Field trip/Workshop B2

Environmental Geophysics

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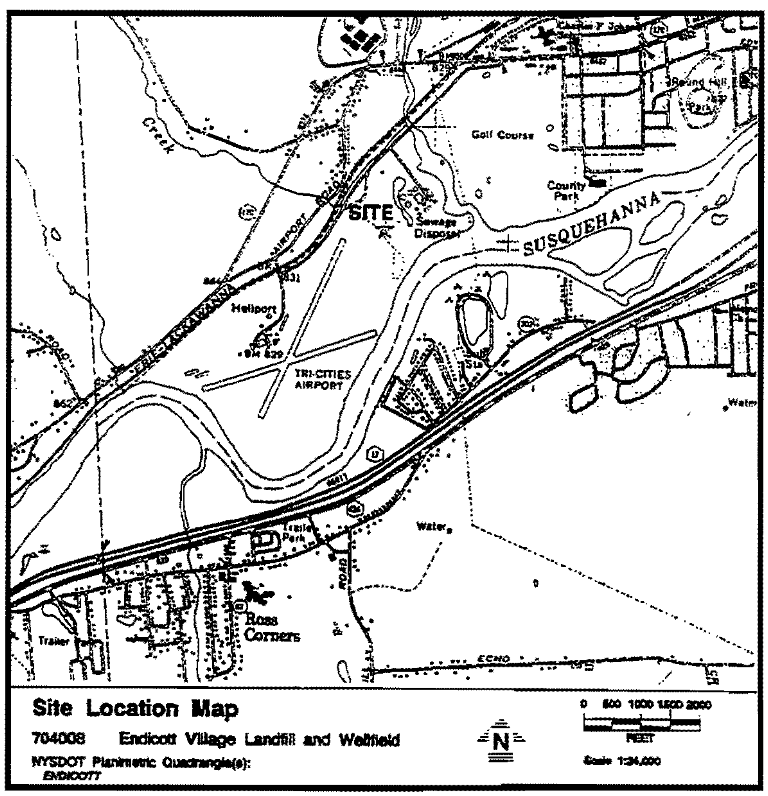
This workshop will include short demonstrations of a variety of geophysical methods commonly applied to environmental hazard assessment problems. We will carry out seismic refraction and reflection surveys, electrical resistivity sounding and profiling as well as a microgravity survey at an abandoned dump/landfill in the Village of Endicott. The dump is located in a former wetland in the flood plain of the Susquehanna River. Aerial photos from 1937 show streams and meander bends at the site. Industrial and municipal waste was dumped there until 1977, when the dump was closed and later capped. The structure and composition of the cap are known, but the content and extent of the waste beneath is largely unknown. The primary water well for the Village of Endicott is located about 600 m east of the dump and is contaminated with vinyl chloride and other volatile organics. Purge wells and air strippers have been installed to remediate water contamination. Ground water flow models indicate the dump is the source of contamination.

Most of the common geophysical methods were developed for oil and mineral exploration, but are now widely used in environmental applications. This is because they are remote sensing methods; they do not require drilling or surface exposures. We have been allowed access to the dump site for a Masters-level feasibility study of the use of various environmental geophysical methods. We are also using the site for an undergraduate/graduate course in environmental geophysics. During the field trip, we will collect data, but will not have time for data processing and analysis. We will demonstrate the primary seismic methods: refraction and common midpoint reflection methods. We will also use electrical resistivity, but in sounding and profiling configurations. We will make a few gravity measurements and discuss the strategies for doing a full gravity survey of such a site. Other methods could be used, but the equipment is not available for the field trip.

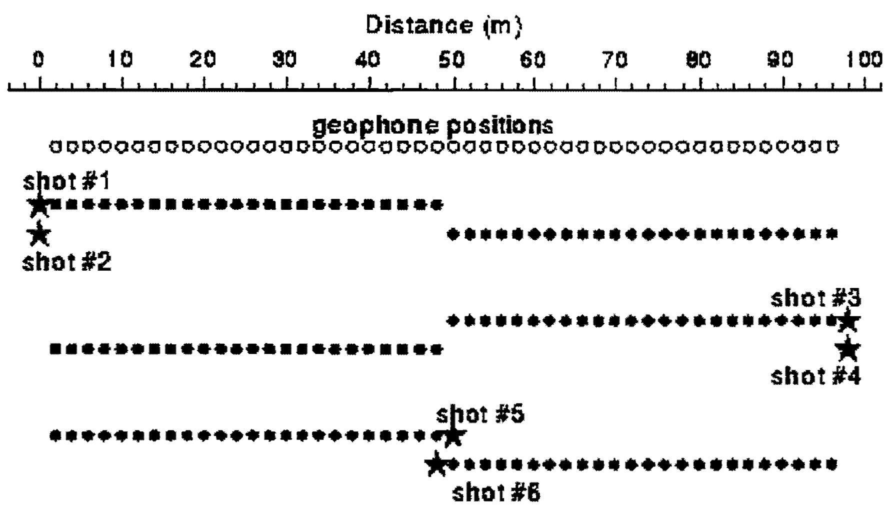


Site Location Map
704008 Endicott Village Landfill and Wellfield
NYSDOT Planimetric Quadrangle(s): ENDICOTT

Magnetic methods could be quite useful in a municipal dump experiment to locate metallic waste. Ground-penetrating radar is becoming an invaluable tool in shallow geological, archeological and environmental problems. However, if the cap of the landfill is predominantly clay, this will shield deeper materials from the electromagnetic waves, making ground-penetrating radar useless for this purpose.

Background

1) Seismic Refraction. A seismic "walk-away experiment" is usually the first seismic data collection effort, intended mostly as a reconnaissance of our site. We set up geophones along a line, with shot points at each end. The shot points are moved away from the geophones (we "walk away") rather than moving the geophones away from the shot point. Our equipment consists of a Geometrics Strataview 24-channel seismograph, geophones, cables, and a "Roll-along switch box" which selects sets of 24 from the 48 geophones we will lay out. We will use a sledge hammer source on each end of the line of geophones, and if possible, will fire a buffalo gun source (a blank 12-gauge shotgun shell detonated at the bottom of an augured hole) from a shotpoint off the edge of the dump. The figure below illustrates an experiment with 2-meter geophone spacing. We will use 1-meter spacing and will have additional shot points located 48 meters from each end. Using the Roll-along switch box allows us to record a 48-channel refraction profile even though our seismograph can record only 24 channels at a time.



Interpretation is the standard seismic refraction approach. We will be trying to determine the seismic velocity and thickness of a set of horizontal (or not) layers. We won't see much of detailed lateral variations in structure; that's what seismic reflection is for. In addition to determining a layered velocity structure, we will want to identify the air wave and ground roll, and to estimate the wavelength of the ground roll in order to avoid spatial aliasing.

For two horizontal layers of constant velocity, find V_1 and V_2 by fitting straight lines to the beginnings of the arrivals on the time vs. distance plots (velocity is change in distance divided by change in time). Extrapolate the line for the faster layer back to zero distance to measure the intercept time, T_2. Then the thickness of the top layer (or depth to the top of the second layer) is $h_1 = \frac{T_2}{2}\frac{V_1 V_2}{\sqrt{V_2^2 - V_1^2}}$ (in m if V is in m/sec and time is in sec).

For three layers, measure the velocities of all three layers as above, and the thickness of the top layer. Also extrapolate the line for the third layer to zero distance and measure its intercept time, T_3. Then the thickness of the second layer (which must be added to the thickness of the first to get depth to the third) is $h_2 = \left(\frac{T_3}{2} - h_1 \frac{\sqrt{V_3^2 - V_1^2}}{V_3 V_1}\right)\frac{V_3 V_2}{\sqrt{V_2^2 - V_1^2}}$. You can continue this way for multiple layers, but the equation for each successive layer becomes more complicated and depends on the results from upper layers.

For two layers in which the interface between the two dips, the velocity of the top layer should be the same from either direction, but the lower-layer velocity will apparently be faster in the up-dip direction (V_{2U}) than in the down-dip direction (V_{2D}). The dip is $\delta = \frac{1}{2}\left[\sin^{-1}(V_1/V_{2D}) - \sin^{-1}(V_1/V_{2U})\right]$. The intercept times will vary as well, so if the intercept time in the up-dip direction is T_{2U}, the thickness at this end is $h_{1U} = \frac{T_{2U} V_1 V_{2U}}{2\cos\delta\sqrt{V_{2U}^2 - V_1^2}}$. Simply replace U with D to get the thickness at the other end.

2) <u>Seismic Reflection</u>. Much of our effort will be in seismic reflection surveys. We will use "Common Midpoint Profiling" (CMP) which gives us multiple samples of reflections from each point at depth. This requires a great deal of processing, and it is difficult to draw conclusions from the raw (field) data. But, the result is a seismic section which looks very much like a depth section, except that the vertical axis is time, not depth. In a CMP survey, the shot (only sledge hammer blows this time) is placed at the end of a line of geophones. After each shot, the shot point and every geophone point is shifted by the same amount (e.g. 1 m). To make this easier, we will use a "Roll-along switch box", which allows us to lay out 48 geophones, but select any set of 24 for each shot. After 24 shots, we pick up the first 24 geophones and shift them to the end of the line (and shift the cables), and continue.

Since reflections occur at approximately the midpoint between shot point and geophone, the spatial sampling of the reflector will be half the geophone interval, and the multiplicity (or "fold") will be up to 12 at any point. In the following diagram, s denotes the shot point, g denotes the geophones, and ^ shows the reflection point (midpoint) for each shot-geophone pair. Below this is the fold, or the number of reflections recorded at each midpoint after the entire experiment is completed. At the ends, the fold increases from 1, but beyond the 12th shot point, the fold remains constant at 12. Part of our processing will be to collect the data together into "common midpoint gathers" and add or "stack" the data for each reflection point. This stacking improves the signal-to-noise ratio and helps us exclude arrivals that are not the reflections of interest (e.g. headwaves, multiple reflections, surface waves, airwave).

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3) Electrical Resistivity. DC Electrical resistivity methods are commonly used for determining depth to the water table or bedrock. This is because the electrically conductive properties vary greatly between dry soil or gravel, saturated soil or gravel, and bedrock. Basically, water enhances electrical conductivity (reduces electrical resistivity), and the presents of salts can enhance this even more. Thus, electrical resistivity surveys are ideal for mapping contaminant plumes which contain ionized compounds.

The equipment and field methods are extremely simple. Four electrodes are placed into the ground. Current is applied from a battery to the outer two electrodes. Voltage and current are measured across the inner two electrodes. If the electrodes are spaced equally with a distance A between each electrode (a Wenner configuration), the apparent resistivity at the center is $\rho = 2\pi A \frac{V}{I}$. If A is measured in meters, the units of apparent resistivity are ohm-meters.

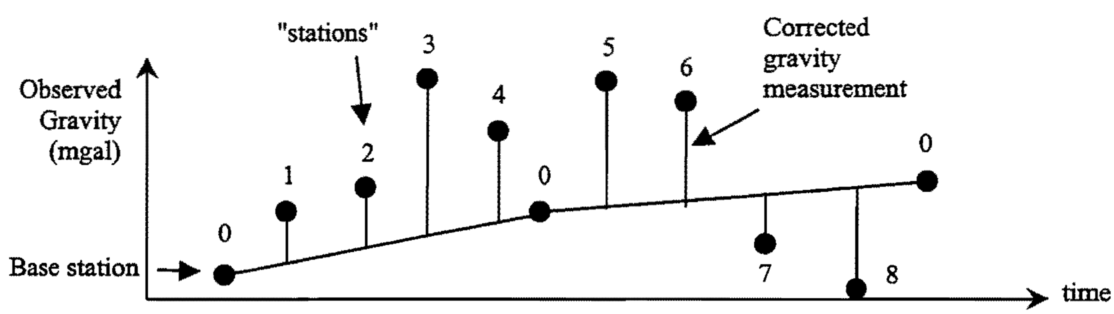
The first experiment will be electrical resistivity *sounding*. In this case, we use a set of cables with electrical contacts at distances of 0.5, 1, 2, 4, 8, 16, 32 meters from the center. The cables are connected to a switch box which allows us to select sets of 4 electrodes, the spacing between which increase by a factor of two each time. Once the electrodes are attached to the cables, it is a fairly quick matter to record apparent resistivity for electrode spacings (A) of 0.5, 1, 2, 4, 8, 16, 32 meters. As the spacing is increased, the portion of the subsurface which is "sampled" by a significant amount of current becomes greater, extending from the surface to increasing depth. Since the actual resistivity of the subsurface materials varies with depth (e.g. at the water table or at bedrock), the apparent resistivity we measure is essentially an average of the properties from the surface down to some depth. Thus, in addition to the predictable change in resistivity with spacing (A), there will be a variation due to the actual resistivity of subsurface materials. If we plot the apparent resistivity vs. spacing (usually on a log-log plot), we can interpret the variations for actual resistivity and depth.

Once the resistivity and depth of a target of interest (e.g. the water table) are determined, we can set up electrodes with a fixed spacing appropriate for that depth, and increment which set of four electrodes are measured each time. In this way, we can measure apparent resistivity along a *profile* horizontally. Variations in depth of the target (e.g. shallower water table) or in the actual resistivity of the material at that depth (e.g. increased concentration of ionized contaminants), will appear as horizontal variations in apparent resistivity.

Electrical resistivity, as with gravity, magnetic and electromagnetic methods, are potential fields methods. This means that what we measure at the surface is the integral or net effect of all of the sources or physical properties within a volume beneath the survey. There are naturally trade-offs between the position, depth and extent of the source which generates a measured anomaly. Data processing and forward modeling can help in interpretation, but there will always be some ambiguity in the results. On the other hand, the physical properties of the material which affect electrical resistivity, gravity and magnetic measurements cannot be determined by any other remote means, and are often the most direct indication of contaminants or properties of environmental concern.

4) Gravity. Finally, we will make a few measurements of gravity to illustrate how a gravity survey of the site is done. Gravity data must be "reduced" to remove as many known effects as possible so that we see the effects of density "anomalies" at depth. These include:

a) *Drift and tides*: The Earth's gravity oscillates on a 12-hour period due to tidal effects, and the gravimeter slowly drifts due to thermal and mechanical effects internal to the gravimeter. To account for both of these, we re-occupy and re-measure gravity at a base station every 30-40 minutes. To make the correction, note the time of each measurement, and the change in gravity between successive base-station measurements, then linearly interpolate the drift correction to be removed from the other measurements. Graphically, this may be done as below, but you can also do this using a spreadsheet or calculator:



b) *Latitude correction*. Earth's gravity is least at the equator and greatest at the poles due to rotation (that's why there is an equatorial bulge). Any survey covering a significant N-S distance must account for this. The degree of variation depends on the latitude, but at our latitude (approx. 42^0N), this is 0.809 mgal/km. We will be interested in gravity anomalies of about 0.1-1.0 mgal across our site. However, the dump covers a N-S distance of about 500 m, so the latitude effect will be about 0.4 mgal, about the size of the effects we are looking for. Note that on E-W survey lines, no latitude correction is necessary unless you want to combine these data with other lines at different N-S positions (for contouring of the gravity anomalies). The latitude correction is subtracted from observed (drift-corrected) data (assuming distance N is considered positive).

c) *Free-air correction.* Earth's gravity decreases with distance away from the Earth's center (with elevation). To account for this, we add a correction of 0.309 mgal/m. Thus, since we are interested in anomalies at the 0.1-0.2 mgal level, it is necessary to measure elevation to an accuracy of about 1/3-2/3 m. If we intend to combine our survey results with others for a regional gravity map, we would need to choose a common datum for each of these surveys (e.g. sea level). For a local survey, however, we can simply choose a convenient datum, such as the lowest elevation in the survey area. Ordinarily, it is necessary to accurately survey for elevation, however due to the engineering of the dump cap, this information is already available.

d) *Bouguer correction.* The Free-air correction ignores the mass of the material between the measurement and the datum. In order to account for this, we estimate the average density of the material between the surface and the datum and correct for the gravity due to an infinite slab with this density. If your datum is sea level, you would want to choose an average density for continental crust (e.g. 2.65 g/cm^3). If your datum is the lowest point in your survey, you will want to choose a density appropriate for the surficial materials (e.g. 2.0 g/cm^3 for wet gravels or 1.5 g/cm^3 for dry alluvium). Whatever you choose, the gravity anomalies you determine will be due to density variations with respect to that assumed density. The Bouguer correction is subtracted from your measured (and corrected so far) gravity according to 0.042 ρ h mgal/m (where ρ is density in g/cm^3). For $\rho = 2.0 g/cm^3$, this is 0.084 h mgal/m (a relatively small effect).

e) The Bouguer gravity anomaly is the result of applying all these corrections. After correcting for drift and tides to get "observed gravity", the Bouguer gravity is $g_b = g_{obs} - dg_{lat} + dg_{FA} - dg_B$. This is what you usually see in maps of "gravity" or "gravity anomalies", and represents the effects of density variations within the survey area. The dump is likely to be characterized as a shallow zone of low relatively density. We can use this to map the subsurface distribution of waste, and perhaps to estimate its total mass.

f) A remaining correction is the *Terrain correction.* This is important in the vicinity of mountains or valleys, but it is difficult to do. The "standard procedure" involves overlaying a template on a topographic map and estimating average elevations within various distance and azimuth bins. In our study area, rather than doing this, you should simply be aware that gravity measurements close to the hills will contain an effect of those hills. The effect (of either hills or valleys) is to subtract from actual gravity (hills pull up, valleys don't pull down as much), so the terrain correction is an addition to observed gravity. There is little topographic relief in the immediate vicinity of the dump, so we can neglect this correction.

Directions to the Village of Endicott dump. From campus, follow Rt. 434 west to "4 corners" in Vestal (the third light beyond the Rt. 26 underpass). Turn right, cross the bridge into Endicott, turn left at Main Street (Rt. 17C and 26). From outside of the area, follow Rt. 17, exit on Rt. 26 north to Endicott. Take the cloverleaf exit to Rt. 17C west

(Main Street). Continue west on Rt. 17C past several lights until you see the En-Joie Golf Course on your left (site of the recent BC Open). There may be road construction on this portion of Rt. 17C. Turn left beyond the golf course (before crossing a railroad bridge), and follow the road toward the Triple Cities Airport. Turn left at the first (and only) street immediately after crossing a creek. Park on the road shoulder or in the large, paved area of the highway department facility. The workshop will be just beyond the paved area.