US Army
Fort Richardson, Alaska

Refined Geologic Interpretations From June 2007 Drilling (AP-5245, AP-5246)

Poleline Road Disposal Area, Operable Unit B,
Fort Richardson, Alaska

March 2008

ERDC-CRREL Letter Report 08-02

US Army Corps of Engineers®
Cold Regions Research and Engineering Laboratory

Refined Geologic Interpretations From June 2007 Drilling (AP-5245, AP-5246)

Poleline Road Disposal Area, Operable Unit B,

Fort Richardson, Alaska

Sarah Kopczynski[1], Colby Snyder[3], Beth Astley[2]

U. S. Army Cold Regions Research and Engineering Laboratory (CRREL)
Engineer Research and Development Center (ERDC)
[1]Hanover, New Hampshire 03755
[2]Fort Richardson, Alaska 99505

[3]Opalia Environmental LLC, Brooklyn New York 11201

March 2008

Prepared for:

U.S. Army Garrison Alaska
Directorate of Public Works
Environmental Department
Fort Richardson AK 99505

PREFACE

This work was completed by Sarah Kopczynski, Research Physical Scientist, Terrestrial and Cryospheric Branch, CRREL, Colby Snyder, Opalia Environmental, and Beth Astley, Research Physical Scientist, Biogeochemical Sciences Branch, CRREL. For additional information about this report, please contact Beth Astley: 907-384-0513 or e-mail Beth.Astley@us.army.mil.

I. Introduction

Two new boreholes (AP-5245 and AP-5246, Fig. 1) were drilled at the Poleline Road Disposal Area (PRDA) during June 2007 to investigate subsurface geologic conditions in two regions considered data gaps. The drilling contract was funded, executed and overseen by the Alaska USACE and CH2MHill. Cold Regions Research and Engineering Laboratory (CRREL) geologists were tasked with providing onsite geological interpretation of these new boreholes.

This technical memo summarizes the geology of the deposits encountered in a language compatible with the Poleline 3D EarthVision Hydrogeological Model. Information from AP-5245 and AP-5246 provided a detailed understanding of the kame, till, basal silt, and bedrock units at PRDA that had not been available to CRREL prior to drilling. These observations enabled refinements to geologic interpretations of pre-existing boreholes at PRDA. Geological findings discussed here underpin revisions currently being made to the EarthVision model by Opalia Environmental and CRREL. A current summary of the 3-dimensional modeling will be presented in a separate memorandum.

II. PRDA Geologic Materials and Features Defined

Regional surficial and bedrock geology are well characterized in past investigations (e.g., Reger 1981; Yehle and Schmoll 1989; Winkler 1992; Kreig 1986; Hunter 2000a,b). Prior investigations of geology local to PRDA is reported in detail by Kopczynski et al. (2003) and three-dimensionally modeled by Snyder et al. (2005). The PRDA area is comprised of a heterogeneous mix of unconsolidated materials derived of glacial and glacial-fluvial processes underlain by bedrock (sandstone, siltstone, mudstone and coal). (Examples of geologic units at PRDA, Fig. 2)

Till: Heterogeneous mixture of cobble, gravel, sand, and silt in varying proportions, deposited by glacial ice; materials commonly dense with a matrix rich in fines and largely unbedded except in local areas of reworking; contains boulders (>2-m); Overall a low permeability deposit.

- **Diamicton Versus Till:** In the past, the term “diamicton” was used instead of till at PRDA. Diamicton is a general term that can be applied to any poorly sorted, low permeability deposit of unknown origin. A diamicton could be a till, or could be an equally heterogeneous landslide or outburst flood deposit. We now use the simpler, more accurate term “till” because June-2007 drilling observations confirm with certainty that these materials are indeed tills.

Kame: Heterogeneous bedded cobble, gravel, sand unit with some silt and occasional pockets of boulders, deposited directly from ice and by glacial melt water; unit includes local lenses and layers of well-sorted bedded sand from centimeters to meters thick; Overall a high permeability deposit.

"Fines": homogeneous (well sorted) deposits of clay - silt occur as isolated lenses, pods and layers throughout the study area; Deposits typically range from several centimeters to approximately 1-meter thick. Fines differ from basal silt because 1) typically occurs in shallower aquifer areas, and 2) generally contains clay. Overall low permeability deposit

Basal Silt: Silt, horizontally laminated, thin to massively bedded; typically extremely dense and compacted; deposited over bedrock by marine and/or glacial-marine waters; thicker in bedrock lows, thinner on highs; Overall a low permeability unit.

Bedrock: fine sandstone, siltstone, and mudstone, with fossils and coal seams; fine grained matrix, generally with thin bedding; known to be locally fractured with secondary calcite filling some fractures; Unknown permeability (dry in some locations, apparently water bearing in others).

Kettle (kettle hole): A kettle is a landform depression generated as blocks of buried ice abandoned by a retreating glacier and buried by sediments; hundreds or thousands of years later, ice blocks melt leaving holes in the land surface. These holes sometimes evolve to contain lakes and wetlands, such as at PRDA. Due to the irregular geometry of ice blocks, the bottom surface of these kettle holes is often equally irregular and includes multiple smaller basins.

III. Methods: Drilling and Interpretation

A. Borehole Drilling

Four boreholes were drilled. Shallow boreholes (0 to 50 feet) were drilled using an auger rig with nearly continuous sampling, though spoon recovery varied from excellent to poor. Deep boreholes (0 to 190 feet) were drilled using a modified rapid-advance air rotary drill rig. During air rotary drilling, spoon samples were collected as often as possible, however frequent cobble and boulder rich layers made it impossible to drive spoon samples for spans up to 20 feet. In these cases, interpretations are made solely from cuttings. A discussion of advantages and limitations of interpretations made from cuttings is provided below.

Auger Spoon Samples: Auger drilling spoon samples were obtained for the first 50-ft of each hole. Material recovered was typically extremely high quality, often preserving original sedimentary structures in till and kame materials. These spoon samples allowed detailed observations of sedimentary properties to be observed in these deposits. Auger drilling was abandoned at each site at 50-ft due to increased frequency of cobbles and boulders which prevented further auger drilling.

Air Rotary Spoon Samples: Air rotary drilling was conducted below 50-ft in each hole. Air rotary injects high velocity air (~70 mph) into the borehole at the formation contact. This high velocity air flow strips the smaller grains (e.g., silt and sand) from the formation and extrudes these fines into the air. This greatly alters the upper several inches of the formation at the bottom of the drill bit. Under conditions of low spoon penetration (e.g., at PRDA ~ 3-8 inches with 200 blows), spoon samples often yielded perfectly clean (silt and sand free) gravel and pebble material. We interpret these materials with great caution because it is likely that air rotary processes stripped away the fine grains.

Air Rotary Drill Cuttings: Cuttings are not ideal for interpreting subsurface geology, especially unconsolidated materials. Most air rotary cutting samples at PRDA generated 70-90% drill-ground rock flour and 30-10% interpretable rock chips. The most notable observations in cuttings were of changes of color, moisture and major grain sizes. Occasional clasts were only partially chipped by the air rotary drill thus it was possible to infer lithology and roundness of host material.

Air Rotary Moisture Observations: Rapid air rotary drilling allowed us to log down-hole changes in moisture with higher certainty than previous ‘slower’ drilling approaches. Often (though not always) during this drilling effort, the drill head moved through formations fast enough to advance past moist or small wet (perched) layers without having water from overlying wet layers infiltrate ahead of the drill head. Attentive monitoring of cuttings allowed us to visually discriminate wet from dry cuttings and provided a more robust “hydrological” understanding of down-hole conditions. However, each time drilling stops to ‘trip out’ drill rods or add casing, overlying water does drip down into the formation leading to questionable observations of insitu moisture at the upper portion of each new drill span. Moisture at 10 ft casing transitions is therefore considered suspect. However usually once the drill moved past the upper 1-2 feet of each new drill span, the cuttings returned to their original ‘dry’ or ‘moist’ conditions. While rapid air rotary drilling reduces certainty of subsurface geology, the significance of a more refined understanding of locations and thicknesses of saturated layers is especially valuable in highly heterogeneous sites like PRDA.

Distinguishing silt versus bedrock/boulders during drilling: Analysis of older borehole logs at PRDA leads CRREL to suspect that prior drilling efforts may have been unable to distinguishing fine-grained gray sandstone from basal silt. Distinguishing the two units can be complicated, especially if logging exclusively from cuttings. Based on June-2007 field observations, CRREL developed the following diagnostics to aid distinguishing bedrock from basal silt.

Drilling through silt:

- required less drill pressure than drilling through boulders and rock,
- the bit rarely ‘bounced’ when drilling through silt, and
- rock material is extremely rare; only two small (~1-cm) unbroken drop-stones found in June-07 after drilling ~30ft basal silt.

Drilling through bedrock:

- required considerably more drill bit pressure,
- often requires that the driller stop the drill, back it up and then re-advance,
- generates quarter-size chips of the lithified rock
- produced layers of coal.

Once bedrock is verified, it is possible to distinguish the sandstone from the mudstone:

- softer mudstone required half the drill bit energy to penetrate,
- harder sandstone and siltstone required twice the drill energy and bounced often.

However, the lack of any bedrock core at this site prevents any quantification of bedrock permeability.

B. Refined Interpretation of Older Logs

Older borehole logs were revised based on the more detailed understanding of subsurface conditions developed in June-2007. Most emphasis is placed on re-evaluating the geology of the AP-4300 series where original driller's field notes are available; these field notes were rich in detail and extremely helpful though in most cases original field notes no longer exist so evaluations were based on completed boring logs. The other logs evaluated were primarily those extending to bedrock. This re-evaluation was not performed on the majority of shallow wells at this site.

We emphasize here that revisions to previously logged geology are based on understanding of regional geological history, fundamental geological processes active in shaping the landscape of PRDA, and new insights gained from June-2007 drilling. These new interpretations are the best possible evaluations of geologic conditions we are able to make based on the data available to us.

IV. Results

A. Geologic Observations at New Boreholes

Borehole Geological Observations at AP-5246 (MW-1): Two boreholes were drilled at this site though only one well was installed (the "deep" monitoring well).

- **No Shallow Water**: Shallow groundwater was not encountered at this site. We did not expect shallow water because it was not present at either the upgradient AP-4344 or downgradient AP-4345.
- **Deep Groundwater**: "Deep" groundwater was encountered at 155 ft to 158 ft, underlain by about 1 foot of silt followed by about 30 feet of dry till. This saturated unit was highly productive. A monitoring well was installed with the screen positioned between 148 and 158 ft. We were surprised to discover the saturated thickness at this site is only 3-5 feet thick and is not located on top of the basal silt. This water appears to be unconfined.
- **Dry Sediments Under The Aquifer**: The till from 161 to 187 feet is believed to be unsaturated, ranging from dry to moist. When the driller pulled the casing back off the basal silt (above 188 feet) the formation did not collapse. If the formation contained water, even low flow conditions in a low permeability aquifer then the formation would have collapsed in the hole.
- **Basal Silt and Bedrock**: Basal silt (about 1-foot thick) was found to overlie coal bearing sandstone bedrock (only 1-foot of bedrock was drilled). Both units were encountered at the bottom of the allotted drilling length (190-ft) and thus it was not possible to further characterize bedrock at this site. Spoon samples from

bedrock were analyzed under a microscope and found to exhibit characteristics consistent with bedrock (Fig. 2, bedding, matrix grain cementation, insitu coal seam), thus we place high certainty in the top of bedrock designation at this site.

Depth (ft)	Geology	Color	Moisture
1 → 5	Soil and Till	Brown	Moist
5 → 17	Till	Brown	Moist
17 → 22	Gravel & Sand	Brown	Moist/Wet
22 → 63	Till with layers of rocks (cobble-boulder-gravel)	Brown Till Grey Rock	Dry / Moist
63 → 67	Gravel	Grey, Other	Dry
67 → 96	Till with layers of rocks (cobble-boulder-gravel)	Brown Till Grey Rock	Dry / Moist
96 → 108	Gravel, Cobble	Grey, Other	Dry
108 → 145	Till with layers of rocks (cobble-boulder-gravel)	Brown Till Grey Rock	Dry / Moist
145 → 155	Silty gravel (possible till?)	Brn / Grey	Dry / Moist
155 → 159	**Gravel**	**Brown**	**Wet**
159 → 161	Silt	Brown	Moist?
161 → 188	Till	Brown	Dry / Moist
188 → 189	Silt ("Basal Silt")	Grey	Dry
189 → 190	Bedrock	Grey	Dry

Borehole Geological Observations at AP-5245 (MW-2, behind the hill): Two boreholes were drilled at this location, but no monitoring wells were installed due to a lack of viable water.

- **Lack of Water**: Shallow water encountered (~8 to 25 ft); this water was affiliated with the wetland. At a deeper location, drillers tried unsuccessfully to develop a very thin water layer (seep) at 105-106 ft depth. This seep was not viable and could not be developed.
- **"Possible" Permafrost**: Drillers claim the drill stem was exceptionally cold to the touch implying, based on their experience, the metal was in contact with permafrost (~50 ft to 90 ft). No physical evidence (e.g., ice chips or frozen materials) was found in the air rotary chips. This lack of physical evidence does not negate the possibility of permafrost being present. Permafrost in the form of nickel-size frozen ice chips was observed at the bottom of AP-4344 in past drilling.
- **Verification of Low-Permeable Till**: Auger-rig till samples reveal till at this location is a silt rich matrix supported gravel-pebble-cobble and boulder material. This material is expected to have a very low permeability. Cobbles and pebbles were coated with original gray-glacial silt rind, suspended in a brown-silt matrix. Silt turns brown when exposed to oxygen rich water or moisture over hundreds to thousands of years. The observation that the inner-most silt rinds on the pebbles and cobbles suggests either a) long term paucity of water / soil moisture in this area, or b) the unit is of such low permeability that infiltration rates of water or soil moisture have historically been low.

- **Basal Silt**: Thick unit of basal silt (~30ft) found to be mantling bedrock. The basal silt was dry, ranging from fine to coarse grained gray silt, and showed subtle evidence of bedding in spoon samples. Two small unbroken subrounded striated pebbles were discovered in the upper unit of the basal silt. These pebbles are interpreted to be original drop-stones in the glacial silt; we also acknowledge the pebbles could also have been remnants of gravel lodged in the drill step from earlier drilling. Origin of the pebbles can not be confirmed; no other pebbles were identified in the basal silt. Pebbles are not found in the types of bedrock at PRDA.
- **Bedrock**: Bedrock encountered at this site is comprised of thick units of alternating 1) fine-grained hard grey sandstone with siltstone layers, and 2) fine-grained soft dark coal rich mudstone and sandstone. Drilling through the sandstone required at least twice the power that the mudstone required. The inferred contact between the basal silt and the top of the sandstone bedrock is clear in spoon samples at the contact (Fig. 2). Bedrock behind the hill is dry (at AP-5245).

Depth (ft)	Geology	Color	Moisture
0 → 8	Wetland Organics	Brown	Moist / Wet
8 → 13	Gravel, with silt & sand	Brown	Wet
13 → 95	Till with layers of rocks (cobble-boulder-gravel)	Brown Till Grey Rocks	Dry
95 → 96	Silt ("Basal Silt")	Brown	Moist
96 → 105	Silt ("Basal Silt")	Grey	Dry
105 → 106	Silt ("Basal Silt")	Brown	Moist-wet
106 → 124	Silt ("Basal Silt")	Grey	Dry
124 →128	Fine sandstone	Grey	Dry
128 → 135	Coal rich mudstone	Black	Dry
135 → 165	Fine sandstone	Grey	Dry
165 → 173	Coal rich mudstone	Red-Brown	Dry
173 → 190	Fine sandstone	Grey	Dry

B. Revision of Older Boreholes

Detailed geological logging of the two new boreholes enabled revision of several previously drilled deep boreholes at PRDA. These revisions represented our best interpretations of limited data; interpretations are based on detailed field observations (June-2007), fundamental knowledge of geological conditions and processes in the area, and conceptual site understanding gained from the 3D EarthVision model of PRDA. Notes and revisions are summarized in bullet form for simplicity.

AP-4355: basal silt and bedrock evaluated

- We find no evidence of basal silt in this well
- Well is located at base of local bedrock high, conceptually consistent with an area where basal silt is more likely not to be deposited
- Designation of bedrock 'possibly' suspect, material was not drilled deeply enough to be conclusive.

- The elevation of 'bedrock' at this location is consistent with what is expected based on trends in the EarthVision model and on regional trends, thus we suggest no changes to this designation

<u>AP-4349</u>: fines, basal silt and bedrock evaluated

- This well is located in an area of shallow bedrock, at the base of the large bedrock cored hill (moraine) just to the south. Locally, the well is situated within an area that hosts several modern kettle wetlands (Fig. 3).
- **Silt**: We evaluate a silt layer situated just on top of bedrock at the bottom of this well to determine if it might be basal silt.
- Conceptually, we expect to find silt layers in this well simply because of where it was drilled (i.e., within a cluster of several kettle-hole wetlands). Coring investigations of basal sediment sequences among 15 kettle-hole lakes and wetlands in the Anchorage and Wasilla region reveal kettles are lined by thick layers of silt (Kopczynski, 2008). The silt is likely derived from a combination of post-glacial silt and lacustrine - wetland silts. Modern extent of wetlands and kettle lakes has become smaller due to 'drying' of the climate since early post-glacial times (Riordan et al. 2006). Based on this, we expect that wells drilled near these kettles will likely encounter silts affiliated with prior larger extents of kettle wetlands and lakes.
- It is also possible that these three modern kettles were once part of one larger kettle. Bathymetry of kettles in the Anchorage-Wasilla area show that large kettle are comprised of several smaller sub-basins, likely where individual ice blocks melted out close to each other. If this is the case here, then we would expect hydrological and chemical trends of AP-4349 to be somewhat more independent from trends measured outside this area.
- The log also shows evidence of brown staining in the silty matrix of the sand/gravel unit, often associated with hydrology of organic rich waters from wetlands and lakes. Several other silt layers are encountered at shallower depths in this hole and are likely part of this original kettle complex. These silts also show distinct brown-orange mottling, which is consistent with the silt mottling observed in silt lenses at AP-5245 proximal to the local wetland at that site. Wetland waters react with iron minerals in silts causing rapid prominent oxidation leaving an orange stain, common in fine grained materials underlying wetlands.
- Based on location of this well, and general properties of the silt described in the log, we suggest this silt is associated with the local kettle wetlands, not part of the basal silt.
- Hydrological properties of both silts are expected to be the same (low permeable). However, distinguishing the two types of silts is important because the presence of this 'wetland' silt here is not evidence that the larger 'basal' silt model unit should be extrapolated to this location. If extrapolation to this location is desired, the appropriateness of such modeling should be guided by silt observations along intervening wells.
- **Bedrock**: We revisit the log to reevaluate designations of bedrock and find descriptions in the log consistent with field observations made in Jun-2007 that lead us to be confident in prior identification of bedrock at this site. The log

indicates claystone / siltstone with a notation of black suggestive of a coal seam or trace of dark claystone.

AP-4353: silt vs. bedrock evaluated

- This well is located in an area of very shallow bedrock adjacent to a large active wetland; the bottom of the well log indicates "weathered bedrock" over "bedrock"
- **Silt**: From a strictly geological perspective, we anticipate finding silt in this area because of the nearby wetland. Kettle wetlands in this region are very commonly lined with silts.
- Additionally, the shallow bedrock in this area has likely been in contact with organic (solute) rich waters from the wetland for hundreds to thousands of years. This interaction could generate a thin mantle of chemically weathered rock called saprolite. Saprolite is a clay or silt chemical-weathering product that is formed in place preserving original structure of the host bedrock. Saprolite commonly forms as an upper mantle of fine-grained sediments over bedrock as the host-rock is oxidized and hydrated causing the original bedrock minerals to be chemically altered by water, oxygen, carbon dioxide and organic acids such as tannins (commonly found in wetlands).
- Recent observations by geologists studying glacial landscapes in Sweden revealed that saprolite layers are predicatively absent in areas where glacial and glacial-fluvial erosion were most active, leaving thick undisturbed saprolite layers in zones where glacial erosion is less pervasive (Olvmo et al. 2005). The observations of Olvmo et al. (2005) are directly portable to Poleline Road and provide a process-based reason to explain why deeply-occurring fine-grained materials (e.g., saprolites, weathered bedrock, and basal silts) are missing from some deep boreholes at PRDA. This notion is further supported by the observation that the boreholes missing these deep fine-grained materials are tend to be clustered on one location, suggesting a specific erosional process (perhaps post-glacial fluvial erosion) stripped away these sediments.
- Evaluation of the log does not allow us to confidently distinguish weathered bedrock from silt at this site. For this reason, we simplify the observations to assign the upper unit to a silt. The silt may be a) a weathered bedrock (saprolite) capping deeper bedrock, b) a silty unit affiliated with the wetland, or c) possibly the 'basal silt'. We suggest the latter is not likely since basal silt is known to be largely absent in the cleared area.
- **Bedrock**: We revisit the log to reevaluate designations of bedrock and find descriptions in the log consistent with field observations made in Jun-2007 that lead us to be confident in prior identification of bedrock at this site. The log indicates claystone / siltstone with a notation of black suggestive of a coal seam or trace of dark claystone.

AP-4551: confidence of prior bedrock designation evaluated

- The deep formation is described as "grey, wet-to-dry, weathered bedrock, low plasticity fines."
- Regrettably, drillers did not drill very far into the formation to verify bedrock properties which would give us confidence that bedrock was encountered, instead

of basal silt. We evaluate descriptions on the log to try to assess confidence of bedrock at this location.

- The above-lying material was "wet" but the unit in question (bedrock?) ranges from wet to dry. It is possible that a) the bedrock(?) is water bearing, or b) the unit is actually dry, but appeared dry-to-wet due to vertical leakage by the above producing layer.
- The low plasticity soil indicates the driller had a difficult time rolling the material into a thread, so it was assumed to contain much silt (ML). The air rotary drilling system could have ground a bedrock surface generating 'rock flour' which would appear similar to ML.
- The Frost-Classification and the Maximum Size (in.) described for the bedrock unit lead to some confusion during analysis of this log.
    - Loggers assign S1 as the Frost Classification (frost susceptibility of said material). According to the Air Force TM 5-822-5 Frost Classification Table, this is a designation reserved for gravely soils (GW, GP, GW-GM, and GP-GM). The S1 designation is also assigned to the above kame unit logged as "well graded gravel with sand." Bedrock classification does not exist on this table, thus the logger had to bin the material in a comparable category. However, based on detailed field observations made in June-2007, if either basal silt or bedrock were encountered, it would have been more appropriate to assign Frost Class of F4 (all silty, clayey and fine grained materials).
    - Loggers also note that the "maximum size is 1 inch," which is inconsistent with basal silt (which only rarely contains drop-stones). Unfortunately, it is unclear to us what the logger is indicating: is the drilling actually returning 1-inch clasts or chips of rock?
- Based on available evidence, we are compelled to guess at what material was encountered at the bottom of the hole. We based our interpretation primarily on the clast size = 1 inch comment and assume that the material is not basal silt, rather it is a harder unit, either A) bedrock, or B) a very tight compact till. It would have been helpful to have photographs and/or original field notes available for analysis.

AP-4348: confidence in the bedrock and possible bedrock significance of topographic low near AP-4348

- One original motivation to drill a hole at AP-4348 was that this location was at the apex of what appeared to be a topographic depression with a series of linked (beaded) wetlands (Fig. 3). The orientation of this topographic low and the orientation of the beaded wetlands are consistent with orientation of regional fault trends and fault splays of the Border Ranges Fault Complex.
- Terrain profiles across the topographic low are generated using LIDAR digital elevation data at PRDA (Fig. 4); these profiles show that the topographic expression of the trench is more pronounced at A-A', but shallows between A-A' and B-B' approaching the PRDA cleared area.
- Though not broadly accepted as a conventional diagnostic (because this idea is new science), researchers in other parts of the world have observed that linearly

aligned wetlands in tectonically active areas are often underlain by faults or fault splays (e.g., Forsberg 2000). Active faulting impacts subsurface geological and hydrogeological conditions, apparently arguing for a hydrologic link between these wetlands and underlying tectonic fractures.

- Bedrock depth in this well is consistent with a subtle low-trend shown in the EarthVision bedrock model. We have not drilled at other locations along this bedrock low thus can not confirm that the low exists or becomes more pronounced to the northeast.
- However, based on the proxy observations from above and the subtle low suggested by AP-4348, we interpret that a local bedrock low may exist. This low may be caused by underlying tectonic features, though a fault is not verified. If a fault or fault splay does pass through this area, two potential geologic conditions may exist in the bedrock local to this fault:
  a) The bedrock along this trend has been mechanically altered by tectonic deformation over thousands/millions of years generating fault gouge. "Fault gouge" is a geologic term describing crushed and ground rock generated by friction along a fault trace as the fault moves; gouge in the fine grained sandstone, claystone and mudstone common to PRDA could be 'silt – like' and low permeability (Surma et al. 2003).
  b) The alternative is that bedrock along a fault is fractured and hydraulically conductive.
- The material above bedrock in this hole is mapped as silt, and is underlain by a thin layer material that is gravel-size. Both observations are consistent with a) fault gouge, or b) basal silt overlying mechanically weathered (fragmented) bedrock chips. We suggest the morphology of the silt unit in this area is possibly influenced by the geometry and orientation of the topographic low and thus this silt may not be connected to the other silts.

AP-4017: basal silt, kame, and bedrock evaluated

- **Kame**: The log indicates a deposit containing fine grained materials occurs just below the till. Taken in the context of the surrounding materials, we consider this zone to be most comparable with the kame unit and have reassigned it as such.
- The kame unit extends to the bottom of the borehole where bedrock is encountered.
- The very bottom of the kame, at the intersection of the bedrock, indicates a sand unit with trace clay. Clay is surprising at this depth; in most locations at PRDA we find clay at much shallower regions, most commonly in the cleared area. Overall, however, this deep sand unit is largely comprised of sand, and thus we include it as part of the kame. We do not re-assign this unit to be part of the basal silt.
- **Bedrock**: the bedrock descriptions in this log are rich with detail and are extremely intriguing. The bedrock encountered here is very much unlike bedrock encountered in bores located away from the cleared area. For example, we draw attention to the following:
  - the host rock is a blue-grey rock, considered somewhat hard
  - fractures are observed, some with visible calcite fillings

    - no water is returned from the fractured bedrock.
- This rock description is consistent with exposures common to several units: Matanuska and Chickaloon Formation (north of Border Ranges Fault) and Valdez Formation (south of Border Ranges Fault). Without visually inspecting the rock, we are unable to assign it to one of these formations. However, if we were able to assign it to one formation versus the other, we could make an argument that the Border Ranges Fault passes through this study area.

AP-4525: kame evaluated

- Kame deposits were determined to exist in two zones within the borehole log.
- Previously (in 2004) these materials were mapped as L_Fine (materials with fine grained materials present in low concentration) and DL (till considered to be more permeable, or 'leaky').

AP-4016: kame, till, bedrock evaluated

- **Kame**: Two zones previously classified as DC (competent till) were revised to be kame. In 2004, these zones were classified as competent till because of the very high cobble boulder content of the deposit. Field observations during June-2007 suggest these cobble-bolder rich zones, with sands and other trace materials, are most commonly affiliated with the kame.
    - In the upper zone, kame is also more appropriate because even though it was dry in places, grey and contained cobbles, it was largely a sand unit and had a distinct PCA odor, which means it was transmitting contaminant, thus is more "permeable" than "impermeable." The odor is noted between 25ft and 45ft, though the PID ranges from 0, 1 and 2.
- **Till**: A zone previously mapped as L_Fine (materials with fine grained materials present in low concentration) was reclassified as a till. In 2004, the original assignment of this zone to L_Fine was due to the notation of clay, which suggested the unit was clayey gravel. However, till-samples from auger drilling in June-2007 reveals tills can be extremely silt rich, sometimes silt-matrix-supported deposits that can contain stringers of very-pure very-fine grey-blue silt, easily mis-logged as clay.
- **Bedrock**: Bedrock classification at this site is intriguing. The log notes a black claystone with fossils, consistent regionally with units of the Matanuska Formation and Chickaloon Formation (north of Border Ranges Fault). Marine fossils are common to the Matanuska Formation, and terrestrial fossils are common to the Chickaloon Formation. The Chickaloon formation also hosts an abundance of coal, which is also observed in other borings at PRDA. All of these rocks are found north of Border Ranges Fault.
- **Possible Fault(?):** This discussion of rock formations is important because it provides qualitative evidence to speculate about the proximity of PRDA to the Border Ranges Fault. If Matanuska or Chickaloon Formation is confirmed at PRDA, it suggests the Border Ranges Fault crosses through the area. Our speculations are based on landfill borehole observations (located just south-southeast of PRDA) where deep bedrock bore logs may contain lithologies consistent with the McHugh Complex (Kreig Associates 1986). The McHugh

Complex occurs on the south side of the Border Ranges Fault. If the fault passes through the vicinity of PRDA, it may have implications to bedrock topographic and fault / fracture related influences over groundwater flow.

  - We stress that these observations are currently based on proxy evidence, which only allows us to speculate. We have no conclusive evidence of a fault at PRDA.

AP-4011 till, kame, silt, bedrock evaluated

- **Tills Mapped**: Two low_fine units in the log were reclassified as tills (300-275 feet) and (240-225 feet). The fine grained matrix is found to be consistent with field observations of tills in the area (e.g., June-2007) and less consistent with a silt or clay deposit with trace gravels.
- **Kame Mapped**: Kame is identified in two zones where previously the material was classified as competent till (DC) and leaky till (DL). The old zone assigned to DL (now mapped as kame) contains a low degree of fine grained sediments and is also water bearing (26 gpm). This implied permeability is more consistent with a kame deposit. The second reclassification of materials to kame (DC to kame) is again based on assigning the very large boulder rich dry materials to kames. Should silt be present, these boulder/cobble pods would be considered for classification to tills. However, this is not the case at this location.
- **Silt Mapped**: Previously (2004) a unit in the middle of the borehole was classified as leaky till (DL). This unit is primarily comprised of silt, but contains some gravel, which is why it was previously classified as DL instead of silt. We reclassify this unit to silt because: it contains substantial percentage of grey fine grained sediments, drilling through the unit was very easy, and the loggers note that (unlike the water bearing material above), water was no longer being returned while drilling through this unit. The latter observation is important. This fine grained unit appears to be perching or "suspending" a water-bearing kame unit. This silt is similar to the silt found at AP-5246 (MW-1) which is also "suspending" a water bearing kame.
- **Bedrock**: The log notes a hard black "organic" (likely coal or fossil) bedded lithology; inter-bedded among the hard black bedrock is the siltstone. This rock is similar to the softer darker mudstone with coal observed in AP-5245 (MW2).
  - Intriguingly, when the drillers tried to develop this well by injecting water, much black liquid was returned (described as looking like "crude oil"). It is possible the material was dark rock dust from drill-grinding of the black mudstone.

AP-3748: Is bedrock present at this site?

- We note for the record that we have included in our model a top or bedrock elevation located just below the bottom of the well indicated in the well log.
- This data point is not available in the published borehole log.
- However, this notation is based on conversations with Scott Kendall, who was onsite for drilling of this well, and told us that bedrock was encountered in the vicinity, but the well was installed above bedrock.

- Original drilling notes are no longer available and thus we are unable to classify this bedrock as being similar to the harder more competent fractured sometimes fossil-bearing rock of the cleared area (see AP-4017, AP-4016, AP-4011), or the more massive lighter-gray siltstone, mudstone found away from the cleared area (see AP-4300 wells; AP-5246, AP-5245).

V. Discussion and Recommendations

Several new observations were made during June-2007 drilling which provide opportunity for refinement of the conceptual geological understanding.

- **Shallow Water**: Shallow water is not encountered down-gradient to the north. This is consistent with wells drilled in the vicinity (AP-4344 and AP-4345). Excluding the wetland, no shallow water table was encountered behind the hill (AP-5246) or at depth. This continues to confirm our previous notion that the shallow water at PRDA is water perched above till and is constrained within the general vicinity of the cleared area.
- **"Deep" Aquifer Down-gradient**: Drilling at the down-gradient (north) site (AP-5246) shows a thin aquifer that appears to be perched or "suspended" by a low-permeability silt layer. This observation is surprising because the aquifer appears to only be a few feet thick. and therefore compels a re-evaluation of the down-gradient deep aquifer geometry and structure The saturated thickness at AP-5246 is 3 feet and perched (suspended) about 30 feet above the basal silt, by a nearly homogeneous (~1 ft) silt layer. To the south at up-gradient AP-4344 (contaminated) we find evidence of a similar thin silt layer; a comparable silt layer may also exist at down-gradient AP-4345. This new interpretation of the thinner perched saturated thickness of the "deep" aquifer revises our conceptual model.. Groundwater and contaminant plume mapping will help infer the exact nature of the deep aquifer(s) observed in the cleared area and further down-gradient.
- **Deep Water Behind the Hill**: Based on AP-5245, subsurface conditions behind the hill (till, basal silt and bedrock) are inferred to be dry at depth at this site, the till, the thick basal silt and bedrock are not transmitting water. This may suggest a geological boundary in this area hydrologically "impeding" westward flow of water through and under the hill.
- **Basal Silt**: In many places, a silt layer exists on top of bedrock; the silt is dry and ranges in thickness from 1-ft to 30-ft. This knowledge led to an expanded interpretation of basal silt among older well logs at PRDA. The basal silt appears to be common in bedrock lows and absent in the cleared area of PRDA where bedrock is higher. Bedrock here also appears to be a slightly different lithology.
- **Kame**: Drilling observations during June-2007 enabled identification of the wide ranges of facies associated with the kame unit at PRDA: a) slightly silty, finer grained sands and gravels, b) gravel-sand-cobble mixture with trace to no silt (most typical), and c) large beds or pods exclusively comprised of cobbles and large boulders. These observations allowed for a revision of older logs which led to a simplification of the PRDA geology. The result generated an expanded extent

of the kame unit which will prove important to inferring hydraulic flow and contaminant migration pathways.

The following suggestions are made based on the findings in this study. We recommend that,

- Shallower geological borehole logs should be revised based on these new interpretations to better map the extent and occurrence of permeable kame units and lower permeable till and silt units.

- Bedrock logs from the landfill and bedrock exposures easily accessible along Eagle River should be evaluated to determine if it is possible to correlate formations to observations at PRDA.

References Cited

Air Force. Frost Class Soil Classification from the TM 5-822-5 Air Force standards report cited in AP-4551

Forsberg B.R.; Hashimoto Y.; Rosenqvist A.; Pellon de Miranda F. 2000. Tectonic fault control of wetland distributions in the Central Amazon revealed by JERS-1 radar imagery. Quaternary International, Volume 72, Number 1, October 2000, pp. 61-66(6).

Hunter, L.E., D.E. Lawson, S.R. Bigl, Peggy B. Robinson, and J. D. Schlagel (2000a) Glacial geology and stratigraphy of Fort Richardson, Alaska: A review of available data on the hydrogeology. Hanover, ERDC/CRREL Technical Report TR-00-3

Hunter, L.E., D.E. Lawson, S.R. Bigl, B.N. Astley, C.F. Snyder, and F.E. Perron, Jr. (2000b) Geological investigations and hydrogeological model of Fort Richardson, Alaska. Hanover, ERDC/CRREL Technical Report TR-00-18

Kopczynski, S.E. 2008. New Constraints on Ice Dynamics of the Upper Cook Inlet, Alaska. Dissertation. Lehigh University, Bethlehem PA, 18015

Kopczynski, S.E., S.R. Bigl, G.S. Baker, J.V. Holmes, D.C. Finnegan, A.J. Delaney, and J.L. Andrews. (2003) Hydrogeology of the Poleline Road Disposal Area, OUB, Fort Richardson Alaska. CRREL Interim Draft Report. Prepared for U.S. Army Alaska Directorate of Public Works, Fort Richardson, Alaska

Kreig R.A. and Associates, Inc. (1986) Geotechnical Investigation, Anchorage Regional Landfill. Anchorage, AK: R.A. Kreig and Associates, Inc., 1503 West 33rd Street

Olvmo, M. Olvmo M, Lidmar-Bergstrom K, Ericson K, Bonow JM. (2005). Saprolite remnants as indicators of pre-glacial landform genesis in southeast Sweden. Geografiska annaler. Series A, Physical geography, 87A(3), 447-460.

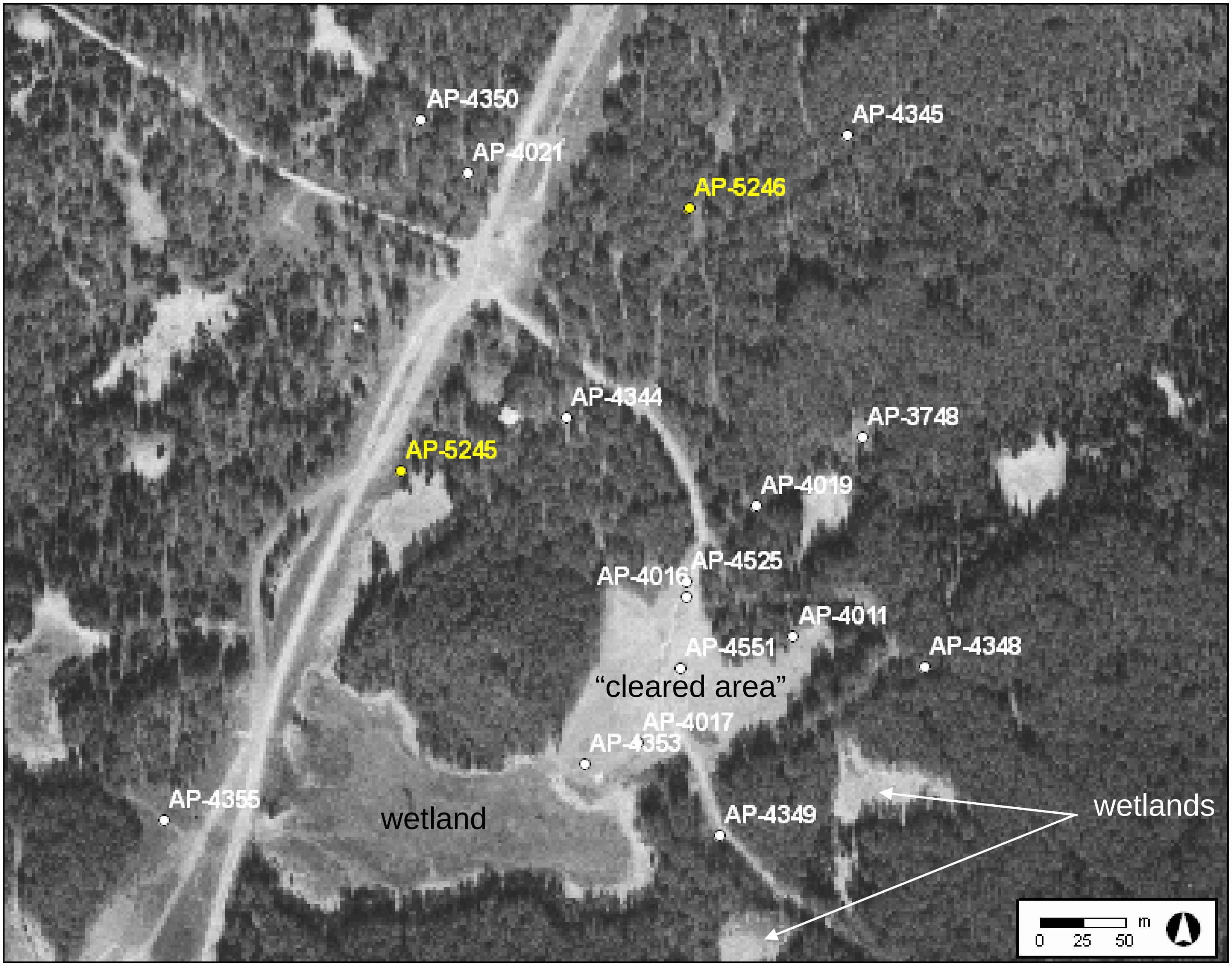
Riordan, B., D. Verbyla, and A. D. McGuire (2006), Shrinking ponds in subarctic Alaska based on 1950–2002 remotely sensed images, J. Geophys. Res., 111, G04002

Reger, R.D., 1981d, Geologic and materials maps of the Anchorage B-8 NE Quadrangle, Alaska, 2 sheets, scale 1:25,000.

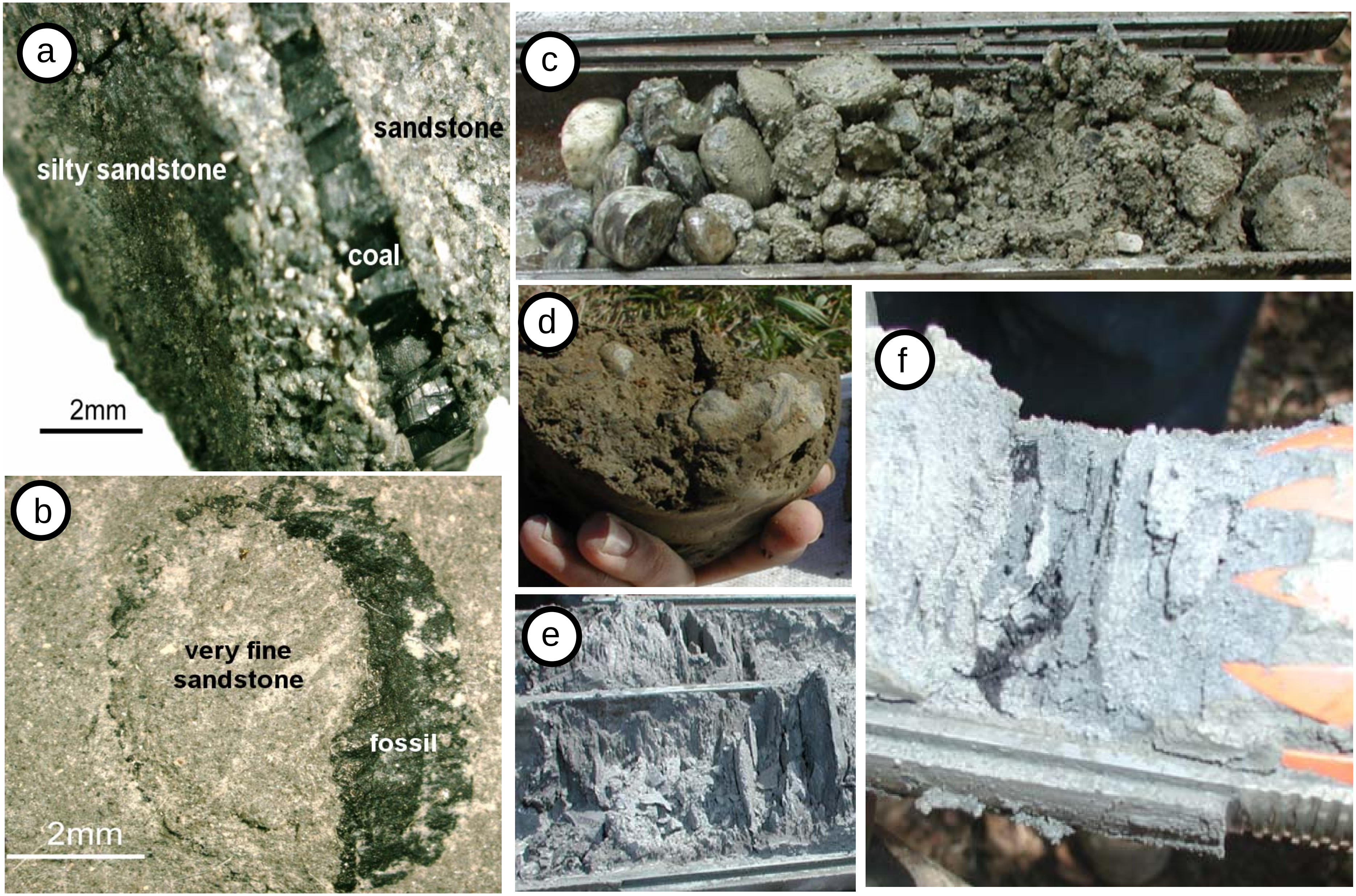
Surma, F., et al. 2003. Porosity microstructures of a sandstone affected by a normal fault. Bulletin de la Société Géologique de France. V. 174(no. 3). Pp. 295-303.

Winkler, G.R. (1992) Geologic Map and Summary Geochronology of the Anchorage 1° x 3° Quadrangle, Southern Alaska. U.S. Geological Survey Map I-2283; 1:250,000

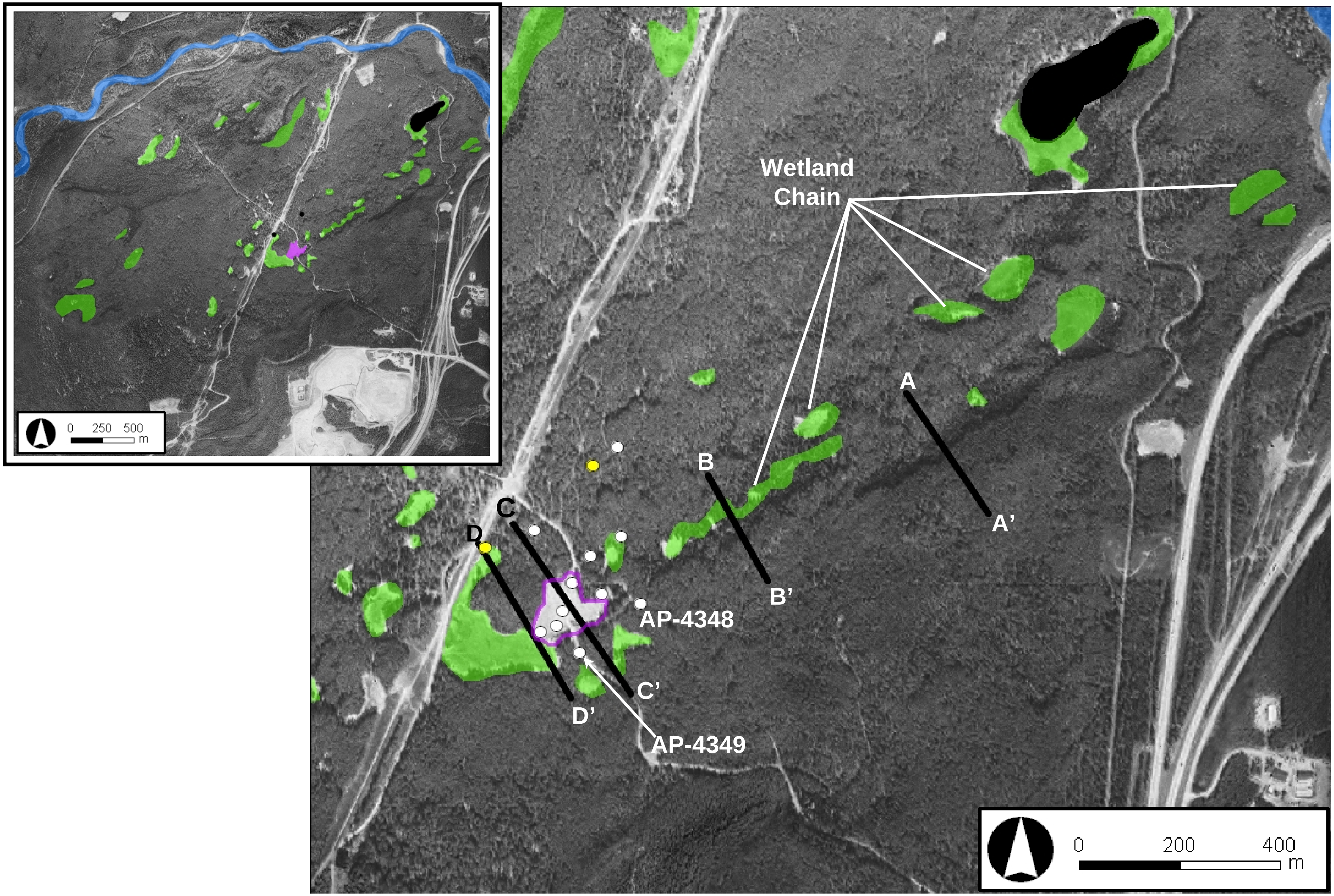
Yehle, L.A. and H.R. Schmoll (1989) Surficial geologic map of the Anchorage B-7 SW quadrangle, Alaska. Anchorage, AK: U.S. Geological Survey, Open-File Report 89-318



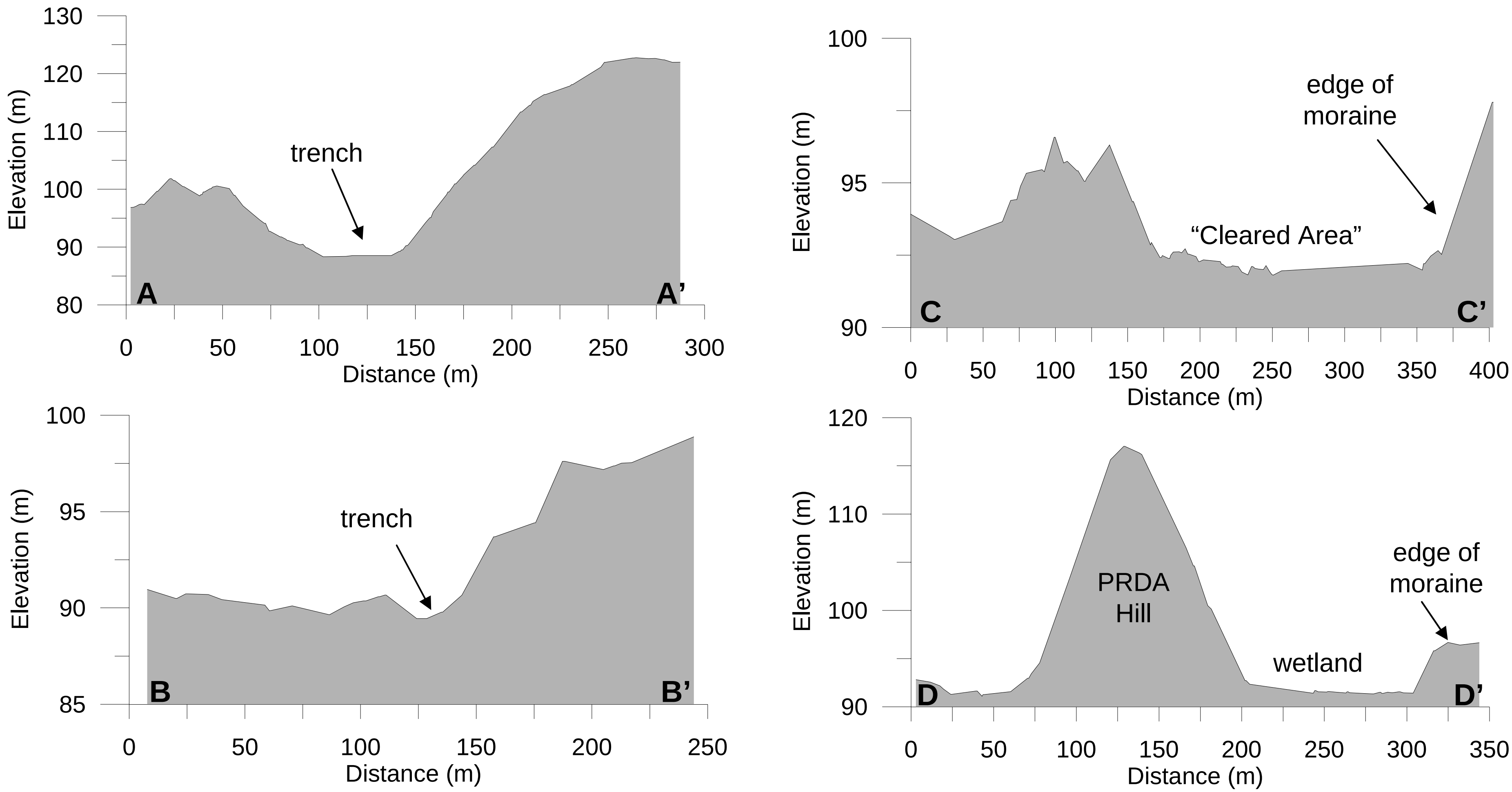
PRDA Geology Interpretations	**Figure 1. Location Map.** New borehole AP-5245 was drilled behind the hill, while AP-5246 was drilled in the down-gradient region between pre-existing bedrock bores AP-4344 and AP-4345.	CRREL Opalia ENVIRONMENTAL LLC



PRDA Geology Interpretations	**Figure 2. PRDA Geology.** Examples of geologic units at PRDA: a) bedrock with coal (microscope photo), b) sandstone with fossil (microscope photo), c) kame, d) till, e) sandstone, f) basal silt	CRREL Opalia ENVIRONMENTAL LLC



PRDA Geology Interpretations	**Figure 3. Wetlands and Trench.** Wetlands for a beaded chain trending NE-SW. The associated topographic depression is evident in the darker shadowed region. Topographic profiles A to D in Fig. 4	CRREL Opalia ENVIRONMENTAL LLC



PRDA Geology Interpretations

Figure 4. Topographic Profiles from LIDAR. Topographic expression of the trench is pronounced at A-A’, but shallows between A-A’ and B-B’ approaching the PRDA cleared area. The flat low topography of the PRDA ‘cleared area’ and wetland are contrasted against the high relief Elmendorf Moraine (C-C’) and local high relief hill at PRDA (D-D’). Both high relief features are composed largely of till, though “may” also be bedrock cored (unconfirmed).

CRREL

Opalia ENVIRONMENTAL LLC