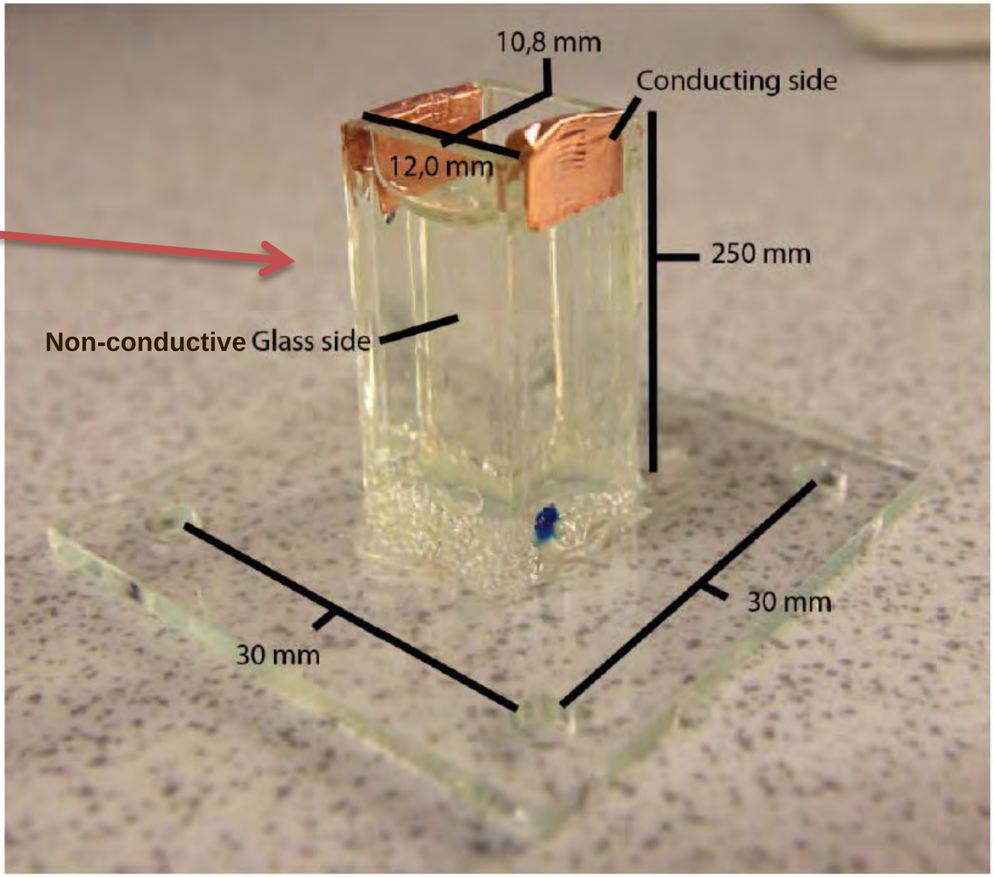
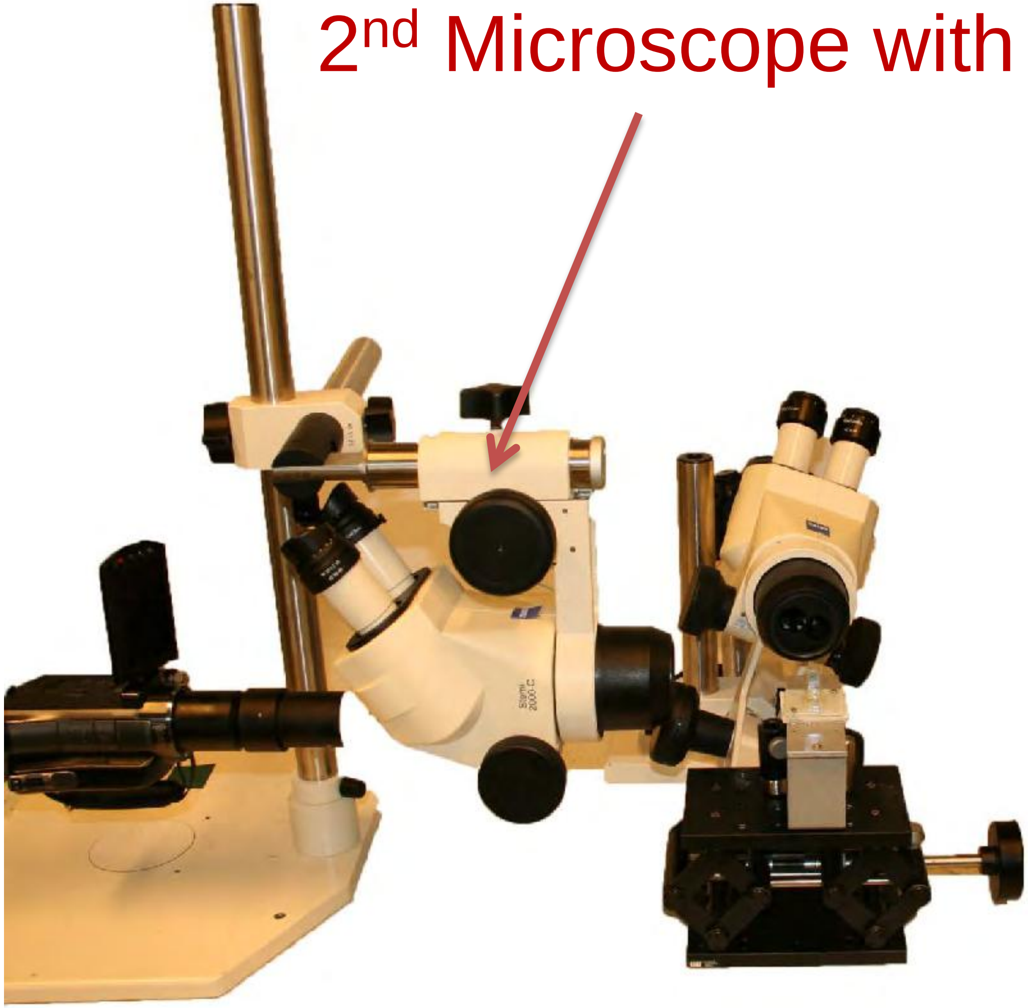
Sample cell



Experimental setup at NTNU Trondheim

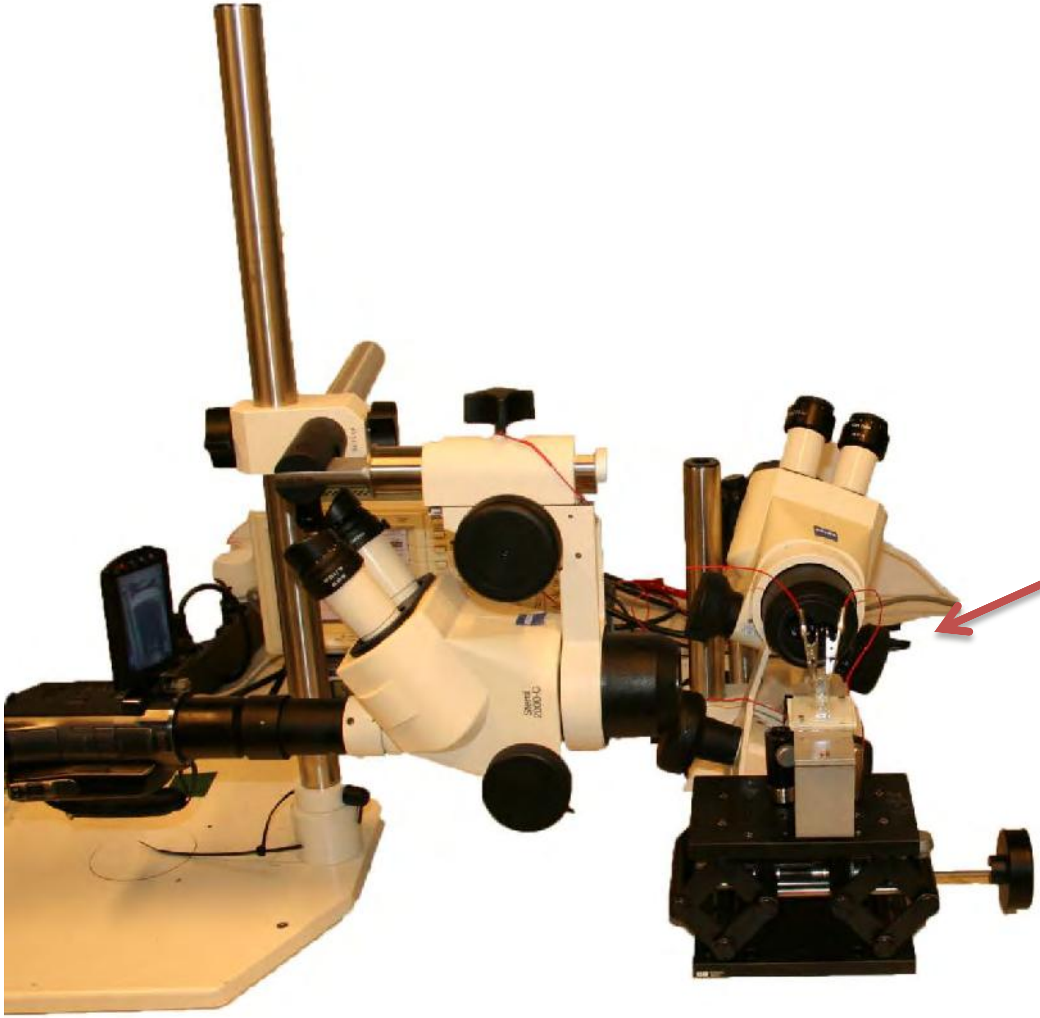
1^{st} Microscope with camera

Experimental setup at NTNU Trondheim



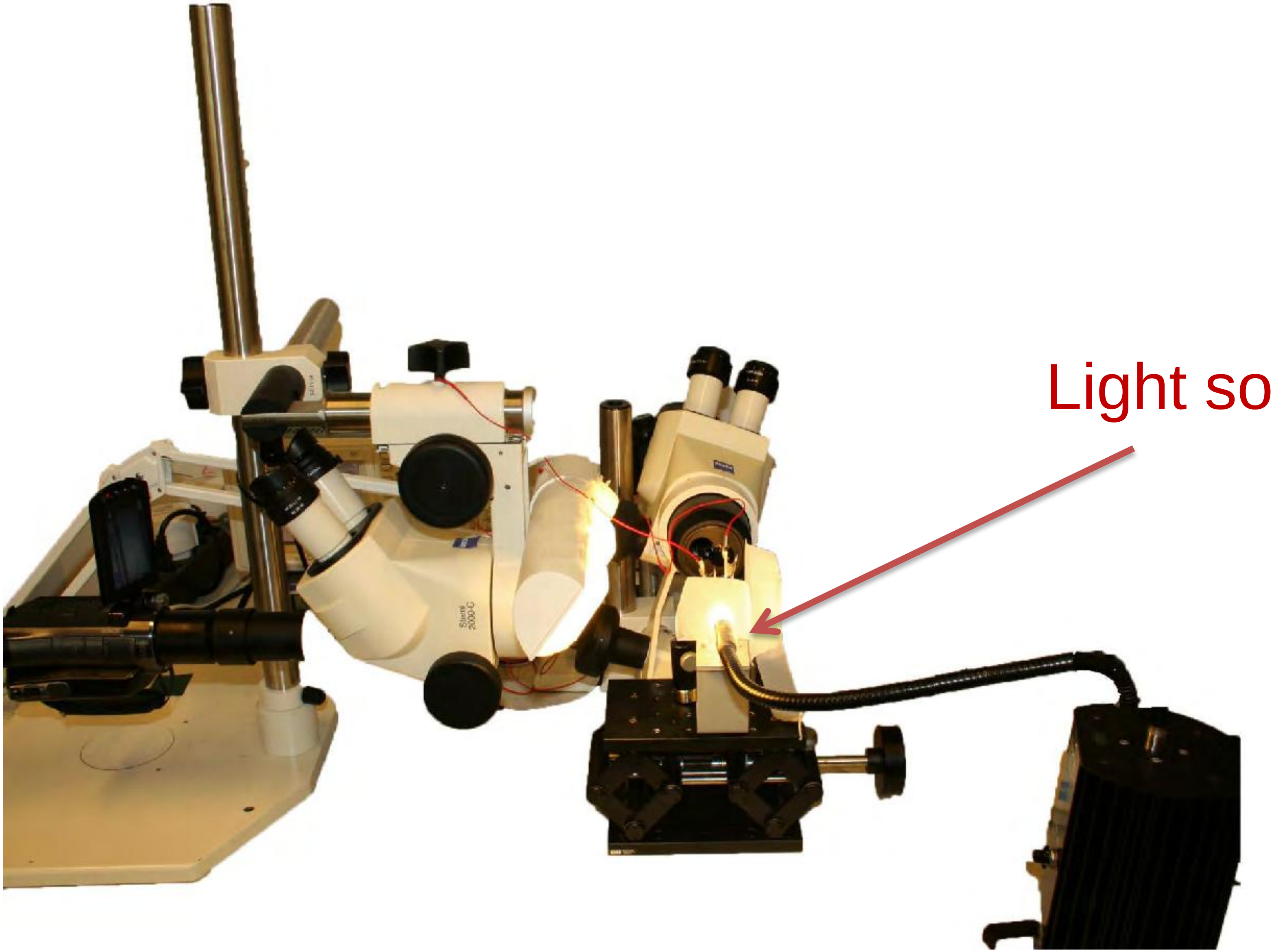
2nd Microscope with camera

Experimental setup at NTNU Trondheim



Electrodes

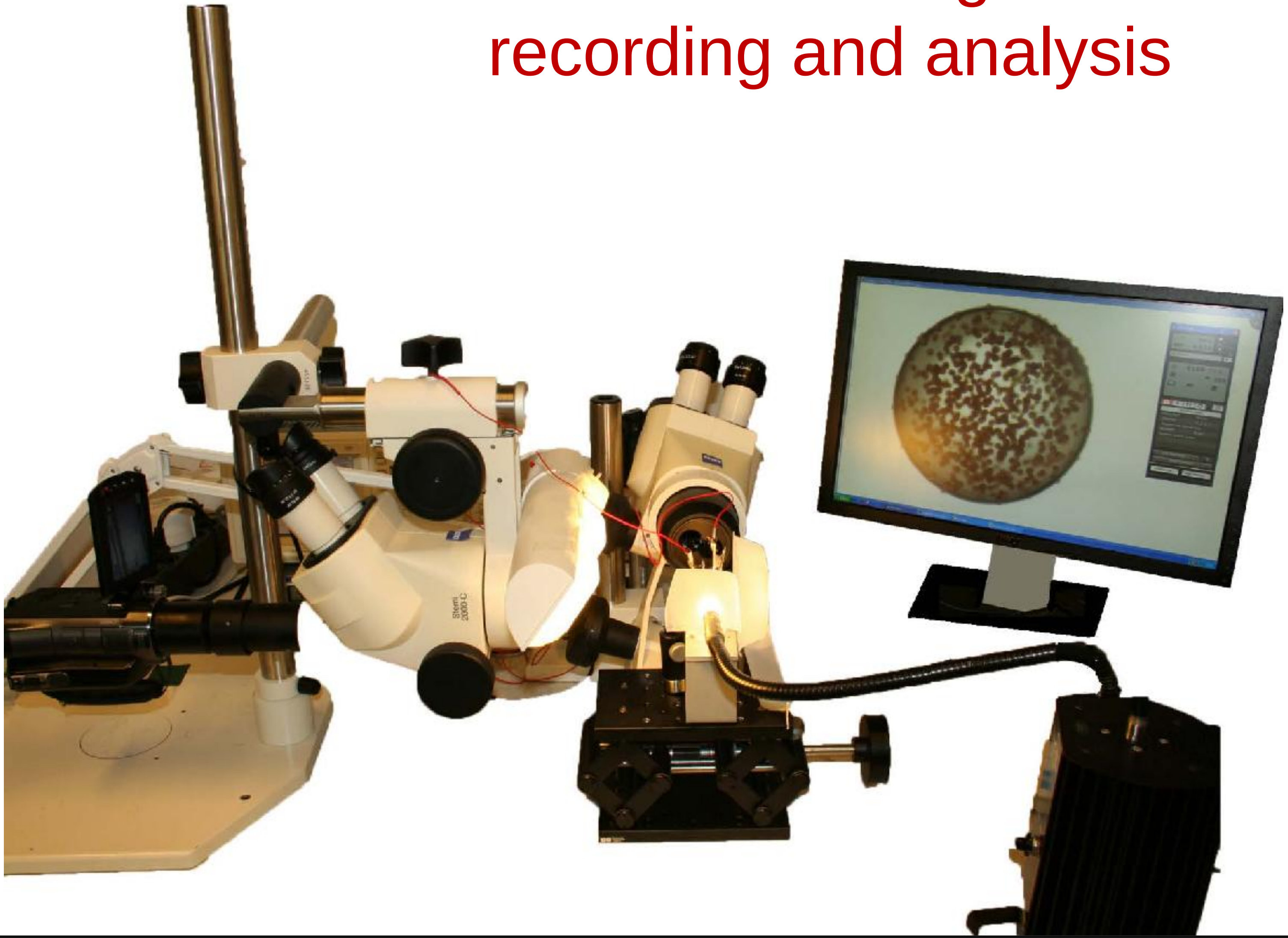
Experimental setup at NTNU Trondheim



Light source

Experimental setup at NTNU Trondheim

PC for image recording and analysis

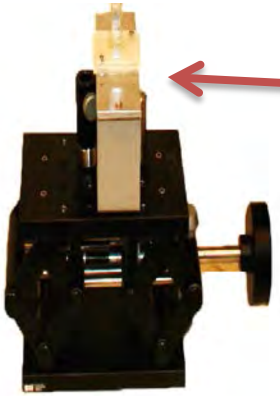


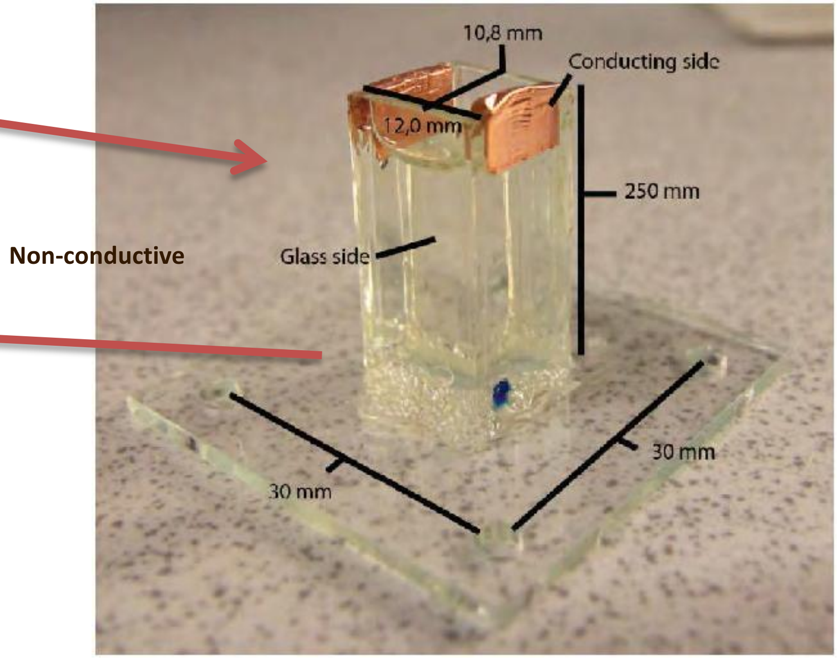
Experimental setup at NTNU Trondheim

Sample cell

2x ITO transparent electrodes

2x glass walls



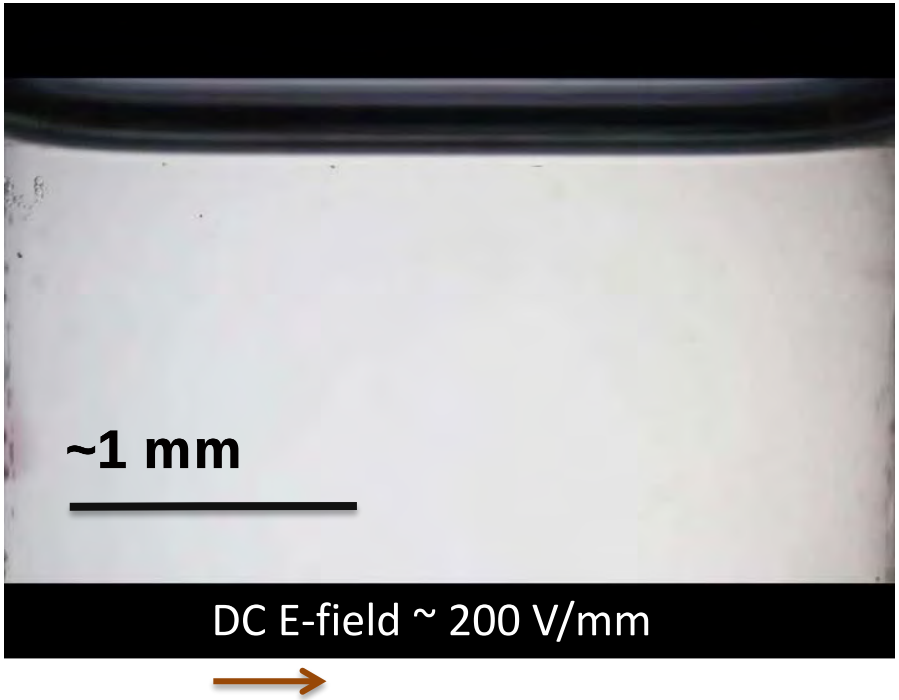


Clay in silicone oil dispersion

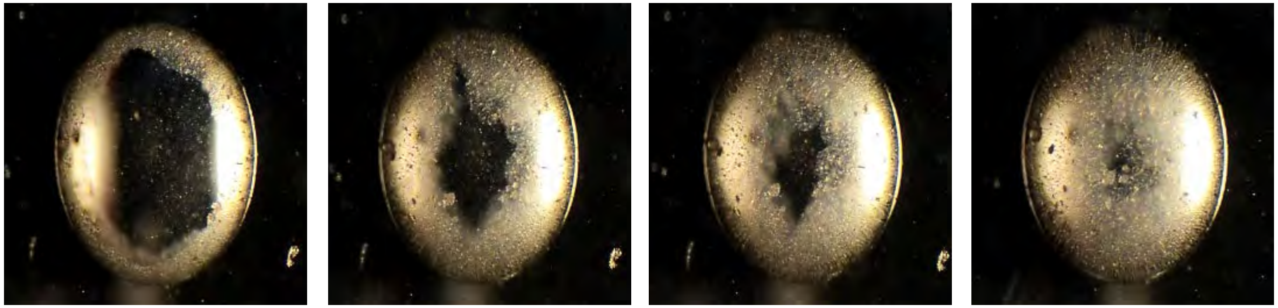
(~ 1 mm diameter drop)

Castor oil

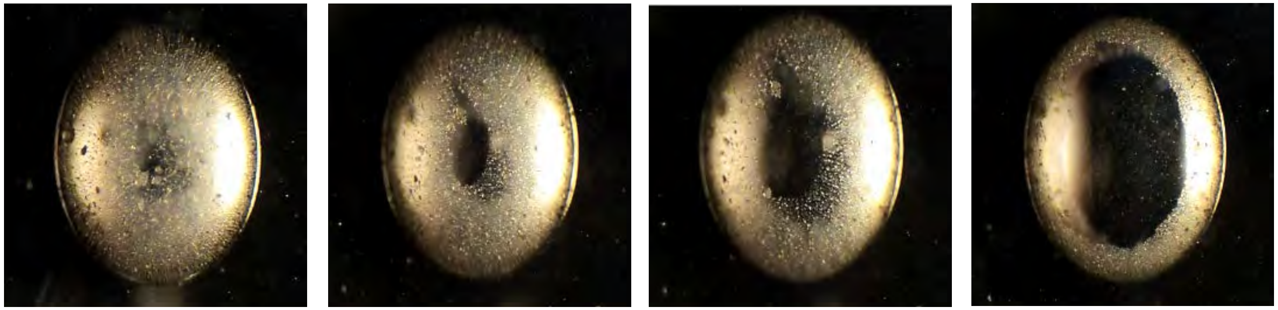
(continuous phase)



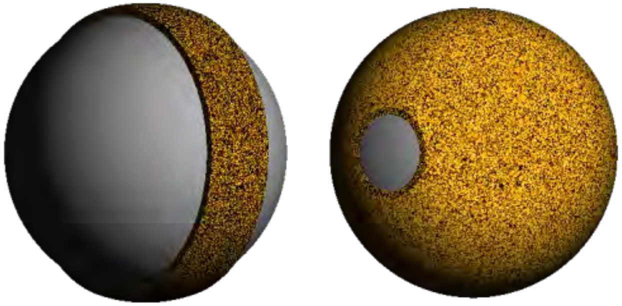
200 → 500 V/mm



200 ← 500 V/mm



Electro-hydrodynamic flow



Dipole-dipole interactions

Active pupil-like colloidal shell (opening - closing)

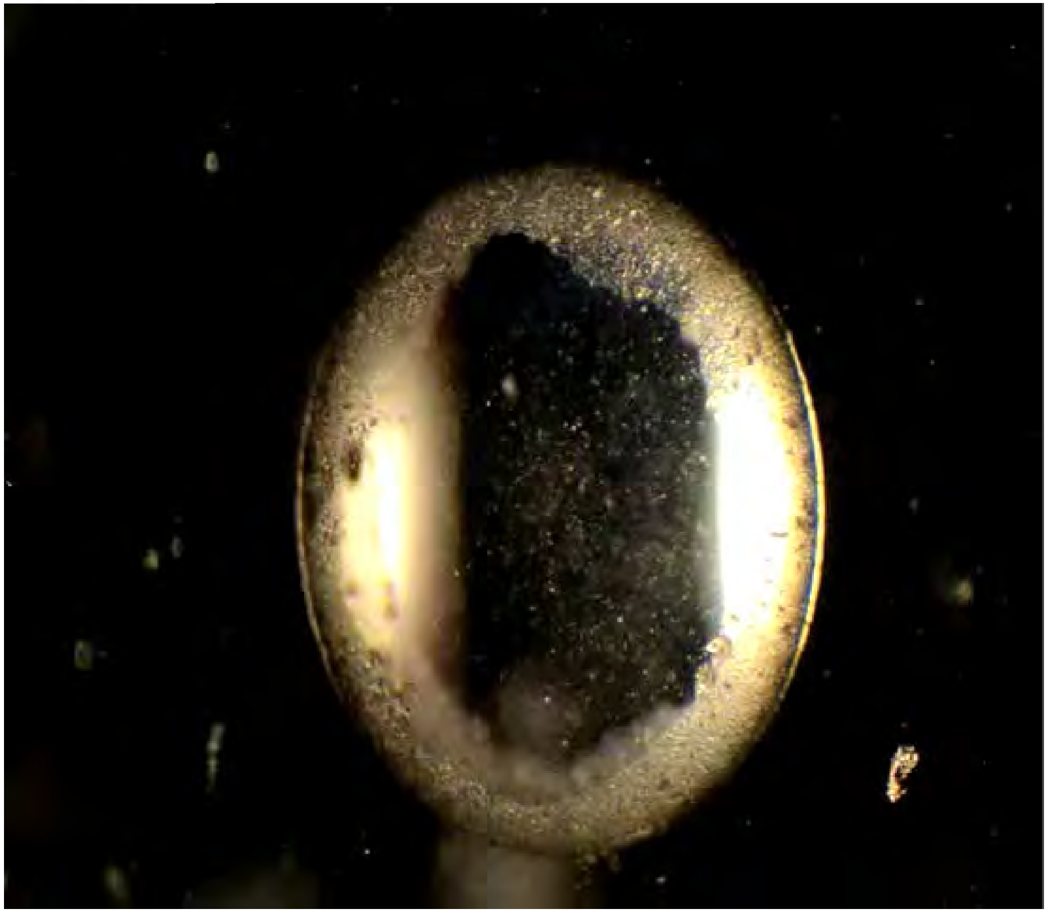
nature COMMUNICATIONS

Published 28 Jun 2013

Active structuring of colloidal armour on liquid drops

Paul Dommersnes[1,2,3,4,*], Zbigniew Rozynek[1,*], Alexander Mikkelsen[1], Rene Castberg[2], Knut Kjerstad[1], Kjetil Hersvik[1] & Jon Otto Fossum[1,4,*]

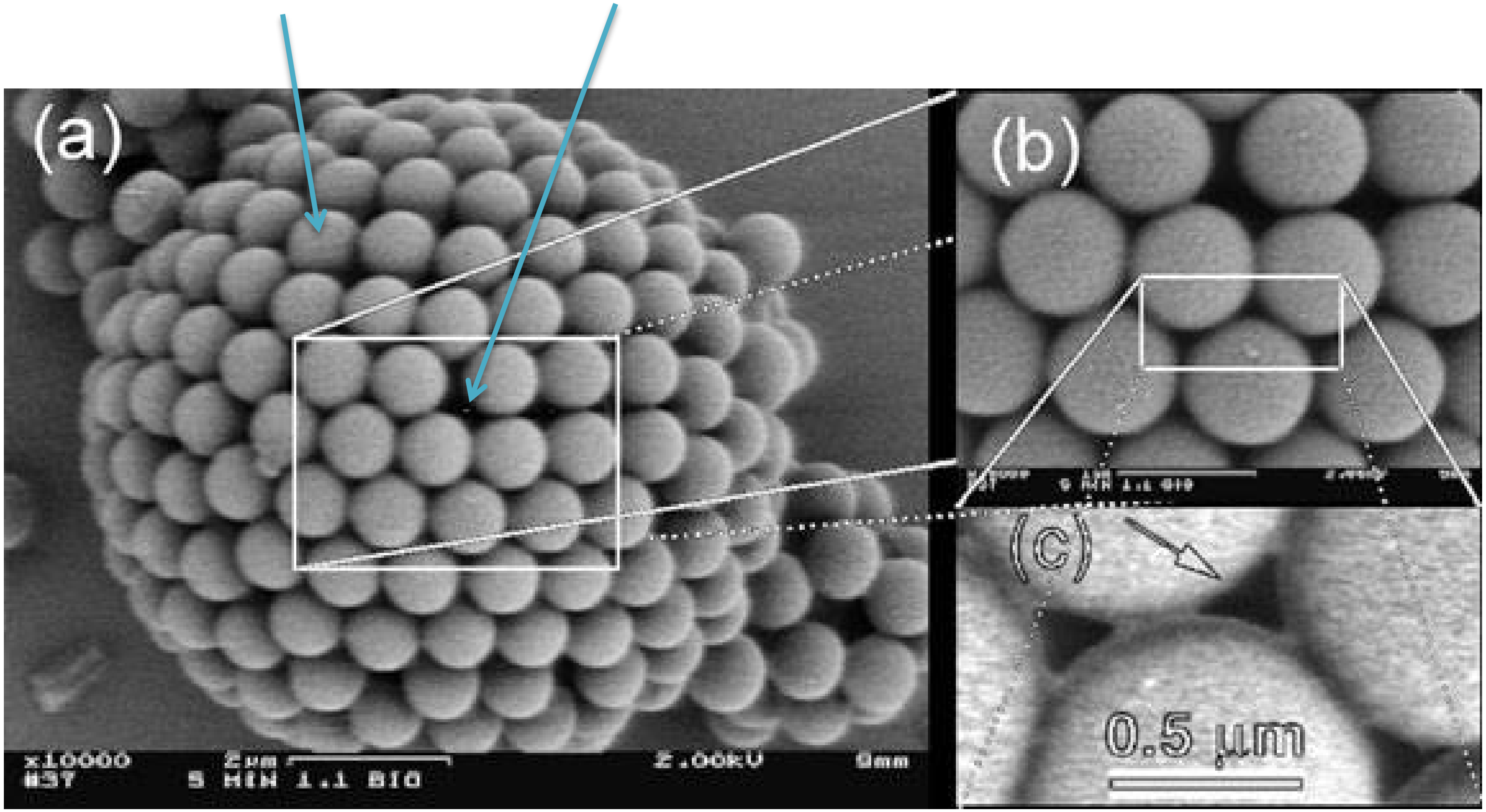
NATURE COMMUNICATIONS | 4:2066 | DOI: 10.1038/ncomms3066



Active pupil-like colloidal shell (opening - closing)

Dynamic Colloidosome

Composition and permeability

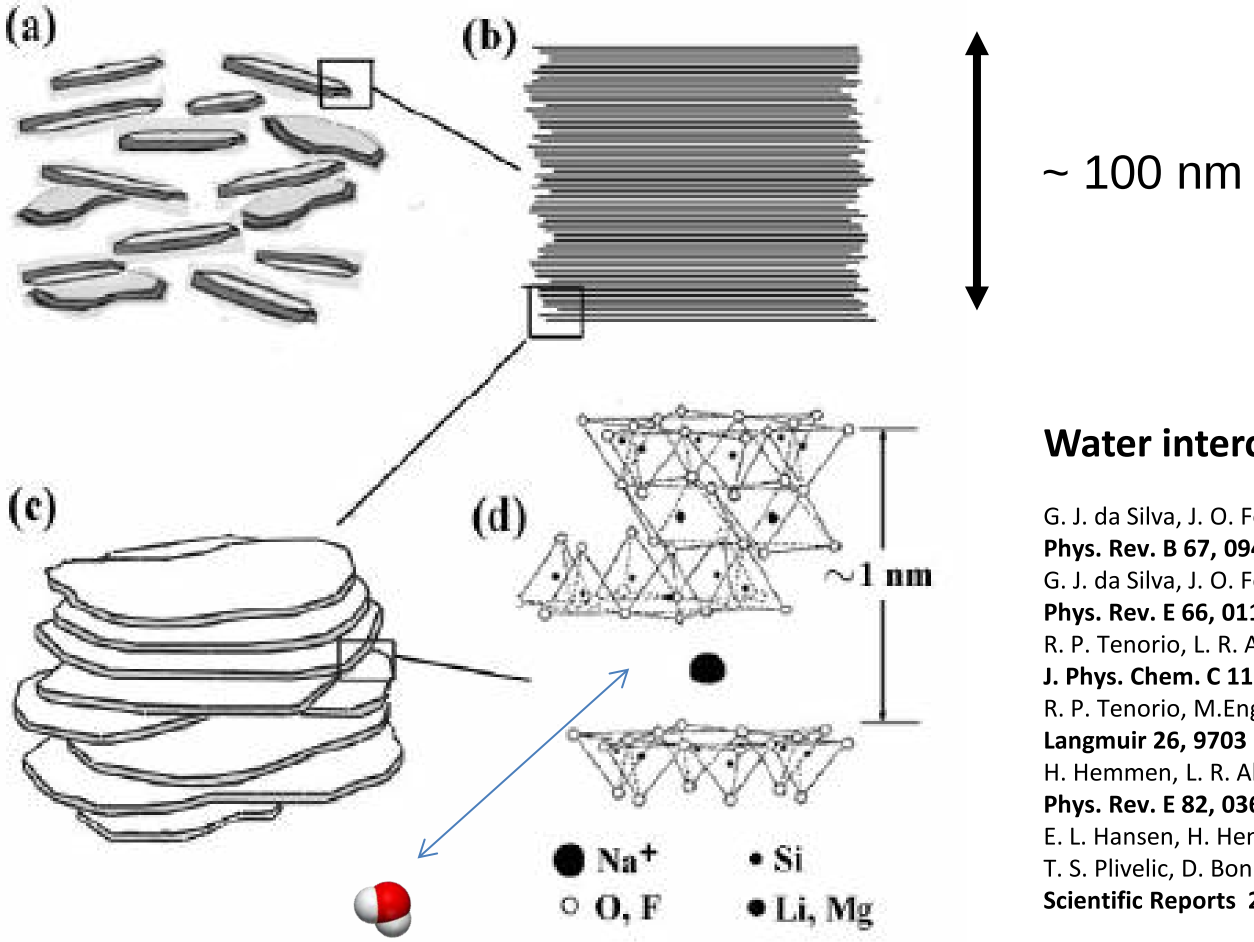


MOLECULAR INTERACTIONS WITH CLAYS: H_2O, CO_2, DRUGS,….

NTNU – Trondheim
Norwegian University of
Science and Technology

Our clay experimental model system:

Q-fluorohectorite synthetic clay: Q_x-$(Mg_{3-x}Li_x)Si_4O_{10}F_2$,
Q is the exchangeable cation (Q = Na^+, Li^+, Ni^{2+}, Fe^{3+}, etc)

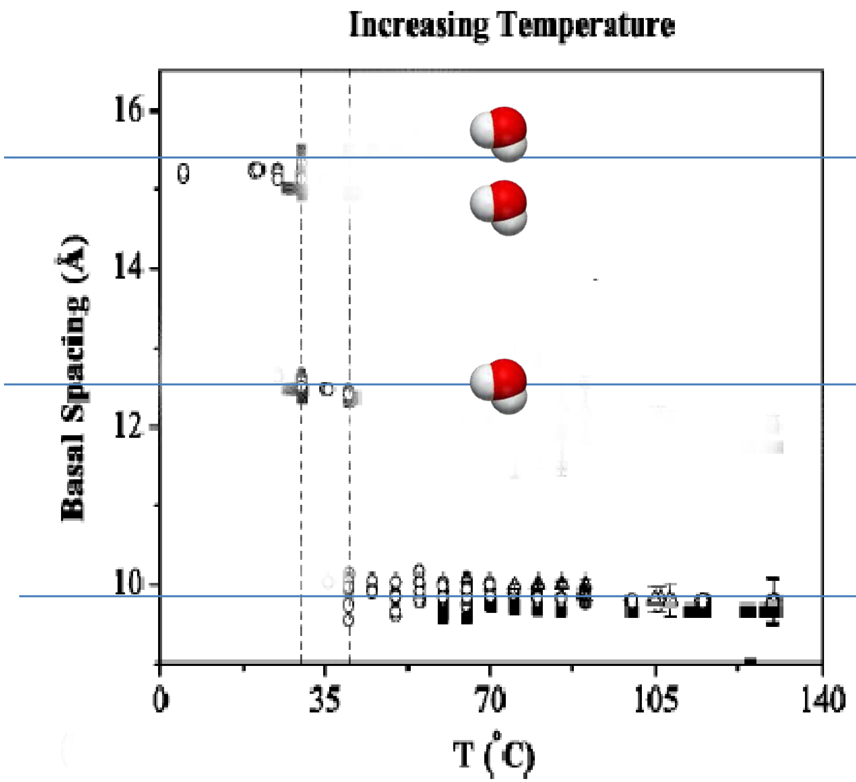


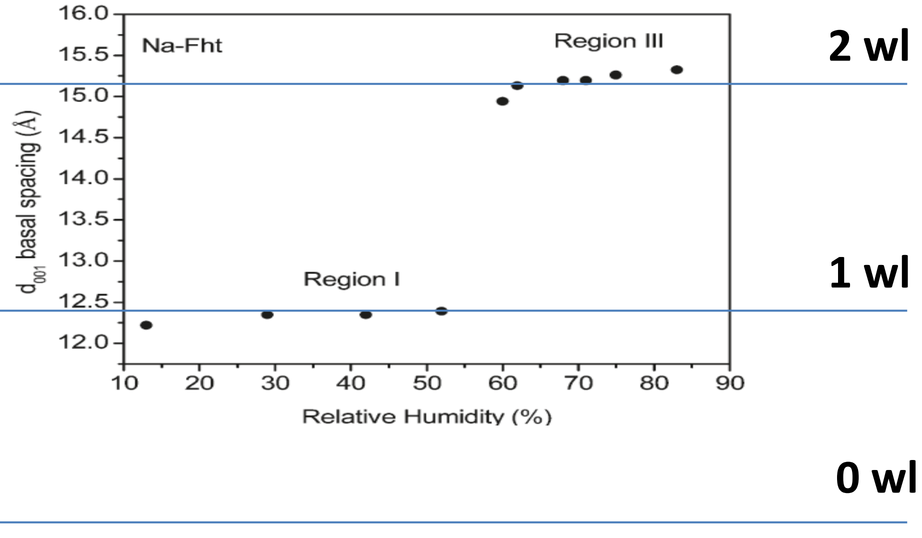
Water intercalation:

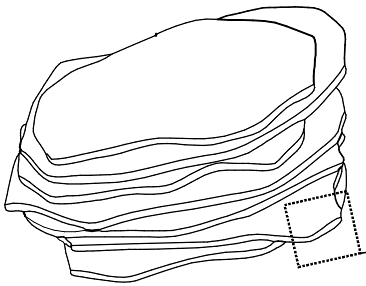
G. J. da Silva, J. O. Fossum, E. DiMasi, and K. J. Maloy,
Phys. Rev. B 67, 094114 2003.
G. J. da Silva, J. O. Fossum, E. DiMasi, K. J. Maloy, and S. B.Lutnaes,
Phys. Rev. E 66, 011303 2002.
R. P. Tenorio, L. R. Alme, M. Engelsberg, J. O. Fossum, and F. Hallwass,
J. Phys. Chem. C 112, 575 2008.
R. P. Tenorio, M.Engelsberg, J. O. Fossum, and G. J. da Silva,
Langmuir 26, 9703 2010.
H. Hemmen, L. R. Alme, J. O. Fossum and Y. Meheust,
Phys. Rev. E 82, 036315 2010.
E. L. Hansen, H. Hemmen, D. M. Fonseca, C. Coutant, K. D. Knudsen,
T. S. Plivelic, D. Bonn, J. O. Fossum,
Scientific Reports 2, 618 2012

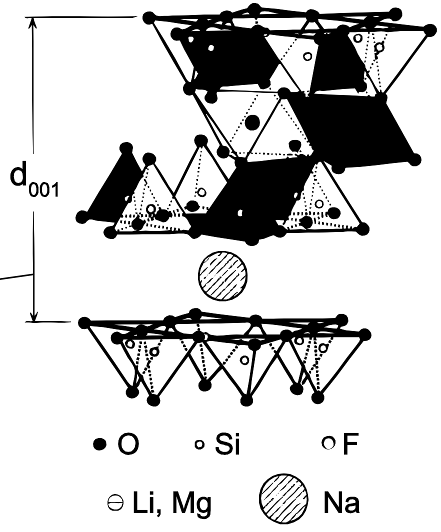
H_2O intercalation controlled by T/RH of sample environment:

Na-fluorohectorite powder in humid air





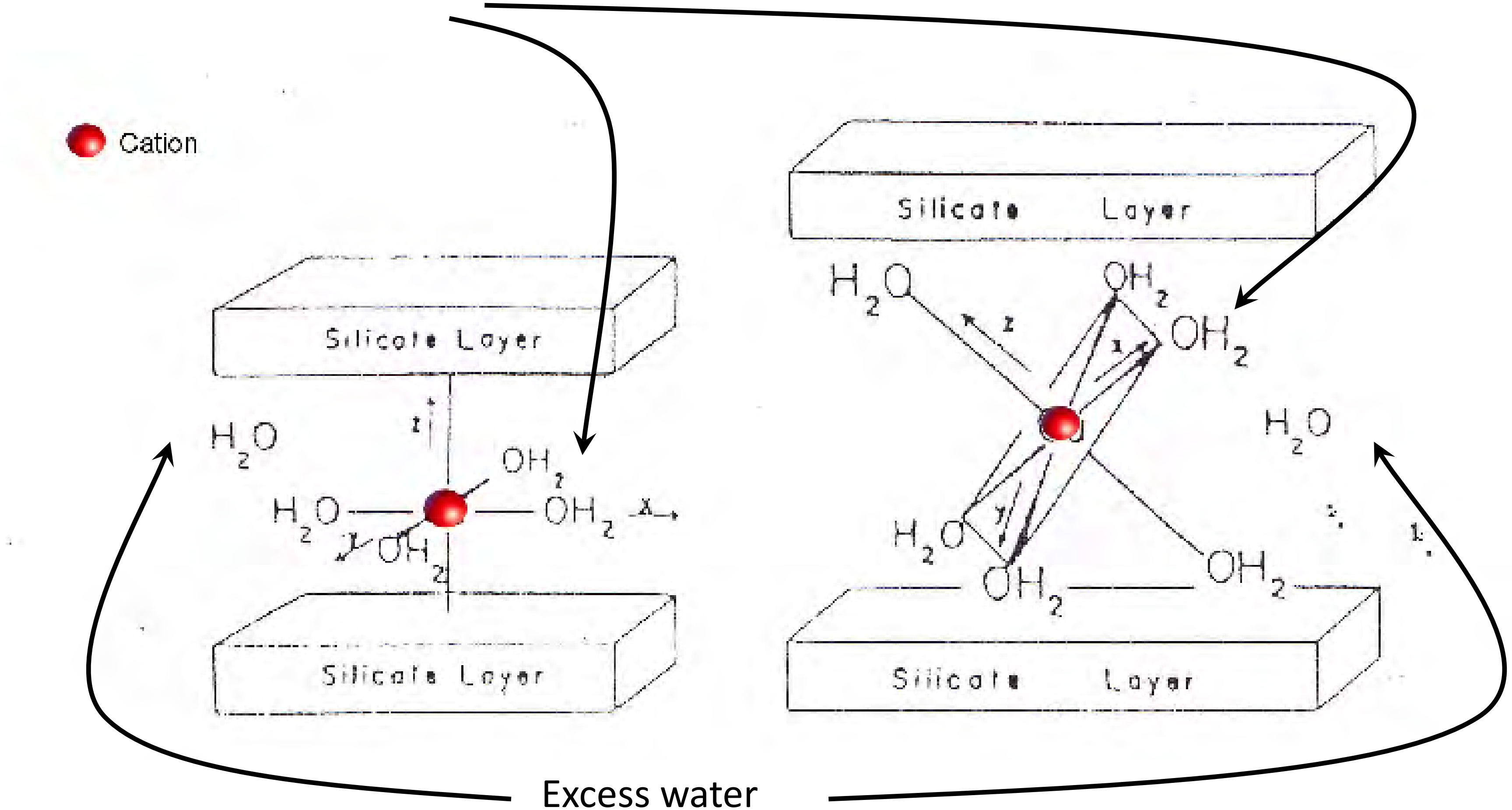




NMR spectroscopy:

R. P. Tenorio, L. R. Alme, M. Engelsberg, J. O. Fossum, and F. Hallwass, **J. Phys. Chem. C 112, 575 2008.**
R. P. Tenorio, M.Engelsberg, J. O. Fossum, and G. J. da Silva, **Langmuir 26, 9703 2010.**

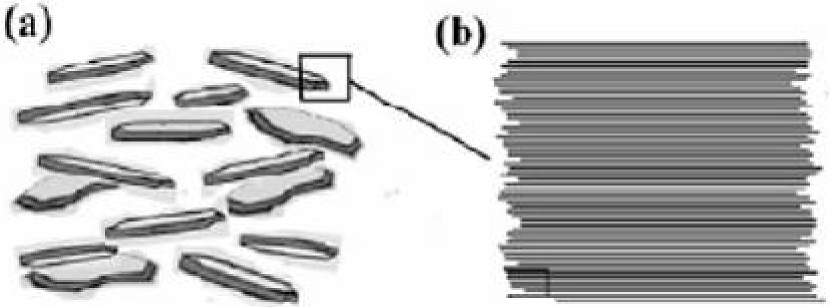
Two kinds of intercalated water:

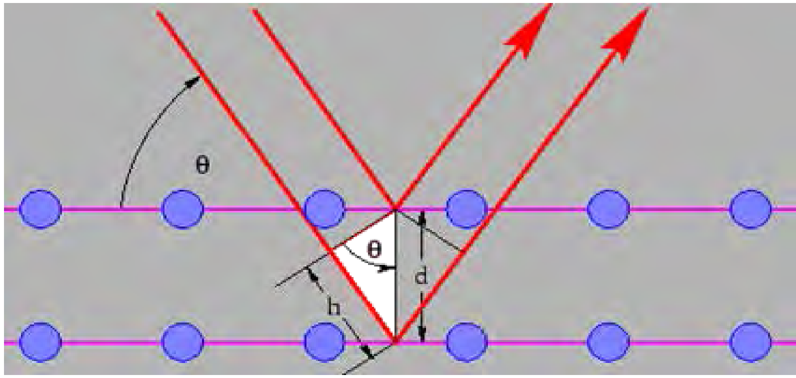


Water ”bound” in ion complexes

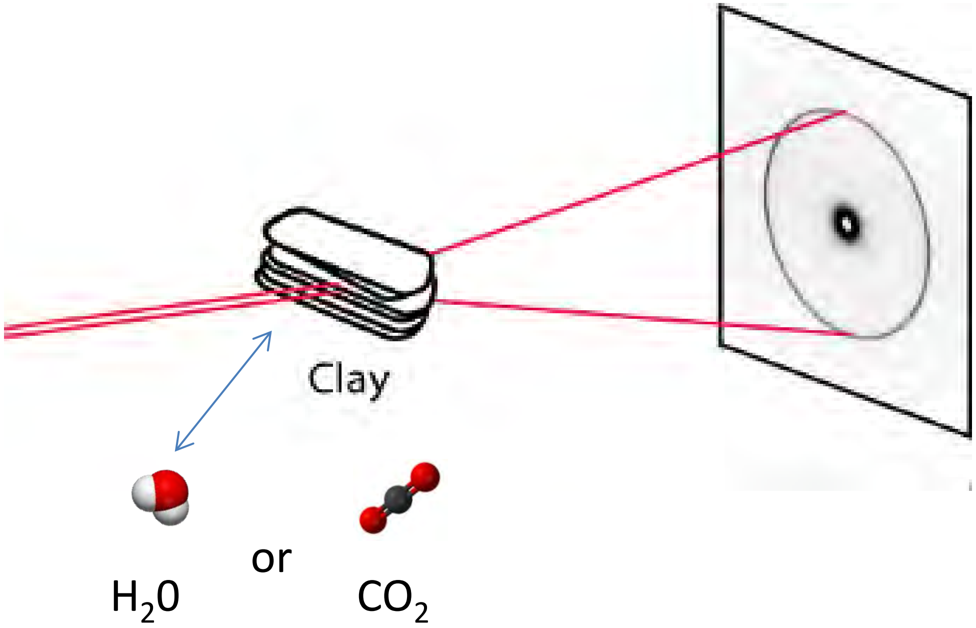
Excess water

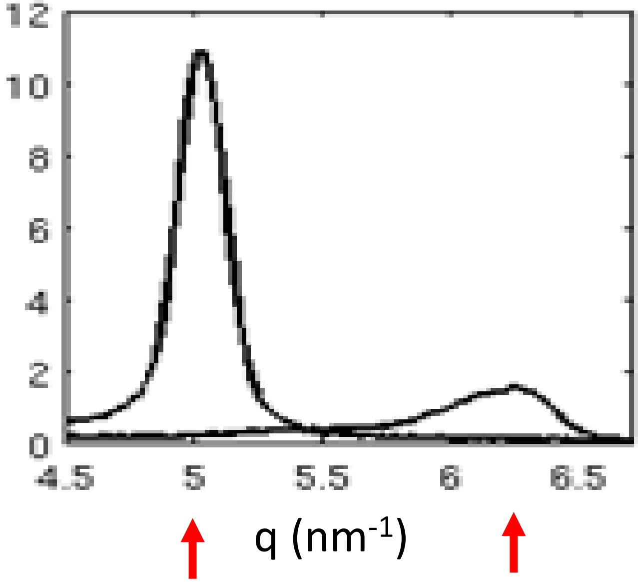
Scattering of X-rays: Bragg’s law:





Constructive interference when $2h = \boxed{2d\sin\theta = n\lambda}$





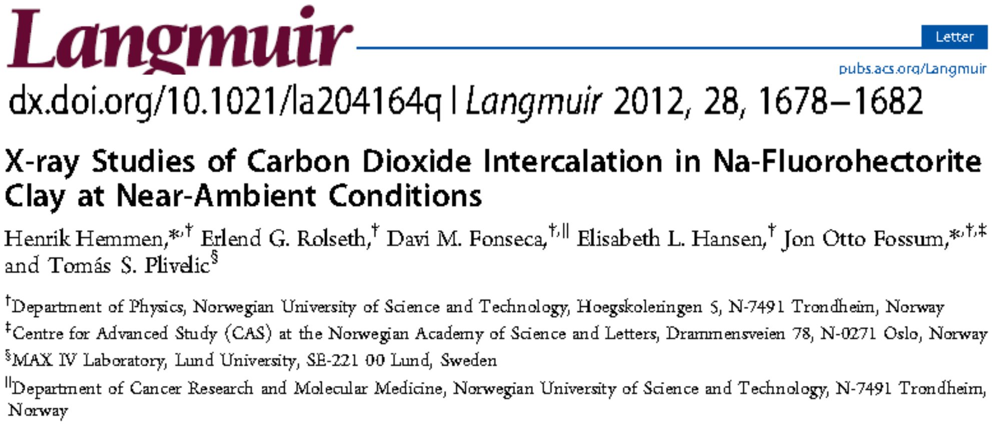
1.25 nm
1 layer H_2O intercalated

1 nm
Dry clay

Before 2012:

J. J. Fripiat, M. I. Cruz, B. F. Bohor, J. Thomas. *Interlamellar adsorpion of carbon dioxide by smectites* Clays Clay Miner. 22, 23, (1974).

The evidence presented in this study clearly shows that CO_2 *at about -70 °C penetrates (intercalates) the smectite structure to a degree dependent upon the nature of the replaceable interlayer cation.*



Langmuir
Letter
pubs.acs.org/Langmuir
dx.doi.org/10.1021/la204164q | *Langmuir* 2012, 28, 1678–1682

X-ray Studies of Carbon Dioxide Intercalation in Na-Fluorohectorite Clay at Near-Ambient Conditions

Henrik Hemmen,[*,†] Erlend G. Rolseth,[†] Davi M. Fonseca,[†,∥] Elisabeth L. Hansen,[†] Jon Otto Fossum,[*,†,‡] and Tomás S. Plivelic[§]

[†]Department of Physics, Norwegian University of Science and Technology, Hoegskoleringen 5, N-7491 Trondheim, Norway
[‡]Centre for Advanced Study (CAS) at the Norwegian Academy of Science and Letters, Drammensveien 78, N-0271 Oslo, Norway
[§]MAX IV Laboratory, Lund University, SE-221 00 Lund, Sweden
[∥]Department of Cancer Research and Molecular Medicine, Norwegian University of Science and Technology, N-7491 Trondheim, Norway

2012 and later: Large number of publications have appeared on clays + CO_2

SCIENTIFIC REPORTS | ARTICLE OPEN

Intercalation and Retention of Carbon Dioxide in a Smectite Clay promoted by Interlayer Cations

L. Michels, J. O. Fossum, Z. Rozynek, H. Hemmen, K. Rustenberg, P. A. Sobas, G. N. Kalantzopoulos, K. D. Knudsen, M. Janek, T. S. Plivelic & G. J. da Silva

Affiliations | Contributions | Corresponding authors

Scientific Reports **5**, Article number: 8775 | doi:10.1038/srep08775
Received 12 November 2014 | Accepted 29 January 2015 | Published 05 March 2015

Dagens Næringsliv | Lørdag 21. mars 2015

DN Dagens Næringsliv

Leire kan brukes i karbonfangst

Vanlig leire kan være like god som mer avanserte materialer fo
fange CO_2.

Forskning viser at ...
Jon Otto Fossum

Karbonfangst står helt sentralt om verden skal greie å redusere klimagassutslippene. Mange materialer prøves ut for å fange CO_2. Nå viser våre nye resultater at vanlig leire kan fungere vel så effektivt som mer avanserte materialer.

Det er ganske oppsiktsvekkende at leire kan fange like mye CO_2 som andre materialer det forskes på. Noen av de andre materialene er dyre, vanskelige å produsere, giftige og i det hele tatt ikke spesielt miljøvennlige.

Et tenkbart anvendelsesområde kan altså være å bruke leire som del av CO_2-filter som kan

Leander Michels (til venstre) og Jon Otto Fossum. En leireprøve legges i det lille kammeret de holder. Ved hjelp av røntgenstråler kan de måle om leiren har tatt opp CO_2. Foto: Per Harald Olsen, NTNU

fremst PhD-student Leander Michels og professor Jon Otto Fossum, forskere fra Institutt for

Det må ha stor overflate og god absorberingsevne. Det bør ofte kunne fange CO_2 selektivt før det

kontakt med vann. De er såkalte lagdelte nanosilikater.

Vi har brukt kunstig fremstilt
re forsøk. Den
rianten av slik leire
være billig å frem-

Forskningen

Hvem: Leander Michel
Otto Fossum m.fl.
Hva: Intercalation and
Retention of Carbon D
in a Smectite Clay pro
by Interlayer Cations
Hvor: Nature Scientifi
Reports 5, 8775

Leiren med det ava
navnet litium-fluoroh
kan holde på CO_2 helt
35 grader celsius unde
normalt lufttrykk. De
fangede CO_2-en blir fr
leiren varmes opp til t
turer over denne gren
Dermed kan vi kontro
CO_2-fangsten.

Våre forsøk viser at slik smektitt kan holde på en mengde CO_2 som kan sammenlignes med andre materialer som er studert i forbindelse med CO_2 fangst.

Jon Otto Fossum, professor ved Institutt for fysikk ved NTNU

Forskning viser at ...
Oppsiktsvekkende funn? Ny innsikt?

ScienceDaily
Your source for the latest research news

Featured Research — from univers

Ordinary clay can be used for carbon capture

Date: April 8, 2015

Source: The Norwegian University of Science and Technology (NTNU)

Summary: Carbon capture will play a central role in helping the nations of the manage and reduce their greenhouse gas emissions. Many materi are being tested for the purpose of capturing carbon dioxide. New results show that ordinary clay can work just as effectively as more advanced materials.

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PUBLIC RELEASE: 8-APR-2015

Ordinary clay can save the day

Smectite proves as good as other materials for CO2 capture

NORWEGIAN UNIVERSITY OF SCIENCE AND TECHNOLOGY

Carbon capture will play a central role in helping the nations of the world manage and reduce their greenhouse gas emissions. Many materials are being tested for the purpose of capturing CO2. But now researchers led by the Norwegian University of Science and Technology (NTNU) have found that ordinary clay can work just as effectively as more advanced materials.

"It is quite remarkable that clay can capture as much CO2 as other materials that are being investigated," says Jon Otto Fossum, professor at NTNU's Department of Physics.

Clay offers many benefits compared to other materials, particularly because other potential materials can be expensive, difficult to produce, toxic and not particularly environmentally friendly.

IMAGE: LEANDER MICHELS (LEFT) AND PROFESSOR JON OTTO FOSSUM, BOTH FROM THE NORWEGIAN UNIVERSITY OF SCIENCE AND TECHNOLOGY, EXAMINE A SMALL CHAMBER USED TO STUDY THE ABILITY OF CLAYS TO CAPTURE... view more

A possible practical future use of this discovery could be to include clays in CO2 filters for industrial-scale CO2 emissions reduction.

"What we are doing is basic research," Fossum says. "It will take more research to develop the technology, so we don't expect clay based CO2 capture to be readily available anytime soon."

Published in *Scientific Reports*

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jon.fossum@ntnu.no
47-911-39194
@NTNU
http://www.ntnu.edu

More on this News Release
Ordinary clay can save the day
NORWEGIAN UNIVERSITY OF SCIENCE AND TECHNOLOGY
JOURNAL
Scientific Reports

KEYWORDS

MULTIMEDIA
Studying Clays for Co2 Uptake and Retention (IMAGE)

TECH TIMES

TAG Smectite Clay , Carbon dioxide , Carbon capture , Greenhouse gases , Greenhouse gas emissions

Ordinary Clay Effective Carbon Capture, Say Experts

By **Rex Maoadangdang**, Tech Times | April 11, 11:46 PM

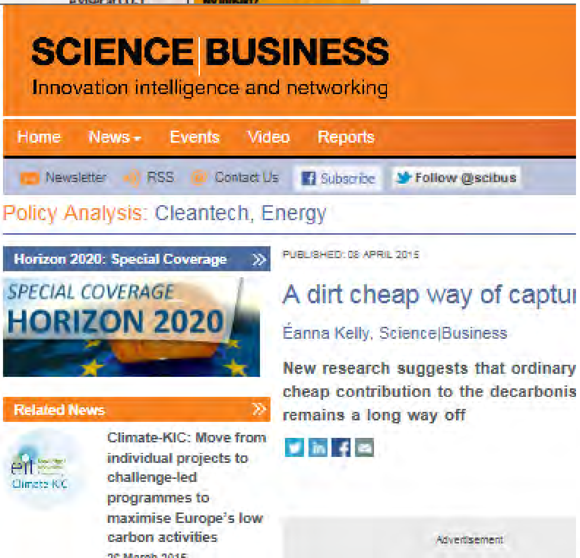
Ordinary clay is a cheap alternative for capturing carbon dioxide, according to a recent study. Compared to other materials, clay is nontoxic, easily produced and environment-friendly.
(Photo : Paul Lim | Flickr)

Carbon capture and storage (CCS) is expected to play a major role in the reduction and management of greenhouse gas discharges from large point sources.

Ionic liquids, metal-organic framework (MOF) materials and even sea urchin-inspired materials are being examined for the purpose of confining waste carbon dioxide at one of the known root causes: industrial smokestacks. These suggested substances, however, are either hard to produce or cost too much.

Based on a recent scientific report, Norwegian researchers have found that ordinary clay could be as effective as these more advanced materials in CCS.

Ph.D. candidate Leander Michels and Prof. Jon Otto Fossum from the Department of Physics at the Norwegian University of Science and Technology (NTNU) are leading a team of scientists from the Universidade de Brasilia, MaxIVLab at Lund University, Slovak University of Technology and Institute for Energy Technology located at Kjeller, Norway on this matter.



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Horizon 2020: Special Coverage

PUBLISHED: 08 APRIL 2015

A dirt cheap way of captu

Éanna Kelly, Science|Business

New research suggests that ordinary cheap contribution to the decarbonis remains a long way off

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Climate-KIC: Move from individual projects to challenge-led programmes to maximise Europe's low carbon activities

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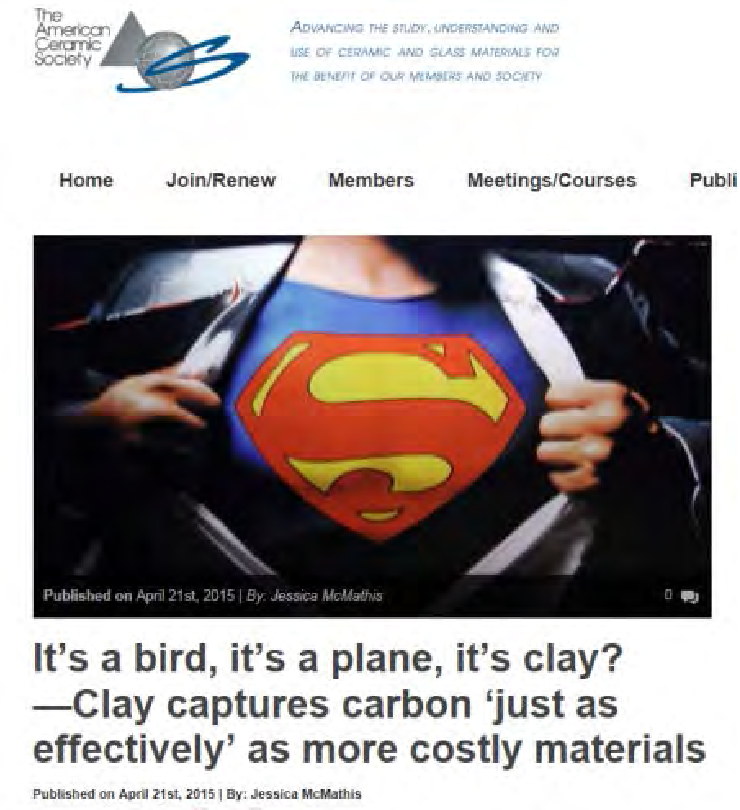


The American Ceramic Society

ADVANCING THE STUDY, UNDERSTANDING AND USE OF CERAMIC AND GLASS MATERIALS FOR THE BENEFIT OF OUR MEMBERS AND SOCIETY

Published on April 21st, 2015 | By: Jessica McMathis

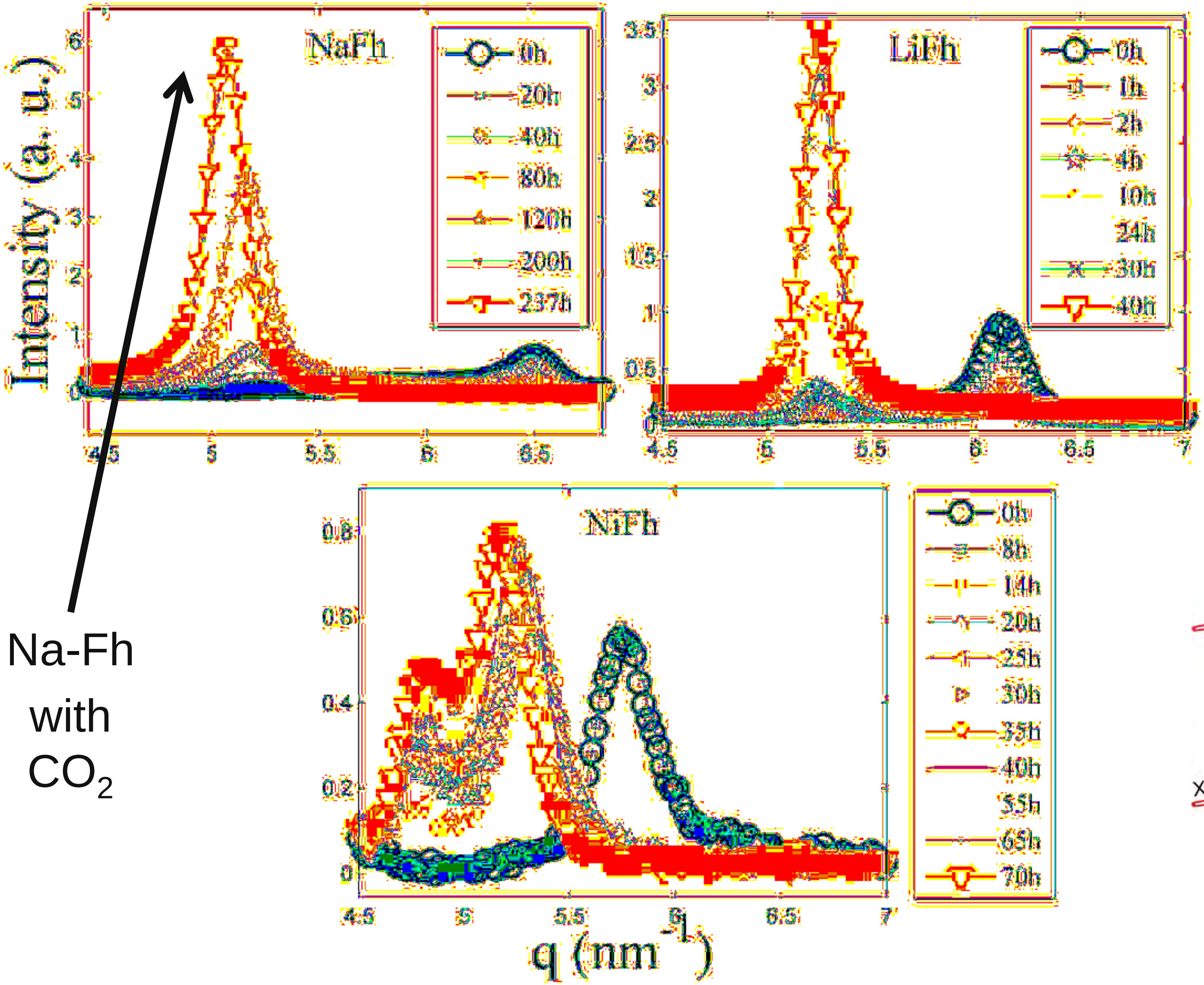
It's a bird, it's a plane, it's clay? —Clay captures carbon 'just as effectively' as more costly materials

Published on April 21st, 2015 | By: Jessica McMathis

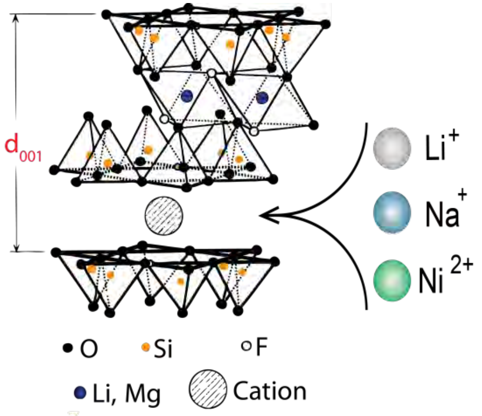
CO_2 intercalation

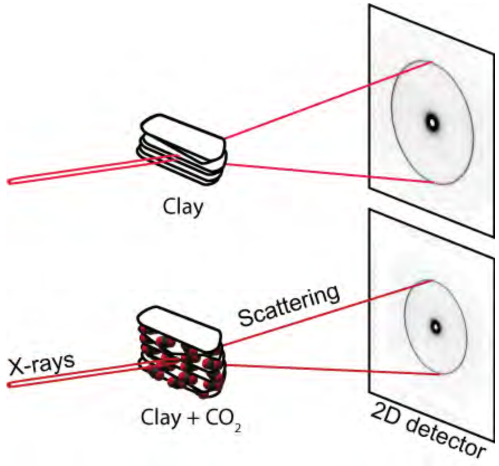
$$P = 20 \text{ bar}$$

$$T = -20^oC$$



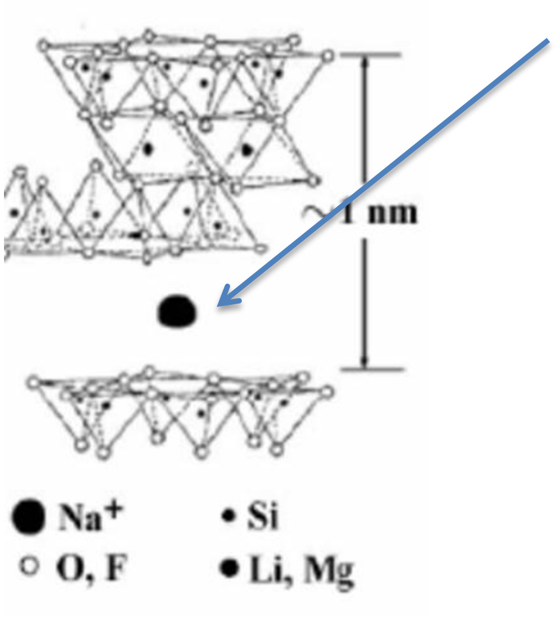
Na-Fh with CO_2

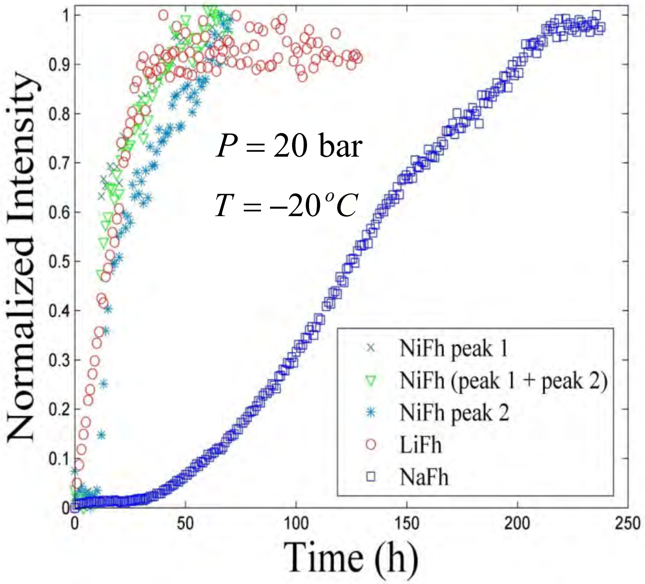




Powders are completelt dehydrated before exposed to CO_2: Blue data points above

Cation dependence



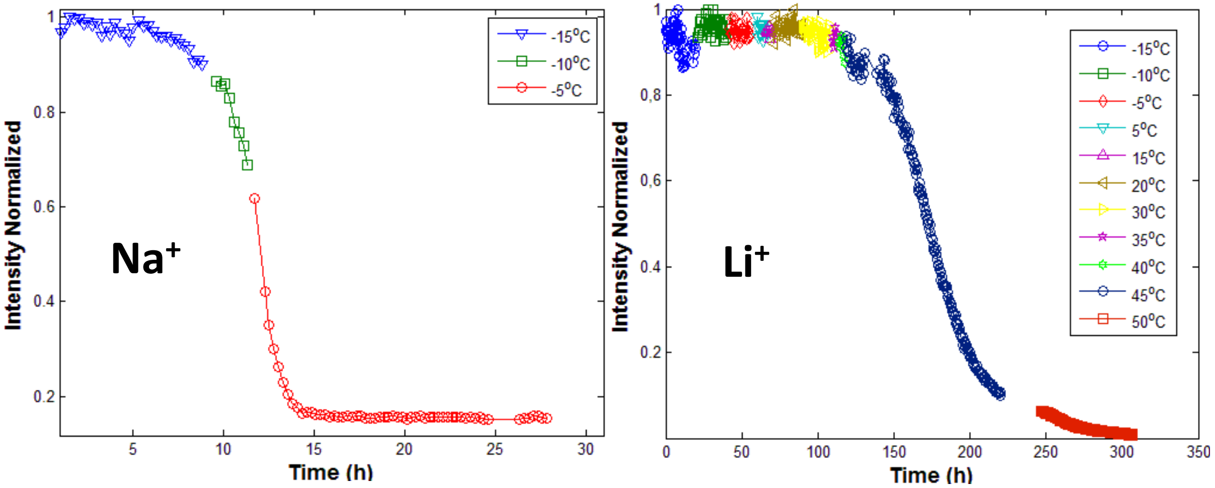


CO_2 Capture:

Faster uptake for:
Lower T or higher p

CO_2 Retention:

- N_2 flushing
- Increasing temperature

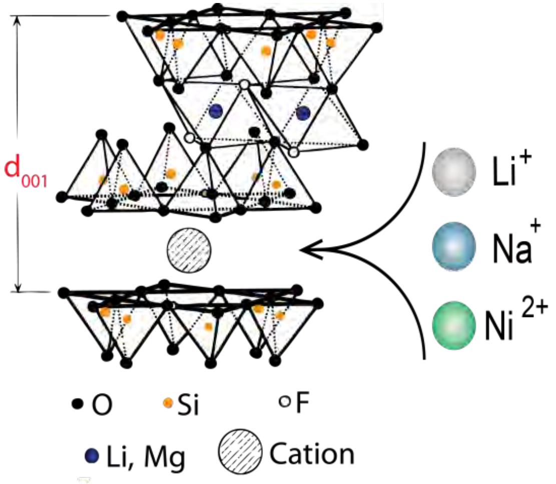


CO_2 polarisibility by Li^+ vs Na^+ ??

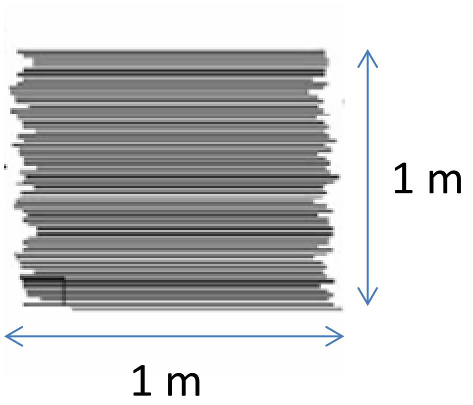
Simplest interpretation:

The clays provide a large surface area available for CO_2 capture.

The cations control capture and release of CO_2 (sometimes modified by clay swelling specifics).

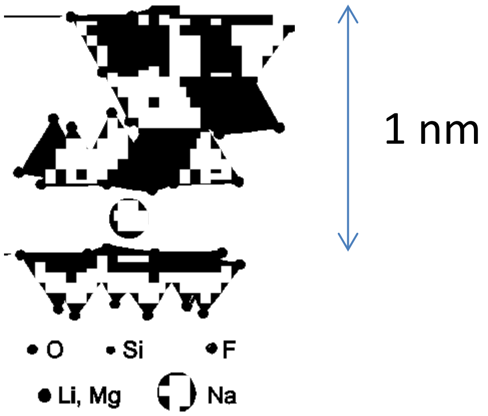


How much CO_2 is captured?



In 1 m^3 of compactly packed clay the total clay surface $2x10^9$ m^2 = 2000 $(km)^2$.
The typical packing density of our clay powder is 0.6, so **the total clay surface area available in 1 m^3 of clay powder** is 0.6x2000 $(km)^2$ **~ 1200 $(km)^2$**.

The lateral unit cell size is ~ < 1 $(nm)^2$, and there is about 1.2 monovalent charge compensating monovalent cations per unit cell area in fluorohectorite, i.e.
~1 cation per $(nm)^2$.



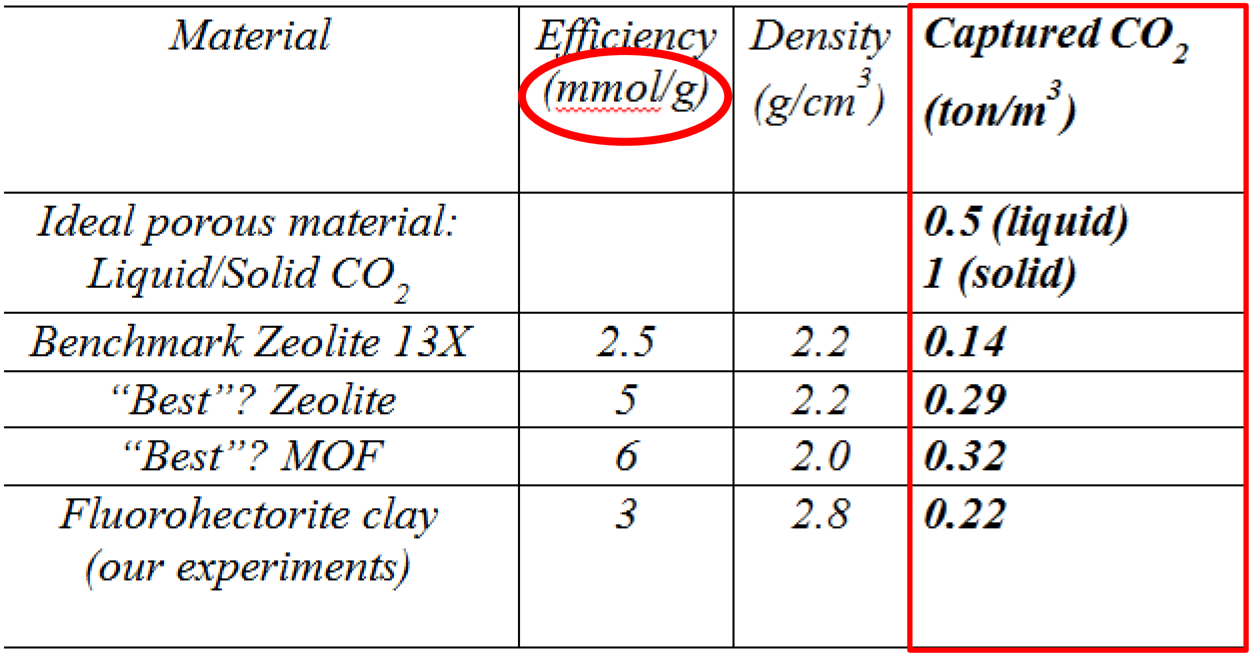
Assumption:
~2 CO_2 molecules captured per cation, (NMR: ~ 2 water molecules complexed per cation at ambient conditions), **which corresponds to ~ 2 CO_2 molecules captured per $(nm)^2$**.

~14% mass increase of the clay when saturated with CO_2, or ~0.22 tons CO_2/m^3 clay.

To check this we did:

pressure composition Temperature (pcT) experiments measure mass increase when sample is loaded with CO_2 => **15% mass increase, confirms assumption above**.

The amount of captured CO_2 for fluorohectorite clay compared with those of other materials.



Material	*Efficiency (mmol/g)*	*Density (g/cm^3)*	***Captured CO_2 (ton/m^3)***
Ideal porous material: Liquid/Solid CO_2			***0.5 (liquid) 1 (solid)***
Benchmark Zeolite 13X	2.5	2.2	***0.14***
"Best"? Zeolite	5	2.2	***0.29***
"Best"? MOF	6	2.0	***0.32***
Fluorohectorite clay (our experiments)	3	2.8	***0.22***

The density of liquid CO_2 is 0.77 ton/m^3 at 56 atm and 20 °C (the density of solid CO_2 is about twice of this) suggesting that ~1 ton CO_2 captured per m^3 is near the theoretical "perfect and unachievable" upper limit for CO_2 capture by any porous material, zeolite, MOF, carbon based, clay, or other.

Our synthetic fluorohectroite clay has about twice as many cations per (nm)^2 as compared to natural clays like bentonite.

Price comparison: Cost of producing synthetic smectites is about 1-10 USD/kg, whereas price of producing MOFs may be about 50 USD/kg.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Clays in BIONANOTECHNOLOGY

Parrots of the Amazones:

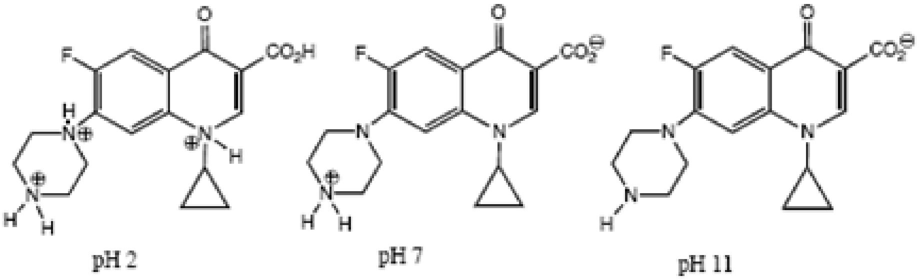
Parrots of the Amazon eat clay at riverbanks for breakfast in order to prevent stomach-ache from alkaloid poisons of the seeds in the fruits they eat for lunch.

Shows that clays may be interesting drug delivery systems

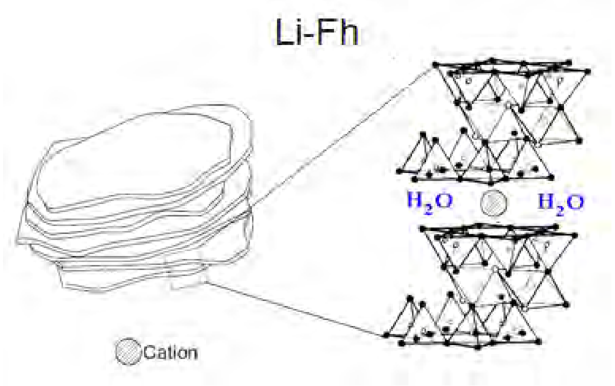
Cipro (ciprofloxacin) is an antibiotic in a group of drugs called fluoroquinolones (flor-o-KWIN-o-lones). It is used to fight bacteria in the body. Cipro is used to treat different types of bacterial infections. It may also be used to prevent or slow anthrax after exposure.

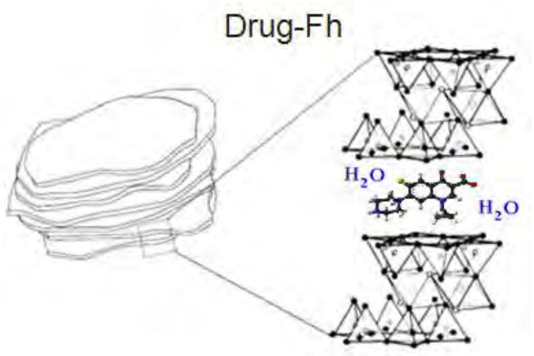
$C_{17}H_{18}FN_3O_3$

Zwitterionic



Positive **Dipole** **Negative**

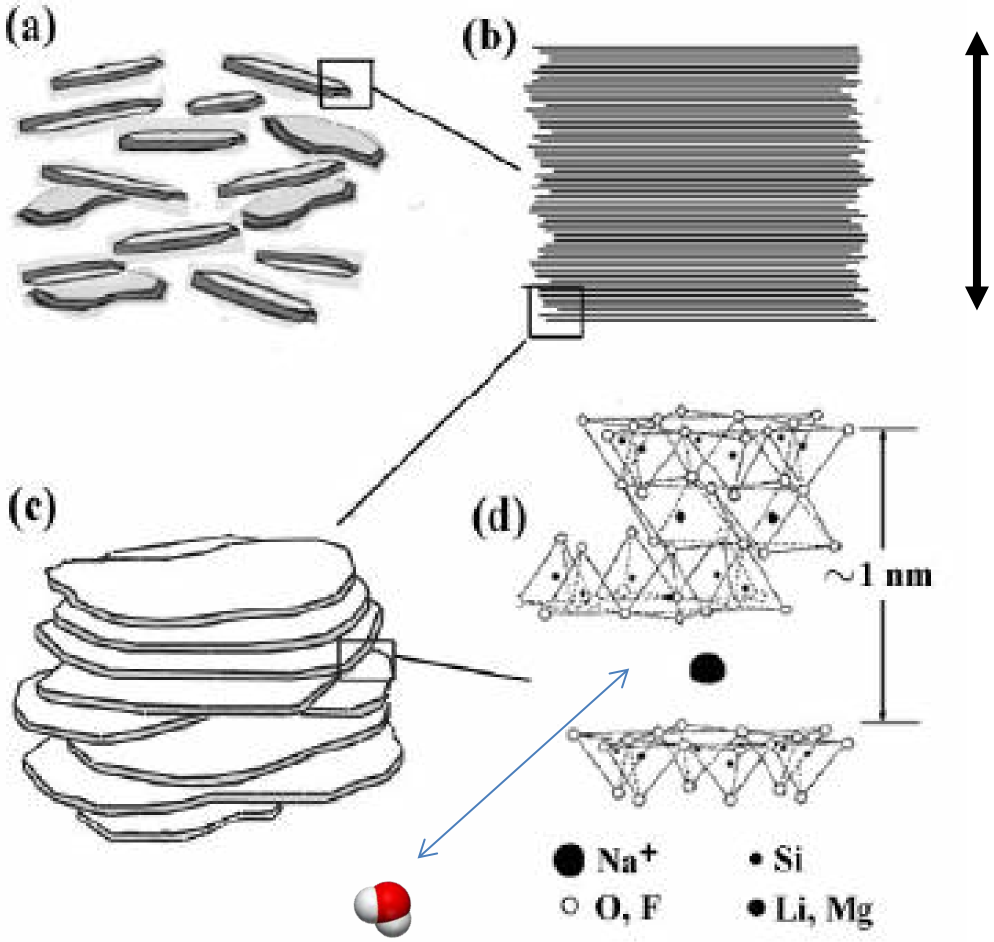




Intercalates by far best for acid pH
Different intercalation mechanism at pH 7?
Rapid release at basic pH
Techniques: XRD, UV-VIS Spectroscopy

Our clay experimental model system:

Q-fluorohectorite synthetic clay: Q_x-$(Mg_{3-x}Li_x)Si_4O_{10}F_2$,
Q is the exchangeable cation (Q = Na^+, Li^+, Ni^{2+}, Fe^{3+}, etc)

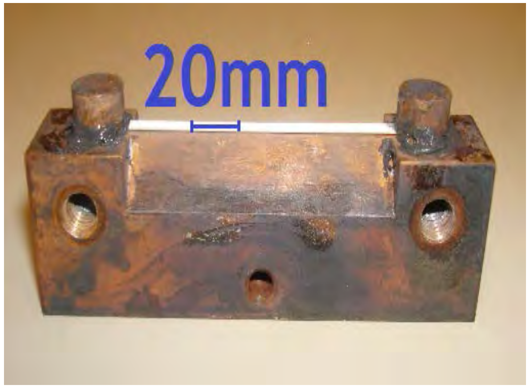


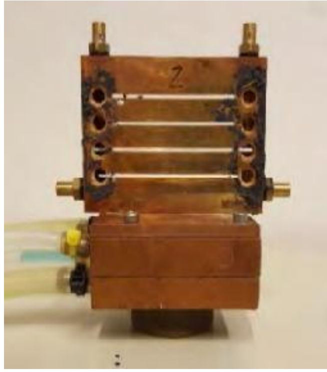
~ 100 nm

Water intercalation:

G. J. da Silva, J. O. Fossum, E. DiMasi, and K. J. Maloy,
Phys. Rev. B 67, 094114 2003.
G. J. da Silva, J. O. Fossum, E. DiMasi, K. J. Maloy, and S. B.Lutnaes,
Phys. Rev. E 66, 011303 2002.
R. P. Tenorio, L. R. Alme, M. Engelsberg, J. O. Fossum, and F. Hallwass,
J. Phys. Chem. C 112, 575 2008.
R. P. Tenorio, M.Engelsberg, J. O. Fossum, and G. J. da Silva,
Langmuir 26, 9703 2010.
H. Hemmen, L. R. Alme, J. O. Fossum and Y. Meheust,
Phys. Rev. E 82, 036315 2010.
E. L. Hansen, H. Hemmen, D. M. Fonseca, C. Coutant, K. D. Knudsen,
T. S. Plivelic, D. Bonn, J. O. Fossum,
Scientific Reports 2, 618 2012

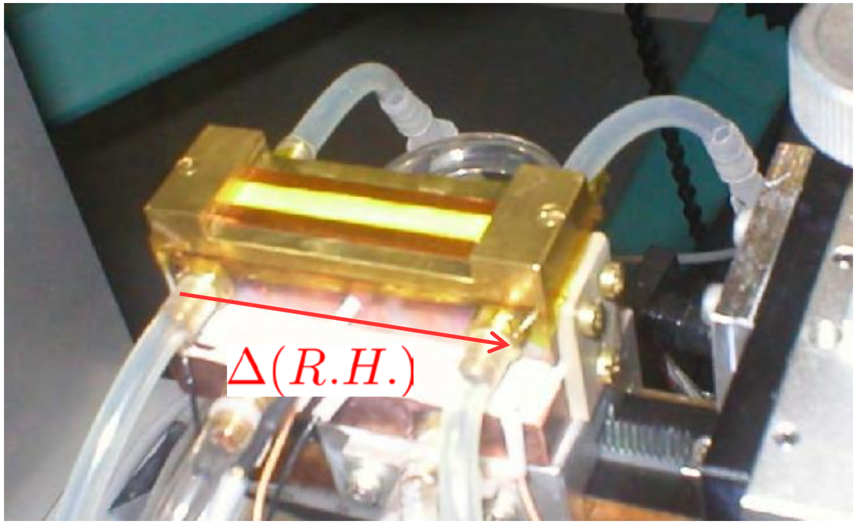
Water Transport Experiment

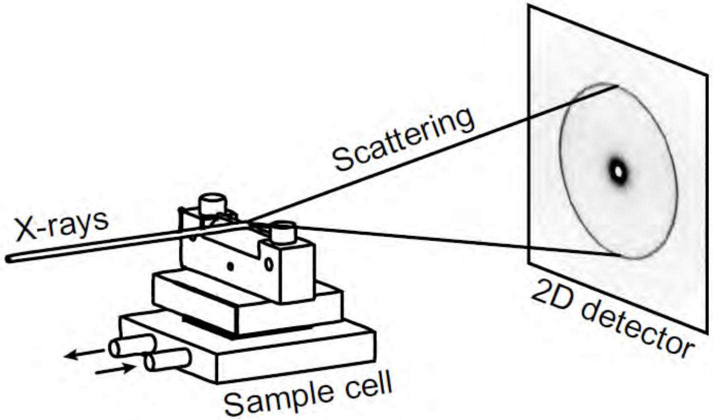


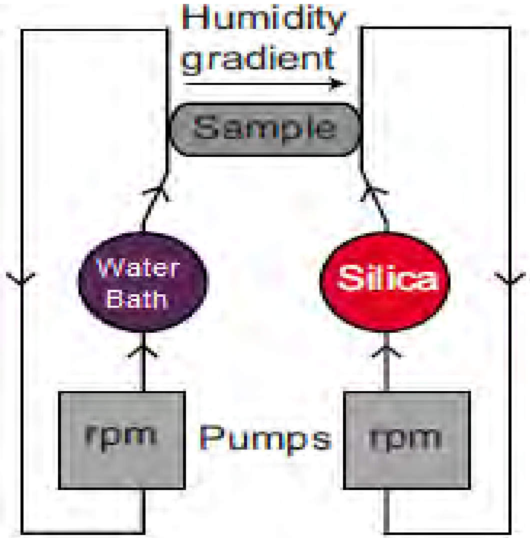


Only 2 cm of the capillary was observed using x-rays

→ Diffusive transport

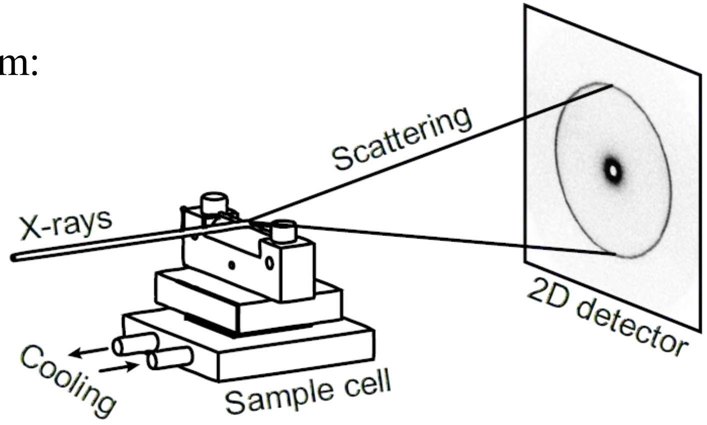




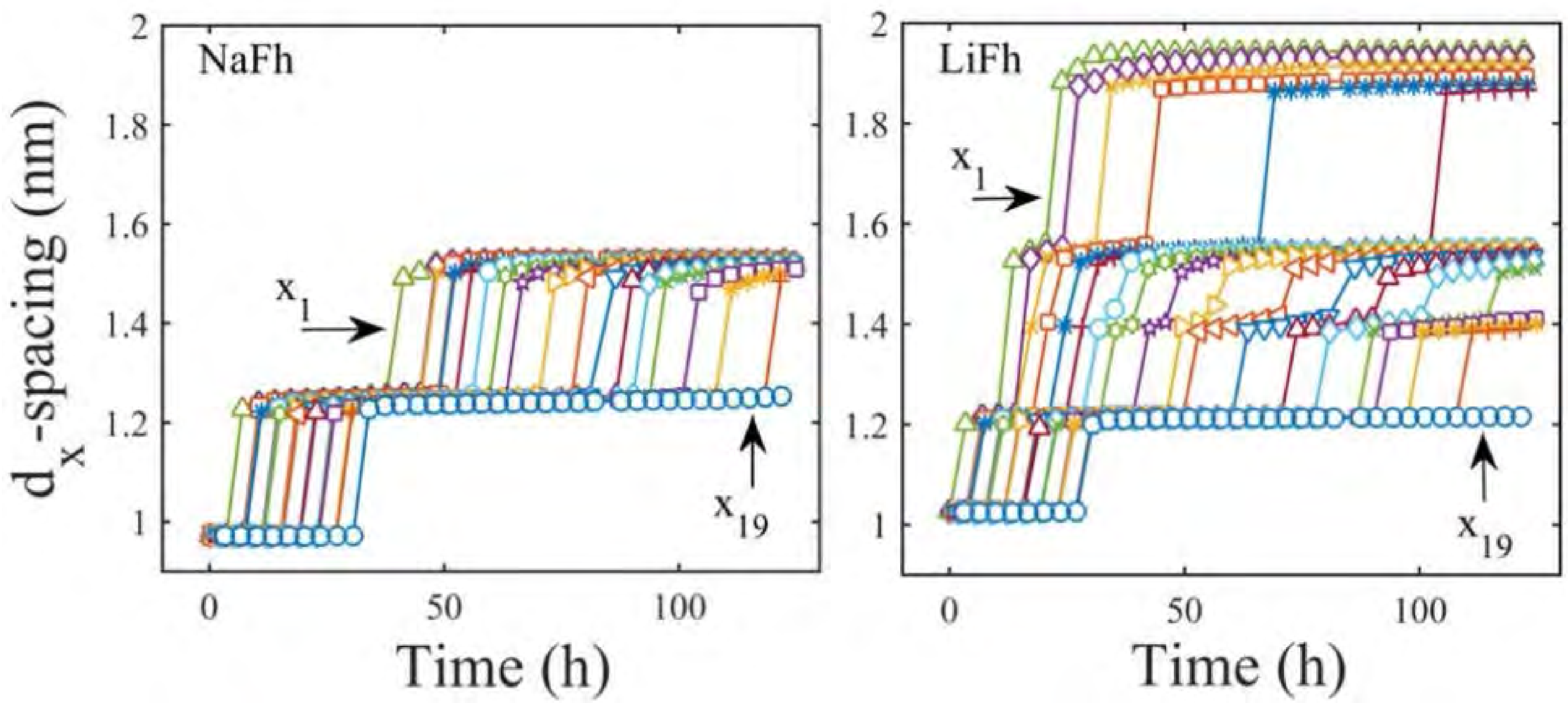


The Fluorohectorite was placed in 1 mm glass capillaries open in both ends, one end exposed to high relative water humidity (96%), the other end exposed to dry air (0.4%)

The sample is scanned forth and back in front of the X-ray beam:

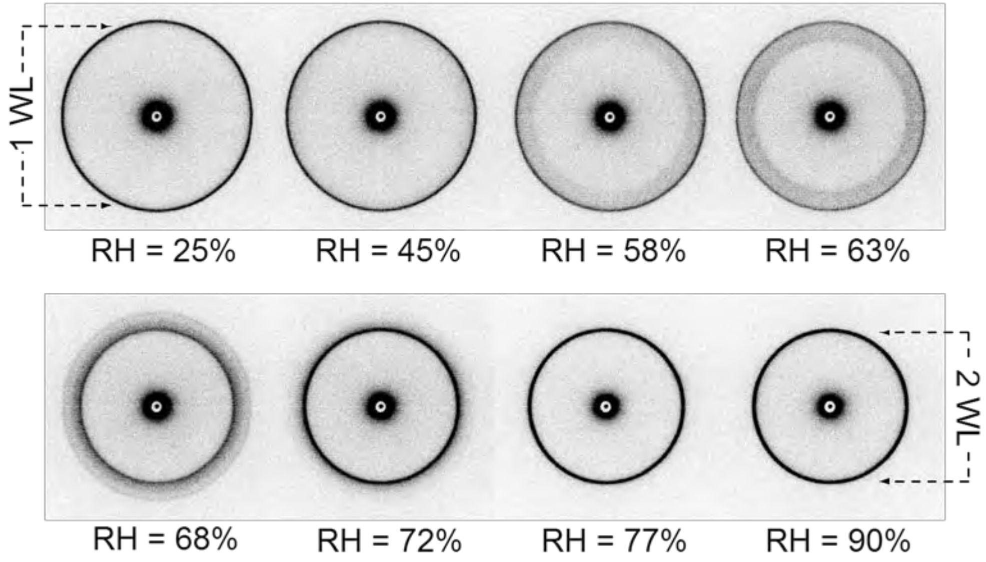


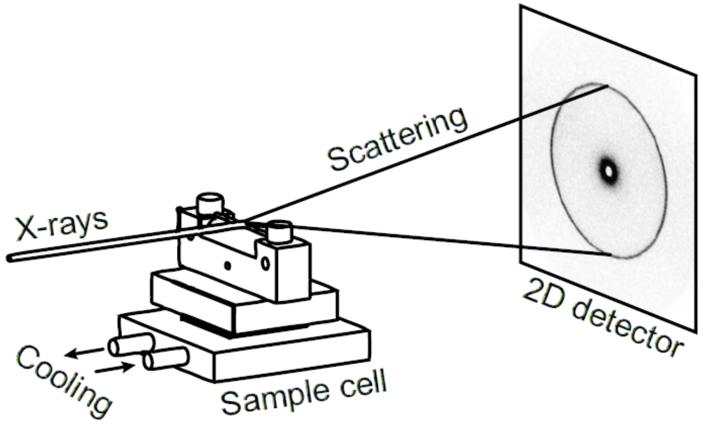
The hydration state is monitored at regular positions *x* as a function of time:



The sample is scanned forth and back in front of the X-ray beam:

- The quasi-isotropic clay powder diffracts the beam, resulting in circular high-intensity rings that denote the structural d-spacing d_{001} :

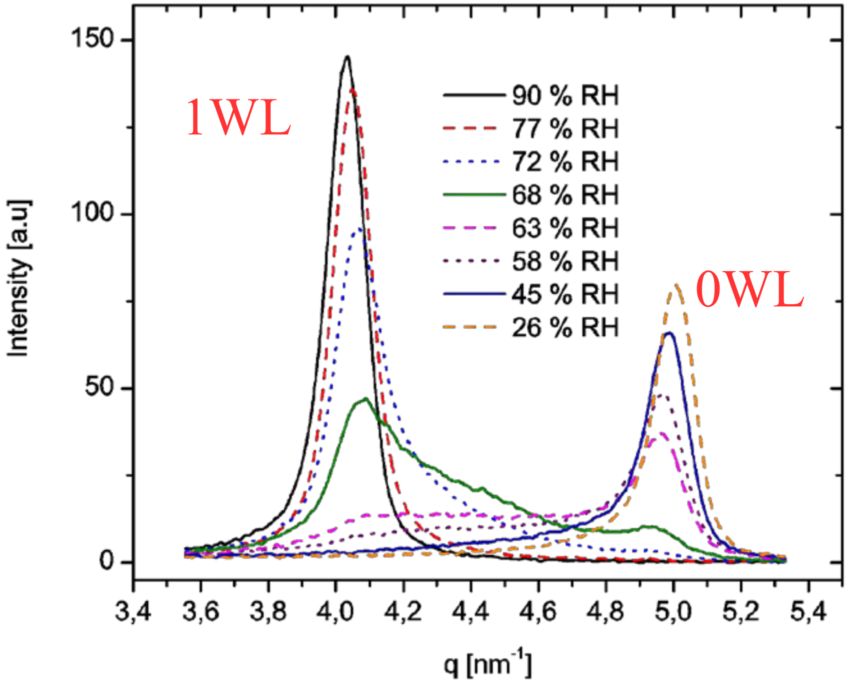




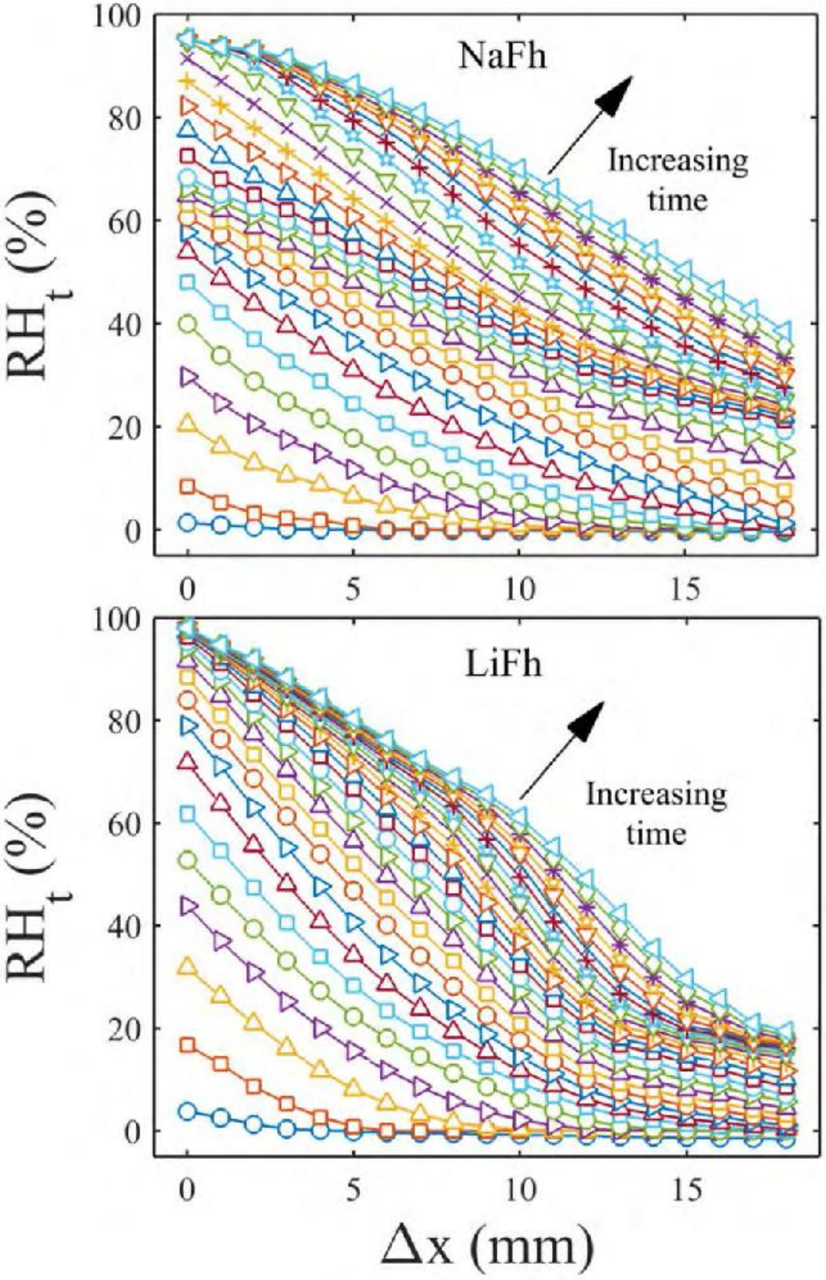
- Azimuthal integration of the rings provides 1D diffraction spectra

- The position of the peak is related to d_{001} :

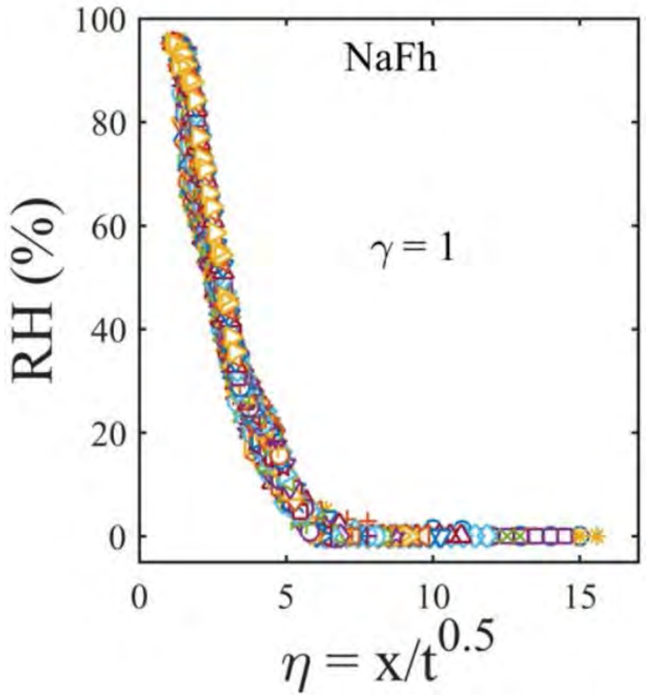
$$q = \frac{2\pi}{d}$$ (Bragg's law)

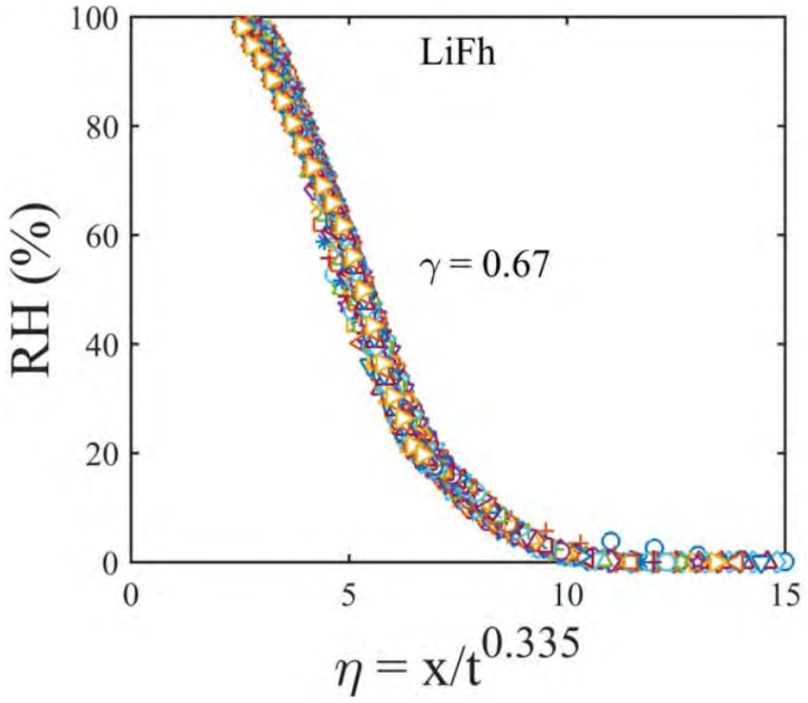


$q = (4\pi/\lambda) \sin\theta$


NaFh
Increasing time
LiFh
Increasing time
RH$_t$ (%)
RH$_t$ (%)
0
20
40
60
80
100
0
5
10
15
Δx (mm)

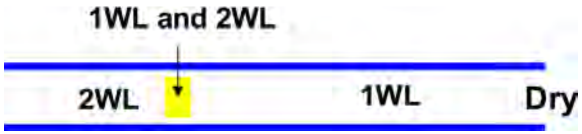
Using the values γ values inferred from the scaling of the intercalation fronts:



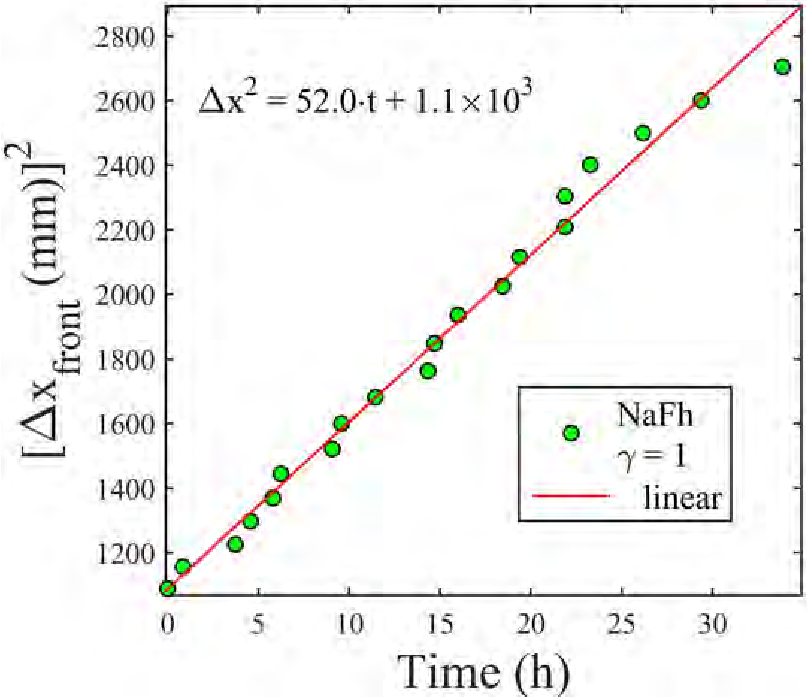


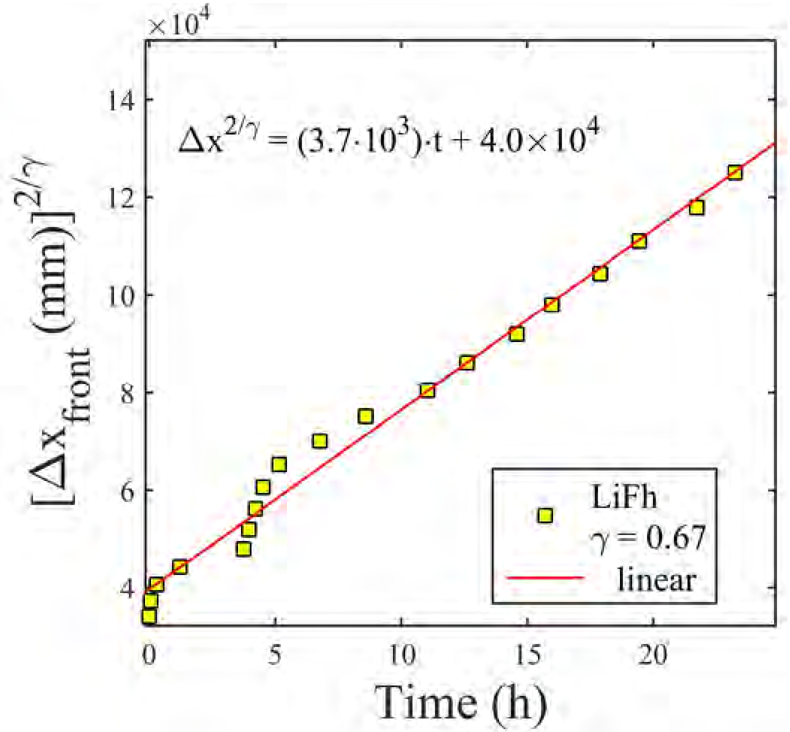
→Suggests anomalous transport for LiFh, normal transport for NaFh
→We now need to consider the concentration field in the mesoporous space

The longitudinal position of the hydration front is monitored as a function of time:



The position of the intercalation front is monitored as a function of time





→Suggests anomalous transport for LiFh, normal transport for NaFh
→We now need to consider the concentration field in the mesoporous space

Time it takes to diffuse 1 m:

NaFh: t_{1meter} ≈ 26 hours/$(2600*10^{-6})$ ≈ 10^4 hours ≈ **1 year**

LiFh: t_{1meter} ≈ 24 hours/$(12*10^4*10^{-9})$ ≈ $2*10^5$ hours ≈ **20 years**

Permanent and safe storage of nuclear waste

The Bentonite Barrier

Swelling properties, redox chemistry and mineral evolution

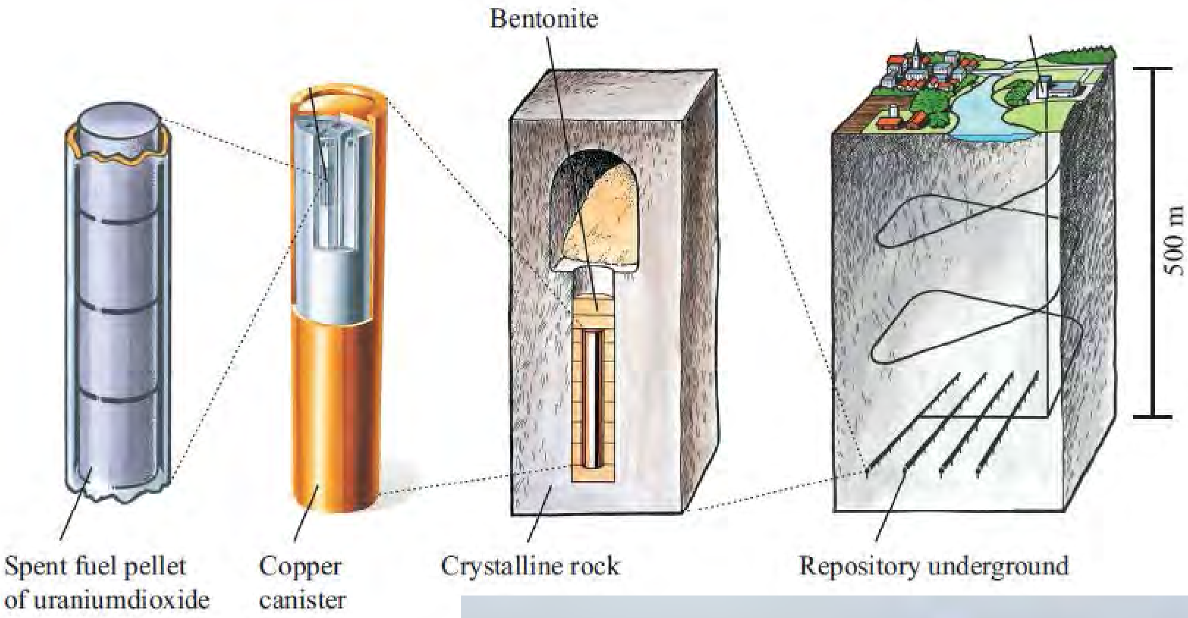
P. Daniel Svensson

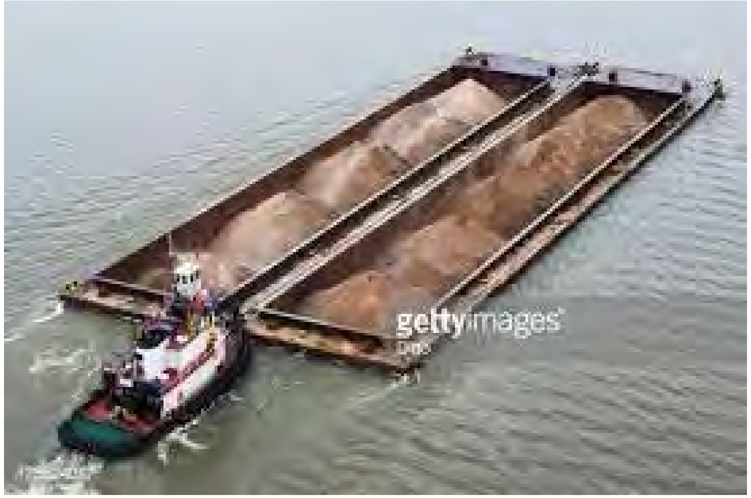
LUND UNIVERSITY

DOCTORAL DISSERTATION
by due permission of the Faculty of Engineering, Lund University, Sweden.
To be defended in public at the Center for Chemistry and Chemical Engineering, Lecture Hall K:C, on March 9, 2015, at 13:15.

Faculty opponent
Prof. Jon Otto Fossum, Norwegian University of Science and Technology

Swedish Nuclear Fuel and Waste Management Company (Svensk Kärnbränslehantering Aktiebolag, abbreviated **SKB**):
Swedish demand for clays as nuclear waste barriers amounts to about one shipload per year.





Synthetic clays?

New development of, or enhancing existing, forestry or agriculture for CO_2 capture and improved living conditions

Trees or agriculture in Sahara or similar dry environments? For large scale CO_2 capture?

www.desertcontrol.com

Kristian P. Olesen

CEO

Patent Holder

Cover the sand with a layer of clay aqueous suspension and add fertilizer in order to capture the evaporating otherwise excaping ground water? (www.desertcontrol.com)

Sinai Desert test site: Before and after soil treatment with NanoClay

Clay based electronics:

Take part in Nature Publishing Group's annual reader survey here for the chance to win a Macbook Air.

NATURE | LETTER

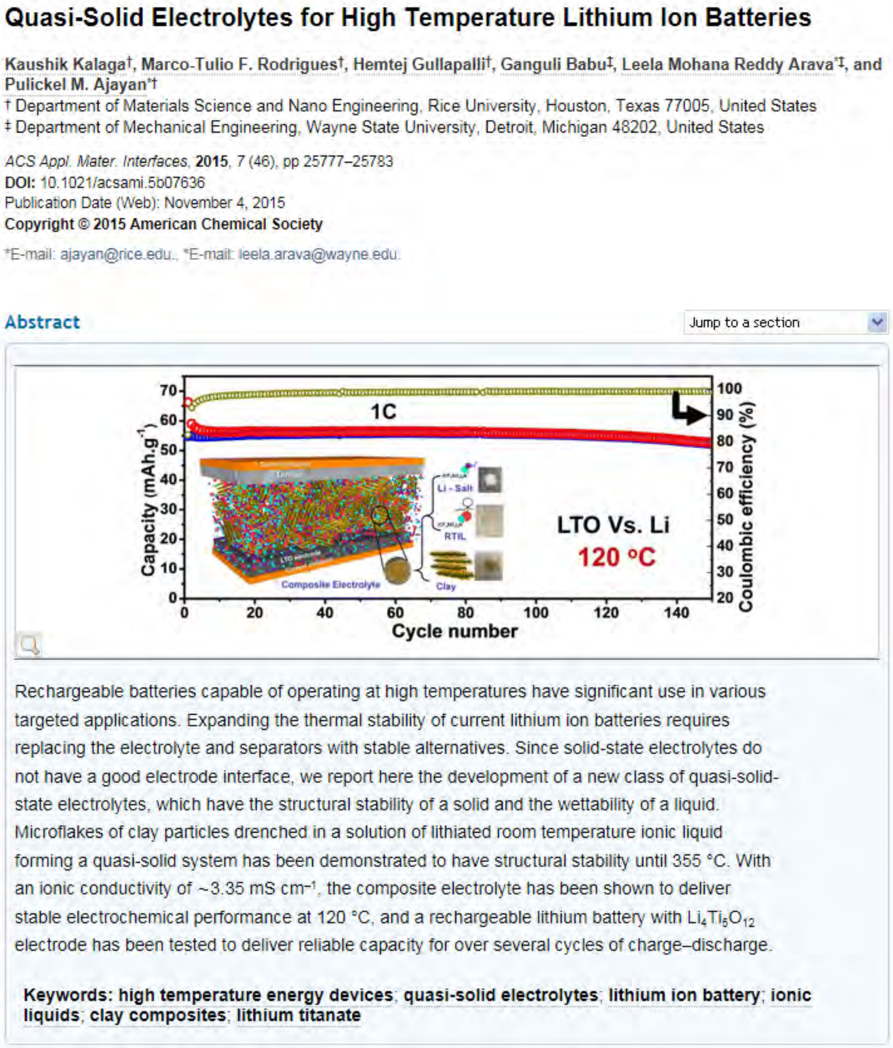
日本語要約

Conductive two-dimensional titanium carbide 'clay' with high volumetric capacitance

Michael Ghidiu, Maria R. Lukatskaya, Meng-Qiang Zhao, Yury Gogotsi & Michel W. Barsoum

Department of Materials Science and Engineering, and A. J. Drexel Nanomaterials Institute, Drexel University, Philadelphia, Pennsylvania 19104, USA

Nature **516**, 78–81 (04 December 2014) | doi:10.1038/nature13970
Received 08 August 2014 | Accepted 13 October 2014 | Published online 26 November 2014



Quasi-Solid Electrolytes for High Temperature Lithium Ion Batteries

Kaushik Kalaga[†], Marco-Tulio F. Rodrigues[†], Hemtej Gullapalli[†], Ganguli Babu[‡], Leela Mohana Reddy Arava*[‡], and Pulickel M. Ajayan*[†]

[†] Department of Materials Science and Nano Engineering, Rice University, Houston, Texas 77005, United States
[‡] Department of Mechanical Engineering, Wayne State University, Detroit, Michigan 48202, United States

ACS Appl. Mater. Interfaces, **2015**, 7 (46), pp 25777–25783
DOI: 10.1021/acsami.5b07636
Publication Date (Web): November 4, 2015

*E-mail: ajayan@rice.edu., *E-mail: leela.arava@wayne.edu.

Abstract

Rechargeable batteries capable of operating at high temperatures have significant use in various targeted applications. Expanding the thermal stability of current lithium ion batteries requires replacing the electrolyte and separators with stable alternatives. Since solid-state electrolytes do not have a good electrode interface, we report here the development of a new class of quasi-solid-state electrolytes, which have the structural stability of a solid and the wettability of a liquid. Microflakes of clay particles drenched in a solution of lithiated room temperature ionic liquid forming a quasi-solid system has been demonstrated to have structural stability until 355 °C. With an ionic conductivity of ~3.35 mS cm^{-1}, the composite electrolyte has been shown to deliver stable electrochemical performance at 120 °C, and a rechargeable lithium battery with $Li_4Ti_5O_{12}$ electrode has been tested to deliver reliable capacity for over several cycles of charge–discharge.

Keywords: high temperature energy devices; quasi-solid electrolytes; lithium ion battery; ionic liquids; clay composites; lithium titanate

Clay based electronics?
Nanolayered materials beyond graphene: Heterostructures and metamaterials

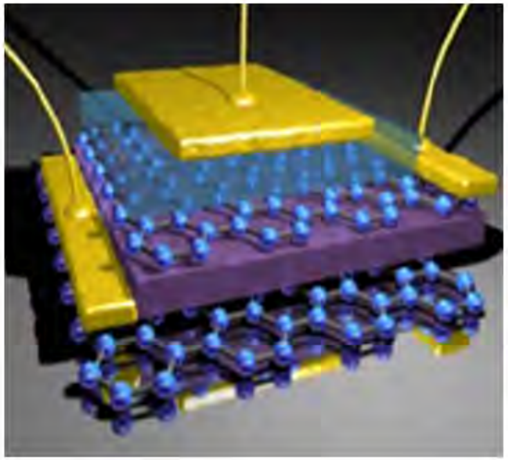


Figure 1:
Principal sketch of our graphene-clay electronic device, manually assembled at Univ. Manchester in Prof. Novoselov's group, using manual exfoliation techniques developed in that laboratory.

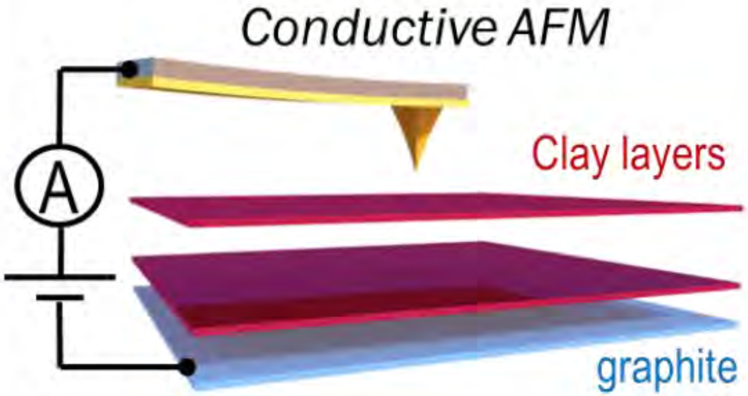


Figure 2:
Principle sketch of experimental set-up for measurements of IV-characteristic of our prototype graphene-clay device. The experiments were performed at Univ. Manchester in Prof. Novoselov's group.

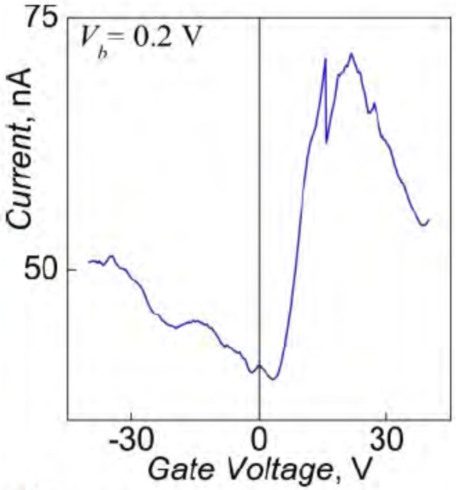
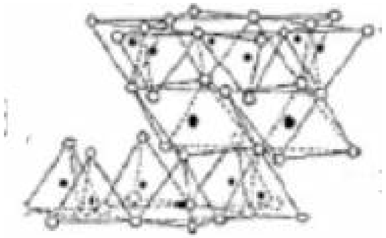


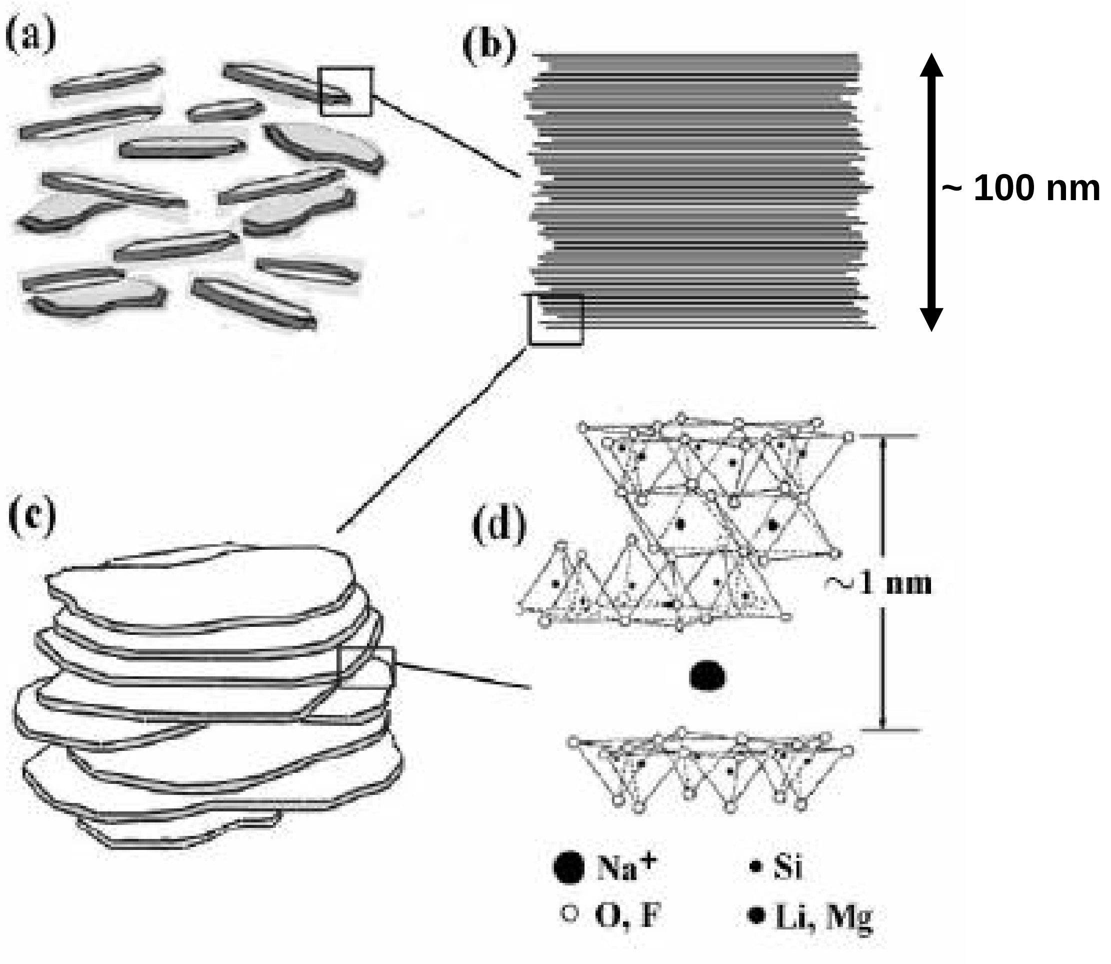
Figure 3:
Preliminary tunneling I-V characteristics for our prototype graphene-clay device. The experiments performed at Univ. Manchester.

Electronic and magnetic properties along or perpendicular to the clay sheets etc.



Our clay experimental model system:

Q-fluorohectorite synthetic clay: Q_x-$(Mg_{3-x}Li_x)Si_4O_{10}F_2$,
Q is the exchangeable cation (Q = Na^+, Li^+, Ni^{2+}, Fe^{3+}, etc)



Sources of fluorohectorite:

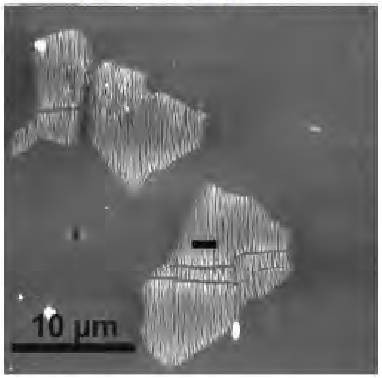
Corning Inc.
x ≈ 0.6 ± 0.05
Lateral ~ 0.5-10 μm
(incl. 20% known impurities)

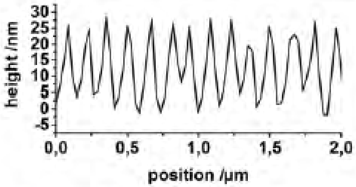
Inorg. Chem.
Univ. Bayreuth, Germany
Prof. Josef Breu
x = (0.2 <->0.6) ± 0.005
Lateral > 100 μm
(pure)

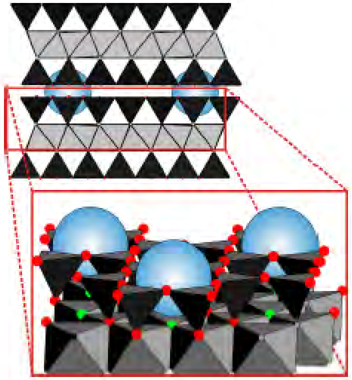
Nanomechanics – Wrinkling

$$E_p = \frac{3E_s\left(1-\nu_p^2\right)}{\left(1-\nu_s^2\right)}\left(\frac{\lambda}{2\pi h}\right)^3$$

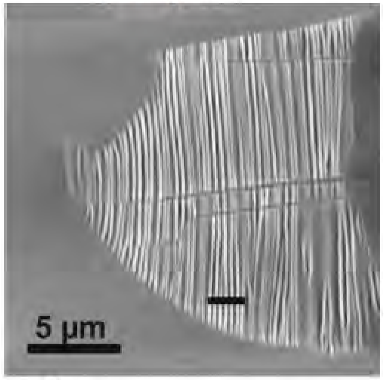
Monolayer

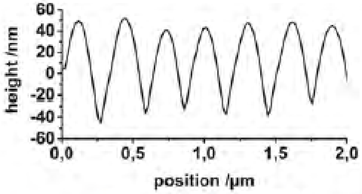






Bilayer





wavelength: 145 ± 7 nm
In-plane modulus: 0.15 ± 0.02 TPa

wavelength: 313 ± 10 nm
In-plane modulus: 0.17 ± 0.01 TPa

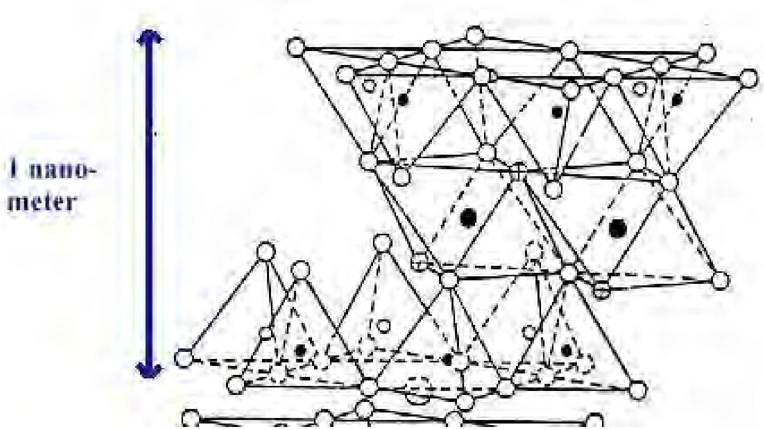
D.A. Kunz et al., *Adv. Mater.* **2013** *25* 1337.
D.A. Kunz et al. *ACS Appl.Mat.Interf.* **2013**. 5, 5851.

CLAY MINERALS AND THE ORIGIN OF LIFE

The confinement by cell membranes offers localized concentration and protection for biomolecules such as nucleic acids, leading to efficient biochemical reactions.

In defining the pre-cellular environment, it is important to address the following questions:

1) **How did biomolecules encounter each other and maintain sufficient proximity to perform complicated biochemical reactions?**
2) **How did the biomolecules survive in the environment without any protection?**

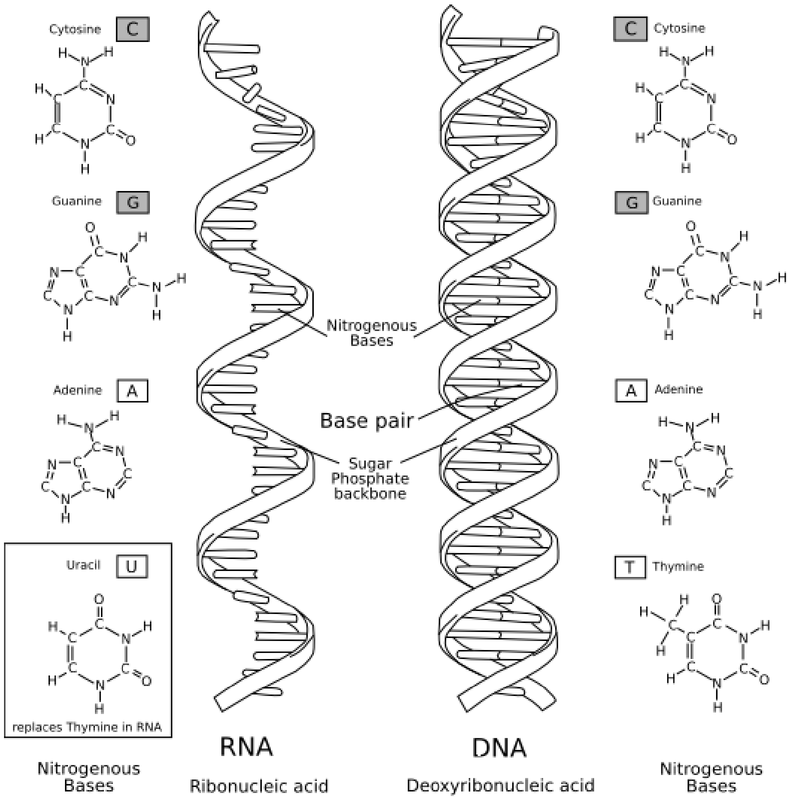


Bernal (1951), first suggested that clay minerals played a key role in chemical evolution and the origins of life because of their ability to take up, protect (against ultraviolet radiation), concentrate, and catalyze the polymerization of, organic molecules.

Clay minerals have been proposed as a likely candidate among solid materials to play roles for life evolution, due to their wide distribution, historical prevalence throughout the timeline of geological and biological events on Earth and their affinity for organic molecules.

For example, clay has been demonstrated to be capable of catalyzing the polymerization of RNA and accelerating the formation of fattyacid vesicles (a protocell model).

Clay -> Selection and Amplification of Chemistry

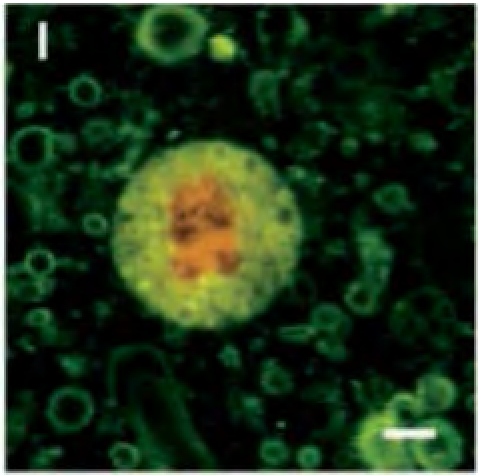


The RNA world refers to the self-replicating ribonucleic acid (RNA) molecules hypothesised to have been the precursors to all current life on Earth.

Supported by several lines of evidence including how RNA was protected on the early earth.

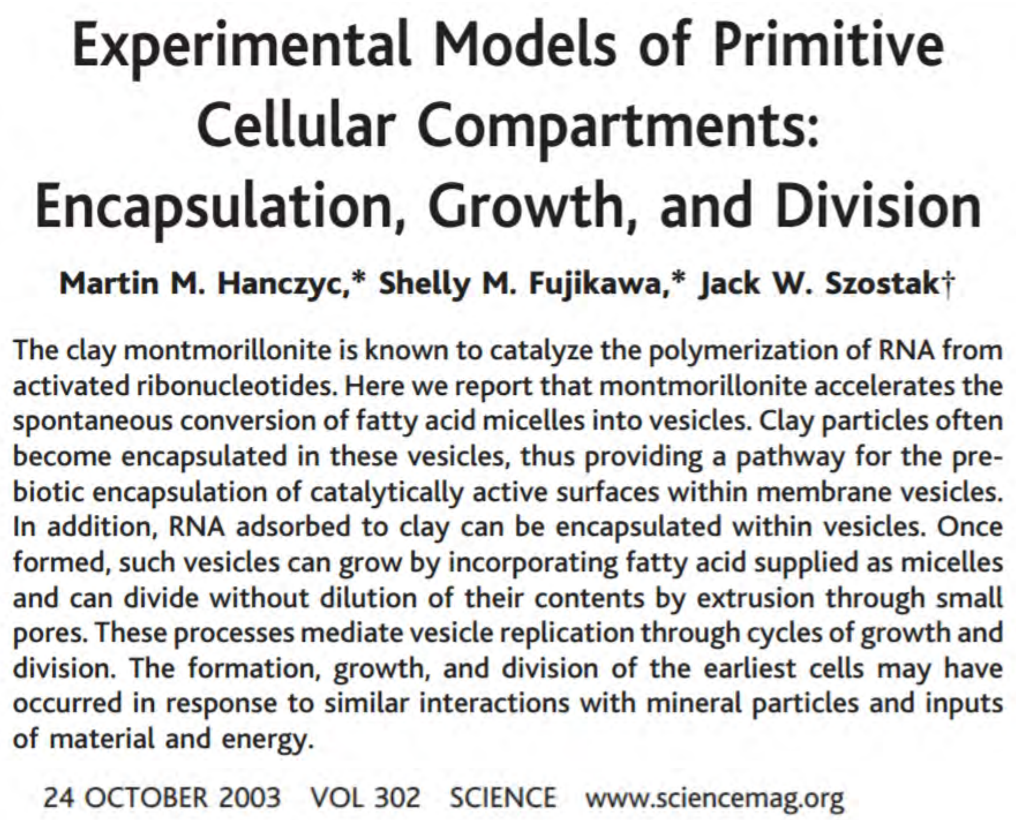
Eventually DNA is thought to have taken over the role RNA in data storage due to its increased stability, while proteins, through a greater variety of monomers (amino acids), replaced RNA's role in specialized biocatalysis.

Smectite clay tends to adsorb organic compounds and this contributes to its ability to catalyze a variety of organic reactions critical to scenarios of life’s origins. It has been shown experimentally that RNA molecules bind efficiently to clays and that montmorillonite can catalyze the formation of longer molecules (oligomers), thus lending support to the RNA world hypothesis.



Life on Earth: Fresh clues hint at how the first living organisms arose from inanimate matter, Alonso Ricardo and **Jack W. Szostak**, Scientific American, September 2009, pp. 54-61

(I) Montmorillonite smectite clay coated with Cy3-labeled RNA (red) trapped inside dye-labeled vesicles (green).



Experimental Models of Primitive Cellular Compartments: Encapsulation, Growth, and Division

Martin M. Hanczyc,* Shelly M. Fujikawa,* Jack W. Szostak†

The clay montmorillonite is known to catalyze the polymerization of RNA from activated ribonucleotides. Here we report that montmorillonite accelerates the spontaneous conversion of fatty acid micelles into vesicles. Clay particles often become encapsulated in these vesicles, thus providing a pathway for the prebiotic encapsulation of catalytically active surfaces within membrane vesicles. In addition, RNA adsorbed to clay can be encapsulated within vesicles. Once formed, such vesicles can grow by incorporating fatty acid supplied as micelles and can divide without dilution of their contents by extrusion through small pores. These processes mediate vesicle replication through cycles of growth and division. The formation, growth, and division of the earliest cells may have occurred in response to similar interactions with mineral particles and inputs of material and energy.

24 OCTOBER 2003 VOL 302 SCIENCE www.sciencemag.org

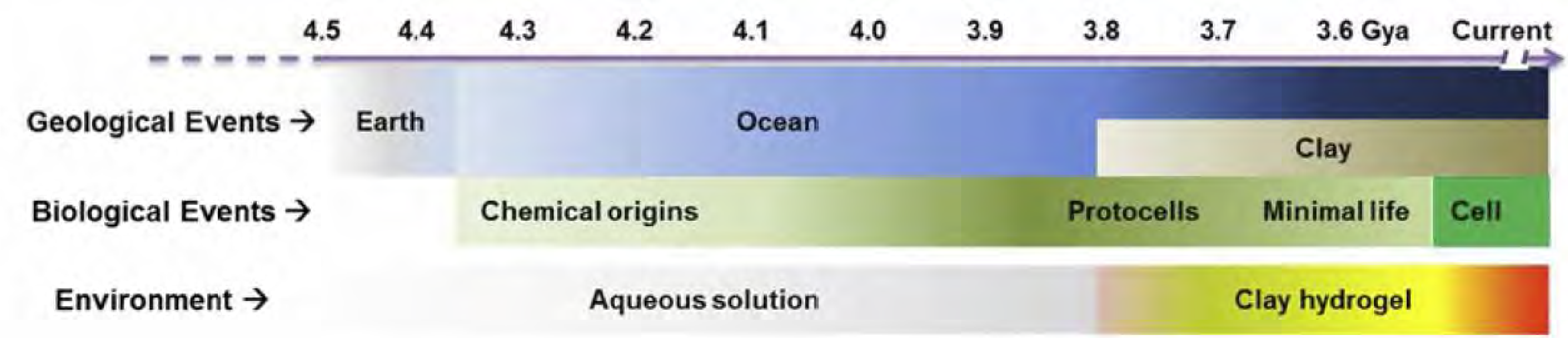
The Szostak Lab

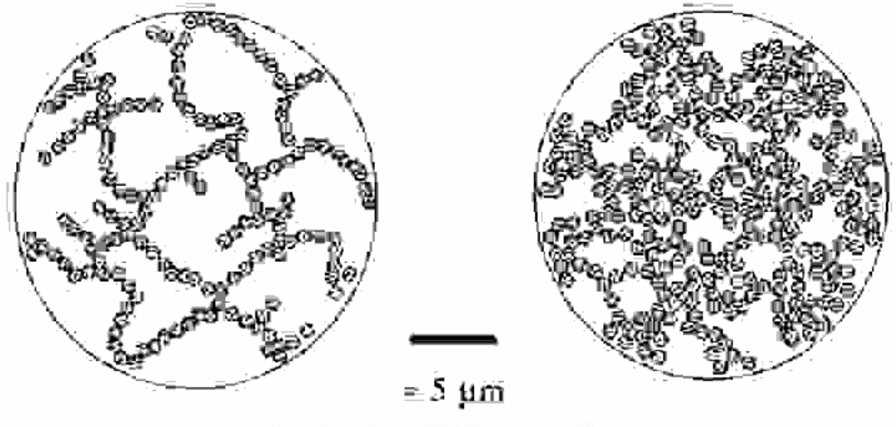
http://molbio.mgh.harvard.edu/szostakweb/

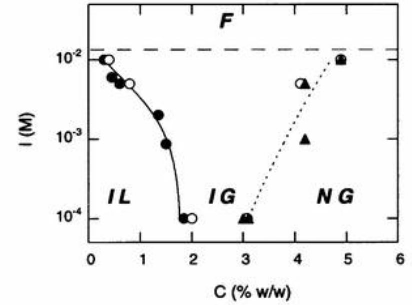
Jack William Szostak : Biologist, Nobel Prize laureate Medicine 2009, Professor of Genetics at Harvard Medical School, and Alexander Rich Distinguished Investigator at Massachusetts General Hospital, Boston

Enhanced transcription and translation in clay hydrogel and implications for early life evolution, Dayong Yang, Songming Peng, Mark R. Hartman, Tiffany Gupton-Campolongo, Edward J. Rice,Anna Kathryn Chang, Zi Gu, G. Q. (Max) Lu & Dan Luo, **SCIENTIFIC REPORTS , 3 : 3165, DOI: 10.1038/srep03165 (2013)**

~ RNA world

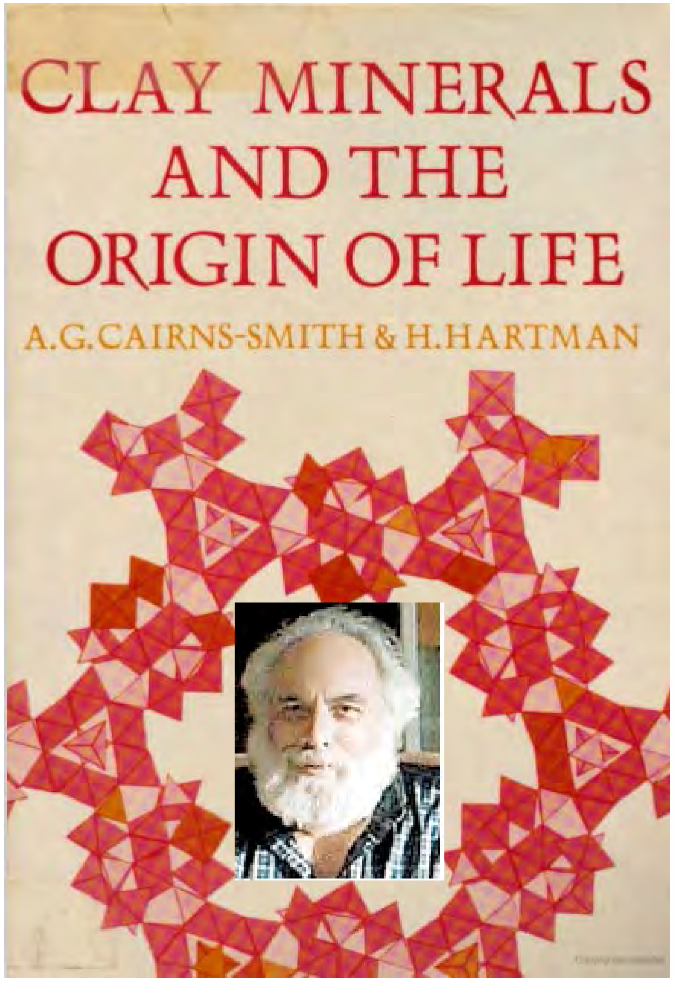






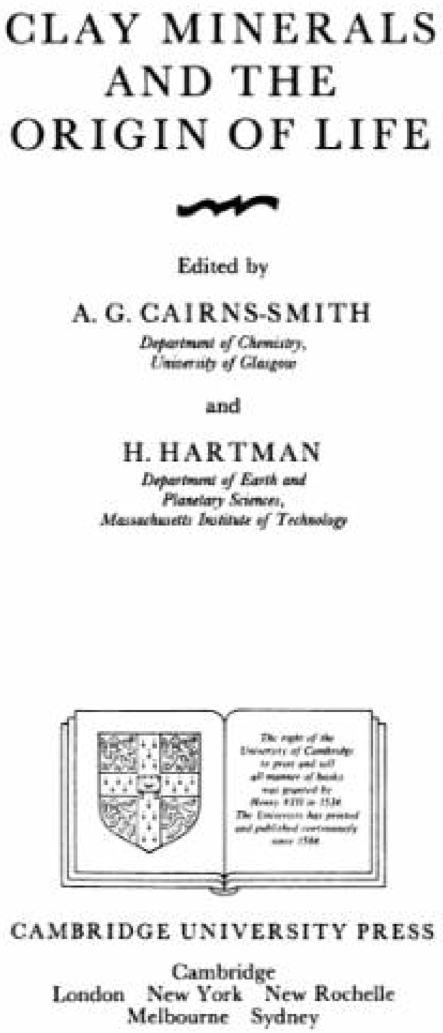
Confinement by clay hydrogel provide an effective environment for localized concentration and protection of nucleic acids.

Bulk-scale clay hydrogel is easily broken down by shear forces into micro-particles, which act as the confinement for biomolecules and biochemical reactions



CLAY MINERALS AND THE ORIGIN OF LIFE

A.G.CAIRNS-SMITH & H.HARTMAN



CLAY MINERALS
AND THE
ORIGIN OF LIFE

Edited by

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Department of Chemistry,
University of Glasgow

and

H. HARTMAN
Department of Earth and
Planetary Sciences,
Massachusetts Institute of Technology

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-The physical basis of life, Bernal, J. D. (Routledge & K. Paul London; 1951).

-Mineral Catalysis and Prebiotic Synthesis: Montmorillonite-Catalyzed Formation of RNA, James P. Ferris, ELEMENTS 1, 145-149 (2005)

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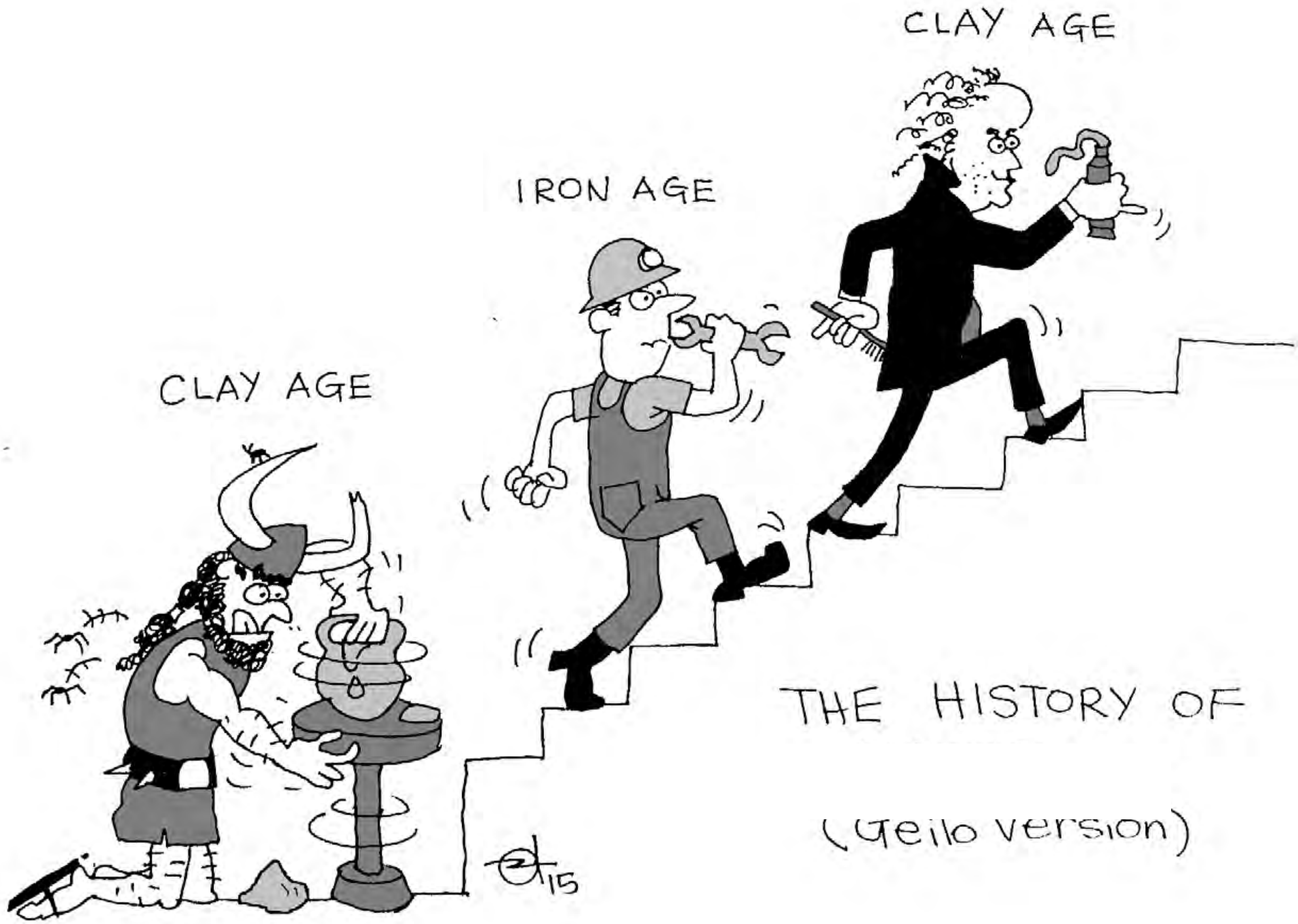
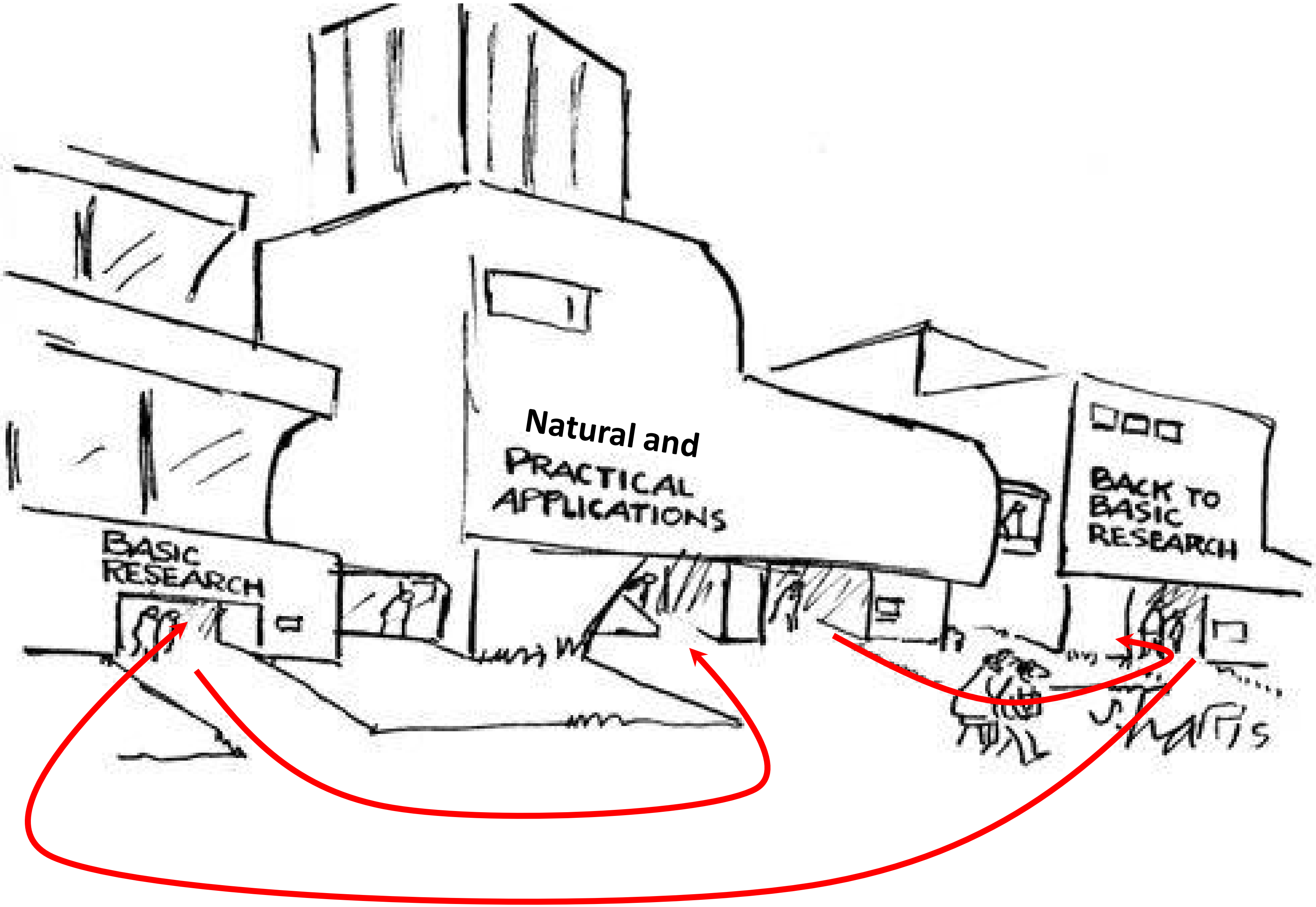
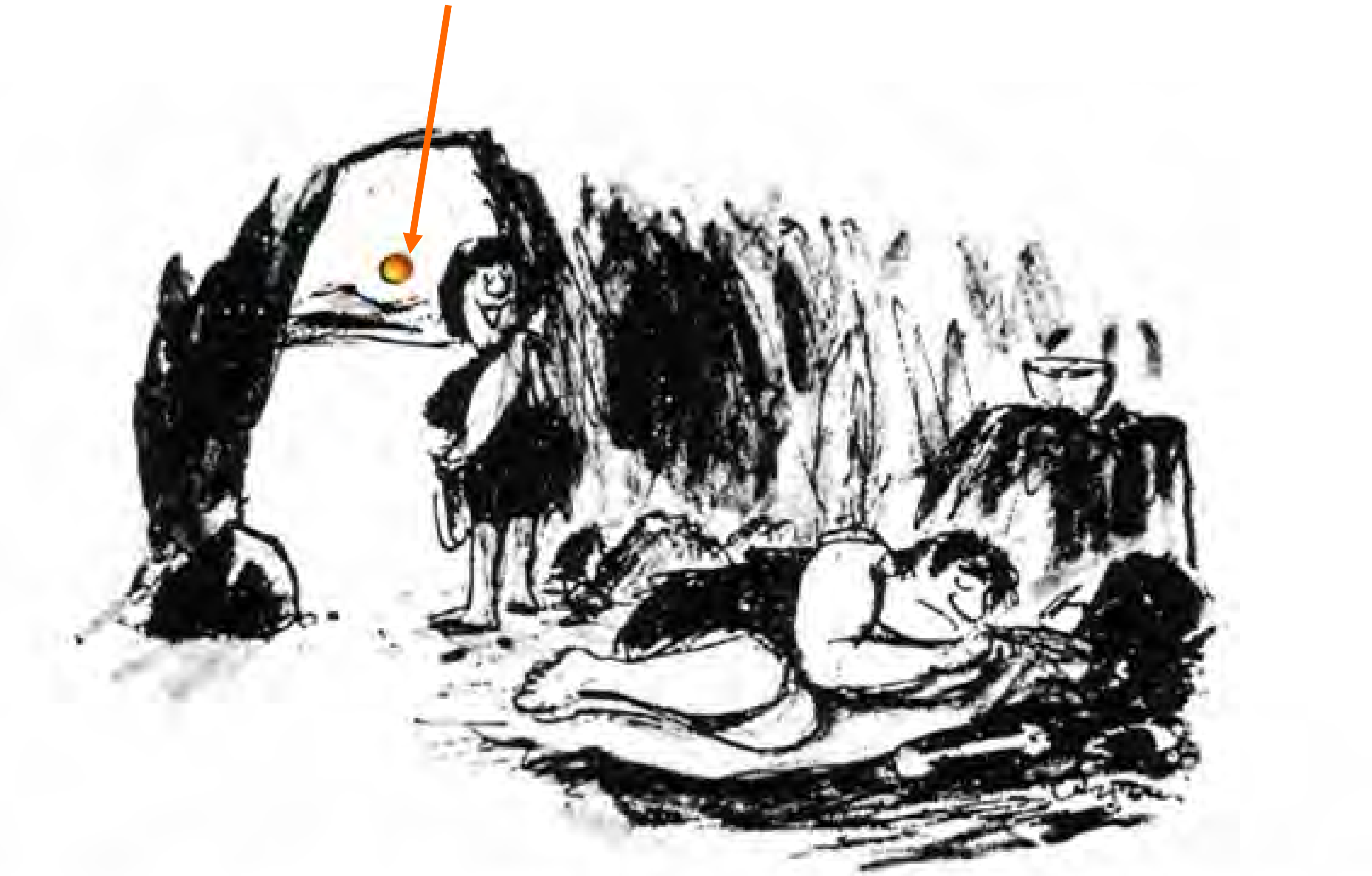
There is lots of work to do, and this is our goal? Liquid or Solid at will? Emerging life?



Drawing by Ernesto Altshuler


Natural and
PRACTICAL
APPLICATIONS
BASIC
RESEARCH
BACK TO
BASIC
RESEARCH
S. HARRIS

We are curiosity driven. Very little industrial funding.

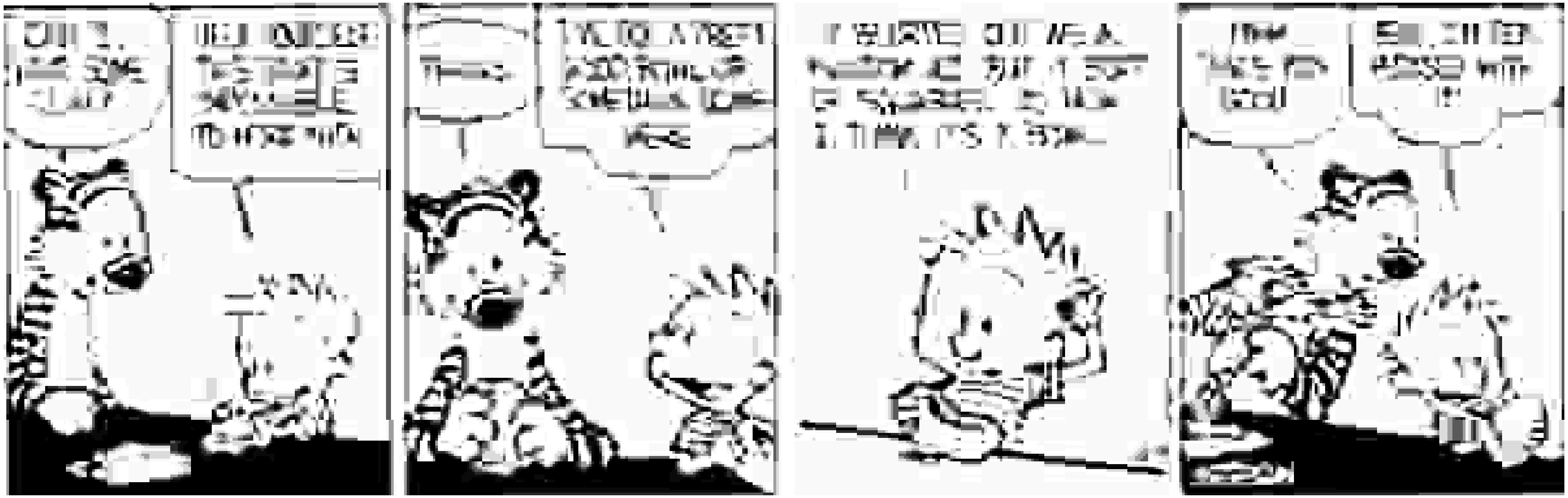


«HEY, SAM, THE BIG ROUND YELLOW THING CAME UP AGAIN»

Acknowledgements to

MSc + PhD students, postdocs,
Collaborators in several countries

Clay baths will prolong your life:



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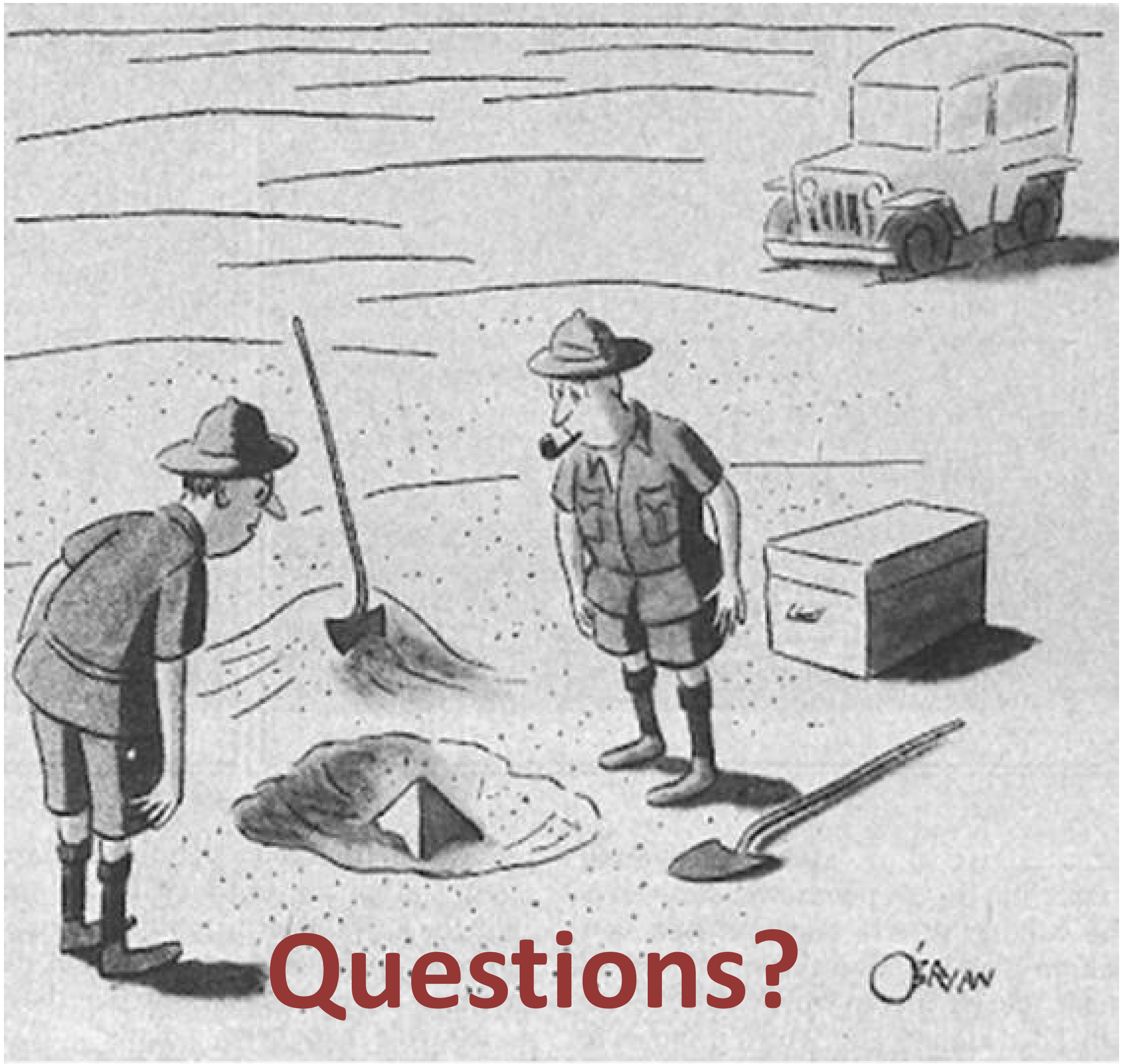

Questions?

"This could be the discovery of the century. Depending, of course, on how far down it goes."