠统康克林组。


2a
2b
4
2c
1a
3
1b

1a



1b



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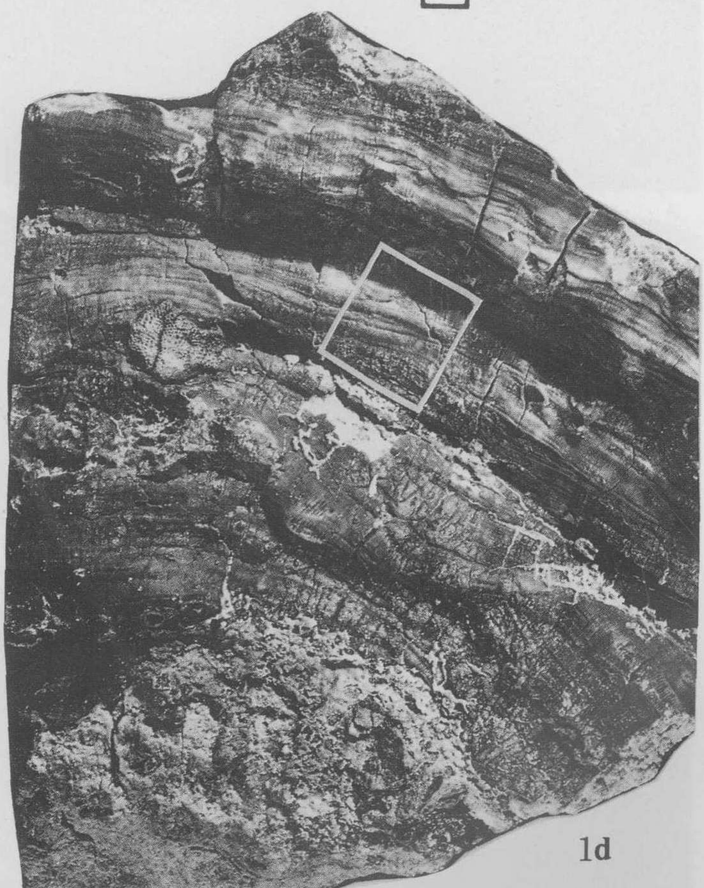

1d

图版 Ⅲ
Plate Ⅲ