Seismic Exploration

My part in Team E research is to research and find the best way to explore for oil and other resources using seismic surveys. In this quest I came to realize that there are many ways to tackle this issue. First let me say that any case of seismic survey is intrusive. This is not a magnetic survey which can be done from a certain distance without actually coming into any kind of contact with the environment you are trying to explore. This kind of survey requires a certain contact that may or may not result in a severe impact on its subject. So first of all, let's explore the concept of seismic exploration.

Overview

The seismic exploration phase is a very important to the exploration activities, because this is the most precise way to approximate where the oil might be, thus enabling to cut down on wrong location drilling. Basically, the more precise the method, the less you have to drill. Seismic exploration varies in precision due to different derivatives of the data. It is possible to construct 2D, 3D and now 4D maps using seismology. The later method is the most precise and it uses repetition of the 3D method. Of course, the more dimensions you have, the more equipment you need and so the cost will rise.

There are many resources available online and offline in order to research seismic exploration method. I will try to introduce the method shortly.

As explained by the Utah BLM Stone Cabin, in the web link http://www.ut.blm.gov/stonecabin/Q&As.htm

"Seismic survey methodologies are tools for analysis of geologic formations and features in the subsurface. The process consists of using a source of energy that is directed into the subsurface and then recorded back at the surface (with geophones) as the energy waves travel through the subsurface and reflect back to the surface. Various types of rock reflect the energy waves differently, and these differences are measured. Data helps show the tops and bottoms of formations, thickness, and structural configurations. It cannot identify pools of oil and gas, but rather, conditions favorable for the possible accumulation of oil and gas."

In simpler terms, in order to map the inner layers of the ground or sea bottom, seismic technology uses sound waves generated at or near the surface that travel downward, later on reflecting at different angles and times from different layers and rocks in the ground. While actually those sound waves change direction, they are being picked up by geophones located at the surface or slightly beneath it. These geophones are connected to a computer which is able to analyze the data and built an actual map of the underneath area.

The Whales and Dolphin Conservation Society (WDCS) published a number of articles regarding the using of offshore seismic survey techniques and their effect on the mammal life. In the following link to an article, http://www.wdcs.org/dan/publishing.nsf/allweb/6B7D8FD1BAB453F4802568FF004B9189, WDCS are addressing the issue that mammals change their migrational patterns especially to avoid as much as possible the "noise source", being the airgun used in offshore exploration.

Different techniques of seismic exploration

Explosives

Seismic geophones are able to collect their data from many sources of sound. One of those sources is explosives. By drilling small holes into the ground, approx. 12 meters deep, and packing them with 10 pounds of capped explosives (directed towards the center of earth), followed by detonation of those explosives, the geophones will be able to get sufficient data to map the are underneath the receivers.

"Thumper" trucks, Vibroseis

30,000 pounds trucks generate vibrations underneath the ground by elevating themselves above the ground on a short pole, thus concentrating their entire weight on this small platter and "shaking" for several second per location, thus sending vibrations to the ground. The rest of the process is very similar to the explosive process because all that is left is the data gathering phase.

Airgun

Airgun is an excellent example of an offshore method. This exploration technique is used with assistance from a ship that actually carries all the equipment necessary to both send signal and to analyze. Such ship will carry an airgun and many receivers at greater distance that actually read the sound data as it is reflected from different rock formations and layers in the ocean bottom. Thus, just as the land surveys, the data being processed by a computer which is later on able to generate a detailed map of several layers underneath the sea bottom.

Data Processing

The data is being received by geophones, which are relatively small devices placed on the ground. Those devices are synchronized with computer and placed on the ground using GPS equipment. This way the computer that analyzes the data has all the variables, the time of the vibrations, the relative distances at which the reflections are measured, and the strength (wavelength) of the vibrations. Different rocks and layers give different reflections of vibration, different changes in frequencies in the wavelength of the vibration. Using this data, gathered from the sensors, the main computer unit is able to constructed a detailed map, thus enabling it's user to analyze the map for possible oil location.

My recommendation

After considering all the information I gathered during my research period, I recommend the usage of explosive technique as our primary seismic exploration technique. The use of such technique will minimize both the intrusion factor of the teams to the ANWR environment and the total damage done to the environment itself. Furthermore, I recommend the use of the Ice Code Drills, especially the 2" drill which is 20kg and can be carried and operated by one person. More information can be found at http://www.icedrill.ch/

A team of 2 people will set of in snowmobiles to drill 12 meter holes. Later, 50 pound charges will be place inside those holes. The drilling time is around 2-4 hours per hole. After placing the charges in the holes, they should place the geophones on the ground to cover the desired area. This area is then should be evacuated, as the charges can be set off from a distance as low as 100 feet away.

Non-Seismic Exploration Techniques

Electrical Resistivity:

Overview: *This process involves placing probes in the ground and passing a current between them. By measuring the resistance of this current you are able to tell within a degree of certainty whether there is oil or not.*

www.digistar.mb.ca/minsci/ finding/resist1.htm

"Electrical and electromagnetic data are analyzed primarily to yield the electrical resistivity of the rock formation where currents have been injected or induced to flow. The resistivity is in turn a strong function of the porosity and pore fluid saturation. (1)"

Potential Problems: *The steel casing of the pipes underground can act as a barrier to the electrical signals.*

"Steel casing severely attenuates electromagnetic signals transmitted or received from within the pipe. The casing typically acts as a low-pass filter, attenuating signal above 10 Hz and virtually eliminating signals above a few hundred Hz. …This means that field measurements are more difficult in steel casing, and field data predominantly reflects casing effects. (1)"

Solutions: *By taking into account the effects that the pipe has on the signal, you can separate it when you interpret the data and just get the information you want.*

"Current research suggests, however, that the shielding effect of the steel pipe is a fairly simple function of the thickness, electrical conductivity, and magnetic permeability of the steel pipe segment surrounding the sensor. Although EM fields are severely attenuated by the steel pipe, the response may be calculated with fairly simple numerical models and separated from the formation effect using straightforward techniques. …Thus, if the properties are obtained, the response due to the casing may be easily separated from the total field, leaving the formation response as a residual. (1)"

Experimental Methods

Earth's field NMR:

By using the earth's magnetic field, you can disrupt water molecules. By measuring this disruption you can have a good idea of whether there is water in an area. This technique is used for finding groundwater but it might be able to be used to find oil as well.

"This technique involves locally perturbing the direction and amplitude of the earth's ambient magnetic field to affect the dipole moment of hydrogen-based molecules (i.e. water or oil) within the pore structures. After the perturbing field is shut off, a decay signal is generated in regions containing mobile hydrogen atoms. These data can be used to estimate the porosity, saturation, and possibly even permeability of these volumes. …Recently, a project has been initiated through the DeepLook consortium to study the feasibility of extending this technology to oil and gas exploration. (1)"

Electrical Vs. Seismic:

Electric is better at telling if there is oil and Seismic is better at telling if there is gas. Seismic is also better at characterizing the structure of the reservoir.

"Although electrical data are sensitive to variations in storage and saturation of reservoir liquids, seismic techniques are more sensitive to the presence of the reservoir gases. In addition, the higher resolution offered by seismic techniques is superior in mapping reservoir structure. (1)"

Magnetic

Overview: *By measuring the magnetic field, you can tell where there is likely to be oil because the rocks that may contain oil have very low magnetic readings. The magnetic field can be measured with an instrument called a magnetometer which can be flown over an area or used on the ground.*

"Magnetic surveys are usually made with magnetometers borne by aircraft flying in parallel lines spaced two to four kilometers apart at an elevation of about 500 meters when exploring for petroleum deposits. …Ground surveys are conducted to follow up magnetic anomaly discoveries made from the air. Such surveys may involve stations spaced only 50 meters apart. …Magnetic effects result primarily from the magnetization induced in susceptible rocks by the Earth's magnetic field. Most sedimentary rocks have very low susceptibility and thus are nearly transparent to magnetism. Accordingly, in petroleum exploration magnetics are used negatively: magnetic anomalies indicate the absence of explorable sedimentary rocks. (2)"

Methods:

Proton-precession magnetometer: *One type of magnetometer which utilizes the disruption of protons in oil to measure magnetism. .*

www.eri.u-tokyo.ac.jp/KOHO/ Yoran2001ep/08_05.html

"One such method involves the proton-precession magnetometer, which makes use of the magnetic and gyroscopic properties of protons in a fluid such as gasoline. In this method, the magnetic moments of protons are first aligned by a strong magnetic field produced by an external coil. The magnetic field is then turned off abruptly, and the protons try to align themselves with the Earth's field. However, since the protons are spinning as well as magnetized, they precess around the Earth's field with a frequency dependent on the magnitude of the latter. The external coil senses a weak voltage induced by this gyration. The period of gyration is determined electronically with sufficient accuracy to yield a sensitivity between 0.1 and 1.0 nanotesla. (3)"

Schmidt vertical-field balance: *Another type of magnetometer that measures the relative magnetic field by observing the torque produced by the earth's magnetic field on the instrument. Using this instrument involves setting up observation stations along the region of interest approximately a half mile apart.*

(**www.xtrsystems.com/ magnetometer/coil**)

"The Schmidt vertical-field balance, a relative magnetometer used in geophysical exploration, uses a horizontally balanced bar magnet equipped with mirror and knife edges. (4) "Field procedure consisted of observation stations located at .5 mile intervals for reconnaissance surveys and .025 mile intervals for detail surveys. (5)"

Evaluation: *The field balance is a more accurate way of exploring for oil when the region of* *interest is shallow.*

"Field experiments showed that aerial magnetometers, proton precession magnetometers, and gravity surveys were not sufficiently accurate to map the small topographic lows of the Precambrian granite. Our conclusion was that only the field balance, …could acquire the necessary data. (5)"

Gravitational

Overview: *This procedure involves taking reading about a kilometer apart throughout the region with a device called a gravimeter. The gravimeter measures the gravitational field and this reading correlates with the density of the region. By studying the differences in the density, you can predict which areas of the region might contain oil*

www.seismo.unr.edu/ftp/pub/ louie/class/492/album02/

"Gravity differences occur because of local density differences. Anomalies of exploration interest are often about 0.2 mgal. …Gravity surveys on land often involve meter readings every kilometer along traverse loops a few kilometers across. …In most cases, the density of sedimentary rocks increases with depth because the increased pressure results in a loss of porosity. Uplifts usually bring denser rocks nearer the surface and thereby create positive gravity anomalies. Faults that displace rocks of different densities also can cause gravity anomalies. Salt domes generally produce negative anomalies because salt is less dense than the surrounding rocks. Such folds, faults, and salt domes trap oil, and so the detection of gravity anomalies associated with them is crucial in petroleum exploration. (2)"

Conventional Gravimeter Vs. Gravity Gradiometry: *A gravity gradiometer is another type of gravimeter that can give more information about the gravitational field of a region. This information can give more accuracy in oil exploration but interpretation of it is underdeveloped and is usually done using techniques for interpreting conventional gravimeter data.*

www.microgsolutions.com/ gradiometer.press.htm

"The conventional gravimeter measures a single component (the vertical component) of the gravity field vector. In contrast, a gravity gradiometer can measure up to five of the nine terms in the gravity field's gradient tensor which completely describes the anomalous gravity field gradient. …Note how the two gradiometer measurements better emphasize the structural highs and lows as well as the bounding fault zones. … interpretation of gravity gradiometry data is presently immature in practice and application. …However, many existing gravity and magnetic interpretation algorithms are easily and naturally adapted to the interpretation of gravity gradiometer data. (6)"

Conclusion: Each of these methods is unique and would provide valuable information in the exploration stage. Based on my research, it is my recommendation that we utilize each of these techniques, in addition to seismic technology, in order to get a comprehensive view of the region. I believe that it is crucial to have as much information as we can from exploration so that we can reduce the impact of drilling needlessly.

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Drilling Methods

Vertical Drilling

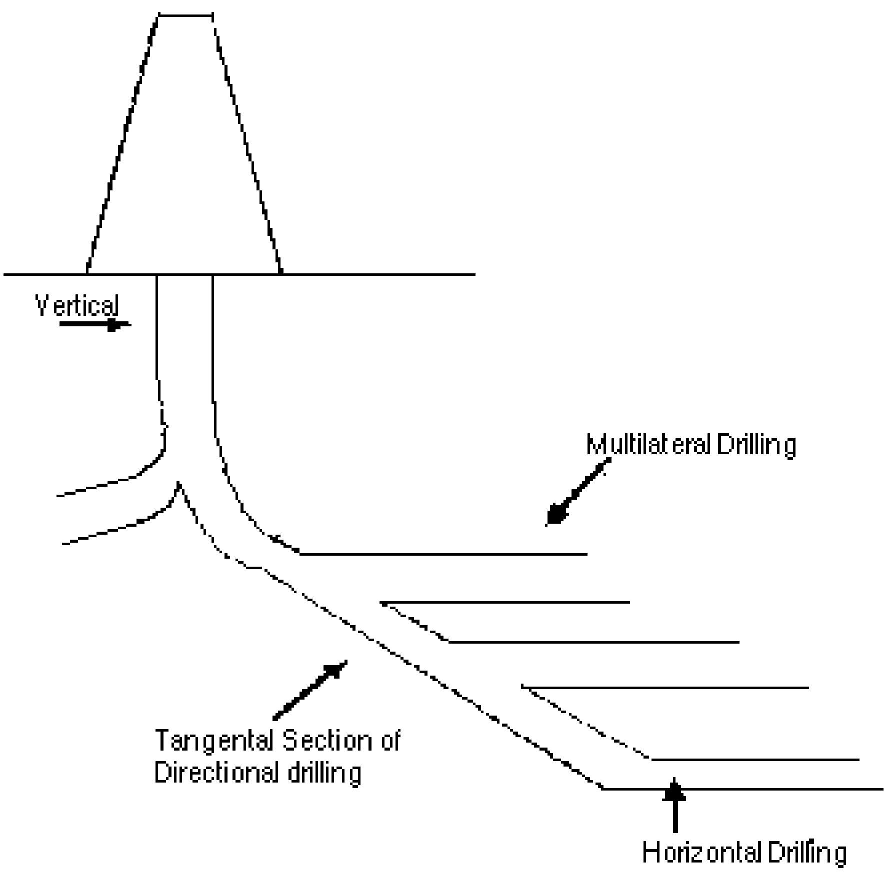
The oldest method of drilling is to drill a vertical well. In this method, a wellbore is drilled with as little deviance as possible directly towards the reservoir; once it penetrates and goes through the reservoir, the well is stopped and the drill string removed. At this point cement is poured down the well to prevent hydrocarbons from flowing down the well once it is perforated. Then the well is perforated, and the pressure in the formation forces the oil out of the rock and up the pipe.

Directional Drilling

Directional drilling is a relatively new technology which allows a well to be drilled along a predetermined path which is not vertical. A directional well has the added benefits of being able to thread through a horizontal strata, in order to obtain the most pipe-to-formation surface area. Directional drilling is useful for a number of reasons, including

- •sidetracking
- •drilling to avoid geological problems
- •controlling vertical holes
- •drilling beneath inaccessible locations
- •drilling to reach oil in reservoirs which would be unreachable by vertical wells.
- •offshore development drilling
- •horizontal drilling
- •increasing oil pressure due to penetration

Directional drilling must be approached carefully. It is not as risky as it used to be due to special tools to help the well deviate in a controlled manner and new technology to keep track of the directional of the well once it has deviated. Often the target of the well is very precise and must not be missed. There is a possibility of drilling many different wells from the same well bore, which dramatically decreases pad size and increases possible production from the well.



Horizontal drilling has the added advantage of being able to thread back and forth through a horizontal reservoir to increase the formation penetration. The horizontal

technique combined with **multilateral wells** allow several formations to be penetrated horizontally at once.
Recommendation: Directional Drilling with other necessary components added as necessary.

Rigs

Drill rigs vary dramatically depending on the depth and the type of formation they are drilling through. Since this information is not offered in the absolute for the ANWR region, it is only possible to speculate on the best rigs for the job. Companies being looked at to supply possible rigs include Anadarko and Schlumberger.

Exploration Drilling

After seismic exploration has taken place, one must go in and drill to to find the the true dimensions of the well. Directional drilling with coring is the best way to do this, making a minimum of holes and still determining the dimensions of the well. This can be drilled from a fairly mobile, lightweight rig. We are still researching exploration drilling techniques.

Rig Components

Drill Bits break down into categories:

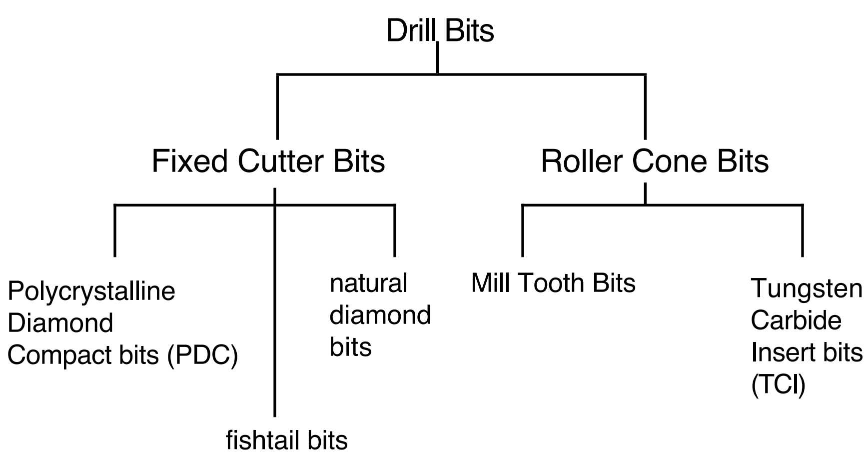


Fig 6-1 Drilling Tech.

Roller cone bits have one, two or three cones that have teeth sticking out of them. The cones roll across the bottom of the hole and the teeth press against the formation with enough pressure to exceed the compressive strength of the rock. They're made for rougher drilling conditions and less expensive; they aren't ideal for small holes, but they are very sensitive to the porosity of the rock they are drilling through (drilling faster or slower depending on the pore pressure) giving the drilling crew a good idea of changes in pressure in the wellbore. Roller cone bits with steel teeth are called mill tooth bits; they withstand high drilling stresses while tungsten carbide bits can drill for long distances without wearing out. Tungsten bits are more expensive;

tungsten carbide insert bits have teeth coated with diamond, which give them an even longer life.

Fixed cutter bits have no moving parts, and therefore only the cutting surfaces become dull. Diamond fixed cutter drill bits produce small rock cuttings called rock flour; they drill through the hardest formations, though slowly, and are also extremely expensive. These bits are only used in formations which have high compressive strength or are very abrasive and would destroy other bits before they made much progress. PDC bits drill with a diamond disk mounted on a tungsten carbide stud; they have the capability to drill very fast (100 feet an hour) and are very costly. They can be built with either steel or molded tungsten carbide bodies (matrix body). These bits are made in many different shapes and can be made to drill directionally; the shape also affects how many cutters can be mounted on the bit. Fishtail bits are of very old design and only suitable for drilling in very soft formations.

The drill bits will need to be replaced as they become dull. The drill will be equipped with a jet to direct the flow of drilling fluid to clean cuttings from the bottom of the hole and allow them to rise to the top of the well bore. There is an optimal speed for the bit, which allows it to clear away the most rock and still maintain a high RPM).

There are many different types of drill bits to choose from and since the exact type of strata to be drilled through in ANWR is unknown, it is almost impossible to select drill bits. Instead, drill bits have been listed to accommodate as many different types of strata as possible. Roller cone bits would be good for exploration drilling; because they are so attentive to the porosity of the hole, it is a good indicator to the drilling crew if there is danger of a blowout. For longer drilling operations in harder formations, PDC bits appear to clearly be the best choice.

Drilling Power

The torque needed to drill the bit may be given by a **top drive motor**, suspended by the traveling block above the drill pipe in the derrick; it turns the drill string. This motor is electrical. New technology includes instead **downhole equipment,** where the torque provided to turn the bit is initiated at the bottom of the hole. The drill bit can be driven by a mud motor, which rotates the bit through the pressure of the drilling mud. This has obvious benefits, like not needing an additional outside power source. The drill collar is placed behind the drill bit in order to give it enough weight to be pressed against the formation while drilling. Drilling fluid is forced down the drill string and is expelled out the jets, lubricating and cooling the drill bit while at the same time carrying the rock cuttings away from the bit, exposing fresh formation to be drilled. The drilling mud performs many crucial functions and also has substantial environmental impact.

Drilling Mud

The drilling mud is essential to safe, efficient and economic oil well drilling. Drilling mud is depended upon for:

•Control formation pore pressures to assure proper well control

Minimize drilling damage to the reservoir

•Stabilize the wellbore so that the hole diameter remains equal to bit diameter, or at least minimizes hole enlargement

•Remove cuttings from under the bit while drilling

•Carry drilled cuttings to the surface while circulating

•Suspend the cuttings to prevent them falling back down the hole when pumping stops

•Release the drilled solids at the surface so that clean mud can be returned downhole

•Keep bit cool

•Provide necessary lubrication to the bit and drill string

• Allow circulation and pipe movement without causing formations to fracture

•Absorb contaminants from downhole formations and handle the difference between surface and downhole temperatures, all without causing serious degradation of mud properties.

(Drilling Tech, 146)

There are approximately six types of mud: dispersed mud, non-dispersed mud, solids free brines, oil mud and invert oil emulsion mud, air mud, and aerated and foamed mud. Dispersed mud means that the clay (cuttings from the well) is dispersed throughout the fluid. This is achieved by adding alkalis to water which increase its polarity; the more polar the water, the more reactive clays will disperse throughout the mud. Montmorillonite may be added to the mud to give it useful properties; this is commercially known as bentonite. The addition of this causes the mud to become viscous, and may help maintain hole stability. Non-dispersed muds rely on the opposite of this effect by using little water and attracting many clay particles to the same electrical charge, enabling the polymer to wrap itself around the clay cuttings, essentially dissolving the cuttings with the mud as the solvent. These are described as encapsulating polymer muds. It is now possible to tailor synthetic muds to specific drilling situations, depending on variables such as: increasing the viscosity of the fluid, increasing the gellation properties, decreasing fluid loss into the formation, and acting as a surfactant, to allow oil and water to mix together in an emulsion. Solid free brines are used when working within the reservoir to minimize damage to the formation. They can be formulated with densities of up to 1.07psi/foot. The brine is unlikely to damage the formation because it won't plug the reservoir with irremovable solids or by causing reactions with formation fluids or solids. This makes solids-free brines useful during completion or workover operations. Oil mud and oil emulsion mud, water is present less then 10% by volume; the continuous phase is the oil. These are mostly no longer used as some of them are toxic, carcinogenic, and flammable, which are undesirable for safety, environmental and health reasons. It is possible to use compressed air instead of mud, but requires specific conditions, namely a formation which can remain stable without hydrostatic mud pressure to support it and there can be no danger of a fluid influx into the well. Aerated and foamed mud is essentially drilling mud injected with air, which in turn lightens the fluid column. This mud is restricted to about 2800 feet as the pressure below these depths cannot be sustained by the mud density. Its lifting capacity is greater than that of regular drilling mud, but will not survive immersions in oil or salt water.

The basic physical properties of mud which should be monitored by the drilling crew are densities, fluid loss, and sand content. As of yet it is hard to make an estimate of how much mud will be needed in order to maintain the wells, because there is still a vary vague idea of how many wells need to be drilled. However, the mud can be reused many times and we are currently working on a way to dispose of it efficiently and safely.

Drilling process

Once an area has been picked and appropriately cleared, the well is spudded by driving a conductor pipe into the ground with a pile driver. This pipe must then be cleaned of rubble using a small drill head which breaks up the rubble and forces it to the surface. The initial size may vary, but the pilot hole may be approximately 12-1/4" in diameter; this may get bigger. Our team is currently researching how to drill to great depths using the smallest holes possible. This pilot hole will later be re-drilled with a larger bit. Slowly a drill bit of approximately 24" inches in diameter (again, we are still researching this and believe it is possible to achieve much smaller hole diameters) will be forced into the ground by the pressure of the drill collars, which weigh approximately 6,000 lbs each. Mud is pumped down the drillstring to clear the the cuttings as the bit begins to cut into the rock; it needs to be moving at an annular velocity of approximately 100 feet per minute to efficiently clean the well pipe (minimum 50 fpm). The amount of mud needed may be calculated by initially subtracting (D^2-d^2) and multiplying by 0.0408 where D equals the diameter of the hole and d equals the diameter of the drill pipe yielding the gallons per foot. Multiply this quantity by the minimum annular velocity, 50 fpm, and it yields the number of gallons of mud needed per minute. It is as yet undecided how big the hole needs to be and how many holes need to be drilled, so only rough estimates may be made. The mud may be reused.

The drainpipe, held up by the derrick or mast, lowers the bit into the ground. When enough drill collars have been applied to give the bit the weight it needs, a crossover pipe is added to the end and then the drill string is solely added to the drainpipe. During this initial phase there may be much mud loss. When the drill reaches the required depth, the cuttings are cleaned out and the the first casing is installed and cemented into the well bore. It is important to cement the pipes in formations which are strong enough to withstand the pressures of drilling. The process is again repeated until the bit reaches the desired depth. There is instrumentation for determining how much the well deviated from its path and it is still being looked into. If a directional well is being drilled, a whipstock or a jet will be used to create the deviation in the desired direction.

Jetting is when a particularly pressurized stream of mud is shot out in the direction the bit should go, essentially eroding the rock in the needed direction. However, this only works in soft formations. The whipstock is tool which is attached to the end of the drillstring and fed into the wellbore head of the drill bit. Its wide, flat edge prevents the bit from following the path it normally would have taken and instead forces the bit to deviate to the side.

Another essential part of equipment for the drilling process is the blow out preventer, which monitors the downhole pressures and uses a system of valves to close access to the hole incase a pocket of natural gas or highly pressurized fluid is hit. It is important to pick a blow out preventer which will be able to handle the pressures which may be encountered along the drilling path.

Once the hole has been drilled, perhaps with several deviated wells traveling horizontally through reservoirs, it becomes necessary to complete the well. First, tubing is run down the well so that the hydrocarbons are not flowing directly up the casing. We will used coiled tubing in the well completion, and we are looking into using it more instrumentally in drilling as well. Coiled tubing is faster and less expensive because unlike regular tubing, it can be fed into the hole faster and does not need to be connected through joints, which takes time to complete. Once each ending of the wellbore is left open or blocked off with cement. When it is left open, it is called and open-ended perforation and the pressure in the formation must be such that the oil will rise in the hole and not sink into the formation below it. Sometimes the pressure is not enough and in order to prevent the loss of hydrocarbons, the finished well will be sealed with cement. When the company is ready to start producing, it will send a few charges down the well, and detonate them, perforating the tubing and allowing the hydrocarbons to flow into the tube.

Once the drill has been perforated and starts producing, a Christmas tree is installed on top. This device allows the operator to control the amount of production or shut down the well entirely if needful, or to direct the flow of the oil once it reaches the surface. Usually, once the Christmas tree is installed the well is complete.

Enhanced Recovery

The initial drilling process will only allow as much oil out of the well as the pressure forces out. The easiest way to stimulate a flagging pressure is by means of pumps to keep the tubing pressure less than the formation pressure. However, soon this no longer becomes feasible and at this point only 5-10% of the oil may have been recovered. Therefore secondary methods have been developed to increase the oil production from reservoirs; these usually involve flooding the reservoir with water and using the water to create pressure, driving the oil before it and up the pipe. This water flooding method may increase oil production by approximately 45% of the original oil concentration. In order to make the well extract the greatest amount of oil, tertiary (enhanced recovery methods) may be used. If the viscosity of the crude oil could be reduced, it would not need high pressures to push it up the drill pipe; therefore by adding solvents or by forcing steam into the well, the now “thinned” oil will flow up the pipe. This method may remove approximately 60% of the reservoir’s initial concentration. Technology is being developed which would utilize microbial recovery systems, limiting the amount of chemicals used. The statistics and environmental impact of EOR are still being researched in-depth by Team e.

Surface Operations

Phase 1: Platform Construction

Once the desired location has been selected from the exploratory data, a drilling site must be prepared. There are many ways to do this - gravel beds, synthetic insulation, and elevated platforms. Choosing between them is the first decision for the production strategy.

Site Preparation:

All drilling operations and equipment need to occur on some surface. In many parts of the world, this would be the ground. However, the 1002 region presents a special challenge because the heat from production equipment would partially thaw the underlying permafrost, causing subsidence and ground shifted which are both highly problematic for both drilling operations and the local ecosystem. Thus there exists the need for some kind of insulation to be present between the production equipment and the permafrost layer.

In most drilling operations on the North Slope, the preferred insulation is several meters of gravel. While effective at preventing thaw, the gravel tends not to be removed from the site once production has terminated and thus permanently scars the landscape. Gravel must also be acquired from a quarry somewhere and so its use in 1002 would necessitate either large rock quarries in a sensitive habitat or rock quarries outside of ANWR and a network of roads to haul gravel in. Landscape degradation, air pollution, and noise factors all make gravel an undesirable surface insulation.

If gravel were to be used, it would be quarried outside 1002 - probably in the established rock quarries near the North Slope - and transported to the production sites in the winter via ice road. Not other transportation option is feasible due to the enormous mass of the cargo. Ice pads would be scraped off and have gravel applied in their place. Once production had ceased, the producing companies would be under federal mandate to remove the applied gravel and see to its disposal outside of ANWR. Again, all transportation would occur during the winter. The de-graveled site would then be replanted and tended to ensure complete habitat restoration. This strategy would effectively double the cost of ground insulation, making other, costlier, methods economically practical.

The obvious alternative to gravel would be to find a synthetic insulator which was considerably more effective per unit depth. Ideally the said insulator would be light enough to be brought in by air, but the quantities required by several multi-acre production sites probably limit transportation to trucks on ice roads or, should the material need to arrive in a time other than the winter, massive hovercraft. Right now, no research has been done in such a material and it's existence is merely hypothetical, but it is conjectured that such would a) come in infeasible quantities, b) be highly expensive, c) and have many other restrictions to follow (non-flammable, highly durable, environmentally sound, etc)

Another insulator option would be to use air. This would require jacking all production equipment off of the ground on steel supports so that a pocket of cool arctic air could form under the production apparatus and prevent permafrost thaw. The advantage of this option is that large quantities of insulating material do not need to be bought in, less area of tundra will be disturbed, and rehabilitation will be easier. The drawbacks of this option are the need to drill steel rods into concrete-like permafrost (presumably by melting the local permafrost enough to drive the supports in) and considerably greater construction costs. The production equipment might also be too heavy to make such elevation structurally practical. Thus the feasibility of this option depends critically on the selected drilling method.

Recent technology from Anadarko, however, suggests that it is more than possible to construct prefabricated, easy to assemble, light weight elevated drilling platforms. These have been prototyped in the North Slope and appear to be both structurally sufficient to support drilling apparatus and surface production equipment and light weight enough to be transported to a location via helicopter or roligon (trucks capable of low impact snow travel). This, then, is the recommended form of site preparation.

Impact: Pinpoint destruction of tundra at support sites, moderate to severe damage to tundra directly under platform due to platform shading. Moderate local fauna disruption during construction. The entire assembly should be relatively easy to disassemble so that no permanent structures remain once production has ended. The tundra damage should be possible to repair.

After the platform materials had been trucked/flown in to the site and assembled, a large derrick would be build to house the drilling apparatus. The current plan calls for drilling many (10-20) wells from each platform and each of these would need to be drilled separately. These wells would radiate outward from the platform to a distance of up to four miles thereby greatly reducing the number of pads necessary for through hydrocarbon extraction. Well construction would be begun and finished in the winter, reserving the summer as a relatively quite and calm time. Wells would be drilled at a rate of one per season per derrick which, with a five years to complete production capacity plan, would mean about three derricks per drilling site.

These derricks are relatively easy to assemble and disassemble and would be rebuilt at the start of each well project. Their primary task would be to secure the drilling equipment itself, but the derricks would also critically facilitate all parts of well completion: well logging, casing installation, concrete pouring, oil conduit installation, and cap-off placement.

In order to prevent well completion delays that might extend the drilling season into the summer, all of the materials needed for each seasons wells will be brought to the site as soon as the ground is roligon passable and the wildlife has diminished in numbers. The casings for future use - galvanized to prevent corrosion during storage and deployment - will be laid to reston the snow (painted white to minimize thermal absorption and wrapped in insulation should it be necessary) and hoisted up on to the platform (by a crane supported from the derrick) when the time has come for their use.

These casing segments will be secured to the well with concrete. This will of course necessitate an on-site concrete mixer which will combine water (see below) with ready-mix dry concrete (also stored with insulation in the snow).

While the drilling proceeds, the Anadarko platform will be extended to be ready for the next season's drilling. The most difficult season will be the first. Once a well is operational, there should be a reliable source of natural gas for electrical power and produced water to use for making drilling mud, concrete, etc.

Phase Two: Construction of worker habitat

The winter construction crew will be considerably larger than the summer production shift. The later will be quite small as they will have only supervision of the machinery, routine maintenance, and environmental monitoring to watch over. A dozen should be sufficient. The number specified by further research should be even better. Permanent housing (on the platform or on an adjacent one) assembled from prefabricated pieces will be constructed during the first winter. During that time, the working crews will be housed in temporary structures temped on the rising platform.

In additional to permanent shelter, the oil crews will need entertainment and fitness opportunities. Movies, books, satellite television are all possibilities for entertainment for the two week shifts and fitness equipment will be rudimentary.

Along with permanent habitat, a first construction priority is the erection of a radio tower for local communication and a satellite receiver to establish reliable communication outside of ANWR. Another very early priority will be to construct some permanent lighting to facilitate winter work. Temporary lighting will be present from the beginning. Electrical power is discussed below.

Phase Three: Assembly of Production Equipment

Once the hydrocarbon stream exists the well, it requires a lot of on site processing before it can be pressurized and fed into the pipeline.

Gathering: Oil will flow from the Christmas Trees atop each well head through a system of small pipelines on top of the platform to the processing equipment.

Oil/Gas Separation: There are three possible methods for separating natural gas out of the oil stream. The first would be to use the traditional separators (for a good description, see [K.M. Sasseen, G.V. Chilingarian, and R.Q. Robertson, "Introduction to Surface Production Equipment," Chapter 1 from G.V Chilingarian, R.Q. Robertson, and S. Kumar, "Surface Operations in Petroleum Production," Vol 1, Elsevier, Amsterdam, 1987.]) They essentially come in three configurations: horizontal, spherical, and vertical - each for successively higher oil/gas ratios. They separate the hydrocarbons by their density and they are really quite mundane - take up some space, need some electrical power, and just sit there and hum. Their major disadvantage is the amount of space they occupy. For this reason, it might be prudent to advise future planners to look into emerging membrane technology for oil/gas separation. At the moment, oil/gas separation does not appear to be a significant issue.

Oil dehydration and sand removal: most of these methods rely foremost on gravity to separate oil (lightest) from water and sand (heaviest). This process is assisted by heat (natural gas fired burners being the most practical), chemicals (to be disposed of outside of ANWR), and electricity (see below). The apparatus for this process will be, along with the oil/gas separators, housed on the Anadarko style platform.

Gas dehydration: new, compact technology currently being deployed offshore calls for vortexing natural gas at supersonic speeds to dry it from all residual water. Since the gas will be produced along with oil, it is being guessed (read: we don't know right now) that the water will be trapped under the oil and when the gas it bubbled out the water will stay behind. This process would therefore be unnecessary. But if it were it would involve the transport of one more piece of equipment and increase the electrical power and, probably, the noise pollution of the facility.

None of these should be significant compared to the existing transportation/power needs and noise outputs.

Oil storage: oil is generally stored in tanks. Of these there are two kinds: bolted steal and wielded steel. Wielded steel tanks have a much higher volume (and therefore exert more weight on the platform) and since they are fabricated in the field, do not comform to the same factory quality control standards of bolted steel tanks. Additionally, the bolted option can be easily disassembled and moved to another location or out of ANWR for disposal.

Oil under storage tends to vent a little bit of natural gas which can be recovered to a) increase productivity and b) mitigate pollution. These recovery mechanisms are fairly standard, fairly easy to transport in and install, and not yet fully researched…

Phase Four: Production

Production will begin as soon as the well is completed, the production equipment is in place, and, of course, the pipeline is connected to the drilling site to ferry hydrocarbons out of 1002. Ideally, the construction of the pipeline will be timed to coincide with the completion of the first wells at the given site so they do not have to site idle. The time for this will, ideally, be at the end of the winter when snow travel is still available and the wildlife which left has not yet returned in droves.

At this point, construction activities will cease. The construction crews will for the most part leave for summer holiday and a minimal crew will remain to keep the oil flowing smoothly. The noise of construction will abate, the all day lighting should become unnecessary, and the platform will attempt to be as inconspicuous in the local environment as possible. Routine maintenance will be carried out and this will be somewhat disruptive, but not nearly as much as full fledged construction and drilling. Or so we think.

Phase Five: Repeat Process

In the second winter, construction will begin anew as more wells are drilled (and hopefully come online). Wells producing nothing will not be completed and the derrick will attempt another hole if the seasonal timing permits. And things will be easier this time.

Because the previous season (hopefully) got some wells on line, there is also produced water coming from the wells as a byproduct. After treatment in which mainly the remaining hydrocarbons are removed (this equipment would, like everything, be situated on the platform), this water would be reinjection in to the deep rock strata (in electrically pumped reinjection wells) until a better use arose. The need to manufacture concrete and form drilling mud provides such a need and our idea is to use the produced water to this end as far as it is possible. Certainly once the wells have matured (and haveproduced much of their oil), the produced water will be coming out in sufficient volumes to satisfy the needs of drilling and well completion.

Initially and until there is enough produced water, the water necessary (we estimate it to be one hundred thousand to one million liters per well) can be gathered from nearby bodies of water (and pumped over the frozen surface in insulated temporary flexible pipelines). This will have an impact on the local water situation, but not nearly as large as the drain from building ice roads.

Electrical power at the platform will be provided by on site generators. Once wells producing some natural gas get on line, some of the gaseous product can be burned in a generator to make power. Until then, the rather perverse method of trucking or flying in liquid natural gas will have to be employed to run the generator.

Phase Six: Reconstruction

At last the day will come when there is no more oil. Depleted wells will be plugged with concrete and then filled with rock tailings left over from the drilling. The production equipment will be disassembled as much as necessary and transported away by whatever craft brought it to the side and taken to new sites or out of ANWR altogether. The habitat dwellings and finally the platform will be broken down and taken away so that no anthropogenic materials remain. As the winter ebbs away, the restoration crew gets to work.

Proposed Preliminary Transportation Strategy

Ground Vehicles

The objective when choosing vehicles is to minimize environmental impact. Thus, vehicles that exert little pressure and will not pierce the tundra were considered. Transportation vehicles will include, but will not be limited to, hovercrafts and rolligons.

Hovercraft- Hovercrafts, also called air cushioned vehicles, operate by using fans to push air under the vehicle and trapping the air with a skirt. Thus the hovercrafts lift above the ground. Ground contact is made primarily by the skirt, which can lightly scrape the surface. Most hovercrafts are amphibious—they can travel over water, land, ice, snow, and otherwise impossible to reach areas like swamps and mud pits. Because hovercrafts do not pierce the land they travel, drag is reduced and operating efficiency is greatly increased. One adverse effect of hovercrafts is noise pollution, but this can be minimized to the noise produced by a typical truck or bus.

Hoverdril Inc. hovercrafts have been previously used to build the TransAlaskan pipeline. Hoverdril claims that its hovercraft exert an average of 0.33 psi and can pass over bird eggs, tundra rodents, and animal burrows without inducing harm or injury. If the fans stop working, or if a large part of the skirt is damaged, air will slowly seep out over the course of a few minutes and the hovercraft will make a gentle landing. Hoverdril hovercrafts may be too big to transport as a single unit and can be disassembled for transport and easily reassembled. They use a 1:50 oil to gasoline ratio fuel, not diesel. Maximum payload of 160 tons; these hovercraft will be used to transport large objects that other vehicles cannot. Operating temperatures range to as low as -57°F. Most damage to the surface caused by skirt contact is made in the first five passes; after five passes no significant additional damage is produced. Noise pollution is an unavoidable bi-product of the air-propellers, but can be minimized.
-source: “Environmental Impact of the Hovercraft”, reported by Dan Turner, Technical VP, Hoverdril Inc., 2003.

Alaska Hovercraft model LACV-30 is a small light hovercraft compared to Hoverdril models. Dimensions approximately 30 ft by 40 ft by 80 ft. Maximum speed of 45 mph. Maximum payload of 30 tons. Fuel consumption at 260 gallons/hour. Endurance of up to 10 hours. These hovercraft will be used to transport smaller objects and can also be used for offshore oil exploration, search and rescue operations, personnel transport, water and fuel transport, and fire-fighting.
-source: http://www.ahv.lynden.com/ahv/lacv-30.html

Other hovercrafts may be also used for small object and personnel transport, rescue operations, and offshore exploration.

Rolligons- Rolligons are off road vehicles that operate on special huge tires designed to exert a low pressure on the surface, specifically around 3 psi. Though this is a higher pressure compared to hovercrafts, it's still a relatively low number, low enough for the U.S. Department of Energy to call it an "ultra-low impact vehicle". Rolligons have a maximum payload of 30 tons. Maximum speed around 20 mph. Rolligons can be used to transport small drill rigs and even drill platforms. Objects that are too large will be transported by hovercraft. Rolligons do not require roads, and so no roads may be necessary.
-source: www.rolligon.com

A note on fuel: diesel fuel will be undoubtedly needed for vehicle operation. There is a new ultra-low sulfer content diesel fuel that drastically reduces particle emissions. This fuel will be used for vehicle operation in ANWR.
-source: Petroleum News Alaska April 7, 2001 vol. 7 no. 14 pg 12

Air Transport

Air transport within ANWR will be by helicopter. Helicopters can land on any flat surface, including directly on the frozen tundra if need be, though a helipad off the tundra would be better. Helicopters used for transportation may not even need to land—it can lower equipment or personnel onto the surface and then leave. Maximum load: 25 tons, though this data is for military helicopters. Commercial copters have yet to be researched.
-source: http://www.defensedaily.com/progprof/army/ch47.pdf

Airplanes will not be used to travel within ANWR because they require airstrips. Given the small size of ANWR, airstrips are not necessary within ANWR and helicopters can cover the entire terrain.

Transportation to and from ANWR will also be conducted by air travel. A permanent airfield will be installed to the west of ANWR because drilling will take place in western 1002. This airfield will be made of gravel, not ice, and will include airstrip(s) and helipad(s). Arriving planes will transport both people and equipment, which will be unloaded and transported to the drill sites by helicopter, rolligons, or hovercrafts. Air travel causes extreme noise pollution and may adversely affect bird populations in ANWR, especially during warm months when birds are abundant. Due to this, air travel will be restricted during summer. All necessary equipment for the summer will be shipped in during winter and stored.

The existing gravel airfield in Kakovik may be used instead of installing a new airfield, but there are a few problems with that:
-Katovik is on Barter Island, and the fact that there is a water barrier between it and mainland Alaska complicates transportation to ANWR. Equipment will need to be transported across this water barrier either by helicopter or hovercraft to the mainland, instead of directly by rolligon as it would if there was no water barrier, and this can be a cumbersome extra step.
-Kaktovik is on to the east of ANWR and will be farther away from the proposed drill site than a western airfield. Though given the small size of ANWR this isn't that big of a deal, lengthened

travel on ground vehicles both increases the impact these vehicles make on the tundra and increase travel time, which may or may not be an inconvenience.

Roads

Given that hovercraft and rolligons may be transporting most of the equipment, access roads may not be needed at all.

If access roads within ANWR are absolutely needed, ice roads will be built. Ice roads are constructed every year for winter use and melt away with the warming of the weather. Because they melt, ice roads leave a minimal physical footprint. Environmental impacts of the ice roads mostly concern the fresh water necessary to build the road. Often the water is taken from nearby rivers and lakes, but at 1.5 million gallons per mile of ice road and lots of road necessary, this can become dangerous to marine life. It is possible to collect snow as it falls and also to melt nearby snow to form ice, but the feasibilities of these options have yet to be determined. There is also the question of is there enough water in ANWR (the place is dry) for both surface operations AND ice roads. The answer to this question may very well be "no". If so, no roads will be constructed and transportation will mainly be conducted by low impact snow traveling vehicles.

A gravel road within ANWR is extremely ill advised because gravel roads cause permanent damage. Unlike ice roads, gravel roads don't go away. They are difficult and often impossible to clean up and they leave a permanent multi-mile scar on the tundra. They will not be used within ANWR even if ice roads are not an option.

A permanent access road to facilities outside of ANWR may be needed. These facilities include pipelines, airfields, control centers, and warehouses that may need to be accessed year round. The permanent road will be constructed of gravel.

Pipelines

Two pipeline systems will be installed, one for liquid oil and one for natural gas.

The oil pipeline system will be composed of a network of pipelines between drill sites that will come together to form one pipeline and head west to connect with the TransAlaskan Pipeline. The TAPS system is currently running at only half capacity, which is about 1 million barrels a day, and will be able to accommodate another one million barrels a day. The oil pipeline will be composed of both above ground and below ground components. Where the permafrost is stable, the pipe will be buried so as to limit above ground disturbances to the environment. Where the permafrost is not stable, the pipe will be above ground, thereby reducing the risk of permafrost melting. Where the permafrost is unstable but the pipe needs to be buried anyways, a refrigeration system will be installed to prevent melting of the permafrost. All pipes will have an internal heating system to keep the oil inside liquid and mobile. For above ground pipes, a vertical loop leak containment system will replace valves. Valves actually provide more openings and therefore are more likely to leak. Vertical loops are just artificial high points in the pipeline that will contain leaks via pressure differences and cascade reactions. Below-ground pipes are more hazardous because if they leak, the oil goes directly into the soil and permafrost. This can be mitigated by installing a rigorous pipeline monitoring system to detect leaks right away and seal them off.

-source on TAPS capacity: Petroleum News Alaska April 7, 2002 vol 7 no. 14 p 13

-source on vertical loops: Pipeline and Gas Journal May 2000 vol 227 issue 5 p 28

Transportation of natural gas is a more complicated issue. Currently no natural gas pipeline exists in Alaska (though the construction of one may begin in the near future) which raises the question of where's the gas going to go once it leaves the drill sites. One possibility is to wait for the construction of a TransAlaskan Natural Gas pipeline, which is currently being debated in Congress, and then connect our gas pipeline to it. This may be the best choice because it requires the least work from us. Another option is to not wait for Congress and just build a TransAlaskan Natural Gas pipeline for ANWR drilling, but this is almost certainly not feasible. A third option is to connect the gas pipeline to an existing gas pipeline in Canada that travels down to the U.S., either the Alliance gas pipeline in British Columbia or the TransCanada pipeline in Alberta. A fourth option is to convert natural gas to liquid synthesis gas and transport the synthesis gas via TAPS. Research into this area is being conducted, but the feasibility and costs have not yet been accurately determined.

-source on synthesis gas: Gas Daily May 21, 1997 vol. 14 no. 98

Oil and Gas Journal June 23, 1997

-also visit Alliance Pipeline at www.alliance-pipeline.com

visit TransCanada at www.transcanada.com

Major geographical obstacles along the routes of pipelines, like rivers, may be bypassed by using horizontal directional drilling to install pipelines beneath. This technique was first used at the Alpine project to cross the Colville River and may be duplicated elsewhere.

-source: Pipeline and Gas Journal May, 2000 vo. 227 issue 5 p 28

Offshore pipelines will also contain both liquid oil and natural gas pipelines. Offshore pipelines are especially prone to leaks and damages. Factors include saltwater environment, seabed ice gouging, and seabed upheaval. The pipes will have to be specially designed to withstand extreme stress and bending strains. Rigorous leak detection systems will need to be installed throughout the subsea region to monitor any and all leaks. Most likely offshore pipeline transportation will be modeled off of the northstar project.

-source on Northstar: Oil and Gas Journal April 30, 2001 pg 100

This is the initial proposal from Team E.

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