Our goal today is to use well log data to correlate deposits between these well holes. We will use the trends in the core geophysical data to identify deposits. Everyone will turn in their own assignments, but please work in groups to discuss this.

**We will learn:**
- How to interpret core geophysical data from well logs
- How to correlate trends in geophysical data

**Well logging**
Well logging, also known as borehole logging is the practice of making a detailed record (a well log) of the geologic formations penetrated by a borehole. The log may be based either on visual inspection of samples brought to the surface (geological logs) or on physical measurements made by instruments lowered into the hole (geophysical logs). Some types of geophysical well logs can be done during any phase of a well's history: drilling, completing, producing, or abandoning. Well logging is performed in boreholes drilled for the oil and gas, groundwater, mineral and geothermal exploration, as well as part of environmental and geotechnical studies.

Wireline logging is performed by lowering a 'logging tool' - or a string of one or more instruments - on the end of a wireline into an oil well (or borehole) and recording petrophysical properties using a variety of sensors. Logging tools developed over the years measure the natural gamma ray, electrical, acoustic, stimulated radioactive responses, electromagnetic, nuclear magnetic resonance, pressure and other properties of the rocks and their contained fluids. Wireline logs can be divided into broad categories based on the physical properties measured.

**Resistivity Log:** Resistivity logging measures the subsurface electrical resistivity, which is the ability to impede the flow of electric current. This helps to differentiate between formations filled with salty waters (good conductors of electricity) and those filled with hydrocarbons (poor conductors of electricity). Resistivity and porosity measurements are used to calculate water saturation. Resistivity is expressed in ohms or ohms\meter, and is frequently charted on a logarithm scale versus depth because of the large range of resistivity

**Porosity logs:** Porosity logs measure the fraction or percentage of pore volume in a volume of rock. Most porosity logs use either acoustic or nuclear technology. Acoustic logs measure characteristics of
sound waves propagated through the well-bore environment. Nuclear logs utilize nuclear reactions that take place in the downhole logging instrument or in the formation.

A common combination of logging measurements includes gamma ray, resistivity, and neutron and density porosity combined on one toolstring. The gamma ray response (Track 1) distinguished low gamma ray value of sand from the high value of shale. The next column, called the depth track, indicates the location of the sonde in feet (or meters) below the surface marker. Within the sand formation, the resistivity (Track 2) is high where hydrocarbons are present and low where brines are present. Both neutron porosity and bulk density (Track 3) provide measures of porosity, when properly scaled. Within a hydrocarbon zone, a wide separation of the two curves in the way shown here indicated the presence of gas. Anderson, M., 2011. Defining Logging in *Oilfield Review*, Spring 2011, v. 23, no. 1, 2 pp.

**Density:** The density log measures the bulk density of a formation by bombarding it with a radioactive source and measuring the resulting gamma ray count after the effects of Compton Scattering and Photoelectric absorption. This bulk density can then be used to determine porosity.
Neutron porosity: The neutron porosity log works by bombarding a formation with high energy epithermal neutrons that lose energy through elastic scattering to near thermal levels before being absorbed by the nuclei of the formation atoms.

Lithology logs: Gamma ray: A log of the natural radioactivity of the formation along the borehole, measured in API, particularly useful for distinguishing between sands and shales in a siliciclastic environment. This is because sandstones are usually nonradioactive quartz, whereas shales are naturally radioactive due to potassium isotopes in clays, and adsorbed uranium and thorium.

Self/spontaneous potential: The Spontaneous Potential (SP) log measures the natural or spontaneous potential difference between the borehole and the surface, without any applied current. It was one of the first wireline logs to be developed, found when a single potential electrode was lowered into a well and a potential was measured relative to a fixed reference electrode at the surface.

Figure 20.20 shows boreholes plotted in Figure 20.21, which shows a detailed cross section extending from the foothills of British Columbia eastward into the plains of Alberta, which illustrates an unconformity. The cross section shows the dramatic thinning of the Marshybank Formation in a basin-ward direction, as a result of erosional truncation, and the eventual disappearance of sandstone (e.g., in 3-30-67-26W5). The Marshybank
comprises upward-coarsening marine sequences that grade into a series of fine-grained, hummocky and swaley cross-bedded and parallel-bedded shoreline sandstones, commonly overlain by coastal plain coals and fluvial units.

**Part I. Correlation**

For today’s lab, we will use well log data from wells drilled along Tompkins Hill, Humboldt County, CA. These wells were drilled for hydrocarbon exploration in the 1960s. We will correlate packages of sediments from well to well. We will make note of repeated section and differences in sedimentary unit depth between wells.

We will correlate from hole to hole, the bases of sedimentary sequences. Use a pencil for your correlations as you will be changing them as you work through this assignment. The well logs are from wells located in the region below. Tape the well logs to the larger piece of paper and draw your correlation lines on the larger piece of paper. The following information may help you select the arrangement of the well logs (consider elevation and spatial location). Label some of the sedimentary units that you correlate, using alphabetical letters, starting with A at the top.

<table>
<thead>
<tr>
<th>Well ID</th>
<th>Elevation (ft.)</th>
<th>Depth at Top of Log (ft.)</th>
<th>Location (Township/Range)</th>
</tr>
</thead>
<tbody>
<tr>
<td>HE 5</td>
<td>764</td>
<td>2080</td>
<td>2564' S / 50' E from NW corner of Section 22</td>
</tr>
<tr>
<td>HE 7</td>
<td>613</td>
<td>1980</td>
<td>1629' N / 353' W from SE corner of Section 23</td>
</tr>
<tr>
<td>HE 8</td>
<td>484</td>
<td>1670</td>
<td>981' N / 2368' E from SW corner of Section 23</td>
</tr>
<tr>
<td>HE 10</td>
<td>575</td>
<td>1330</td>
<td>2200' S / 2650' E from NW corner of Section 23</td>
</tr>
</tbody>
</table>
Our goal today is to use geophysical data collected from sediment cores to correlate deposits between these sediment cores. We will use the trends in the core geophysical data to identify turbidites with similar trends. Everyone will turn in their own assignments, but please work in groups to discuss this.

**We will learn:**

- How to interpret core geophysical data from turbidite stratigraphy
- How to correlate trends in geophysical data

Core samples are collected on land and at sea by the hydrocarbon, mining and construction industries, as well as by the military and by paleoseismologists. For academia they are now an essential part of climatic research. The cores come as soft sediment encased in plastic sleeves. They can yield information about the properties of rock or sedimentary strata. These geophysical properties can be used as proxies for different parameter that might be useful for industry. The hydrocarbon industry, for example, needs accurate data on the porosity, grain size, and correlation parameters to surrounding geology, whereas the construction industry and the military may be interested in geotechnical properties such as P-wave velocities, density and water content. The range of parameters that can be measured includes P-wave velocity, gamma density, magnetic susceptibility, electrical resistivity, color line-scan imaging, X-ray fluorescence, color spectrophotometry, and natural gamma spectrometry. Sediment cores may also be analyzed using Computed Tomographic X-Rays, resulting in CT-scans (3-D X-Rays). Line-scans of the CT data can provide an independent view of density. Core data can be correlated by looking for matching sequences in these parameters (*Figure 1*). *Figure 2* shows the region from where the cores in *Figure 1* were collected.

For today’s lab, we will use core log data from sediment cores collected offshore of Oregon. These cores were initially collected to disprove the results of a paper published by Adams (1990), who concluded that turbidites cored in the 1960s were initially triggered by Cascadia subduction zone earthquakes. Unfortunately for the scientists in 1999 and 2002, they were unable to disprove Adams (1990).

Paleoseismologists use integrated stratigraphic correlation techniques, including visual lithostratigraphic description (color, texture, and structure, etc.), CT image analysis, and lithostratigraphic log correlation of Multi Sensor Core Logging (MSCL) geophysical data (Fukuma, 1998; Karlin et al., 2004; Abdeldayem et al., 2004; St-Onge et al., 2004; Hagstrum et al., 2004; Waldmann et al., 2011) to correlate turbidites based on the turbidite “architecture” (Amy and Talling, 2006). Stratigraphic correlation using geophysical signatures representing vertical turbidite structure is a primary tool for testing individual
deposits for their areal extent, a significant part of the criteria used to discriminate seismoturbidites from other possible types. A positive correlation, regardless of the originating details, is indicative of a co-genetic origin. Down-core geophysical properties for individual turbidites are reflections of the vertical grain size distribution of the bed (Kneller and McCaffrey, 2003; Amy et al., 2005; Karlin and Seitz, 2007; Goldfinger et al., 2012). Lithostratigraphic correlation techniques have been used to correlate stratigraphic units since the 1960’s (Prell, 1986; Lovlie and Van Veen, 1995). In detail these “fingerprints” represent the time-history of deposition of the turbidite and, in several cases linked to plate boundary earthquakes, have been shown to correlate between independent sites separated by large distances and depositional settings (Goldfinger et al., 2008, 2013). The turbidite itself is commonly composed of single or multiple coarse fraction fining upward stacked units termed “pulses.” The rarity of a fine tail (Bouma Td and Te; Bouma, 1962) or subsequent hemipelagic sediment between pulses indicates there is commonly little or no temporal separation between units. The lack of temporal separation of the pulses in Cascadia has been inferred to represent deposition over minutes to hours, so most likely represent sub-units of a single turbidite (Goldfinger et al., 2012).

**Figure 1.** Correlation Diagram for Tertiary Anderson Fan sands. These turbidite sand deposits are found in the wells drilled in the Table Bluff, Thompkins Hill, and Grizzly Bluff regions, as well as found in outcrop at the Price Creek and Scotia sites.

Density and magnetic susceptibility tend to co-vary with particle size; larger particles and magnetic minerals are generally denser (Thompson and Morton, 1979). **Figure 3** shows core geophysical data for sections from cores 96PC and 108PC, collected in the deep sea offshore of Sumatra (Patton et al., 2013,
2015). Note how the gamma density (light blue) and CT density (dark blue) co-vary with the magnetic susceptibility data (red).

The technique that people use is known as flattening and ghost tracing data from one core upon another. Flattening core data to particular stratigraphic horizons (Major et al., 1998) is a test of the hypothesis that the stratigraphic sequences in the cores correlate and represent the same sedimentary history. This is accomplished by the use of “ghost” geophysical traces from different cores that are iteratively compared to search for the presence or absence of a similar stratigraphic sequence. A proposed sequence is then “flattened,” that is all of the geophysical and image data in the core diagram are “hung” on proposed uniform time horizons, represented by the bases and tops of each turbidite. The proposed correlation lines are then horizontal, or “flat.” This is accomplished by changing the vertical scale of each core to match a reference core. The thicknesses of the turbidites naturally vary between cores at a single site and between cores from different sites for a variety of reasons. Because turbiditic and hemipelagic sedimentation rates vary for cores at different sites, the thicknesses of stratigraphic units also vary for those core sites. It is this variability in stratigraphic thickness that is removed when several core sequences are flattened, scaling the core data to match these variations in thickness and sedimentation rate and placing the cores on a time basis in the vertical axis (Tearpock and Bischke, 2002). This allows the interpreter to see the stratigraphy as if there were a simple pancake stratigraphy with the first order depositional variability largely removed and the characteristics if each bed emphasized. Figure 4 shows an example of this flattening technique for two cores offshore of Sumatra (Patton et al., 2013).
Figure 3. Turbidites in cores 96PC and 108PC are plotted with turbidite division systems (Patton et al., 2015). Plotted from left to right are gamma density, CT (computed tomographic X-ray) density, lithologic log (pattern), CT imagery, turbidite division, core depth (cm), lithologic log (grayscale texture), texture (particle size phi scale including, from left to right, clay, silt, very fine sand, fine sand, medium sand, coarse sand, very coarse sand, and gravel), and point magnetic susceptibility (mag. Sus.). The deposit type (single pulse or multi pulse) and turbidite structure divisions present (included divisions) are listed for each turbidite.
Figure 4. Correlation of sedimentary units using standard stratigraphic correlation techniques between cores RR0705-55PC and RR0705-57PC. A. Bathymetric map with cores plotted as brown dots and depth contours with 500 m spacing. Cores 55PC and 57 PC are located in the trench approximately 120 km from each other. B. Stratigraphic correlations between these cores using lithology, CT, and geophysical properties. Multi Sensor Core Log (MSCL) data are plotted beside RGB imagery and CT imagery that displays lower density material in darker grey and higher density material in lighter grey. Gamma density, CT density, and point magnetic susceptibility are plotted left to right as light blue, dark blue, and dark red. The certainty of any individual correlation is ranked and designated by line symbology. C. MSCL data for core 57PC is “flattened” to stratigraphic horizons in core 55PC on the left, and 55PC is flattened to 57PC on the right. The core data being flattened is transparent and plotted on the outside of the core data they are being flattened to. The un-flattened core data are scaled at the same vertical scale as in B.
Part II. Correlation

We will correlate from core to core, the bases of turbidites. First we will correlate cores with no numerical age control from cores collected in the western Atlantic Ocean. Then we will correlate two cores that each have radiocarbon age estimates for the sediment underlying the turbidites. Sequentially number the turbidites that you have correlated in each correlation figure, beginning with #1 for the uppermost turbidite.

A. Antilles Correlation

We will correlate two pairs of cores from the Lesser Antilles, a magmatic arc related to subduction of the Atlantic plate beneath the Caribbean plate. These cores were collected while I was at sea this summer on the Poquois Pass, a French research vessel. These core pairs are in sedimentary basins near the base of the continental slope northeast of Guadeloupe (Figure 5). Correlate the bases of turbidites. Do as many as you can.

B. Cascadia Correlation

Now we will correlate one core pair from core data from two different sedimentological settings (one core is from the base of a submarine canyon and one is at the base of a piggy back basin ridge along the continental slope). Both of these cores are from the northeast Pacific Ocean and were used to develop
GEOL 332 Lab 10 B
Turbidite Correlation

the earthquake chronology along the southern and central Cascadia subduction zone (Goldfinger et al., 2012). We will use the radiocarbon ages as a first order control for our correlations. Note that there may be errors beyond the analytical errors listed in the figure (i.e. the age may not best represent the sediment sampled in the core; e.g. the sediment may be older or be younger than the radiocarbon age). Use a pencil for your correlations as you will be changing them as you work through this assignment. Correlate the bases of turbidites. Do as many as you can.

References:

GEOL 332 Lab 10 B
Turbidite Correlation

GEOL 332 Lab 10
Stratigraphic Correlation

Name: __________________________________________ Date: ____________________

Team Name: ______________________ Team Members: __________________________________

__________________________________________________________

Part III. Report

Please submit your correlation diagrams for Lab 10 A and Lab 10 B, along with a 3 page report that summarizes your findings. Please be as scientific as you can. This report and correlation diagrams are due in two weeks. Work on this project and report as a group, but everyone must submit their own report and correlation diagrams.

Introduction:
• Describe what this lab is about.
• Mention why this method is used for hydrocarbon exploration. You may want to do some online research about this.
• Mention why this method is used for submarine paleoseismology.

Methods:
• For Lab 10 A, in your own words, describe what well log properties are, what they might be used as proxies for in the sediment cores, and the correlation methods used in this lab. You might want to do additional research about well log data.
• For Lab 10 B, in your own words, describe what core geophysical properties are, what they might be used as proxies for in the sediment cores, and the correlation methods used in this lab.

Results:
• For Lab 10 A, list the number of sedimentary packages that you were able to correlate. State whether these are sand or shale deposits. If you can quantify this, mention the number of sand and the number of shale units (or give a percentage).
• For lab 10 B, list the number of turbidites that you were able to correlate in each correlation diagram.

Discussion:
• This results section should provide the basis for an interpretation of the geologic history recorded in the sediments collected in these cores.
• Based on your correlations, what can you say about the sedimentary history found in these cores? Be bold in your interpretations.

Conclusion:
• A summary of your report.