FLUIDS FOR TRENCHLESS TECHNOLOGY
- Rheology and Microstructure -

by
Marika Santagata, David Geier, Wendell Solomon

Funded by the National Science Foundation (NSF)

PURDUE GEOTECHNICAL SOCIETY WORKSHOP

May 7, 2007

OUTLINE

- **INTRODUCTION**
  - TRENCHLESS TECHNOLOGIES
  - FLUIDS FOR TT
  - NEED/OPPORTUNITIES FOR RESEARCH
- **OVERVIEW OF EXPERIMENTAL PROGRAM**
- **RESULTS**
- **FINAL REMARKS AND OPPORTUNITIES FOR FUTURE WORK**

INTRODUCTION

- TRENCHLESS TECHNOLOGIES

  large family of methods utilized for installing and rehabilitating underground utility systems with minimal surface disruption and destruction resulting from excavation *(Trenchless technology center)*

e.g. HORIZONTAL DIRECTIONAL DRILLING
MICROTUNNELING
PIPEJACKING

- Critical role in building the infrastructure for energy delivery

Example: NATURAL GAS *(AGA)*

- supplies nearly 23 percent of all of the energy used in the United States;
- is delivered to customers through a 2.2-million mile underground pipeline system

- Broader relevance of TT in "Energy" context
  - Energy efficient installation
  - Energy efficient delivery and transport

- Broad applications of TT

  - the total length of underground utilities (water, sewer, gas, petroleum, electrical, telecom) in the US is in excess of 20 million miles (NTSB)
  - for water and sewer alone the US deferred maintenance costs > 100 Billion$ each/ yr (EPA, WIN)
  - Funding gap in excess of 23billlion$/year (WIN)

➡ **Value of techniques that can extend the reach of the construction and rehabilitation dollar.**

Potential of trenchless technologies to enhance the efficiency of utility construction and upgrade.

▪ FLUIDS FOR TRENCHLESS TECHNOLOGIES

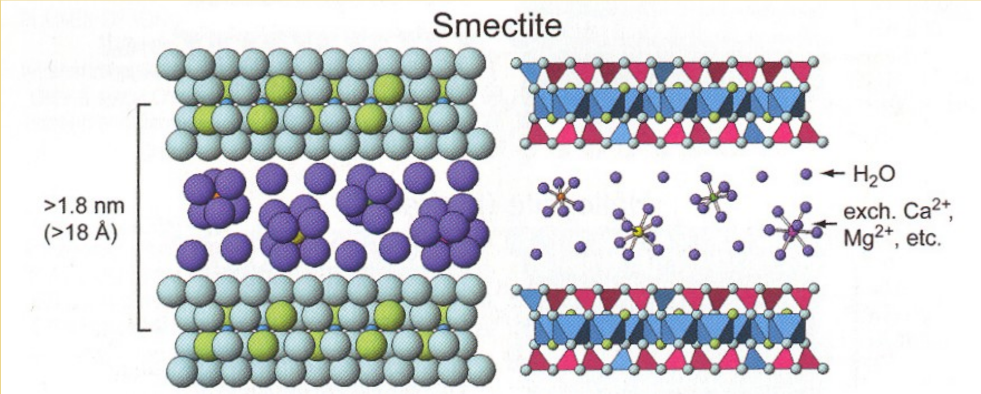
Fulfill four critical functions

- LUBRICATION
- CAKE FORMATION AND FILTRATION CONTROL
- SPOIL/CUTTING TRANSPORT
- SOIL CONDITIONING

- All directly tied to economics and effectiveness of methods.
- Characteristics required can often be in conflict.
- Performance of a fluid in each function is inherently linked.
- Soil conditions and equipment limitations pose additional constraints.
- Additional challenge: variable nature of the formations and/or changes in environmental conditions.

▪ Materials

- Large variety of fluids
- Bentonite based products most common



Schulze 2002

- Bentonite alone or treated with:

  - polymeric additives (polyacrylamides [PAs], partially hydrolyzed celluloses [PHPAs], carboxymethyl celluloses [CMCs], and polyanionic celluloses [PACs])

  - waxes;

  - polymeric and glass microbeads;

  - surfactants.

▪ OPPORTUNITIES/NEED FOR RESEARCH

- Critical role of drilling fluids widely recognized
- Extensive evidence of the technical and financial impact of the use of slurries and the selection of the appropriate material(s). *(e.g. Pellet and Kastner 2002)*

HOWEVER

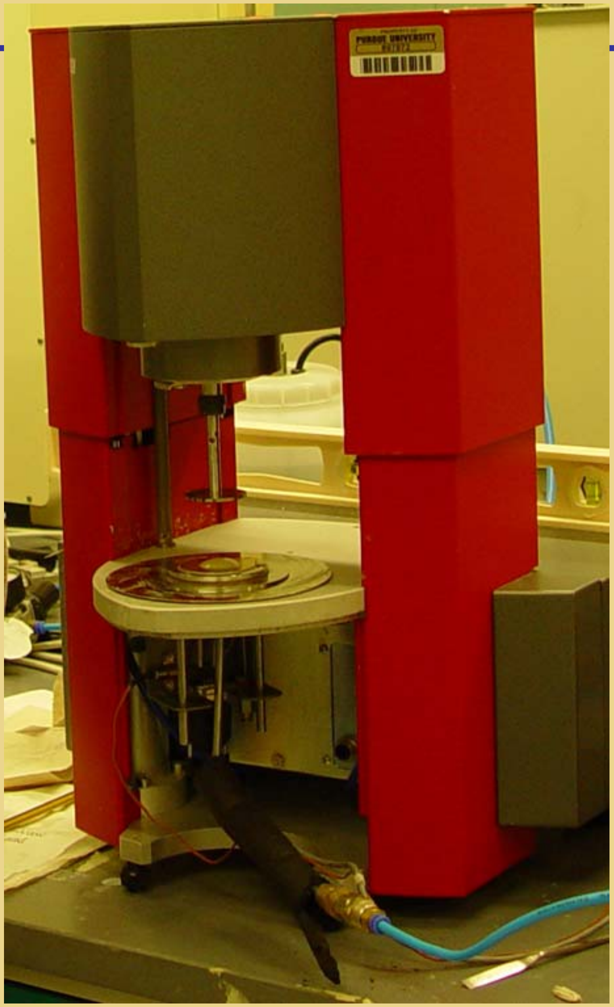
- use largely based on the experience of suppliers and contractors
- poor documentation on the fluids used in case histories
- lack of fundamental understanding of mechanical behavior and particle interactions in fluids
- performance not linked to fundamental behavior

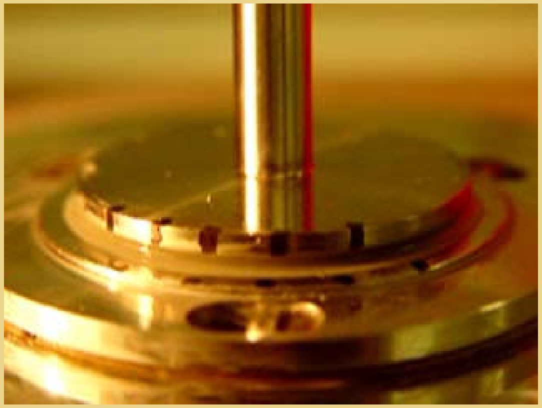
OVERVIEW OF EXPERIMENTAL PROGRAM

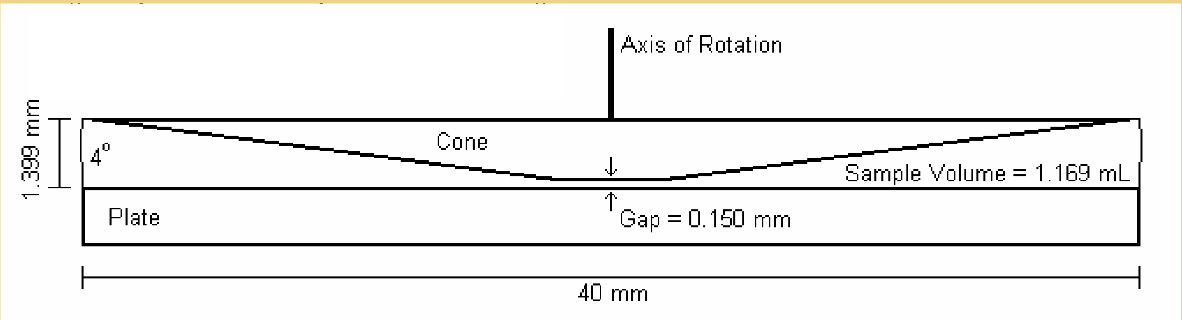
- RESEARCH OBJECTIVES
  - Apply advanced rheometrical techniques to the study of bentonite based dispersions
  - Gain insight into fundamental aspects of behavior
  - Probe microstructure

- MATERIALS
  - three different bentonite based commercial products
    - pure bentonite
    - bentonite + sodium poli-acrylate (QG)
    - bentonite + polyanionic cellulose (BG)
  - alone and in combination with select polymeric products
    - PHPA
    - PAC
    - Xanthan
  - clay concentrations from <1% to 13%

- EQUIPMENT
  - Rheologica Viscotech
  - Stress controlled (range =0.06-2984 Pa)
  - Test types possible:
    - Flow behavior
    - Oscillatory
    - Creep and recovery







RESULTS

- RHEOLOGY OF MONTMORILLONITE DISPERSIONS
- LINKING RHEOLOGY TO MICROSTRUCTURE
- MICROSTRUCTURE OF MONTMORILLONITE GELS

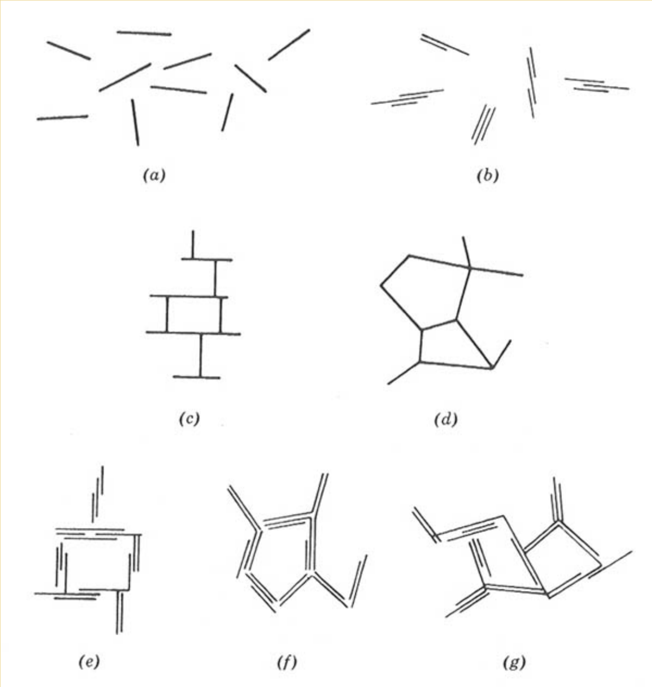
RHEOLOGY OF MONTMORILLONITE DISPERSIONS

- Newtonian only at very low concentrations (<1-2%) with viscosity linked to volumetric solid fraction

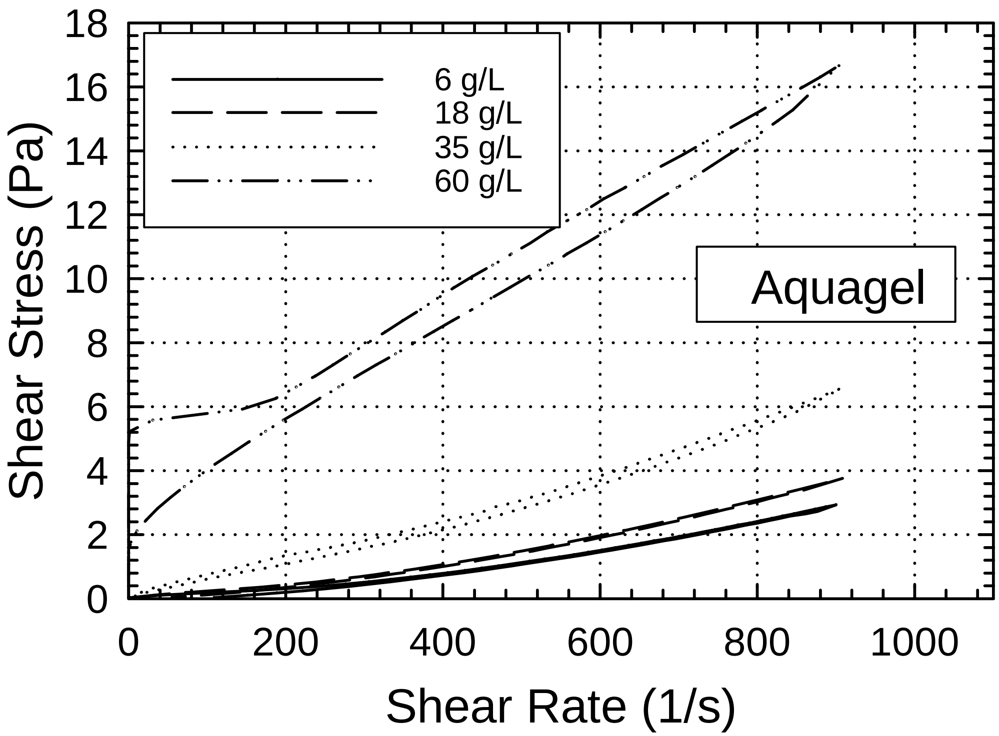
  (note increase in effective volume fraction with hydration)
- At higher concentrations increased interactions between particles
- Development of double layer

  → interparticle forces acting

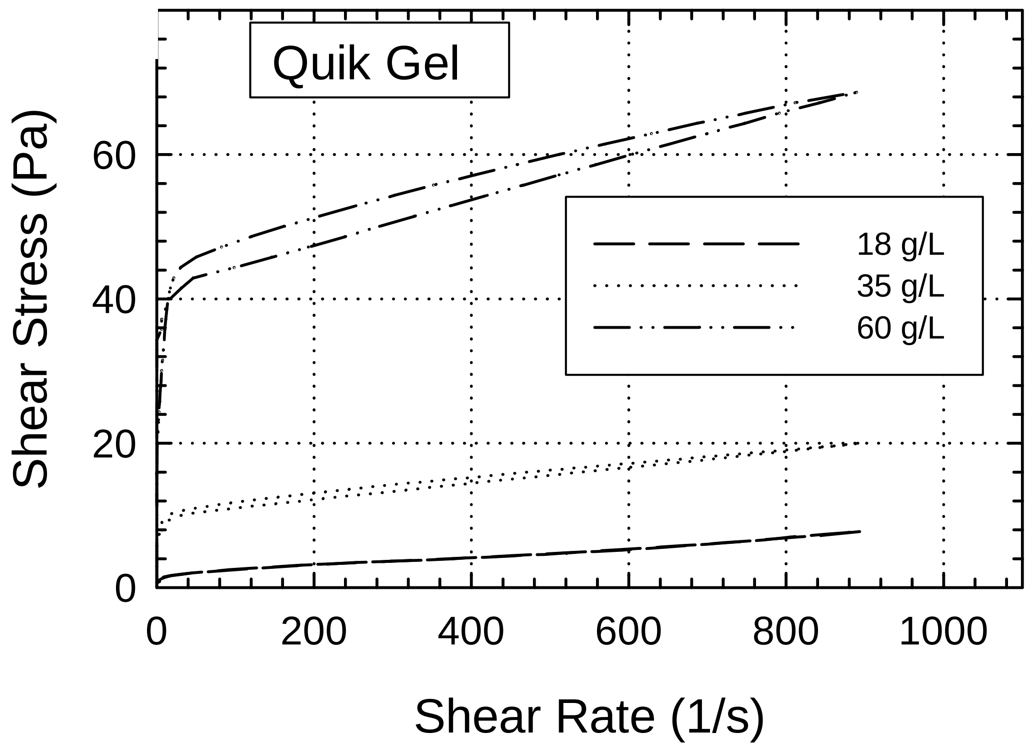
  → mode of particle association



(Van Olphen, 1977)



Aquagel
6 g/L
18 g/L
35 g/L
60 g/L
Shear Stress (Pa)
Shear Rate (1/s)
0
2
4
6
8
10
12
14
16
18
0
200
400
600
800
1000

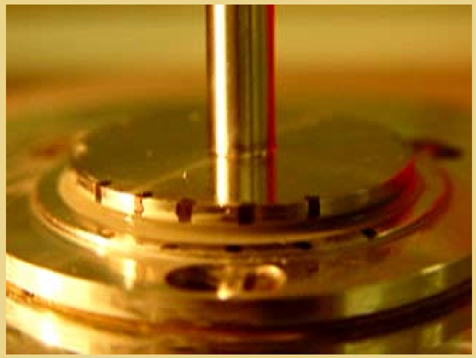


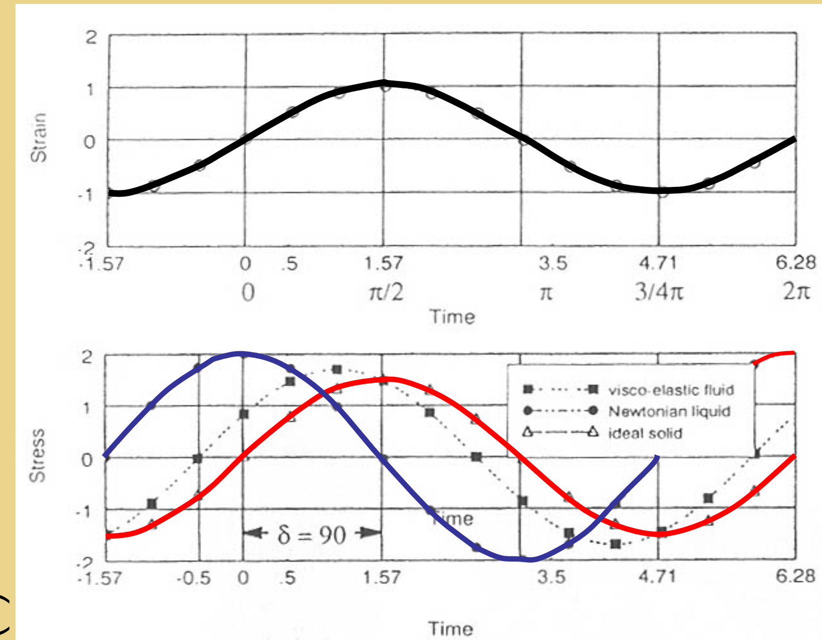
Quik Gel
18 g/L
35 g/L
60 g/L
Shear Stress (Pa)
Shear Rate (1/s)
0
20
40
60
0
200
400
600
800
1000

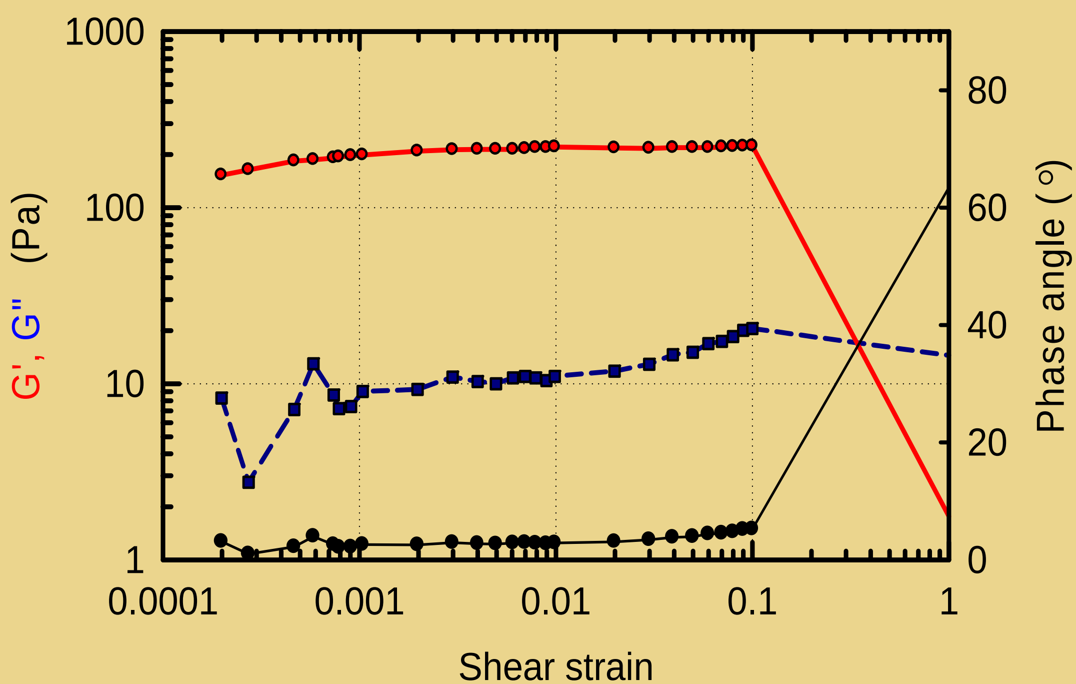
BEYOND VISCOSITY MEASUREMENTS
IS IT A SOLID OR A LIQUID?

DYNAMIC TESTS

- *STRAIN SWEEP*
  f=1 Hz







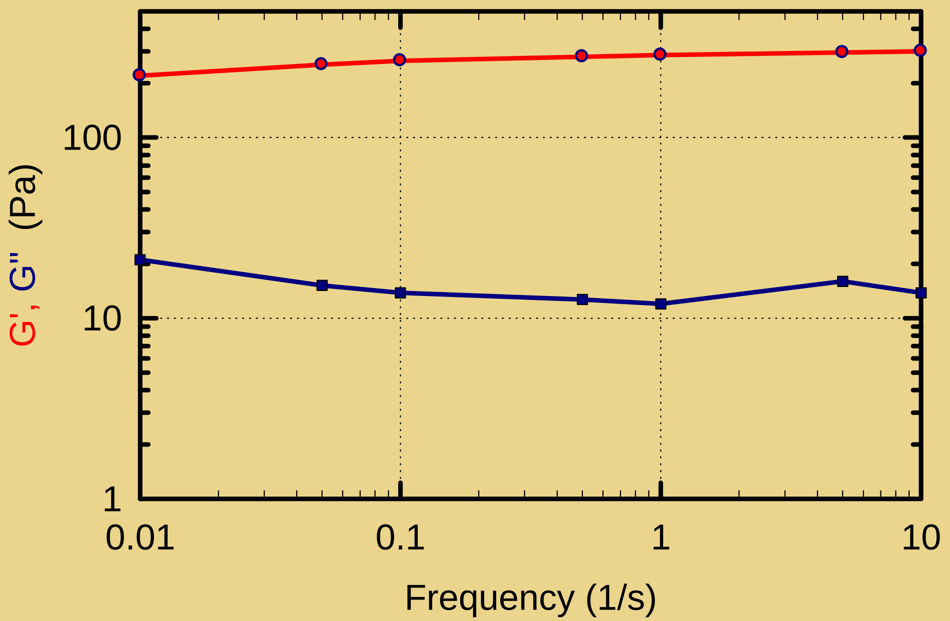
G* = Complex Modulus

G' = Storage or elastic modulus

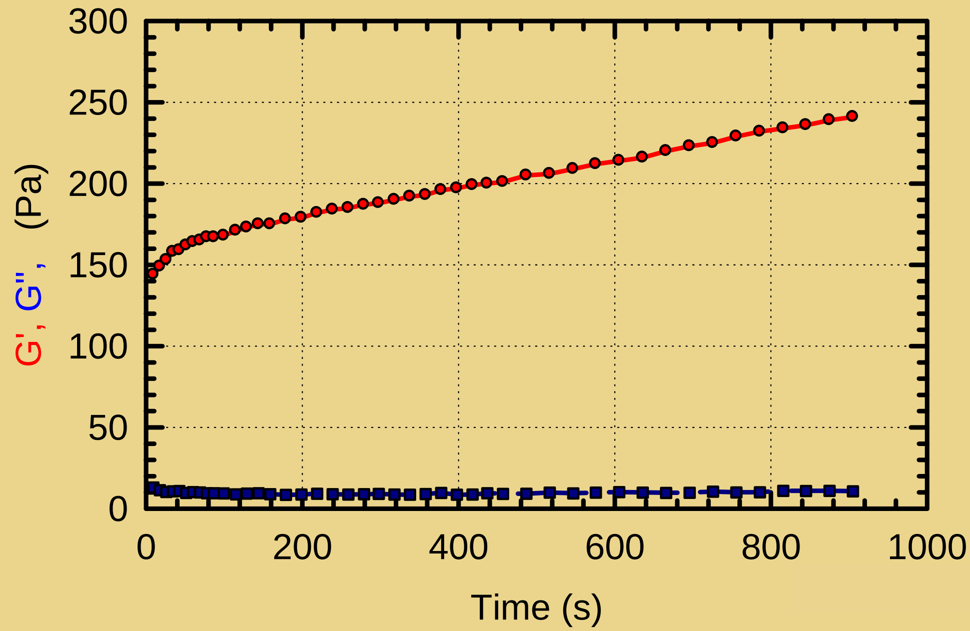
G" = Loss or viscous modulus

δ varies between 0° (elastic) and 90° (viscous)

- FREQUENCY SWEEP
  γ=0.01



- Can monitor rebuilding of thixotropic structures
  → OSCILLATIONS IN TIME

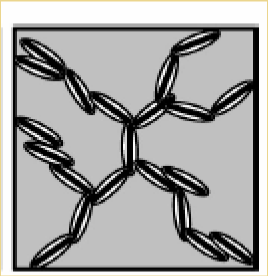


LINKING RHEOLOGY TO MICROSTRUCTURE: NOT ALL GELS ARE CREATED EQUAL

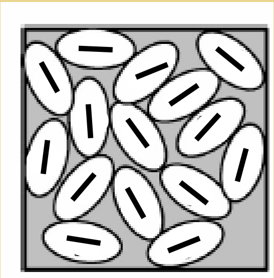
- visco-elastic behavior is associated with the formation of a gel

"single particle association that fills an entire space"

(van Olphen 1977)



ATTRACTIVE GEL

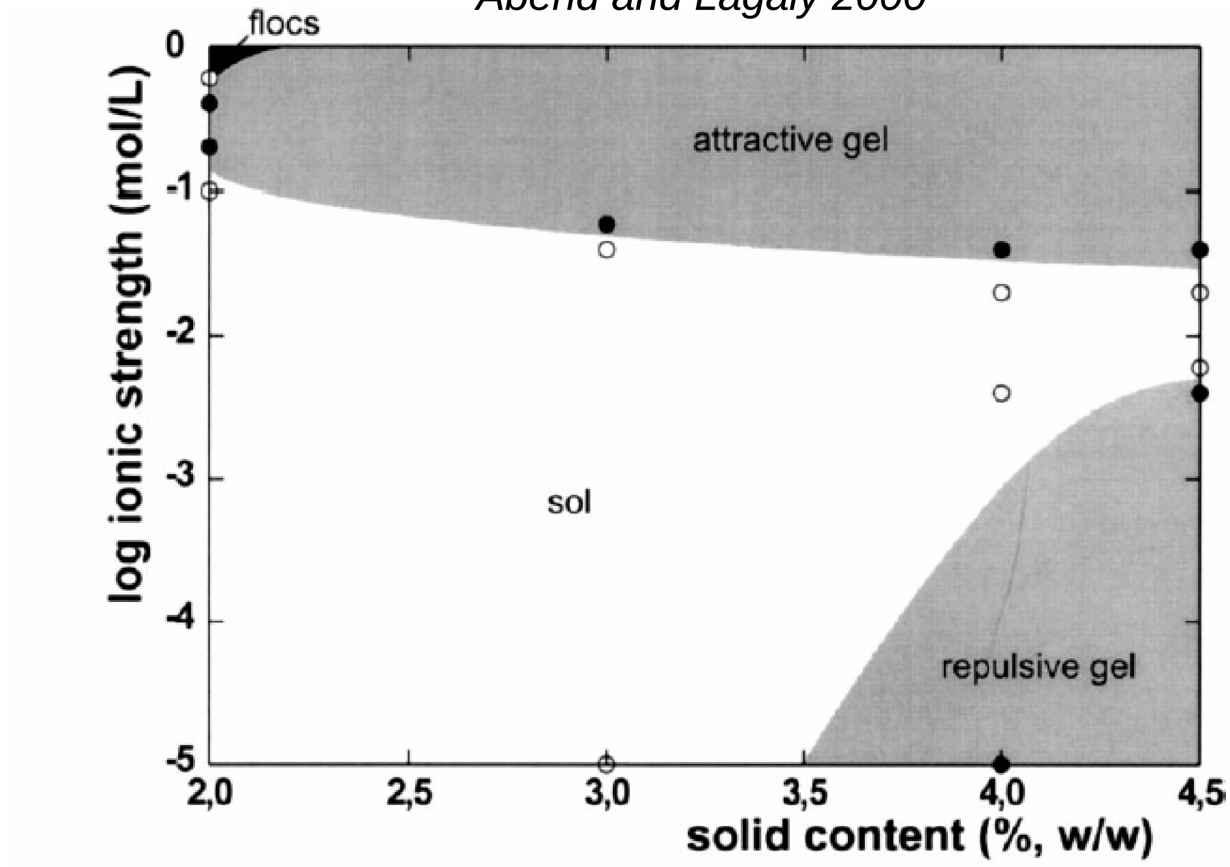


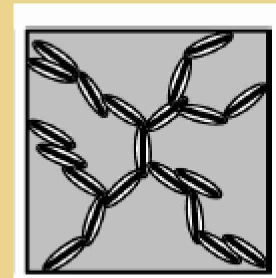
REPULSIVE GEL (GLASS)

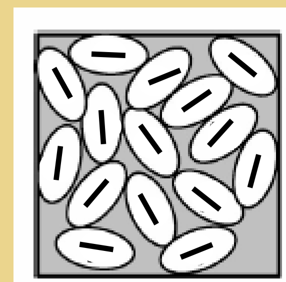
(adapted from Tanaka et al. 2004)

SOL-GEL DIAGRAM FOR A WYOMING BENTONITE

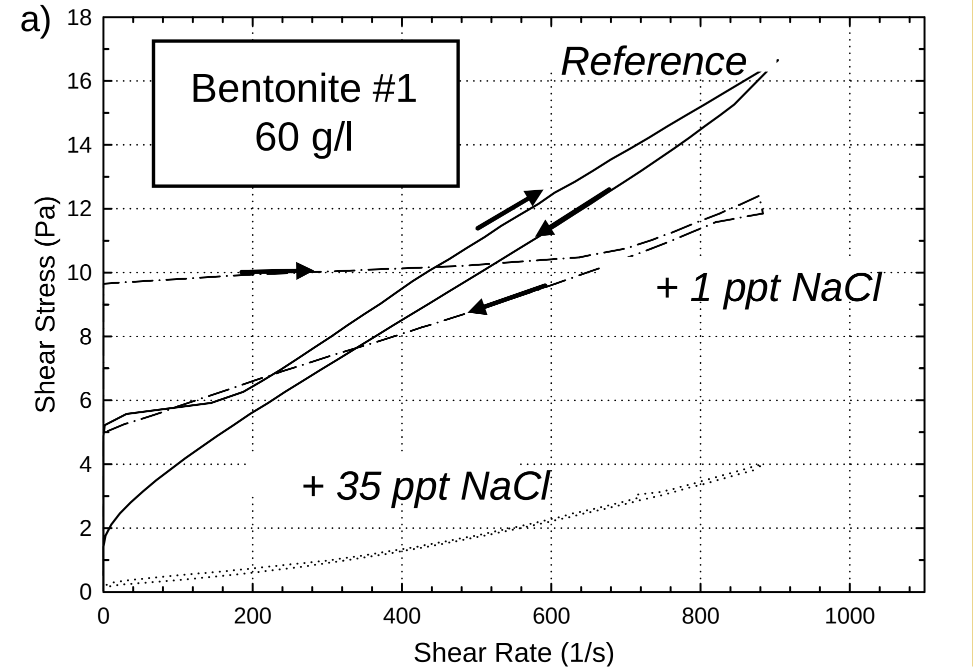
Abend and Lagaly 2000

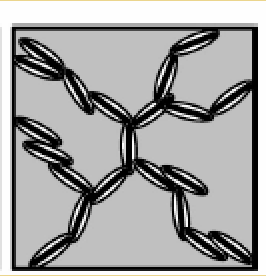


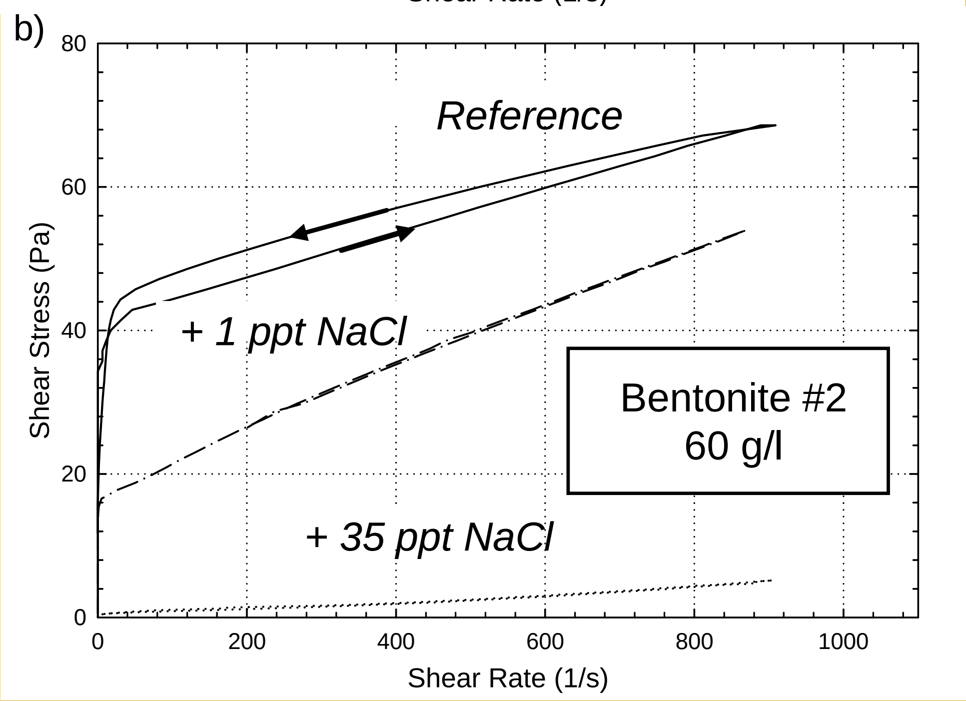


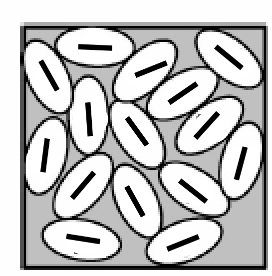


- Marked dependence of microstruture and rheology on concentration, particle size, cations, pH, additives


a)
Bentonite #1
60 g/l
Reference
+ 1 ppt NaCl
+ 35 ppt NaCl
Shear Stress (Pa)
Shear Rate (1/s)
0
2
4
6
8
10
12
14
16
18
0
200
400
600
800
1000




b)
Bentonite #2
60 g/l
Reference
+ 1 ppt NaCl
+ 35 ppt NaCl
Shear Stress (Pa)
Shear Rate (1/s)
0
20
40
60
80
0
200
400
600
800
1000



MICROSTRUCTURE OF MONTMORILLONITE GELS: "ORDER IN MUD"

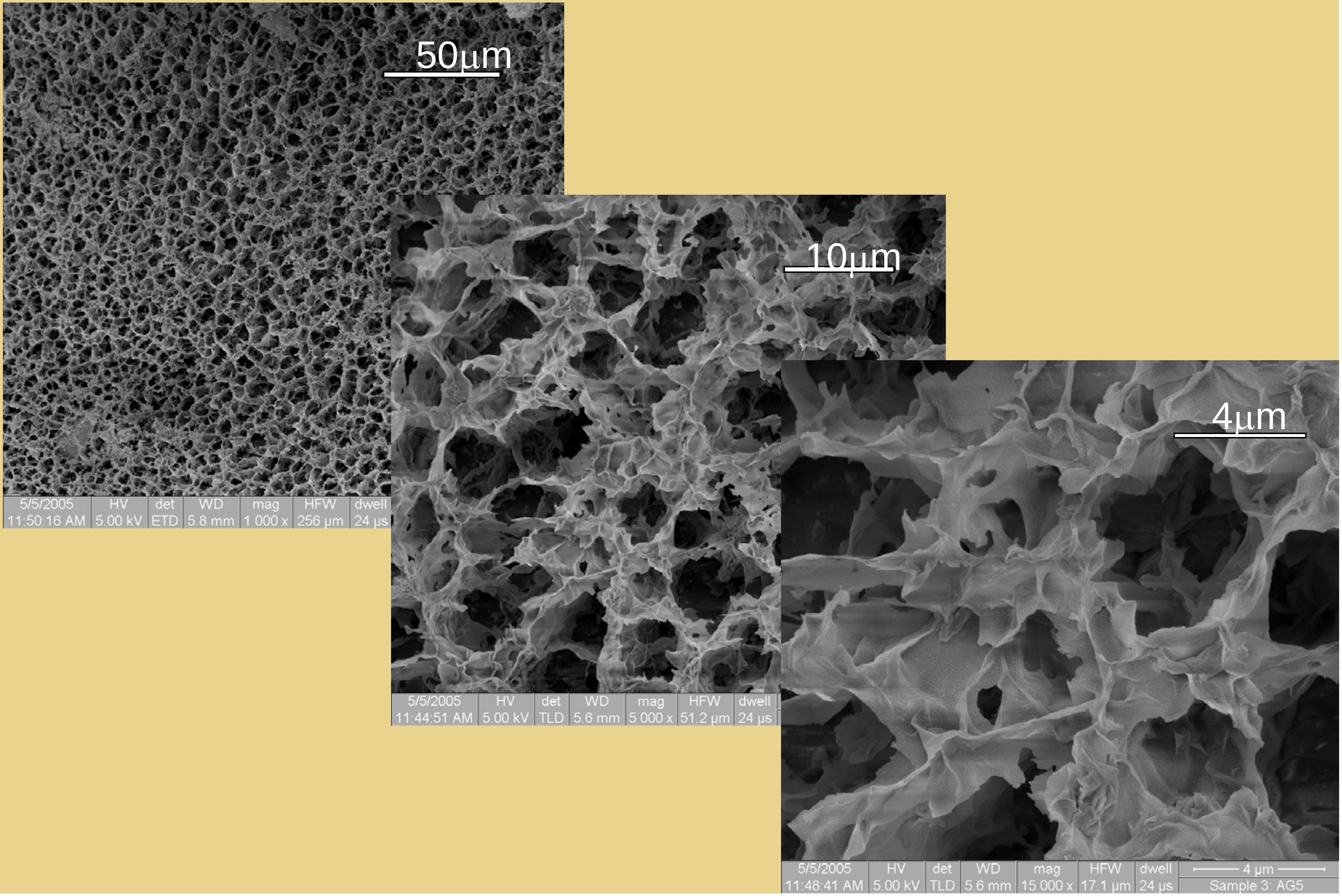
- CRYO-SEM WORK

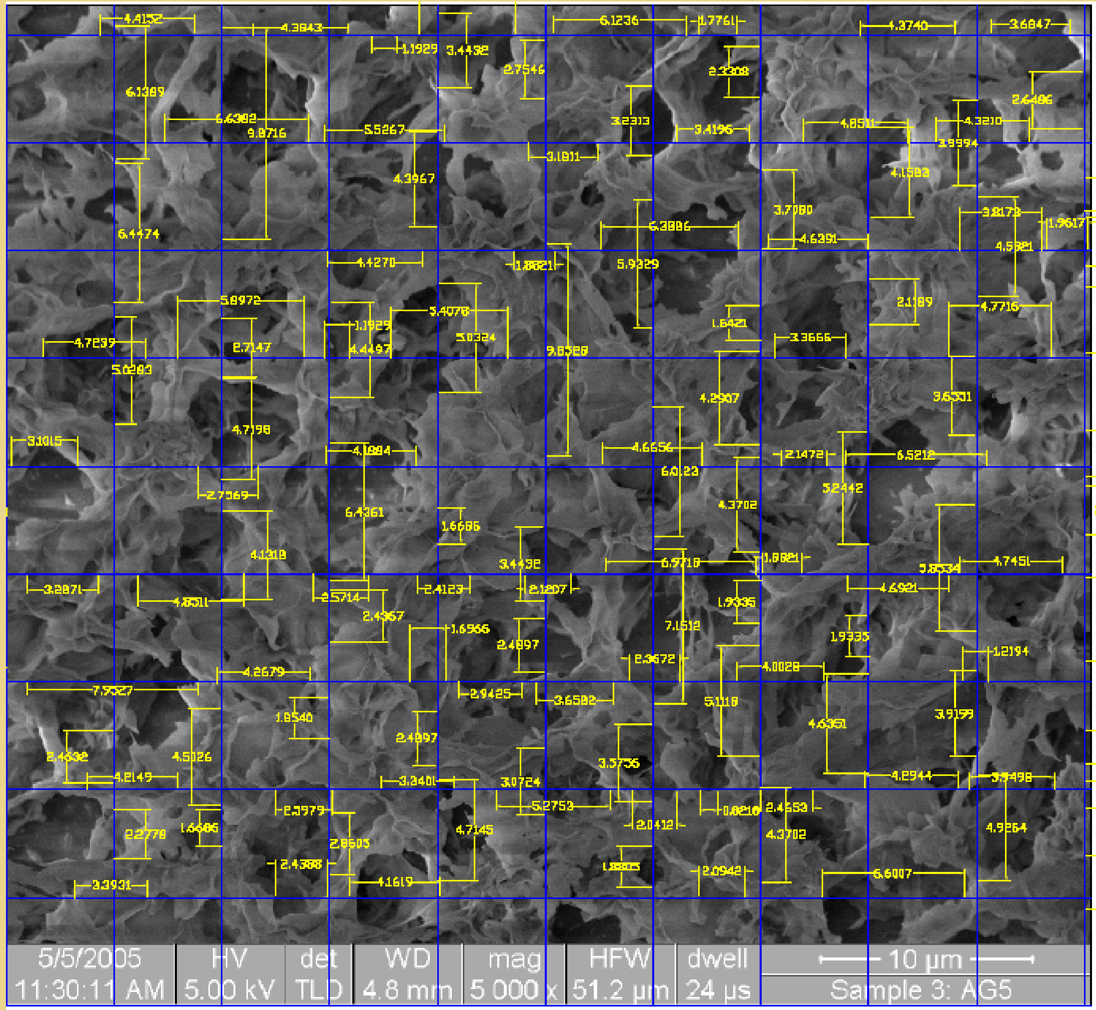
- Images obtained using the FEI NOVA nanoSEM

- Procedure:
  - Samples flash frozen by plunging into N_2 slush;
  - cooled in a pre-chamber to -160°C;
  - fractured with a cooled scalpel to produce a free-break surface;
  - sublimated at -85°C for 15 min;
  - sputter coated with Pt;
  - transferred to the microscope cryostage, and imaged at -130°C.

- "Wet" microstructure preserved

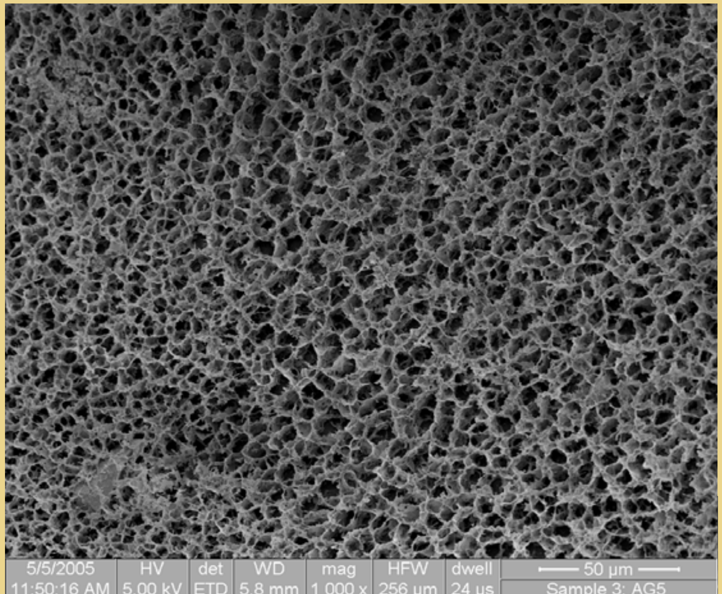
- “ORDER IN MUD”

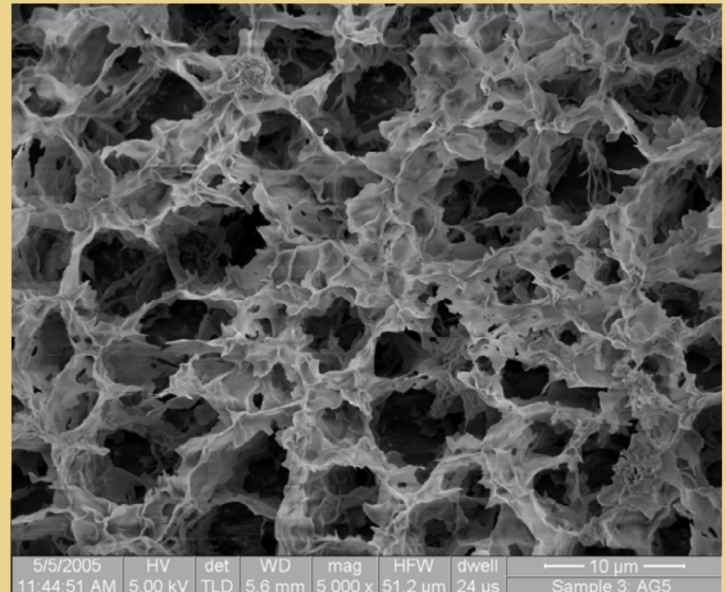

50µm
5/5/2005 11:50:16 AM | HV 5.00 kV | det ETD | WD 5.8 mm | mag 1 000 x | HFW 256 µm | dwell 24 µs
10µm
5/5/2005 11:44:51 AM | HV 5.00 kV | det TLD | WD 5.6 mm | mag 5 000 x | HFW 51.2 µm | dwell 24 µs
4µm
5/5/2005 11:48:41 AM | HV 5.00 kV | det TLD | WD 5.6 mm | mag 15 000 x | HFW 17.1 µm | dwell 24 µs
4 µm
Sample 3: AG5


5/5/2005
11:30:11 AM
HV
5.00 kV
det
TLD
WD
4.8 mm
mag
5 000 x
HFW
51.2 µm
dwell
24 µs
10 µm
Sample 3: AG5

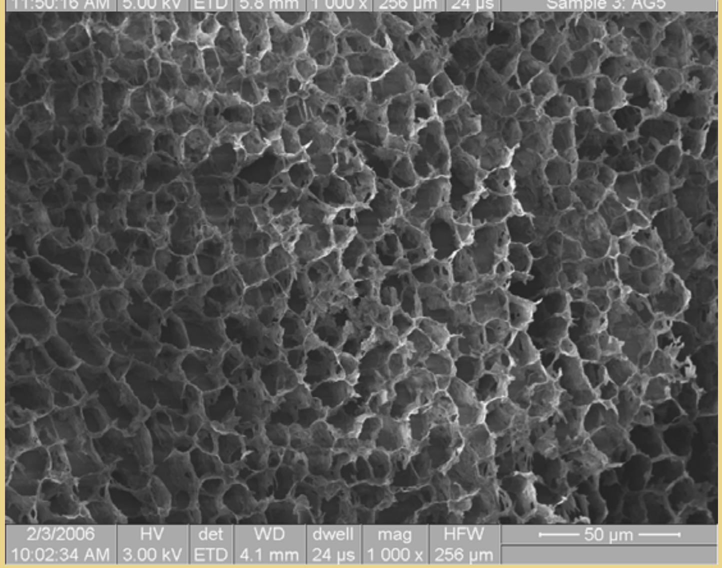
▪ EFFECT OF CLAY CONCENTRATION

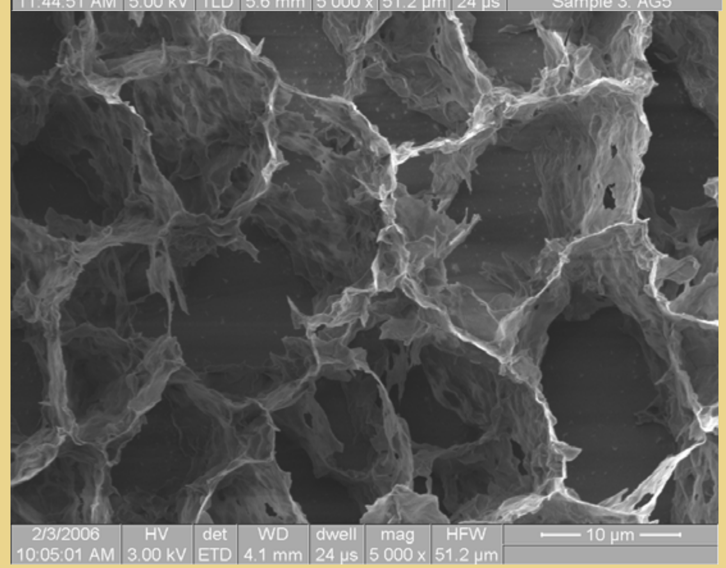
110 g/l



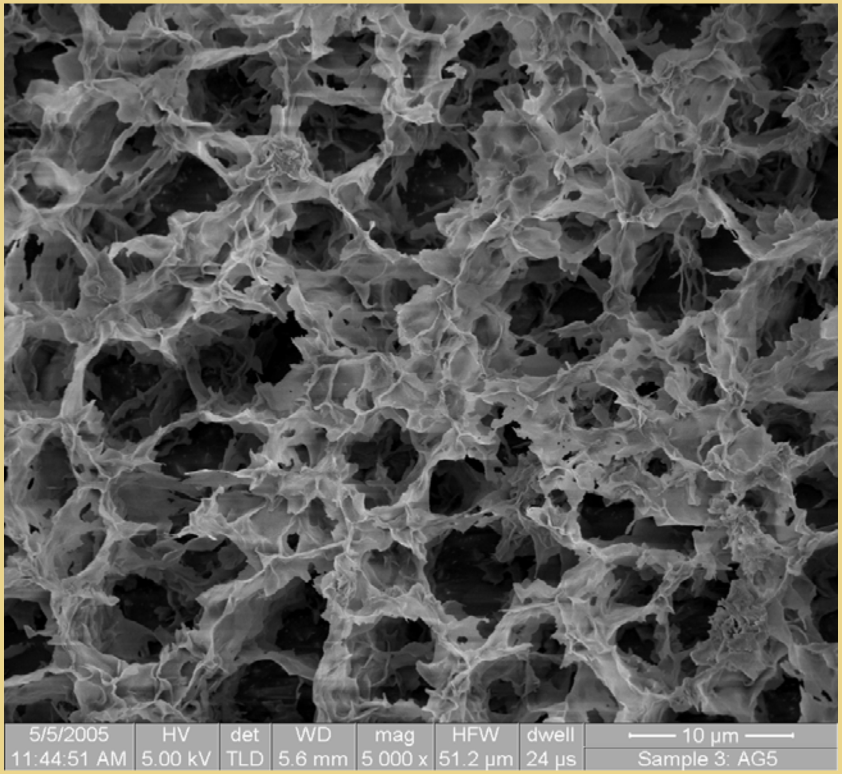


60 g/l

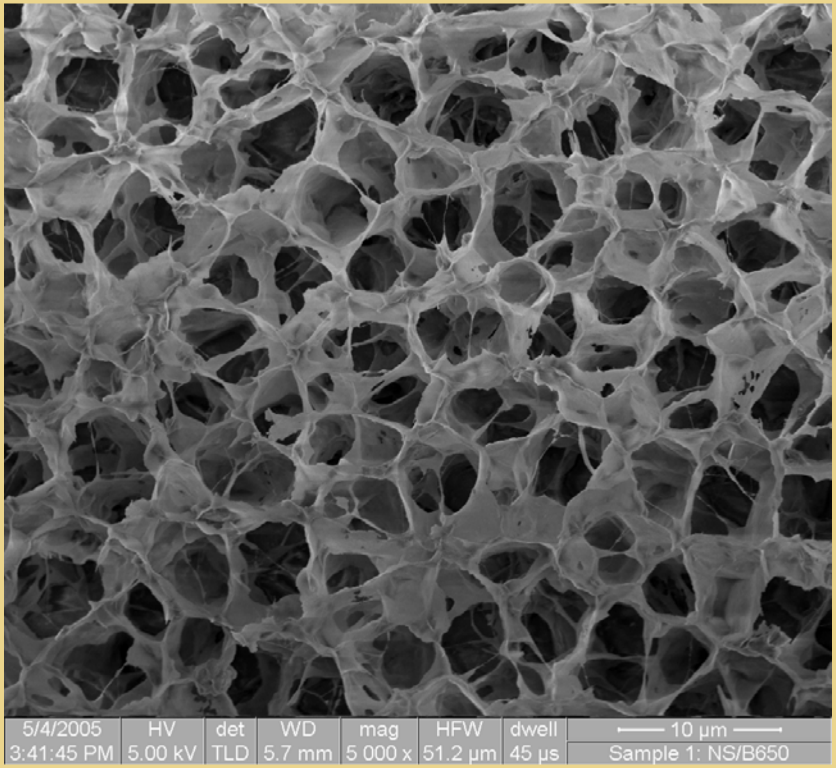




- EFFECT OF POLYMER ADDITION



110 g/l
Pure bentonite



90 g/l
Bentonite w/ PAC & Xanthan

FINAL REMARKS

- Complexity in rheological behavior of bentonite-based fluids
- Insights gained from combining rheological measurements with direct assessments of the microstructure
- Opportunities offered by advanced imaging techniques
- Potential for engineering rheology of clays

OPPORTUNITIES FOR FUTURE WORK

- Advanced measurement and modeling of rheological properties
- Integrated evaluation of the performance of the fluids
- Development of framework for the selection/ design of trenchless technology fluids
- Design of new materials (e.g. “conversion” fluids)

ACKNOWLEDGEMENTS

- Funding: NATIONAL SCIENCE FOUNDATION

  Award # CMS-0301729

- SEM work: Debby Sherman (Purdue Life Sciences Microscopy Facility)

- Materials: Baroid

- Rheometer access: Prof. Osvaldo Campanella (Purdue ABE)

THANK YOU