第5卷第3期
1987年9月

沉积学报
ACTA SEDIMENTOLOGICA SINICA

Vol.5 No.3
Sept.1987

云南昆阳、海口磷矿的富集机理

曾允孚 杨卫东

（成都地质学院沉积所）

内容提要 本文阐明滇东早寒武世昆阳、海口磷矿沉积于牛首山古陆及滇中古陆之间的海湾泻湖环境，有利于两侧的深海槽盆洋流上升，可以将分散磷质不断带到浅水海湾之中；具有高本底值磷质的古陆，由于迳流也提供一定的磷质；由于磷质及其它生命元素源源不断供给，使得温暖、浅水海湾的菌、藻生物大量繁殖，有效地固定了海水中分散的磷质并沉聚于海湾底部沉积物中。昆阳磷矿与海口磷矿之间近东西向水下隆起的存在，从搅动的浅水产生磷质沉积物的簸选，导致较粗的颗粒磷块岩的富集。经过早期成岩阶段的酶、菌作用，使孔隙水中磷质聚集形成胶结物，进一步使颗粒磷块岩品位更富。

主题词 磷块岩矿床 富集机理 滇东昆阳 海口磷矿
第一作者简介 曾允孚 男 60岁 教授 矿床沉积学

一、引 言

昆阳、海口磷矿位于云南省东部，昆明市西南，滇池西侧（图1）。昆阳、海口磷矿是滇东早寒武世成磷区主要的磷块岩矿床，是中外驰名的富矿带。许多学者都在区内作过调查、研究工作，在矿床勘探、开采和区域地层、古生物研究方面取得了不少新进展。本文拟在前人研究和勘探资料的基础上，通过沉积相分析，重点讨论昆阳、海口磷块岩矿床的富集机理。

二、矿区地层及矿床地层特征

昆阳、海口磷矿赋存于下寒武统渔户村组中谊村段。其底板是渔户村组小歪头山段白云岩，二者以冲刷面或整合接触；顶板为渔户村组大海段白云岩，二者渐变过渡。昆阳矿区内著名的梅树村剖面（国际Є／Z界线候选剖面之一，图2），可作为地层划分对比的标准。

昆阳、海口磷矿是矿田一级单位，下属昆阳和海口两个矿带。昆阳矿带包括昆阳磷矿区及其西延部分；海口矿带包括海口磷矿区及其西延部分。两矿带分别位于香条冲背斜的两翼（图3）。昆阳矿带位于南翼，倾向南偏西；海口矿带位于北翼，倾向北偏东。两矿带构造简单，均以宽缓的单斜岩层为主。

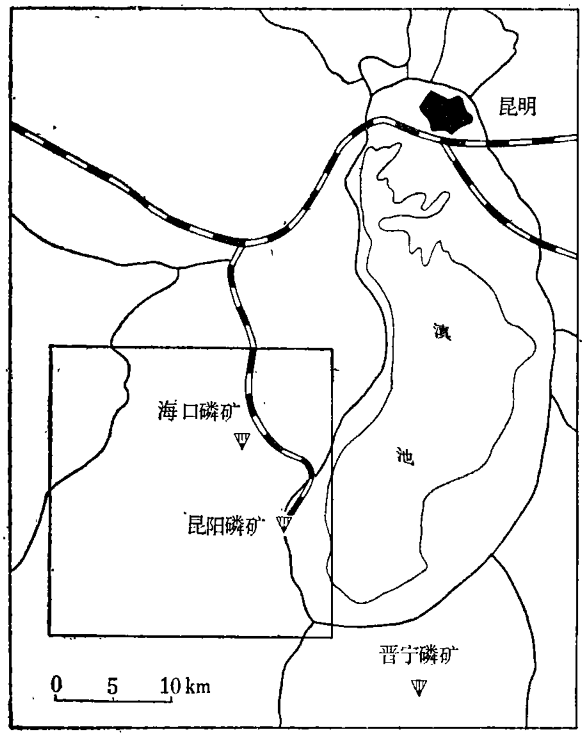


图 1 磷矿及研究区位置图

Fig.1 Location of the phosphorite deposit and studied area

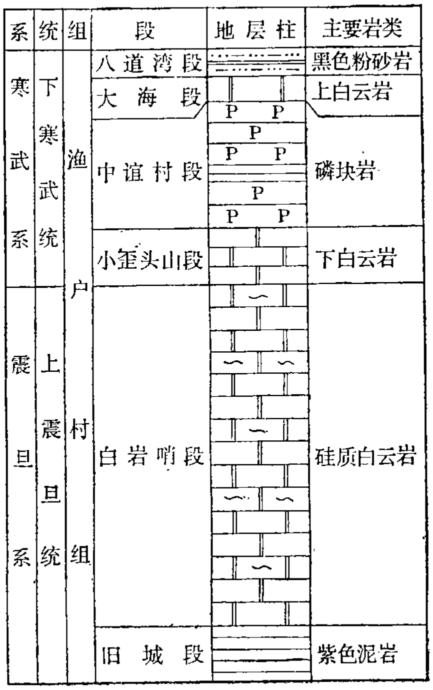


图 2 梅树村剖面地层划分

（据罗蕙麟等，1981）

Fig.2 The stratigraphic division of the Meishuchun section (from Luohuilin, 1982)

昆阳矿带中谊村段分上下含矿层。其间夹白云质泥岩，风化后黄白色，俗称白泥层，厚几十厘米至1.6米不等。上下含矿层均以砂屑磷块岩为主，次为砾屑磷块岩、生物屑磷块岩和球粒磷块岩，另夹少量白云岩及硅质岩条带。下矿层厚1.5至6.8米，平均厚3.5米，局部缺失；P_2O_5的含量为8.7—38.8%，平均29.5%。上矿层厚1.9至14.8米，平均厚5.8米；P_2O_5的含量8.2—37.8%，平均26.3%[1)]。

海口矿带中谊村段也分为上下含矿层，但夹层不同。海口矿带中谊村段夹层为石英砂质粗晶白云岩，厚度数米至数十米不等。下矿层以砂屑磷块岩和生物屑磷块岩为主；上矿层下部多为砂屑磷块岩，上部砂屑磷块岩与含磷白云岩互层。下矿层厚3.5至7米，平均厚4.5米；P_2O_5的含量为21.5—31.2%，平均24.5%。上矿层厚6至10米，平均厚7米；P_2O_5的含量为7.5—25%；平均20.4%。

三、大地构造及古地理背景

滇东早寒武世成磷期大地构造状况是：上扬子地块呈台地产出，西侧为滇青藏海

1）厚度和品位据云南化工地质队勘探资料综合。

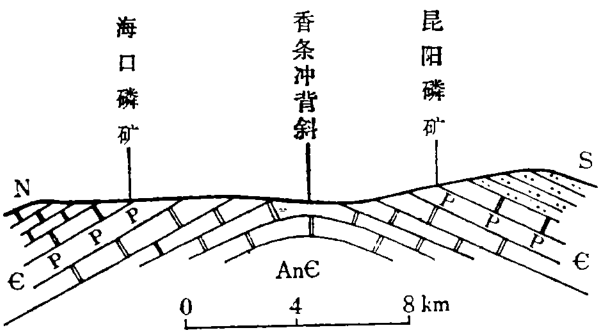
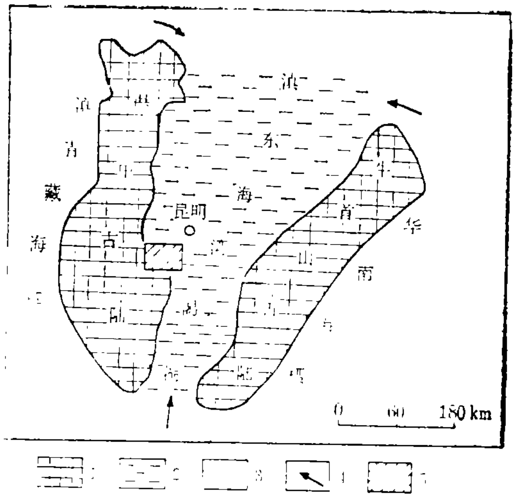


图 3 海口磷矿至昆阳磷矿横剖面图

Fig.3 The cross section from Haikou phosphorite deposit to Kunyong phosphorite depostion



1.古陆2.海湾泻湖3.海盆海槽4.海水流入方向5.研究区

图 4 滇东早寒武世成磷期古地理图

（据王崇武等，1982）

Fig.4 Paleogeographic map during phosphorite formed in early Cambrian, East Yunnan (from Wang Chongwu, 1982)

盆，东侧为华南海槽。牛首山古陆和滇中古陆分别位于上扬子地块的东西两侧的边缘，中间为一裂陷盆地。

早寒武世成磷期，滇东及其周缘地区在古构造及古海水面的控制下，呈现出图 4 所示的古地理面貌。正是在这种古地理背景条件下，滇东广大地区成为海湾泻湖环境，提供了磷酸盐沉聚的有利地带。其原因是：

1.滇东早寒武世成磷期的海湾泻湖与东西侧的深海槽、盆连通，这样通过洋流上升，深水分散的磷质可源源不断地进入聚磷盆地。

2.海湾泻湖两侧磷质背景值较高的古陆（牛首山古陆和滇中古陆，P_2O_5 含量达 0.25%），可以通过地表迳流供给部分磷质。

3.磷质及其它生物元素的源源供给，促使浅水海湾生物大量繁盛。生物有效地固定了海水中分散的磷质，并且作为磷的载体，死亡后沉聚在海底。工作区磷块岩中发现的大量磷质菌藻类生物化石（图版 I，1、2、3、4）和小壳动物化石，证实了这一点。

四、沉积相分析

昆阳、海口磷矿的主要矿石类型是砂屑磷块岩。为了阐明这类磷块岩的富集环境，便于讨论磷块岩矿床的富集机制，下面对两矿带代表性剖面进行沉积相分析。

1.昆阳矿带梅树村剖面相分析

该剖面位于昆阳磷矿二采区。含矿的中谊村段厚11.6米，下与小歪头山段白云岩呈

冲刷面接触，上与大海段含磷白云岩逐渐过渡。剖面结构如图5所示。

下矿层下部以砂屑磷块岩为主，间有砾屑磷块岩。具有叠覆波痕、干涉波痕和干裂构造，反映了水位频繁变化和间歇暴露等潮汐作用特性，属典型的潮间环境。

下矿层中部为中粒砂屑磷块岩，亮晶磷灰石或白云石胶结。具中厚层及板状层理，含丰富小壳化石，无暴露标志，应属潮下浅滩沉积。

下矿层上部为中到细粒砂屑磷块岩，填隙物为微晶磷灰石或玉髓。夹有硅质球粒磷块岩条带。具薄板状层理，靠顶部出现滑塌构造。与中部比较，小壳化石明显减少。这些特性表明其沉积时海水有所变深，应为浅滩外缘环境。

夹层为含磷的黄白色云泥岩，层极薄，具水平层理，表明其形成的水动力很弱，为滩外浪基面之下较深水泻湖沉积。

上矿层宏观面貌与下矿层相似，但组构变化与下矿层相反，即下矿层自下而上粒度由粗变细，上矿层则由细变粗。上矿层下部为薄板状层理，至中部则发育大型交错层理，再往上出现各种潮汐层理和垂直虫管，偶见微型干裂，白云质组分逐渐增多。这些特征表明上矿层的沉积环境是逐渐变浅的，从潮汐浅滩过渡到潮间、潮上。

昆阳矿带沿走向基本稳定。矿带西部的二街剖面沉积相特征与梅树村剖面大同小异。两剖面之间的局部地段缺失下矿层，夹层直接覆于底板小歪头山段之上，且底板顶面有一薄层铁质风化壳（张朝显，私人通信），说明下矿层沉积时，那里曾一度暴露。

2.海口矿带鸣矣河剖面沉积相分析

该剖面位于海口矿带中段鸣矣河勘探区东南垭口，含矿的中谊村段厚23.6米，与下伏小歪头山段以硬底接触，与上覆大海段连续过渡，剖面结构如图6所示。

下矿层下部为一套磷基细砂屑磷块岩，致密质纯，块状层理，小壳化石稀少，属潮下浅滩（外缘）沉积。

中部为泥质粉屑磷块岩，层系薄，层面具微型波状凸起，小壳化石稀少，蠕虫爬迹丰富。可能为浪基面附近的滩外较深水沉积。

上部为生物碎屑磷块岩。生物化石以磷质软舌螺为主，壳长而直，尖端对尖端定向排列，沿层面密集分布，这是波浪作用的标志，因此为典型的潮下生物碎屑浅滩沉积。

夹层为石英砂质粗晶白云岩。石英砂为中细粒，分选、磨圆较好，在重结晶的白云岩中分布极不均匀。在白云岩中见有脉状、羽状层理，板状交错层理（图版Ⅰ，7），说明其形成于潮坪环境，其中磨圆分选良好的石英砂粒，可能是沿岸风成砂被潮水携带到潮坪沉积物里混积的产物。

上矿层下部与下矿层下部的微相相似，但粒度较粗，中下部有一层具滑动构造，含白云质组分较高的砾屑磷块岩，滑动方向（消除岩层倾角影响后）为北北东20°，说明其沉积时有近于向北倾斜的缓坡存在，致使斜坡上部（潮坪沉积）的含白云质泥组分较多的沉积物往下滑动。

上矿层中部磷块岩与白云岩互层，向上白云质组分增多，至顶部则过渡为含磷白云岩。具脉状、波状等潮汐层理，属潮坪沉积。

海口矿带的其它剖面均可与此对比，这里不再赘述。

通过上述两剖面沉积相的分析可以看出，构成矿层主体的杂质少、品位高的颗粒磷

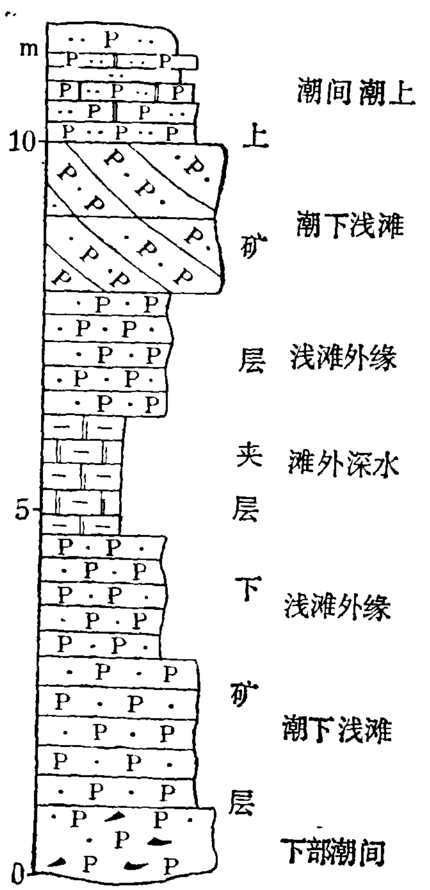


图 5　梅树村剖面中谊村段沉积相分析

Fig.5　The analysis of sedimentary facies of Zhongyichun Member at the Meishuchun section

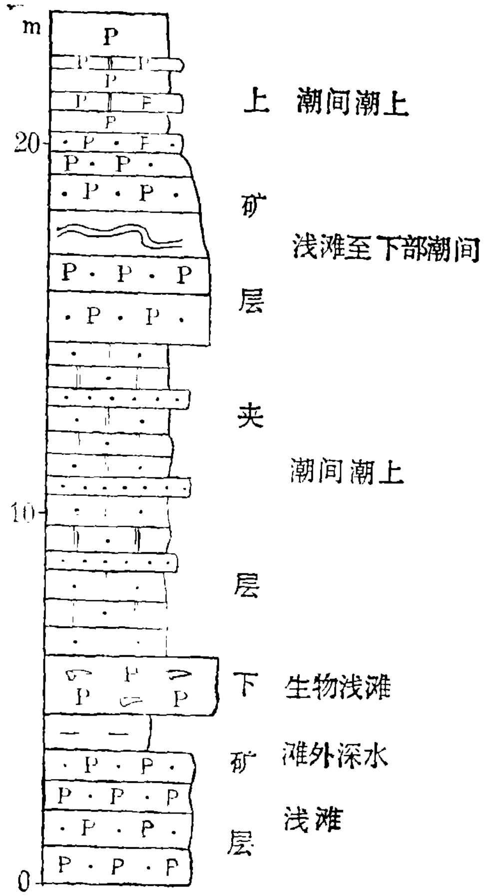


图 6　鸣矣河剖面中谊村段沉积相分析

Fig.6　The analysis of sedimentary facies of Zhongyichun Member at the Mingyihe section

块岩皆形成于潮下浅滩环境。换句话说，水动力能量较高的潮下浅滩是适于磷酸盐富集的环境，水动力能量较弱的滩外深水环境和潮坪环境由于陆源泥质和内源碳酸盐泥的混合而不利于磷酸盐富集。

五、水下隆起是控制磷酸盐富集的重要因素

昆阳、海口磷矿之所以能够富集成矿，是受特定的因素控制的。通过构造、矿层厚度及沉积相的研究对比，推断两矿带间、大致平行香条冲背斜的轴线，有一东西向水下隆起存在。正是该水下隆起所造成的特定的浅滩环境条件促使了磷酸盐的富集。说明该水下隆起存在的证据有：

1.构造背景

滇东区前寒武纪除发育纵向断裂系（它们控制裂陷盆地的边界和纵向延伸）外，还有横向断垒系的存在，它们控制着裂陷盆地内微地貌的变化，是古水下隆起存在的构造背景。此外，构成香条冲背斜的两翼地层均为宽缓的单斜岩层，伴生的次级褶皱和断裂极为少见，特别是经勘探查明，两翼矿层沿水下隆起倾斜方向有1—2‰的增厚率，由此推断，该背斜可能是原水下隆起的基础上，整体抬升形成的。

2.沉积相特征

昆阳矿带与海口矿带相距很近，但地层厚度、岩相及微相特征有着明显的差异（图5、6），说明二者之间的沉积相不可能是连续过渡的，而这种不连续为水下隆起的存在提供了必要的证据。

3.暴露及斜坡标志

在昆阳矿带和海口矿带相邻的矿层中均发现了干裂构造。昆阳矿带近水下隆起轴部的局部地段，下矿层缺失，底板顶面具铁质风化壳，表明含矿段沉积时隆起的脊部是暴露或间歇暴露的。在昆阳矿带下矿层和海口矿带上矿层均发现滑动构造（图版Ⅰ、8），且滑动方向相反与水下隆起两侧缓坡倾向基本一致。

综上所述，可以判断该水下隆起是存在的。而它的存在又控制着磷酸盐的富集，表现在以下几个方面：

1.水下隆起两侧温暖、搅动和极浅的海水环境，是藻类生物繁衍的最佳场所。藻类有效地固定了海水中分散的磷质，使之以生物及生物化学的方式沉聚下来。

2.水下隆起两侧还具有一定的地球化学有利条件（如温度高、蒸发强、和CO_2逸出等），从而有利于磷酸盐以化学的方式沉聚。这种沉聚机理类似于Riggs提出的“成磷机器”。

3.水下隆起为较高水能的浅滩环境（图7），那里原始沉积的沉积物经受机械改造和分选，比重较轻的非磷酸盐颗粒以及较细粒的悬浮组分被簸选走，而比重较大的磷酸盐颗粒便在水下隆起的两翼聚集下来。

4.水下隆起两侧的浅滩在早期成岩阶段为活跃的潜流带，加之在沉积物中酶、菌（图版Ⅰ，3）的作用下，有机质的分解，大大提高了孔隙水中磷的浓度，而富磷的孔隙水在磷质砂屑中频繁流动，可产生大量的磷酸盐胶结物（图版Ⅰ，5、6），使初步富集的磷酸盐进一步富集。

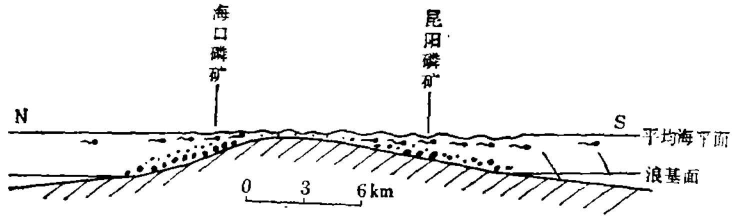


图7 研究区磷矿形成时期沉积环境示意图

Fig.7 The illustrated diagram of the sedimentary environments at studied area during the formation of the phosphorite deposit

六、结　论

综上所述，昆阳、海口磷矿的富集过程（图 8 ）可归结如下：

磷质通过洋流上升或地表迳流源源进入成磷盆地；生物或生物化学作用使海水中分散的磷质转移到沉积物中；机械改造使磷酸盐富集；成岩胶结使磷酸盐进一步富集。

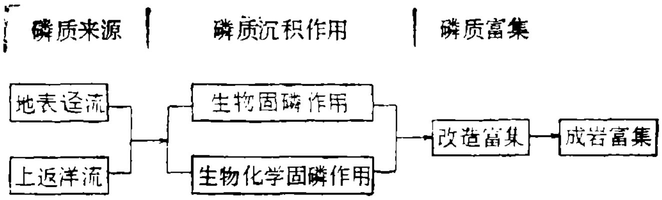


图 8　昆阳及海口磷矿富集过程示意图

Fig.8　Enrichment processes of the Kunyang and Haikou phosphorite deposit

参 考 文 献

〔1〕曾允孚、王宝清，1984，峨眉—雷坡地区早寒武世初期麦地坪段磷矿沉积环境，《第五届国际磷块岩讨论会论文集》2，145—166页，地质出版社，

〔2〕武希初，欧阳麟，1984，滇东寒武纪最早期磷块岩的岩相古地理研究，《第五届国际磷块岩讨论会文集》2，167—184页，地质出版社。

〔3〕王崇武等，1984，云南早寒武世初期磷块岩矿床地质特征，《第五届国际磷块岩讨论会文集》2，185—215页，地质出版社。

〔4〕Baturin C.N., 1982, phosphrites on the sea floor (Origin, composition and distrubution) Developments in sedimentology 33, p.219—223, p.279—292, printed in the Netherlands.

MECHANISM OF ENRICHMENT OF KUNYANG AND HAIKOU PHOSPHARITE DEPOSITS, YUNNAN CHINA

Zeng Yunfu　　Yang Weidong

(Institute of Sedimentary Geology and Mineral Resources, Chengdu College of Geology, Chengdu, Sichuan)

Abstract

The study area is located on the southwest of Kunming and the west of Dianchi Lake in the eastern Yunnan, where is an important phosphorous producting area in China. Two phosphorous deposits are involved in this area (Fig. 1) - the Kunyang

phosphorite deposits and the Haikou phosphorite deposits. They are well known for the great reserves and outstanding quality.

The stratigraphy of phosphorite-bearing layers are considered as the Zhongyichun member, Yuhuchun Formation in the Meishuchun section of Kunyang (Fig.2), which is one of the international candidate sections of Cambrian /Precambrian boudary. The tectonic setting of the eastern Yannan during the early Cambrian when the phosphorite was deposited, the Yangtze cratonic massif occurred as a platform and was flanked by the Yunnan-Qinghai-Tibet sea basin on the West and the South China Sea trough on the east. The middle of Yunnan and Niushoushan paleocontinents extended along the west and east margins of craton respectively and a rift basin was in the middle.

Early Cambrian phosphorite was deposited in embayment lagoon environment. Fig. 4 shows the paleogeography of that time. Several favourable conditions were provided to the enrichment of phosphorite deposits in the embayment lagoon, because of the paleogeography situation.

1. The dispersion phosphorous in deep sea could continuously migrate to the shallow bay by upwellings since the bay was connected with the deep sea basin and trough.

2. Certain amount of phosphorous was supplied by the runoff from the paleocontinents which has high basic amount of phosphorous.

3. Due to the continuous supply of phosphorous and other biogenic elements by upwelling and river discharge, the shallow bay was rich in organisms. There are bacteria and algae (plate I -1, 2, 3, 4) which are well known as the abundant organisms in the early Cambrian. The small shelly fossils, as the pioneer of Phanerozoic invertebrates also occurred. Those organisms efficently fixed the dispersive phosphorous of sea water and made the possibility for them to deposit on the bottom of bay.

These three points mentioned above provided favourable conditions for the shallow bay to collect phosphorous, and never lose or only lose little of them. As a result, a great quantity of phosphate could be accumulated.

However, the distribution of the Kunyang and Haikou phosphorite deposits indicates that the final enrichment of phosphorous must be controlled by particular factors. The Kunyang and Haikou phosphorite deposits lie along two flanks of the Xiangtiaochong anticline (Fig. 3) in the middle-west part of the shallow bay. A paleosubmarine uplift is inferred between two deposits by the study of tectonics (Fig. 7), the thickness of ore layers and sedimantary facies. It is predicted that the extended is parallel to the trend of Xiangtiaochong anticline.

1. Tectonic setting. In addition to the longitudinal fault system created the rift basin, there is latitudinal-horst fault system which could be thought as the geological background for the paleo-submarine uplift.

2. Thickness. According to the exploration data, the thickness of ore layers of two deposits has a increasing tendency along the downdip slops of the inferred

uplift with a ratio of one or two permillage.

3. Sedmmentary facies. There are a lot of differences in the thickness of ore layers, lithology and the sedimentary characters (Fig. 5, 6) between the Kunyang and Haikou deposits which are only less than 10km apart. Also mud cracks are observed as the exposure features. Scourand fill structures and cross bedding (plate I-7) are common and some slump structures (plate I-8) have been found with northward and southward dip along two flanks of inferred uplift respectively.

In fact, it could be concluded that the paleosubmarine uplift existed and uplift was considered as an important control factor of phosphorite enrichment.

It is based on:

1. The submarine uplift created a warm, disturbed and very shallow water environment (Fig. 7) along two flanks. This kind of environment was favourable to the organism productivity. Biologic fixation of phosphorous occurred. Phosphate was deposited as microstromatolits, algal-pellets, organic skeleton or biochemistry-originated sediments.

2. Such environment is also favourable for the chemical precipitation of phosphate. For the mechanism of this process, an analogy could be traced to Rigg's "The phosphate-forming machine."

3. The resorting and winnowing of sediments, resulting from disturbed shallow water led to the accumulation of the coarser phosphate grains along two flanks of the uplift (Fig. 7).

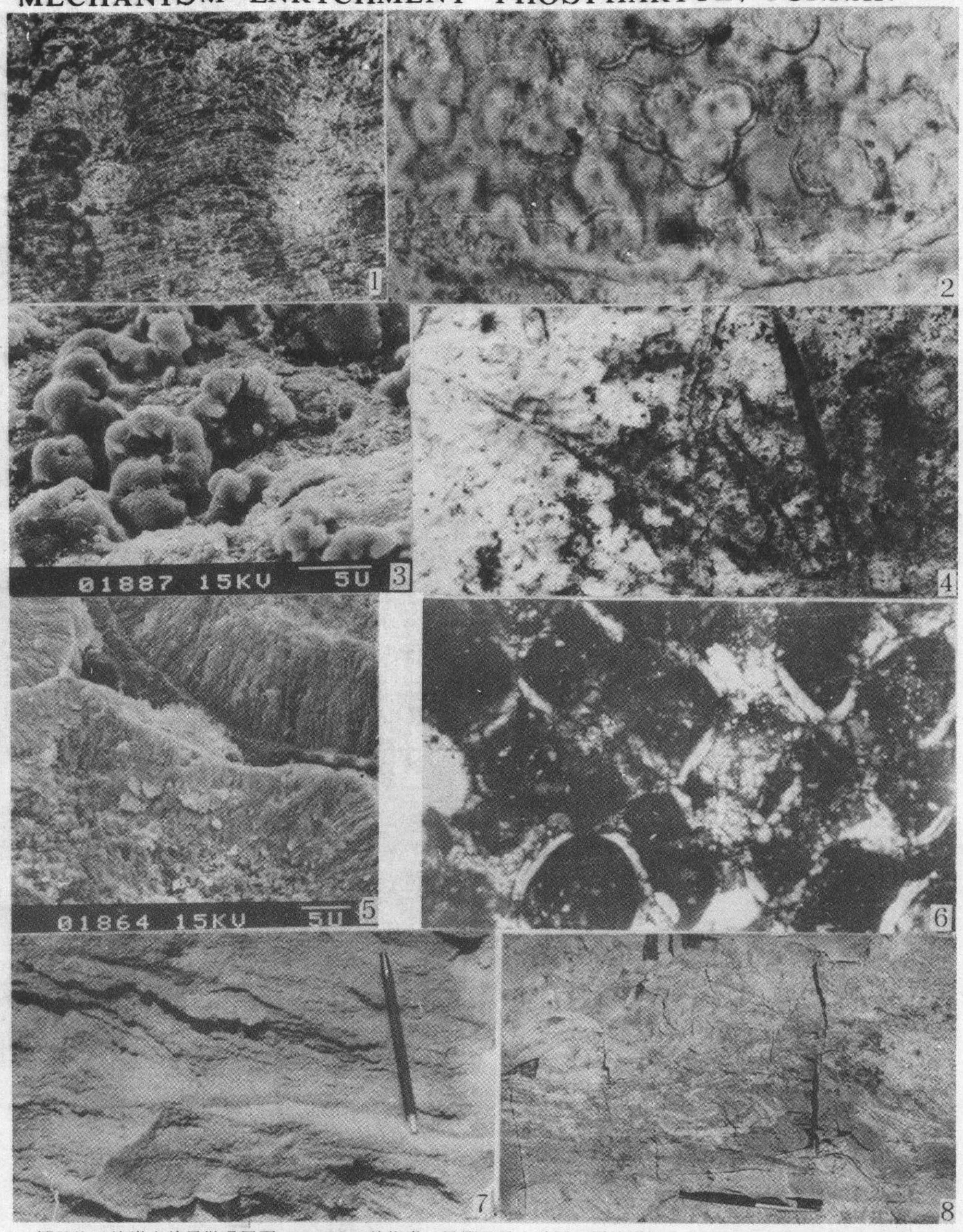
4. During the early diagenesis, the organic matter in sediments was decayed because of activity of bacteria and enzymes. The organic phosphorous went into interstitial water. When the concentration of phosphorous reached 8-9 mg/'per liter (Beturin, 1972), calcium phosphate began to precipitate as cements in the intergranular space. Good porosity and permeability of the reworked sediments make the universal phosphate cements occurred as isopach rim around grains (plate I-5, 6). Sometimes phosphate replaced other constitutes. Then phosphate was enriched further in the sediments.

Fig. 8 shows a conclusions of the enrichment processes of Kunyang and Haikou phosphorite deposits.

(1) Phosphorous supplied by upwelling and runoff and got into shallow water bay.

(2) Biologic phosphorous fixation and biochemical phosphorous fixation resulted in phosphate depositing as algal-stromatolites, pellets, organic skeleton, or biochemical sediments.

(3) Phosphate was initially enriched by mechanical reworking and (4) further enriched by early diagenesis.



1．凝胶状磷块岩中的显微叠层石，×115，单偏光，昆阳磷矿上矿层（据沈丽娟，1986）　2．硅苓藻球粒磷块石，×430 单偏光，昆阳磷矿下矿层（据沈丽娟，1986）　3．砂屑磷块岩胶结物中的菌藻类化石，扫描电镜，鸣矣河剖面上矿层　4．云苓砂砾屑磷块岩中的似原孔藻，×430 单偏光，昆阳磷矿下矿层（据沈丽娟，1986）　5．砂屑磷块岩中等厚环边胶结物，扫描电镜，海口磷矿下矿层　6．砂屑磷块岩，×100．正交偏光，海口磷矿下矿层　7．板状交错层理，海口磷矿鸣矣河剖面夹层白云岩　8．滑动构造，海口磷矿上矿层