Exploring the Excited Skin: Gigapixel Imaging of Soil Profiles and Landscape Contexts

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ABSTRACT
Soil profile pits are a primary in situ tool in understanding soil genesis and structure. When considered in the context of the landforms that underlie them, and when seen as a small revelation of the ‘excited skin’ that gives rise to plant communities and land uses, profiles can deepen our appreciation of soil’s critical importance in landscape-level processes and sustainability. This paper discusses how gigapixel imaging can assist in visualizing soil profiles and their details online, remote from the site, for both pedagogical and research purposes. It also demonstrates how the GigaPan.org system can serve as a convenient and accessible clearinghouse for linked soil, geological, plant community, and spatial landscape data.

Keywords
Gigapixel imaging, soil science, soil profile, landscape, geology, plant communities, Pennsylvania

INTRODUCTION
Despite Nikiforoff’s (1959) poetic and quite accurate description of soil as the earth’s ‘excited skin’, soil as a subject of environmental learning and scientific research has suffered from a certain lack of charisma. Recently, however, pressing issues of climate change and carbon sequestration, secure food and energy sources, and the intricate interplay of soil and water quality have re-energized soil science and sub-fields such as pedology, agrology, and environmental soil science. More broadly, a growing list of professional and economic sectors are considering soil’s inherent capacity for sustaining life, human and otherwise.

In our physiographic region, the Ridge and Valley physiographic province of central Pennsylvania, soil patterns are a strong determinant of historic settlement. The carbonate soils of the valleys, which formed from Cambrian and Ordovician limestones and dolomites, are some of the most fertile in the country. Rural and then urban settlement patterns and economies evolved from the bounties sprung from these nurturing soils. Less fertile, more acidic soils associated with the sandstones and shales of the ridges, while inhospitable to agriculture and development, accommodated vast forests and successive waves of resource extraction and usages, from charcoal and timber throughout the 1800s to a wide range of more recent recreational activities. Now, there is a growing awareness of the vital ecosystem services provided by soils and the vegetation communities and hydrological processes associated with them.

At Penn State University, the Landscape Architecture major has added Soils 101 Introductory Soil Science, taught by the second author, to its required curriculum. LArch 272 Ridge & Valley Field Course is taught by the first author and follows on the heels of Soils 101 after the Spring semester. It includes fieldwork by landscape architecture students in the soil profile pits described below. As we will discuss, Soils 101 and LArch 272 students are using GigaPan online resources to enhance integrated landscape-level understanding by linking to landform, plant community, and other spatial data.

After the lead author participated in the Fine Foundation GigaPan workshop in May 2009, two potential GigaPan possibilities arose. The first was collaborative and interdisciplinary: Could gigapixel imaging, along with the GigaPan system’s elegant snapshotting and data linkage capabilities, help faculty in the Departments of Crop and Soil Science and Landscape Architecture document and communicate soil profiles in an introductory, multi-disciplinary learning environment? More
pointedly, could it help resolve the persistent difficulty of visualizing soil structure, processes and contexts in off-site lectures and labs? The second was specific to soil science: Could gigapixel imaging co-operate with 3D and other high-resolution technologies to advance soil science research? Could it serve as a tool to help gather data and generate new understandings of soil genesis and structure? The following is an overview of our explorations of these queries.

**CASCADEING SCALES AND LINKED SYSTEMS**

Before delving into soil profiles, it is helpful to see how gigapixel imaging and online resource networking can help researchers and students understand the various contexts in which these profiles are nested. A soil pit is useful in that it allows us to pull back a bit of the earth’s surface to reveal connections to broader forces (e.g. geophysical and biological) and human agency across cascading spatial and temporal scales; it’s this dynamic, iterative interplay between clearly focused details and larger realms that allows the complexities of cause-and-effect to be visualized and, thus, more fully understood. So any tool that can jar us from our tendency to dwell on the object (i.e. a soil profile detail) and help us see the bigger picture, or tell a fuller story, is a useful tool indeed.

The suite of gigapixel imaging technologies allows us to both represent and contextualize soils information in several ways. The GigaPan.org website serves as a portal through which one can access the soil profiles and their embedded details; we might term these functions *in situ contextualization* and *in situ representation*. The overall profile plays a dual role: it is a singular image representing a vertical cut of soil in which layers are immediately apparent. At the same time, it is the context for many smaller objects and features. Having examined the profile panorama and its snapshots, one may then access links to other profiles or other digital resources that elaborate on or extend soil-related storylines. In other words, the website also serves a ‘value-added’ purpose as a clearing-house to link the profile to images and data on the physical forces behind soil-building processes (what may be termed generative contexts), as well as the role of soils in underlying and sustaining landscape patterns and processes (expressive contexts).

A key pedagogical intent of Soils 101 (discussed in more depth below) and LArch 272 is that students understand relationships and connections between seemingly separate processes and systems. This is where gigapixel imaging and online data are so helpful. To demonstrate, a likely path of inquiry using the Hagerstown profile is shown below. Note that, while illustrated as a linear sequence, generative forces may interact at multiple scales through time, both beyond and within soil profiles. And some expressive contexts (e.g. vegetation) may also play a generative role, as noted in a following section.

In situ representation / In situ context: soil profile panorama (Figure 1, below) ⇒ [http://gigapan.org/gigapans/32535/](http://gigapan.org/gigapans/32535/)


In-situ contextualization: link to soil series data ⇒ [http://www2.ftw.nrcs.usda.gov/osd/dat/H/HAGERSTOWN.html](http://www2.ftw.nrcs.usda.gov/osd/dat/H/HAGERSTOWN.html)

Generative context: link to nearby geology stratigraphy profile ⇒ [http://gigapan.org/gigapans/23973/](http://gigapan.org/gigapans/23973/)


Generative context: link to geology map ⇒ [http://www.dcnr.state.pa.us/topogeo/gismaps/geomaps.aspx](http://www.dcnr.state.pa.us/topogeo/gismaps/geomaps.aspx)

Expressive context: visual landscape (360° pan) ⇒ [http://gigapan.org/gigapans/51453/](http://gigapan.org/gigapans/51453/)


Expressive context: link to plant community data (Fike, 1999, p. 11) ⇒ [http://www2.ftw.nrcs.usda.gov/osd/dat/H/HAGERSTOWN.html](http://www2.ftw.nrcs.usda.gov/osd/dat/H/HAGERSTOWN.html)


In a more neutral sense, both soil profiles and landscape panoramas may also be placed in their geospatial context using the Google Earth geolocation feature on the GigaPan.org website. As data sets become more fluidly and visually integrated, we believe students and researchers will be more likely to grasp the inherent interconnectedness of earth, ecological, and human systems.

**IN THE PITS: GIGAPIXEL IMAGING OF SOIL PROFILES**

The soil profile images shown below (Figures 1 and 2) and available interactively at GigaPan.org were taken in Fall 2009 at Penn State University’s Larson Agricultural Research Center, some 10 miles southwest of the University Park main campus. An aerial view of the study area, showing a setting of productive rural landscape in the foreground and the rise of Tussey ridge in the background, is available at [http://cropsoil.psu.edu/courses/soils101/labs/AgronomyFarm.html](http://cropsoil.psu.edu/courses/soils101/labs/AgronomyFarm.html).
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Why Soil Profiles?
A soil profile is the result of five interacting soil-forming factors: time, climate, parent material, topography, and organisms (Jenny, 1941). The interplay of these soil forming factors results in the additions, losses, transformations and translocations (Simonson, 1959) of materials that make up a soil, and that are exhibited as distinct soil morphologies like color, structure, and root and rock fragment distribution. A soil scientist will excavate a profile because they believe that position in the landscape is important to the story of how the landscape and the soil formed; they are using the soil’s morphology to better understand how the interplay of the five soil-forming factors has resulted in the profile they see. In a way, a soil profile is to a landscape what a page is to a book. Each tells part of the story, and in the case of the soil profile, multiple locations across a landscape can help explain how that landscape and its soils formed; as discussed above, the landscape is both generative and expressive. In the classroom, it is important that we convey these ideas to the student, and that they become adept at making observations linking landscapes and their resulting soil profiles.

Soil Parent Material
A soil can be strongly influenced by the parent material (in our area, limestone, sandstone or shale) from which it forms. For example, in the two GigaPan soil profile images, we see distinct differences in each soil’s color that are due in part to the respective parent materials. However, the effect of one soil-forming factor is often also dependent on another. First, we notice a striking difference in soil color. We see the red Hagerstown soil profile (Figure 1) contrasts starkly with the brown Andover soil profile (Figure 2). The Hagersotwn soil profile reveals very old soil, which is the result of hundreds of thousands of years of soil development (time) from the weathering of limestone (parent material) (Figure 3, left) and the addition of atmospheric dust (parent material) (Ciolkosz et al., 1990). Because of the small particle size of the leftover weathering products of the limestone and dust, the soil has a high clay content, which also results in visible soil structure of the ped (the aggregated units of the profile). The Andover soil pit, which is derived from sandstone and shale parent materials that have slid down a mountain slope over time (colluvium), is much younger (<20,000 years old) and has formed in the time since the last glaciation. Because it is younger, less weathering has occurred and less iron has accumulated in the profile. In addition, because it is on a sloped landscape position, some soil movement is likely occurring, which results in the soil’s development clock being ‘reset’. However, because the shale can weather out small particle sizes that quickly can produce clay, the profile also has well-developed structure.

Soil Horizons
In our two soil profiles, we use soil color differences within each profile to see different layers (horizons). Like a profile, soil horizons are also a direct result of the different processes that result in a soil (Simonson, 1959). There are six master horizons (O, A, E, B, C, and R), but only five are actually soil; the R horizon (Figure 3, left) denotes bedrock, giving us a glimpse of the profile’s generative context. The O horizon is defined by its surface location and dominance of organic material, the A by its location at the surface and high organic material content (less than an O), the E by its loss of weathering...
products, the B by its accumulation of weathering products, and the C by being little affected by soil development and closely resembling the parent material. A quick way to find obvious horizons is to squint at a soil profile. This simplifies what one sees, and forces the eye to rely solely on color, contrast or brightness differences to identify the different horizons. For example, using this technique in both profiles will allow one to quickly identify the surface horizon, which is darker in color than the horizons below.

**Water Movement and its Effect on Color: Redoximorphic Features**

Another important difference between the two profiles is caused by differences in water movement through each profile. The Hagerstown profile is in a valley landscape position that has a deep water table. This results in a soil with an aerobic environment (oxygen is present) throughout the year. The Andover soil profile is in a landscape position where water is elevated in the profile for periods of the year. This results in the soil experiencing periods of the saturation where oxygen is either very low or completely lacking in the profile. When saturation occurs the mineralogy of the soil can change, resulting, for example, in the movement of iron out of the profile, or to local zones of accumulation. These zones of loss and accumulation (depletions and concentrations) are called redoximorphic features, and can indicate a soil’s tendency to experience periods of saturation. The depth to which such features are found can be used to indicate the height to which the water table can rise in the profile and give us an indirect estimate of the water table depth; water table depth is one of the most important pieces of information we can glean from a soil profile description using soil morphology interpretation. Another clear example of the effect of soil color can be seen at the top of both profiles. In both soils, a dark surface layer is clearly visible. This is the result of organic material from decomposing organisms at the surface. The boundary between the bottoms of these dark layers is clear too, although it is wavier in the Andover profile. The darker horizon in the Andover profile is enhanced by the periods of the year when the soil is saturated and organic matter decomposition greatly reduced.

![Figure 3. Snapshots showing soil profile details. Limestone (left) in R horizon of Hagerstown soil profile. Millipede (right) emerging from a biopore in the A horizon of the Andover soil profile. For zoomable versions, see http://gigapan.org/gigapans/32535/snapshots/97889/ and http://gigapan.org/conversations/97779/.](image)

**Soil Biology**

Soil organisms play an important role in soil development and the prevention of soil development. For example, we can see a millipede in the Andover profile (Figure 3, right) and evidence of earthworm activity in the Hagerstown profile near the surface of the profile where organic matter is high (see snapshot at http://gigapan.org/conversations/147023/). Soil organisms are important in incorporating organic material deeper in the profile, but are also responsible for decreasing organic matter at the surface. Millipedes are detritivores, feeding on decaying plant matter and incorporating nutrients into upper soil layers. Worm, millipedes and other burrowing invertebrates incorporate organic material at various depths, creating tunnels that allow for water and gas movement. Plants also contribute organic matter to the surface of the soil via the decomposition of plant material each fall and through root growth and subsequent death. Finally, we can also see the
effects of soil microbes in our Andover soil profile where we see redoximorphic features—soil microbes are critical in different aspects of redoximorphic feature production.

**IMAGING TECHNOLOGY AND FIELD SET-UP**

The megapixel panoramas shown above were taken in the field using a GigaPan EPIC 100 robotic mount housing a Canon Powershot SX10 10-megapixel resolution digital camera. The unit was mounted on a SLIK Able 300DX tripod and set up firmly on the base level of each of the two soil profile pits at the Larson Agricultural Research Center. Camera distance to profile center points was in the 2-2.5 meter range. The camera was set to full 20x optical zoom (560mm-equivalent telephoto). We manually focused at a spot approximately 1/3 the horizontal distance between the image center point and edges to provide consistent sharpness throughout the profile images and reduce the effects of perspective distortion. Fields-of-view were reasonable: 13.3° width for the Hagerstown profile and 5° width for the Andover profile. To maximize depth-of-field the lowest ISO setting (80) was used; bright light conditions also allowed fairly high aperture settings. Direct sunlight, in particular, strongly influenced image quality and accessibility of zoomed snapshots. In comparing the two Andover profiles (http://gigapan.org/gigapans/32497/ and http://gigapan.org/gigapans/32500/), one may see that we experimented with shifting natural lighting conditions. We were also aware that, while they appear initially as flat vertical planes, under closer scrutiny soil profiles have significant topography. Near-macroscopic details, such as biopores and ped structures, were considered under varying light/shade conditions for best results. While online equipment reviewers have cited chromatic aberration (color fringing) and corner sharpness as a problem at full telephoto, these issues weren’t a concern in our profile panoramas. Photographic data were merged on a MacBookPro with a 2.8 GHz Intel Core 2 Duo processor using GigaPan Stitch version 0.4.3865 (Macintosh) software, and subsequently uploaded to the GigaPan.org site using GigaPan Uploader version 0.4.3865.

Before moving on to soils further afield, we intend to produce several more Larson farm profile images of different soil series arranged along the valley-to-ridge transect. Improvements to the image capture and developing process are planned. We have recently purchased a GigaPan Epic Pro unit and a Canon EOS Rebel T1i digital SLR that will be equipped with a telephoto lens with near-macro capability. We will also apply studio test experiences (see: http://gigapan.org/gigapans/36322/) to bring the field camera at full zoom to its near-macro limit (which for the Canon SX10 was roughly 1.8 meters). The latest GigaPan Stitch and Uploader software (version 1.0) proved considerably faster than earlier versions during processing and uploading of the 360° site panoramas. One lighting alternative that we intend to test as an alternative to often fickle natural lighting is tungsten studio lights powered by a portable generator. Collectively, these imaging systems improvements should help us attain even greater detail and clarity in our soil profiles.

Earlier (c. 2002) virtual tours of soil profile pits at the Larson farm, part of the then Soils 101 curriculum, are much less useful than our gigapixel images, with limited ability to see soil structure (see http://cropsoil.psu.edu/courses/soils101/labs/Buchhoriz.html ). As of the time of writing, seven panoramas come up during a GigaPan.org keyword search for ‘soil’, of which six originate from our Penn State team. The seventh image addresses soil erosion, not soil genesis or morphology. There is, then, ample opportunity for expanding the genre of gigapixel imaging of soils and soil contexts.

**GIGAPIXEL IMAGING IN SOIL SCIENCE LEARNING AND RESEARCH**

The Introductory Soil Science course at Penn State University has an enrollment of 170–190 students each semester, representing 7 colleges and 30 majors. A foundational element of the course is for students to develop an understanding of the processes and factors (articulated above) that result in soil formation and how the interplay of these results in the tremendous variety of soils that comprise the fabric of the earth’s ‘excited skin’. Accomplishing this objective has been challenging given the diverse student body and the confines of a static lecture hall. GigaPan imaging brings multiple landscapes and soil profiles into the lecture hall in a dynamic and interactive format. The imaging allows students to visualize and contrast several soil formation factors and processes. Using just the two soil profiles and associated landscapes that we have imaged from central Pennsylvania allows students to see how contrasting parent materials, topography, and organisms have resulted in soil profiles with very different characteristics. They may also see how soils strongly influence landscape features. For example, the expressive context of the Hagerstown soil may be seen in surrounding vegetation and land use patterns at http://gigapan.org/gigapans/51453/ . Such visualization helps students link formation factors with resulting soil capabilities and limitations: relatively level, deep, stone free, and well-drained Hagerstown in contrast to the more sloping, very stony, poorly drained Andover. During the lecture the instructor can easily move back and forth between the contrasting soil profiles and landscapes, and with previously defined snapshots can rapidly zoom to show key differences such as parent material, horizon development, color and drainage features (e.g. see redoximorphic feature at http://gigapan.org/conversations/98519/ ). Thus, in a few minutes in the lecture hall students experience a virtual tour of
contrasting soil profiles and landscapes—a journey that would take at least three hours as a field trip. The virtual field trip augments student learning during the three actual field trips made later in the course.

Soil’s physical, chemical, and biological characteristics and processes are also covered in this fundamental course. GigaPan images allow classroom visualization of soil color, structure, porosity, hydroxymorphic features, root penetration, and biopores, as well as how these features change with depth and from one soil to another. The visualization helps students to better grasp the impact of soil morphological features on soil processes.

Students are encouraged to utilize the web-accessible soil profile and landscape pans to conduct their own exploration and search for features discussed in lecture. In future semesters we will develop homework assignments in which students will be asked to search for examples of soil features, identify and describe soil horizons, and compare and contrast different soils. The web-based GigaPan system is also ideally suited for our on-line Introductory Soil Science course, allowing virtual field trip experiences where instructor-led real world field trips are not feasible.

Our goal is to build a library of GigaPan soil profile and landscape images from around Pennsylvania, the U.S. and the world. Construction of such a library will require many cooperators from many regions. As this library grows, so too will the virtual experiences and horizons of students from a variety of backgrounds interested in soils. In our introductory and even upper-level Soil Science courses, logistics and expense limit field trips to central Pennsylvania. The GigaPan soil profiles library will permit virtual field trips, conceivably, to any part of the globe.

Although gigapixel images of soil profiles are a useful pedagogical tool for soil science, they cannot entirely substitute for laboratory and field soils experience because not all soil characteristics and processes can be visually perceived. To learn soil science, students need to get their hands in the dirt. They need to feel soil texture, break out soil aggregates and break them to subunits, experience a hard and brittle fragipan or a soft and friable A horizon, and smell an O horizon. And students need laboratory experiences to understand soil chemistry and soil microbiology.

We are also beginning to explore the integration of gigapixel images with ongoing, complementary soil imaging research. For instance, our NextEngine laser scanning and model generation capabilities are helping to advance the instructional techniques used to depict real-world processes such as the genesis of a soil and landscape (Figure 4, A). This is especially beneficial in a large state like Pennsylvania, which can have long travel times for field site visits. A field soil profile can be scanned in situ or sub-sampled via a soil monolith (Figure 4, B) and scanned at the laboratory.

![Figure 4. Complementary soil imaging technology: A. NextEngine 3D scanner and mount scanning a sample of a soil profile (a soil monolith). B. Example 3D soil scan from the NextEngine scanner. C. Surface crust used in a case study highlighting the effect of acidic mine drainage on soils. D. NextEngine 3D scan of the surface crust in (C) showing light colored salts at the surface.](http://vimeo.com/9963364)

We can also complement the GigaPan and 3D scanning technologies with additional educational resources to further develop a student’s learning experience. For example, we utilized a research project examining acid mine drainage (AMD) and its effect on a landscape. First, a documentary video was created that highlights the story behind the research project (see http://vimeo.com/9963364 ). In this case, a former graduate student strives to remediate the AMD soils and associated surface crusts on her great-grandparents’ homestead in Sylvan Grove, Pennsylvania. Research on the site’s AMD crusts
(Figure 4, C) is focused on determining the seasonal changes in surface chemistry and mineralogy. Samples of intact crust are photographed under a high-resolution stereoscopic microscope and scanned with the NextEngine scanner (Figure 4, D). Combining these technologies with GigaPan imagery and profile descriptions can greatly enhance a student's field experience without ever having to leave campus. We have yet to fully synthesize these various images electronically, but anticipate that the GigaPan.org website will be a convenient and widely accessible locus for a portfolio of soil profiles, snapshots and laser scanning links.

**CONCLUSION**

Gigapixel soil profile images, detail snapshots, 360° site panoramas and georeferences can facilitate the visualization needs of soil researchers and students. As both a portal and a clearinghouse, the GigaPan.org website offers flexibility and accessibility in linking previously rather isolated data sets. By making connections between earth processes, soils, and landscape features, these tools help to tell the story of generative forces on, and landscape expressions of, various types of soil. And combined with 3D scanning technology, gigapixel images hold potential to advance soils-oriented inquiry at a variety of levels and across disciplines.

The ‘excited skin’ may seem an unlikely subject for gigapixel imaging technology. In our experience, however, the assemblage of GigaPan-based equipment, software, and online data hosting is proving to be a very effective part of the toolkit for soil science learning and research, and holds great potential for expanded interdisciplinary application.

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