In situ Deposited Non-Aqueous Phase (IDN Sediments: A Conceptual Model for NAPL Emplacement

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Processes of LNAPL Emplacement in Sediments

• Two general Conceptual Models describe the emplacement of petroleum hydrocarbons as LNAPL within the sediment regime
  – Advective Transport from a Land-based Source
  – In situ Deposition through the Water Column

• These two processes of emplacement produce different physical conditions

• “In situ deposition” is of particular importance due to the extent of potential impacts and history of discharges into surface water bodies
OPA Depositional Emplacement

- Release of separate phase product occurs via a discharge directly to the surface water
  - Discharges via pipes or other point source
- With agitation, LNAPL forms “beads” that accumulate solid particles
- Oil-Particulate Aggregates (OPAs) become dispersed in the water column and are deposited with other particulates
- The resulting sediment consisting of OPAs forms as a layer at the base of the water column – along the existing sediment interface
Conceptual Model for IDN Formation

- Oil + Particles = OPAs
- OPA’s $> 1.0$ (1.02) g/cc induces deposition
- OPA Deposition = \textit{In situ} Deposited NAPL Sediment (IDN)
- Oil emplacement by deposition
IDN Sediments

- IDN Sediments:
  - form discrete stratigraphic layers
  - reflect the depositional conditions
  - may cover large areas (several acres)
  - are composed of discrete beads of NAPL that are separated by solid particles – NAPL is retained within the solid matrix

- The degree of encapsulation by the solid particles affects the potential for NAPL mobility and interaction with the porewater
• IDN sediments are typically stratified, documenting depositional origin
• Laminations vary in thickness ranging from millimeters to inches
• Once deposited IDN sediments become buried
• No evidence to indicate NAPL is released, unless pore structure is disturbed
IDN Investigations

- Physical conditions of IDN sediments were investigated at two sites
- Both sites are brackish and tidally influenced
- Historical discharges of NAPL have occurred
- Sediments range in grain size from gravel to clay, but clays and silt are dominant
- Previous investigation documented presence of NAPL through various screening technologies
Methods and Approach

• Multiple cores collected at both sites by vibracore
• Initial core extruded and characterized: visual observations, texture, PID, UV light, sheen tests
• Selected sediment intervals from co-located cores were forwarded intact for chemical and physical testing
• Testing included:
  – Particle size
  – Porosity
  – Bulk Density
  – Fluid Saturation
  – Hydraulic Conductivity
  – Fraction organic content
  – Centrifuge Analyses
  – X-ray tomography
TPH Impacts

• TPH analyses at both sites documented mid-range $C_{12}$-$C_{28}$ hydrocarbons
• TPH concentrations in the sediments typically ranged from 30,000 to 115,000 mg/kg
• No observed free flowing oil from sediments
• UV and sheen tests did indicate the presence of separate phase

Site 1 Sediment

Site 2 Sediment
Particle Size

- Grain size analyses documented that fine silt and clay were the dominant particle size for the majority of the IDN sediment strata.
- Over 50% of the particles were less than 0.02 mm in size.
- Finer particle sizes enhance the capability of an OPA to become fully encapsulated, since more particles are required to adhere to the oil bead to produce deposition.
IDN Pore Structure

- Site 1 dominated by smectite clays
- Site 2 composed primarily of chlorite and illite clays
- Pore structure also varied between sites based on SEM micrographs
  - Site 1 dominated by laminated structure
  - Site 2 pore structure was more open, with more visible pore openings
IDN Physical Measurements

IDN Sediments are typically characterized by:

- High Porosity
  - 50-80 % porosity

- Low Bulk Density
  - <1.0 mg/cm³

- Low Hydraulic Conductivity
  - < 10⁻⁵ cm/sec
• NAPL saturation values range from 1 to 28 % by vol.
• Majority of LNAPL saturations are below 10 % by volume
• Higher saturations correspond to larger grain size
Fluid Mobility

- Fluid mobility was evaluated via centrifuge technology

- Applied standard upland approaches
  - NAPL Mobility
    - x1000G
  - Capillary pressure curve analysis
- Water is readily displaced under 1000G of induced pressure
- Centrifuge studies indicate NAPL is not readily mobile
- NAPL is retained within pore network
Centrifuge studies document NAPL, if evacuated, is a secondary fluid.
NAPL released only after 20 to 30 % of water saturation is evacuated.
Centrifuge results demonstrate NAPL is present in smaller pores.
Capillary Pressure Curve: Effluent Composition

- LNAPL distribution retained in smaller sediment pores
- Even in sandy sediments, LNAPL is not released until 20% of water is expelled from pores
- Results indicate LNAPL, when encapsulated, is immobile under natural conditions
Summary: *In Situ* Deposition

- Two primary LNAPL emplacement processes in sediments
  - Groundwater Transport
  - *In Situ* Deposition from OPAs

- *In situ* deposition produces petroleum hydrocarbon as LNAPL entrained and encapsulated within the sediment matrix: IDN Sediments
Summary: IDN Sediments

- IDN sediments cover large areas
- IDN sediments and are derived from long-term historic discharges and contain large volumes of NAPL
- NAPL is encapsulated as a result of the OPA formation process
- OPA structure is retained upon deposition
- Encapsulation mitigates NAPL mobility and NAPL – pore water interactions
- Research is on-going to measure the encapsulation process and the effects of the process on the environment
- Additional field investigations needed to further characterize IDN sedimentary environments
