glacier flow was southwestward into western New York from the Adirondacks. The glacier carried an undiluted heavy mineral assemblage containing red garnets as well as purple garnets. In contrast, garnet ratios in the younger, Almond and Valley Heads drift suggest glacier flow from north of Montreal, southwestward into the Lake Ontario depression and thence southward into western New York, carrying an undiluted heavy mineral assemblage that contains little red garnet.

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Chinoptilolite: A New Occurrence in North Carolina Phosphorite

Abstract. *The zeolite, clinoptilolite, has been identified in a Miocene phosphorite deposit in North Carolina. It occurs in great abundance in the clay fraction of the phosphorite both as well-formed, separate crystals and as clusters of crystals attached to granular particles.*

Zeolites are found in many localities as alteration products of pyroclastic rocks and volcanic glass. Here we describe a unique occurrence of the zeolite mineral clinoptilolite in the clay fraction of an extensive phosphorite deposit in Atlantic coastal plain sediments.

The zeolite was discovered in a representative drill core furnished by the Texas Gulf Sulphur Company, from Beaufort County, North Carolina. The stratigraphic section at this point includes (from youngest to oldest): post-Miocene unconsolidated quartz sands and clays; Upper Miocene Yorktown formation composed of marl (that is, calcareous clay) and clayey silts; Middle(?) Miocene phosphorite which overlies, unconformably, Middle Eocene Castle Hayne limestone. The phosphorite consists of pellets of brown, fine sand-size collophane and phosphatic shell, bone, and tooth fragments mixed with abundant angular quartz sand and clay. The phosphate mineral is isotropic, but x-ray and chemical data identify it as a fluorapatite. Many of the pellets contain included material such as quartz fossil debris, organic matter and glauconite.

Indications of the zeolite were first observed during x-ray diffraction analysis of clay from the phosphorite zone. Subsequent microscopic examination of the clay mixture revealed numerous, transparent, blade-like crystals with an average length of about 10 μ (Fig. 1). The crystals have perfect cleavage in one direction and exhibit interference colors of extremely low order. The indices of refraction are $n_\alpha = 1.483$ and $n_\gamma = 1.488$ (Na D), which lie within the range for clinoptilolite.

The interplanar spacings (Table 1) also agree with those of clinoptilolite, but another zeolite, heulandite, gives a similar x-ray pattern. Following the method of Mumpton (*1*), we heated a sample overnight at 450°C. This treatment causes the heulandite pattern to disappear, while the clinoptilolite pattern is unaffected. Although a decrease in peak intensity could be noted, the North Carolina material was essentially unchanged after heating.

Further microscopic study of a concentrate of the zeolite showed that it is present both in isolated crystals and in clusters of crystals attached to granular particles. These particles are green, appear slightly anisotropic, and have n (Na D) approximately equal to 1.53. They contain no obvious minerals or structures, such as shards, although some opaque inclusions are present. The grains apparently form nuclei for the growth of the crystals. The relationship suggests that the zeolite has been derived by alteration of these grains. It may be significant that clinoptilolite (a zeolite of low calcium content) has formed rather than the more calcic heulandite. This association of zeolite and granular matter is like that described by Bonatti (*2*) in recent Pacific pelagic sediments, where palagonite (devitrified basic glass) is altering to the zeolite, phillipsite.

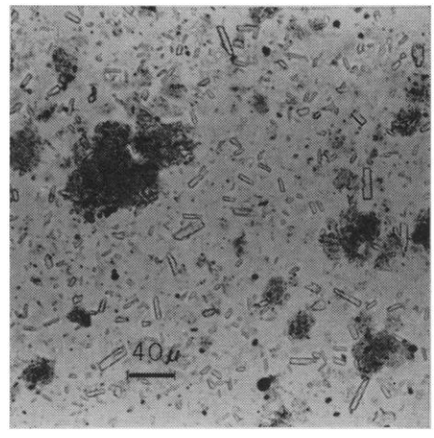

Fig. 1. Photomicrograph of zeolite crystals.

Table 1. X-ray diffraction data for clinoptilolite from North Carolina and Hector, California. (Ni-filtered CuK_α radiation.)

North Carolina (oriented sample)		Hector, California (data from Mumpton, *1*)	
d(Å)	I/I_0	d(Å)	I/I_0
8.98	10	9.00	10
7.91	7	7.94	4
5.90	1	5.91	1
5.24	1	5.24	3
4.48	1	4.48	2
3.96	10	3.96	10
3.90	4	3.90	8
3.75	1	3.73	1
3.45	1	3.46	2
3.12	1	3.12	3
2.97	2	2.97	5
2.79	3	2.82	3
2.70	1	2.72	1
2.69	1	2.68	1

The top of the phosphorite lies 30 m below the surface and the zone is 20 m thick. Large quantities of clinoptilolite exist uniformly throughout the phosphorite, but none is found in the sediments above or below this zone. Information is lacking as yet on the lateral distribution of the mineral.

The unusually high fluorine content of marine phosphorite has been commented upon by many authors. A number of explanations have been given for this excess fluorine, but none has been definitely established. It is worthy of consideration that volcanic detritus may be a partial source of fluorine in the North Carolina phosphorite.

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