Uranium and phosphate resources in the Cooper Formation of the Charleston region, South Carolina

by

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Abstract

Phosphate deposits formerly exploited in the Charleston district were formed by weathering and reworking of the Cooper Formation (Eocene and Oliogcene). Previous workers have shown that unusual concentrations of uranium occur in phosphate-rich nodular material formed during subareal weathering. We found that the old mining district is on an erosional high of the Cooper Formation and in a topographic depression, but that the process of weathering enrichment of the Cooper Formation extends beyond the mining district.

Fresh sediments from the Cooper Formation average 14.5 ppm uranium and 1.0 percent P_2O_5 for Oliogcene samples and 5.6 ppm U and 0.15 percent P_2O_5 for Eocene samples. Zones of secondary enrichment over undifferentiated Cooper Formation average 2 m thick and have average values of 60 ppm U and 5.4 percent P_2O_5. No deposits clearly of economic importance were found, although detailed studies may reveal such deposits.

Introduction

The Charleston area was the first major phosphate mining district in this country, and between the years 1867 and 1938 it produced 13 million long tons of phosphate rock (Malde, 1959). Florida phosphate captured the industry toward the end of this period. The material mined was mostly nodular phosphate in the uppermost zone of weathering of the Cooper Formation (Eocene and Oliogcene) and in overlying detrital accumulations. P_2O_5 contents of the nodular phosphate range from 20 to 29 percent (Rogers, 1915; Malde, 1959). Altschuler and others (1958) found that nodular Cooper sediments in a widespread area also contain unusually high (300-1200 ppm) uranium concentrations.

One purpose of the present investigation is to document the extent of resources similar to those of the Charleston phosphate district. The lithologies exploited in the mines extend far beyond the mining district. The weathered Cooper Formation is present at shallow depth under most of the area of Charleston, Berkeley, and Dorchester Counties, and is weathered over much of its extent.

A second purpose is to compare grades of material in composite samples of whole rocks with grades of nodular material. Most published chemical analyses of Charleston phosphate are for nodular material. Malde (1959), however, gives compositional ranges for enriched Cooper Formation of 6-8 percent P_2O_5 and 60-80 ppm uranium. The miners were able to beneficiate nodules easily, so nodule composition was the most important chemical factor to them. However, at best, nodular material of this type forms a discontinuous hardpan layer.

A third purpose is to find whether lithologic differences within the Cooper Formation has affected the extent of weathering enrichment. The Cooper Formation is known to consist of two parts, each containing different sediment types.

Two USGS (U.S. Geological Survey) projects with which we are associated have produced new information that is the basis for this resource work. One is a program, funded by Coastal Plains Regional Commission, to determine whether mineral resources in the Charleston area can be discovered with the aid of aeroradiometric maps. The other is the Charleston project (funded by Nuclear Regulatory Commission under Agreement No. At(49-25)-1000), the purpose of which is to discover causes of Charleston area seismicity by areal mapping and study of shallow subsurface stratigraphy. Lithologic and geophysical logs for auger holes and water wells were generously provided by the South Carolina Division of Geology and the USGS office in Columbia.

Distribution of Cooper Formation

The age and stratigraphic relationships of the Cooper Formation have been studied for decades. Reviews by Malde (1959) and Pooser (1965) show that Ruffin (1843) first referred to this unit under the heading "Marl of the Ashley and Cooper Rivers and their branches" and included it in his "Great Carolina Bed." Cooke (1936) summarized the existing data and decided upon a late Eocene age for the Cooper, but later (Cooke and MacNeil, 1952), he preferred an early Oliogcene age for at least part of the Cooper. Malde concluded that the Cooper ". . . is considered to have been deposited throughout the Oligocene." Pooser (1965) also assigned the Cooper to the Oligocene, but with reservations. In their study of the biostratigraphy of the Clubhouse Crossroads Core (fig. 1), Hazel and others, (1977), and Hazel (1976), confirmed the Eocene and Oligocene age span for the Cooper. At Clubhouse Crossroads, the upper 48 m of the Cooper is of late Oligocene age, whereas the lower 14 m is of late Eocene age. The intervening unconformity represents the early Oligocene, a duration of about 5-6 million years (Hazel and others, 1977).

The Cooper Formation overlies the Santee Limestone, (Eocene), and both are unconformably overlain by Pleistocene, Holocene, and locally upper Tertiary deposits. The top of the Cooper seems to be a subareal erosional surface in most places.

The Cooper Formation extends far beyond the Charleston phosphate district, which was centered on the Ashley River from North Charleston to Middleton Place. Plate 1 shows the distribution of the Cooper Formation beneath Pleistocene (and locally upper Tertiary) deposits and the location of outcropping Cooper sediments. Contours on the top of the Cooper Formation show that depth to Cooper ranges from 0 to 20 m. Note that the old Charleston mining district is on an erosional high in the vicinity of the Ashley River.

As good exposures are relatively few, plate 1 was compiled mostly from results of our auger drilling and inspection of lithologic and gamma logs from other auger holes and water wells.

Aeroradioactivity patterns

Outcrops of Cooper sediments and cultural enhancements of weathered Cooper material (phosphate strip mines, dense road systems containing phosphate aggregate) produce the largest aeroradiometric values in the area. Ground checks suggest that the radiation in these places is 30-120 μR/hr, or from 5 to 20 times local background radiation. Spectral radioactivity surveys by the Energy Research and Development Administration (ERDA) (1975a-c) show that Cooper-related anomalies are produced almost entirely by uranium. Anomalies of uranium only, however small, on ERDA surveys of the entire region are a powerful predictor of Cooper outcrops (or Cooper-derived material) throughout the map area. Enrichment of uranium (and presumably phosphate) is thus a characteristic of weathered Cooper sediments over most of the extent of Cooper formation, as predicted by Altschuler and others (1958).

Plate 1.--Map showing sample locations, thickness of concentration zone, and preliminary structure contours on Cooper Formation.

Legend

Extent of Cooper Formation present under Pleistocene and (locally) Tertiary deposits

5 — Structure contours on the erosional upper surface of Cooper Formation, in meters relative to mean sea level. Contour interval 5 m

Outcrop area of Cooper Formation

AH3 ⊙ — Auger hole from which samples were chemically analyzed

0.9 △ — Water well with gamma log or outcrop traversed with scintillometer; thickness of zone of concentration in meters (± 0.2 m)

.048 × — Sample of nodular-hardpan phosphate analyzed for this report or by Altschuler and others (1958); U content listed in percent

Former phosphate strip mines

Uranium and phosphate in unweathered Cooper Formation

Most descriptions of the Cooper sediments have emphasized their uniformity and massive nature (see Malde, 1959, p. 9). Study of the Clubhouse Crossroads core, in conjunction with an auger drilling program near Charleston, has shown that the Oligocene and Eocene parts of the Cooper have distinctive lithologies. The Oligocene sediments are typically olive-brown, muddy, calcareous sand containing phosphate and glauconite, whereas the Eocene sediments are light olive-green silty, plastic, calcareous clay that does not contain much phosphate.

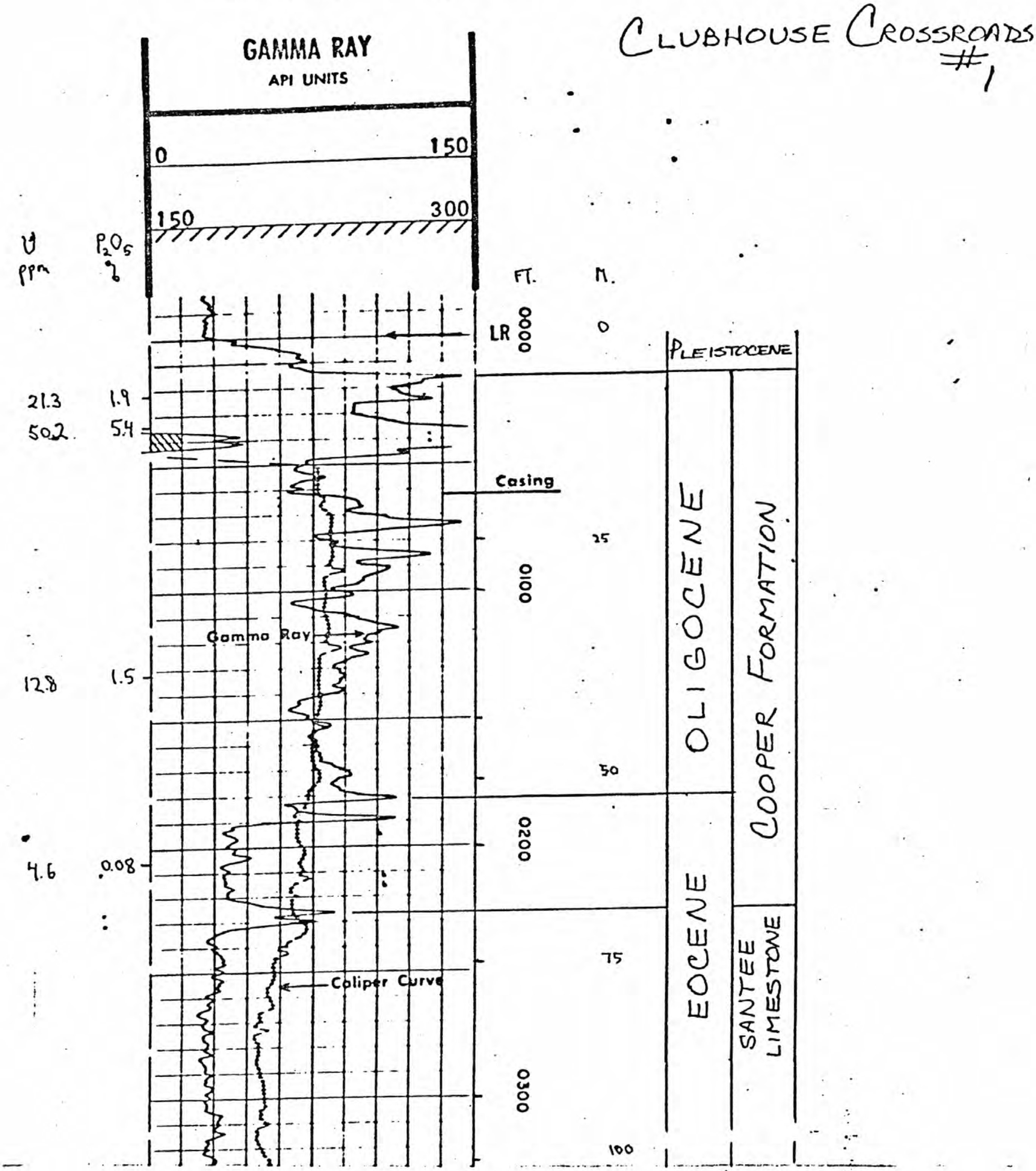
This difference in lithology is directly reflected in the analyzed U and P_2O_5 contents of unweathered Cooper sediments (table 1). The Oligocene strata have 2-3 times more U and 6-7 times more P_2O_5 than the Eocene beds. This relationship may also be seen on the gamma log for Clubhouse Crossroads (fig. 1). The Eocene materials show typical intensities (omitting phosphate pebble beds) of 35 to 45 API (American Petroleum Institute) units. The Oligocene strata (omitting near-surface beds) have values as high as 140 API units, and typical values are from 75 to 100 API units. Gamma intensity values (API units) shown on the log for four phosphate pebble beds are: 115 at the base of the Pleistocene (5.2 m), 120 and 105 within the Cooper (56 and 57.9 m), and 88 at the base of the Cooper (62.9 m).

Table 1.--Concentrations of U and P_2O_5 in unweathered samples of Cooper sediments of Oligocene and Eocene age. Data also included in table 2.

Oligocene Samples	U (ppm)	P_2O_5(%)	Depth (m)
CCC #1	12.8	1.5	40
AH-3	14.0	0.36	15-17
AH-38	16.8	1.2	15-17
Mean	14.5	1.02	

Eocene Samples	U (ppm)	P_2O_5(%)	Depth (m)
CCC #1	4.6	0.08	63
AH-2	3.5	.08	11-12
--	9.1	.30	12-13.5
AH-9	5.5	.15	9-11
GS-4	6.4	.16	16-17
AH-38	6.4	.16	18.5-20
	3.8	.14	23-24.5
Mean	5.6	0.15	

Figure 1.--Gamma log for the Cooper Formation in Clubhouse Crossroads 1. Uranium and P_2O_5 contents of analyzed samples are shown at left.



An initial conclusion, therefore, is that the pattern of enrichment in weathered Cooper sediments probably reflects variations inherited from the underlying fresh Cooper sediments. That is, the weathered Oligocene part of the Cooper may be systematically richer than the weathered Eocene part. Not enough is yet known about the distribution of the sediment of the two ages to prove this or to map the subcrop boundary on plate 1.

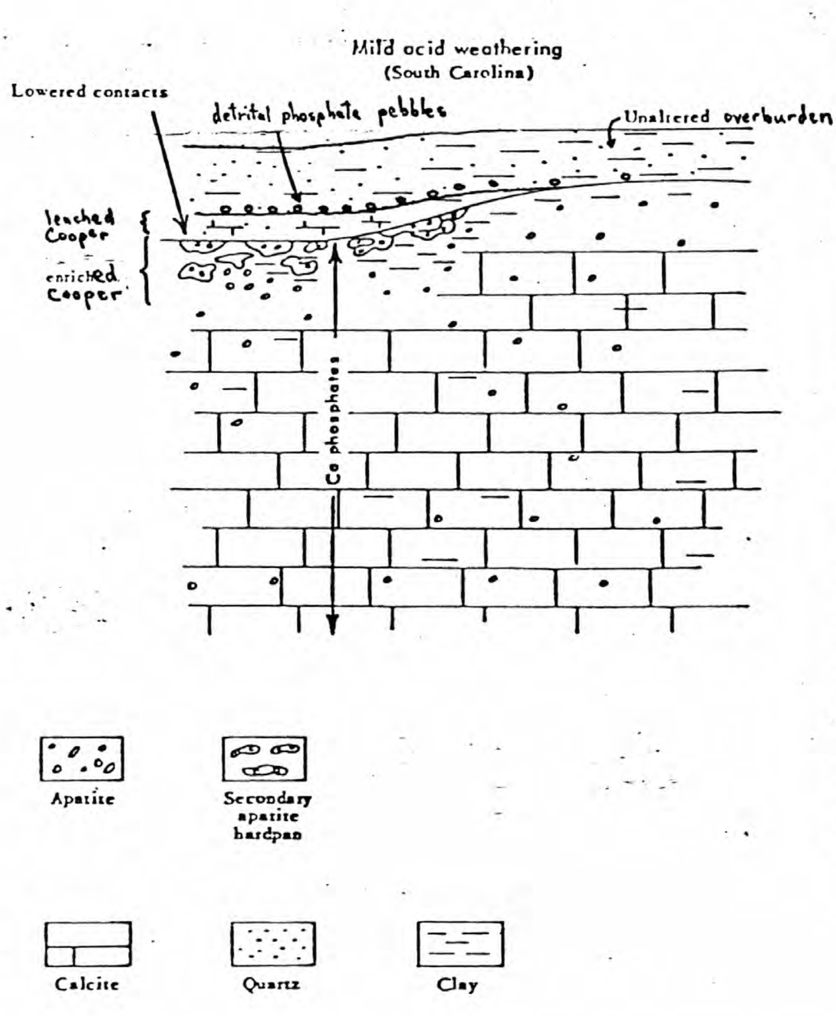
Models for weathering enrichment of phosphate and uranium

Altschuler and others (1958) explained the formation of uranium and phosphate concentrations in weathered Cooper Formation. Their model (fig. 2) is consistent with our observations and forms a basis of the following discussion.

Subareal weathering of the Cooper Formation removes calcium carbonate, and the deposit is thus residually enriched in phosphate and uranium. Over the Oligocene part of the Cooper, residual enrichment by a factor of as much as 2 can occur, as calcium carbonate constitutes 30 to 50 percent of the rock. Uranium and phosphate are subsequently leached from a depleted upper horizon and precipitate as an intergranular cement of apatite in a lower accumulation zone. Uranium and phosphate move laterally as well as vertically down the water table gradient, so that the zone of accumulation is thinner over interfluves and thicker near streams.

Most of the weathering must have taken place in the pre-Pleistocene, as most nodules are in pre-Pleistocene and basal Pleistocene matrix, and fresh calcareous Pleistocene deposits overlie leached Cooper Formation.

Figure 2.--Schematic representation of uranium and phosphate enrichment over Cooper Formation, modified from Altschuler and others (1958).



Nature of new phases	Basic to neutral; secondary apatite.
Process	Phosphatization of limestone.
Type of enrichment	Residual.
Locus of uranium enrichment and hardpans	Near surface of active weathering.

At the Carolina Giant Cement Co. quarry near Harleyville (EF 17), the results of analyses of samples and of scintillometer readings show a configuration of uranium (and presumably phsophate) enrichment schematized in figure 3. The enrichment zone is thicker and slightly richer under a Pleistocene(?) channel. This configuration is entirely consistent with the model of Altschuler and others (1958).

Gamma logs (locations shown on pl. 1) suggest that the thickness of the zones in which weathered Cooper Formation is enriched in uranium (and hence in phosphate also) ranges from about 0.3 m to about 5 m, and averages about 2.0 m. Malde's (1959) table 4 shows phosphate determinations of samples from two auger holes that imply enrichment thicknesses of about 2.4 m and greater than 1.6 m (plate 1 and table 1). Our inspection of Cooper outcrops in the banks of the Ashley River and Goose Creek suggests a range of enrichment thickness from 0.9 to more than 2.5 m. Our analytical results (table 2) from samples representing relatively large depth intervals do not lend themselves to accurate calculation of enrichment thicknesses but do suggest values from 0 to more than 4 meters. Thus, several methods of evaluation consistently suggest that enrichment thicknesses range from 0 to 5 m, and average about 2 m.

The analytical data (table 2) show that enrichment zones, so defined, range from about 2 to 18 percent P_2O_5 and from about 25 to 145 ppm uranium, and average about 5.4 percent P_2O_5 and 60 ppm uranium. Our data show a roughly linear relation between phosphate and uranium contents.

Although sequences of enrichment in one auger hole are orderly, the amount and thickness of enrichment and phosphate-uranium ratios vary from location to location. Some sample sites were chosen to test the effect of position within drainage basins; however, the thickness of the sample intervals precludes detailed interpretations.

Table 2.--U and P_2O_5 contents of fresh and weathered Cooper Fmn. Rapid rock phosphate analyses by Floyd Brown and others, USGS, Reston, Va. Delayed neutron U analyses by H.S. Millard and others, USGS, Denver, Colorado.

Locality number (fig. 1)	Depth (m)	U(ppm)	P_2O_5 (%)	Surface Elevation (m)	Depth to top of Cooper (m)	Comments
AH 59				3	12	relative physiographic low
	12-13.5 m	25.0	2.1			
	13.5-15 m	86.5	7.3			
AH 38				3	8.5	relative physiographic low
	9-11 m	46.6	2.3			
	15-17 m	16.8	1.2			typical Oligocene (?)
	18.5-20 m	6.4	.16			Oligocene-Eocene boundary; Eocene bryozoan limestone
	23-24.5 m	3.8	.14			typical Eocene (?)
AH 2				6	6	relative physiographic low
	8-9 m	8.7	.22			soft sugary olive-green; Oligocene
	11-12 m	3.5	.08			stiff, plastic; Eocene
	12-13.5 m	9.1	.30			stiff, plastic; Eocene
AH 9				5	6	
	6-7.5 m	2.9	.08			sandy, dry, olive; Oligocene
	7.5-9 m	20.8	2.0			clayey, dry; Eocene
	9-11 m	5.5	.15			clayey, dry; Eocene

CCC 1				6,0	5	Clubhouse Crossroads core; relative physiographic low;
	7 m	21.3	1.9			leached (from gamma and lithologic logs)
	11 m	50.2	5.4			enriched (from gamma and lithologic logs)
	40 m	12.8	1.5			typical Oligocene
	63 m	4.6	.08			typical Eocene
GS 4				6,5	3.5	relative physiographic high; heavily weathered
	6-6.5 m	36.6	3.9			muddy; calcareous fine sand; Oligocene ; weathered
	6.5-7 m	38.7	4.3			greener; Oligocene
	9-10 m	62.3	6.0			typical Oligocene
	16-17 m	6.4	.16			typical Eocene
AH 3				30	13	relative physiographic high;
	13-15 m	48.4	4.6			dark olive-green, leached, passing down to olive brown;
	15-17 m	14.0	.36			Oligocene
EF 17				25	4.5	Carolina Giant Cememt Co. quarry; see fig. 4
	5 m	84.8*	8.0			weathered top of Cooper
	8 m	13.2	2.4			base of Cooper; glauconitic sand with phosphatic hardground
AH 4				30	12	relative physiographic high but poorly drained
	14.5-15 m	32.9	1.7			
	18.5-20 m	4.5	.48			

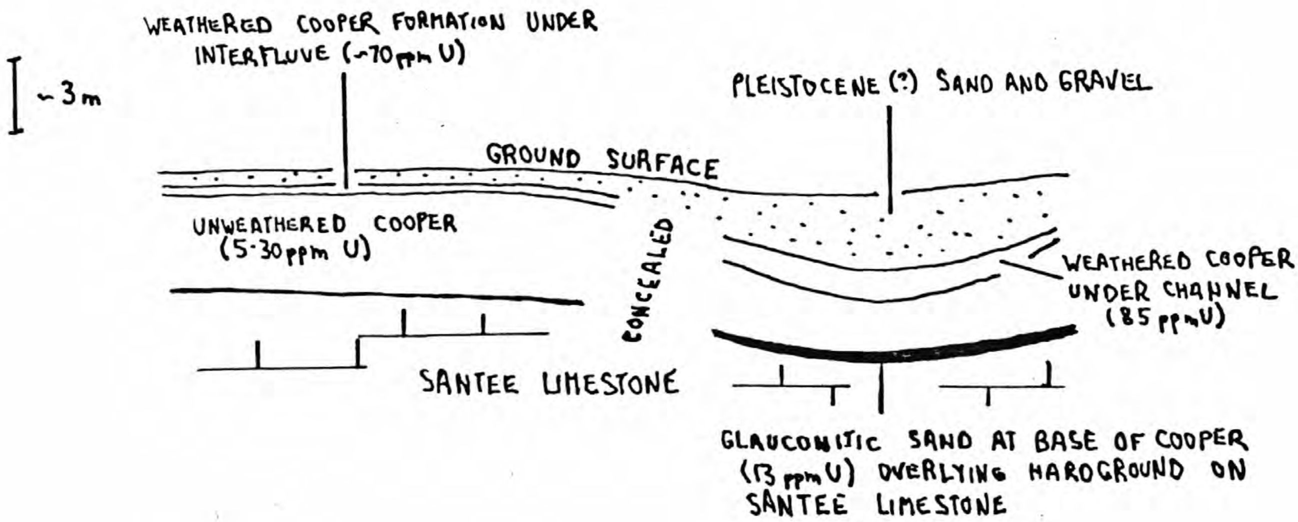
*Also contains 31 ppm Th

AH 18				5	8	relative physiographic high
	12-13.5 m	43.9	2.1			
	13.5-15 m	43.9	2.0			
EF 39C			P_2O_5 not analyzed	Natural	Outcrop	stream bank outcrop
	.3-.7 m	82.7				
	.7-1 m	80.4				
EF 40C				Natural	Outcrop	stream bank outcrop contains nodules
	1.5-2 m	145.9				
	2-2.5 m	63.6				
	2.5-3 m	77.6				
	3-4 m	70.5				
EF 40B				Natural	Outcrop	stream bank outcrop
	.8-1.7 m	28.3				
MH 1				4.5	8	relative physiographic high
	5.5 m	3.9	.36			weathered Eocene
	7 m	3.2	.36			weathered Eocene
	9 m	3.3	.36			weathered Eocene
CNC 1				8.5	7.5	relative physiographic high
	8.8 m	23.9	1.7			weathered Oligocene; pebbly
	9.2 m	21.7	1.7			Oligocene (?)

249				11	7	from Malde (1959) table 4; relative physiographic high
	7.2-7.3 m	U not analyzed	9.6			
	7.3-7.5 m		5.2			
	7.5-7.6 m		3.8			
	7.6-7.8 m		3.2			
	8.1-8.4 m		2.8			
	8.4-8.7 m		2.4			
	8.7-9.0 m		2.1			
	9.0-9.3 m		2.4			
	9.3-9.6 m		2.1			
	9.6-9.9 m		1.8			
253				9	5.5	from Malde (1959) table 4; immediately adjacent to physiographic low
	5.5-6.1 m	U not analyzed	8.6			
	6.1-6.4 m		8.2			
	6.5-6.9 m		8.7			
	6.9-7.0 m		7.2			
	7.0-7.2 m		5.6			
	7.2-7.3 m		6.1			
	7.3-7.6 m		6.7			

CNC 15				9	6.5		relative physiographic high
	9 m	20.2	1.8				Oligocene, weathered
	10.5 m	22.2	1.8				Oligocene
CA 3					6.5	6	
	15.3 m	47	8.5				Mixed with Pleistocene material; contains phosphate pebble
	15.9 m	41	6.9				Oligocene (?)
	16.8 m	40	7.1				Oligocene (?)
CA 4					8	3	relative physiographic low
	12.2 m	33	4.8				Mixed with Pleistocene material
	12.2-12.5 m	123	13.9				Oligocene; contains pieces of phosphate nodule

Figure 3.--A schematic cross section of deposits on the west side of the Carolina Giant Cement Co. quarry, Harleyville, S.C.



Summary

Figures given above imply an average thickness of 2 m and average compositions of 60 ppm U and 5.4 percent P_2O_5 for the zone of concentration over the 4600 km^2 of Cooper Formation subcrop considered in this study. Local variations caused by position within drainage is a complicating factor. The Oligocene part of the Cooper sediments typically contain greater amounts of U and P_2O_5 than do the underlying Eocene part. The subsurface distribution of Oligocene and Eocene sediments should, in part, control the concentrations of these elements found in a given area.

Though these resources are relatively large, grades are far below those presently considered economic, and the utility of the resource is further limited by its small thickness. The highest grade material found is in the old Charleston phosphate district. Although most of this material is mined out, recovery was locally poor, and high-grade deposits may remain. The area of Hollywood, southwest of Charleston, seems somewhat promising as the concentration zone is consistently thick there, and uranium and phosphate contents are above average in one sample. Further detailed work could delineate areas in which concentrations are greater than the averages listed here.

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