Bone Phosphorus Dominates Fixed Tree Island Soil in the Everglades WCA3

Gumbo Limbo Island

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Fig. 1. A satellite view of Shark River Slough and adjoining ridge of the southern Everglades (Schwadron, 2006). Gumbo Limbo Island study site (red star).
Fixed Tree Island Soil P

• The amount of phosphorus (P) in fixed tree island soils is higher than in the surrounding waters and subaqueous soils (Sklar and van der Valk, 2002).

• Possible sources of P include:
  – Guano
  – Windblown particles
  – Bones in the soil
  – Upwelling groundwater
Sources of P (Wetzel, 2002)

Trace P in High P in bones is not mobile in soil, but is taken up by plants

Our Hypotheses

High P in bones is not mobile in soil, but is taken up by plants

Plant Litter containing P moves
Soil P on Gumbo Limbo Island

• In 2008, we conducted a study of the soil properties on Gumbo Limbo Island in Water Conservation Area 3A along with the soil water, slough water, and guano.

• The soil on the island summit is an alkaline kitchen midden soil (Petrocalcic Hapludoll) with abundant char and animal bones down to 190 cm, with shells, charcoal, and limestone, a fluctuating water table below a shallow petrocalcic horizon, an apparent pre-habitation soil surface at 190 cm and limestone bedrock at 202 cm.
## Soil Profile

<table>
<thead>
<tr>
<th>Depth (cm)</th>
<th>Horizon Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 to 5</td>
<td>^Au1</td>
</tr>
<tr>
<td>5 to 18</td>
<td>^Au2</td>
</tr>
<tr>
<td>18 to 26</td>
<td>^Au3</td>
</tr>
<tr>
<td>26 to 47</td>
<td>^Bku</td>
</tr>
<tr>
<td>47 to ~72</td>
<td>^Bkum</td>
</tr>
<tr>
<td>~72 to 96</td>
<td>^BCku</td>
</tr>
<tr>
<td>96 to 114</td>
<td>^Cku1</td>
</tr>
<tr>
<td>114 to 156</td>
<td>^Cku2</td>
</tr>
<tr>
<td>156 to 190</td>
<td>^2Cku3</td>
</tr>
<tr>
<td>190 to 202</td>
<td>3Ab</td>
</tr>
<tr>
<td>202 +</td>
<td>4R Limestone</td>
</tr>
</tbody>
</table>

2,3,4 = different parent materials  
^ = partially human-transported  
u = artifacts  
k = secondary carbonates  
m = continuously cemented  
b = former stable soil now buried
Red and blackened bone and white shell fragments.

Secondary CaCO$_3$ is gray. Uncemented masses above the pen and cemented petrocalcic horizon below the pen.

Wavy petrocalcic surface indicated by nail, knife, and pen. It formed in the soil during an extended period where evapo-transpiration exceeded precipitation ~2 to 4K Y.B.P.

Roots stop at the top of the petrocalcic.
Hypotheses

The breaking and burning of bones and animal parts by humans coupled with weathering of very small fragments releases high amounts of Ca and P where it is sequestered in-situ as secondary mineral precipitates of **apatite** \((\text{Ca}^5(\text{PO}_4)_3\text{OH})\) (Graf, 2009) and **calcite** \((\text{CaCO}_3)\) in the high pH soil.

Bones account for the P throughout the soil. Guano and dust are minor P contributors. Groundwater is a non-factor for P in the soil.
Methods

- **Soluble P** was measured by ICP directly in soil and slough water and in bird guano droppings taken off plant leaves. Soil water was seen at 114 cm.

- **Total P** was measured by HCl digestion in bulk unwashed soil (sieved to < 2 mm but not ground) and then in the water-washed sand-only fraction.
Results

• Bones > 2 mm made up 4 to 44% by volume but decreased sharply in the horizon just above the limestone and in the subaqueous soil offshore.

• Burned bones, char (ashes), shells, charcoal, and artifacts were found in all horizons down to 190 cm, supporting human habitation and human contribution to soil accumulation on the island head.
> 8mm Burned Bones, Snail, and Pottery in Horizon 2
> 8 mm Bones, Snail, Gar Scales, and Cemented Soil in Horizon 7
Large Bones, Limestone, and Cemented Soil in Horizon 8

Bones

Limestone

CaCO$_3$
Table 1. Particle Size Analysis

<table>
<thead>
<tr>
<th>Hor. Name</th>
<th>Sand % weight</th>
<th>Silt % weight</th>
<th>Clay % weight</th>
<th>Gravel % vol.</th>
<th>Modifier</th>
<th>Texture Class</th>
</tr>
</thead>
<tbody>
<tr>
<td>Au1</td>
<td>61</td>
<td>34</td>
<td>5</td>
<td>30</td>
<td>Gravelly</td>
<td>Sandy Loam</td>
</tr>
<tr>
<td>Au2</td>
<td>53</td>
<td>42</td>
<td>5</td>
<td>55</td>
<td>V. Grav.</td>
<td>Sandy Loam</td>
</tr>
<tr>
<td>Au3</td>
<td>56</td>
<td>39</td>
<td>5</td>
<td>20</td>
<td>Gravelly</td>
<td>Sandy Loam</td>
</tr>
<tr>
<td>Bku</td>
<td>48</td>
<td>47</td>
<td>5</td>
<td>33</td>
<td>Gravelly</td>
<td>Sandy Loam</td>
</tr>
<tr>
<td>Bkum</td>
<td>58</td>
<td>37</td>
<td>5</td>
<td>62</td>
<td>V. Grav.</td>
<td>Sandy Loam</td>
</tr>
<tr>
<td>BCku</td>
<td>59</td>
<td>36</td>
<td>5</td>
<td>30</td>
<td>Gravelly</td>
<td>Sandy Loam</td>
</tr>
<tr>
<td>Cku1</td>
<td>59</td>
<td>36</td>
<td>5</td>
<td>11</td>
<td>Sandy</td>
<td>Loam</td>
</tr>
<tr>
<td>Cku2</td>
<td>64</td>
<td>32</td>
<td>4</td>
<td>19</td>
<td>Gravelly</td>
<td>Sandy Loam</td>
</tr>
<tr>
<td>2Cku3</td>
<td>82</td>
<td>15</td>
<td>3</td>
<td>19</td>
<td>Gravelly</td>
<td>Loamy Fine Sand</td>
</tr>
<tr>
<td>3Ab</td>
<td>34</td>
<td>31</td>
<td>35</td>
<td>5</td>
<td></td>
<td>Clay Loam</td>
</tr>
</tbody>
</table>

4R --------------- LIMESTONE -----------------------------------------------

The clay increase indicates weathering limestone bedrock when water tables were lower > 5,000 Y.B.P. or a subaqueous soil in deeper water. There were few bones and no artifacts in the lowest horizon.

The gravel was mostly bones and shells, with some pottery and limestone.
<table>
<thead>
<tr>
<th>Hor. Name</th>
<th>TC</th>
<th>% Soil &lt; 2mm</th>
<th>Org. C (calculated)</th>
<th>Inorg. C</th>
</tr>
</thead>
<tbody>
<tr>
<td>^Au1</td>
<td>14.8</td>
<td>6.7</td>
<td>=</td>
<td>8.1</td>
</tr>
<tr>
<td>^Au2</td>
<td>9.9</td>
<td>3.9</td>
<td>=</td>
<td>6.0</td>
</tr>
<tr>
<td>^Au3</td>
<td>9.3</td>
<td>3.6</td>
<td>=</td>
<td>5.7</td>
</tr>
<tr>
<td>^Bku</td>
<td>9.8</td>
<td>3.9</td>
<td>=</td>
<td>5.9</td>
</tr>
<tr>
<td>^Bkum</td>
<td>5.5</td>
<td>1.4</td>
<td>=</td>
<td>4.1</td>
</tr>
<tr>
<td>^BCku</td>
<td>3.9</td>
<td>0.5</td>
<td>=</td>
<td>3.4</td>
</tr>
<tr>
<td>^Cku1</td>
<td>3.2</td>
<td>0.1</td>
<td>=</td>
<td>3.1</td>
</tr>
<tr>
<td>^Cku2</td>
<td>4.0</td>
<td>0.6</td>
<td>=</td>
<td>3.4</td>
</tr>
<tr>
<td>^2Cku3</td>
<td>3.9</td>
<td>0.5</td>
<td>=</td>
<td>3.4</td>
</tr>
<tr>
<td>3Ab</td>
<td>14.5</td>
<td>6.6</td>
<td>=</td>
<td>7.9</td>
</tr>
<tr>
<td>4R</td>
<td>-----</td>
<td>--------------</td>
<td>---------------------</td>
<td>---------</td>
</tr>
</tbody>
</table>

Soil pH ~8 throughout
Table 3. Other Nutrient Sources

<table>
<thead>
<tr>
<th></th>
<th>Ca</th>
<th>K</th>
<th>Mg</th>
<th>P</th>
<th>Tr</th>
<th>S</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soil-Water</td>
<td>114</td>
<td>1</td>
<td>26</td>
<td>0.1</td>
<td>0.5</td>
<td>21</td>
</tr>
<tr>
<td>Open-Water</td>
<td>73</td>
<td>3</td>
<td>11</td>
<td>Tr</td>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td>Guano</td>
<td>155</td>
<td>238</td>
<td>45</td>
<td>34</td>
<td>2301</td>
<td></td>
</tr>
</tbody>
</table>

Elements by direct ICP analysis, no extraction used (Mullins and Heckendorn, 2005).
% Wt. Sand-sized Bone

Fluctuating Water Table
Fluctuating Water Table

Petrocalcic Horizon

Impervious Surface

% P in > 2 mm bones
% P in < 2 mm soil
Soil P Distribution - 1

• Soil water percolates through the rooted surface layers and may perch above the petrocalcic where roots concentrate. Large soft masses of CaCO$_3$ reinforce this concept.

• Organic acids and rainwater cause weathering of bone and allow uptake of P by plants above the petrocalcic. Underneath the petrocalcic there are no roots for plant uptake.
Soil P Distribution - 2

• The alkaline soil water causes precipitation of weathered phosphorus as apatite and prevents movement of P in the soil in soluble forms.

• Bone content explains total P distribution and content. P movement to island tails may occur as plant leaves take up P from the soil if leaf litter is moved to the tails by wind, water or animals. Guano and dustfall may contribute small amounts of P to island heads and tails.
**P Source or Sink? Both?**

- The island soil is a large sink for P because it is a sink for bones brought in by humans and possibly animals. Now, only animals bring in bones.

- The island soil is also a sink for guano P and windborne P, but they occur in trace amounts.

- P in the upwelling groundwater is not a source because P is not mobile in the soil. Besides, the level of P in slough water is a trace amount.

- The island plant leaf litter may be a source of P to island tails and nearby subaqueous soils.
Conclusions

• Further investigation of petrocalcic horizon surface topography and extent along with a soil sampling transect study crossing across sloughs and island edges and tails are needed to further explain P dynamics.

• P in bone fragments sufficiently explains the source, quantity and distribution of total phosphorus throughout the soil, although trace additions from the other sources are possible.

• Soil testing combined with archaeological evidence have preserved a record of island-building, climate change, soil weathering and secondary mineral precipitation.
Acknowledgements

• The South Florida Water Management District conducted some field work, provided air boat transportation, and funded the project.

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