The effect of the structure of clay minerals on their electrical properties

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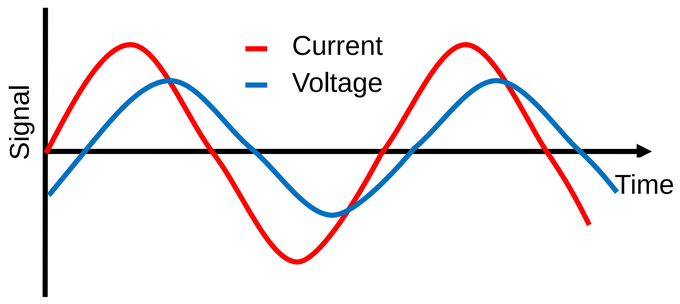
Background

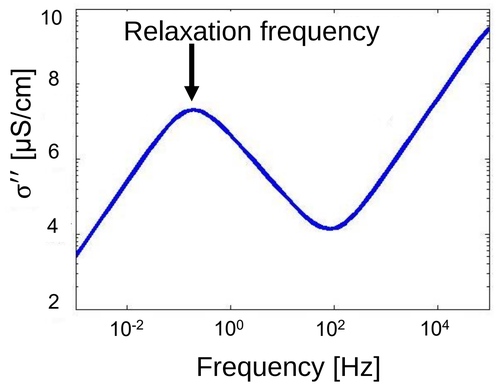
The subsurface is a fundamental resource for water, food, and is essential for sustaining life. Characterization of the subsurface is a scientific and engineering challenge. Clay minerals are an important active component of the subsurface. They are adsorbents for inorganic metals and organic solutes, and therefore critical part of plants and environmental processes.

Recently, there is an increasing interest in utilizing geoelectrical methods for subsurface characterization because they are non-invasive, not expensive and can be used to map properties of the subsurface.

Compared to other geoelectrical methods, spectral induced polarization (SIP) is highly sensitive to the surface and the bulk properties. Using this method, we can explore and monitor solid-water interfacial processes of the subsurface and quantify the relationships between structure and electrical properties of clay minerals.

Using the SIP method, we measure the electrical potential that results from the injection of an oscillating current (typically 1mHz to 1kHz). The ratio between the current and the potential is the complex electrical conductivity σ^*.



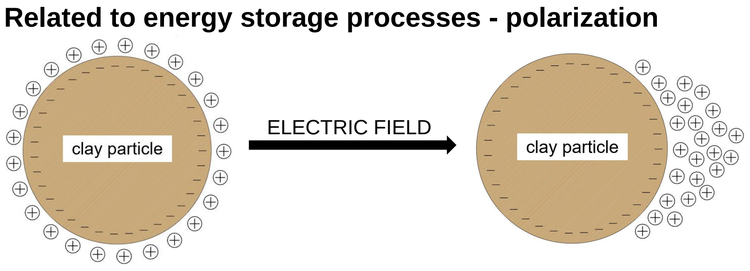


$$\sigma^* = \sigma' + i\sigma''$$

σ' (In-phase conductivity) – Related to dissipation processes

σ'' **(Quadartue conductivity) – Related to energy storage processes - polarization**

Stern layer polarization:



Objective

Characterizing the effect of physicochemical properties on SIP signature of clay minerals

Clay minerals properties:
- CEC – cation exchange capacity
- Mineral structure

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SIP signature:
- Magnitude of polarization
- Relaxation time

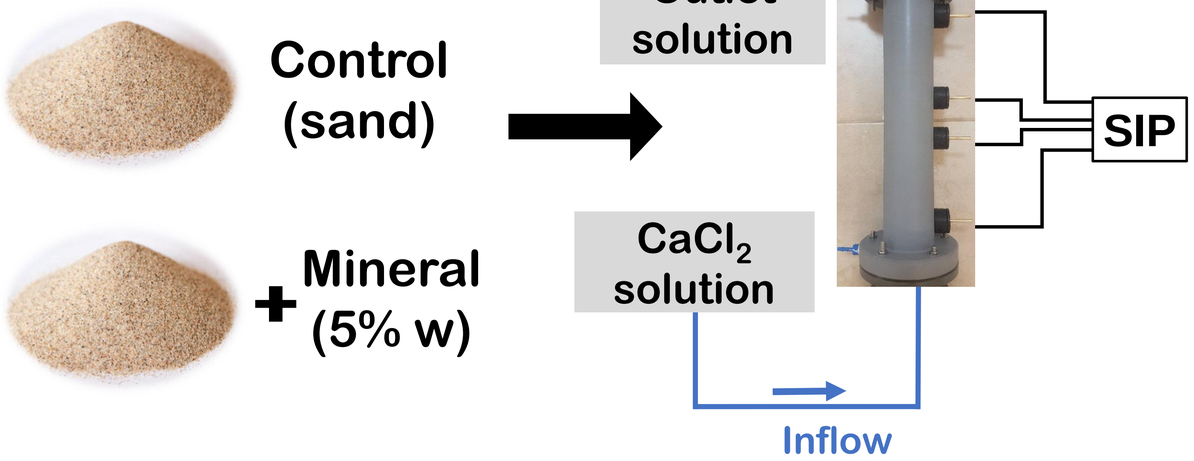
Methods

physicochemical experiments:

- CEC (cation exchange capacity) – values were taken from the suppliers and from the literature
- SEM (scanning electron microscope) images

Electrical experiments:

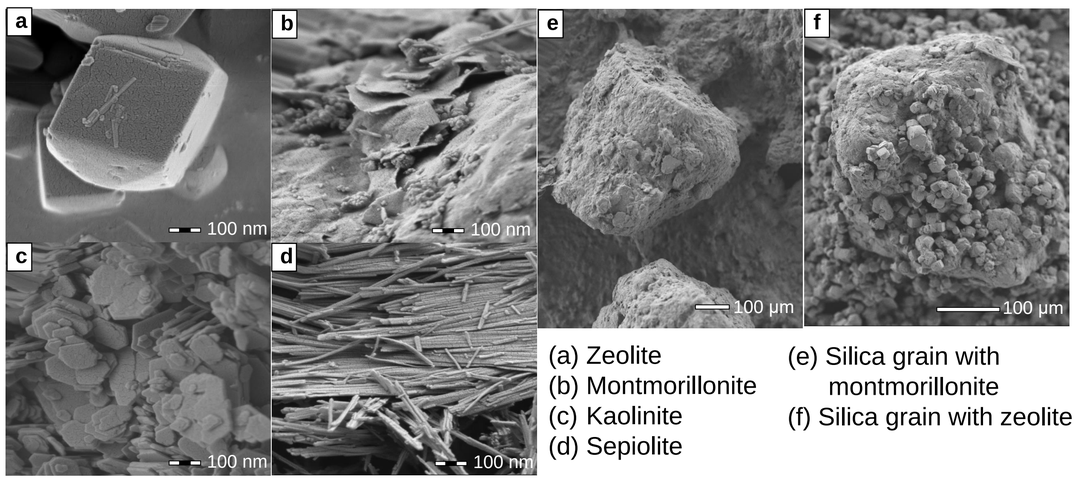
We used a mixture of sand and clay minerals



CEC Results

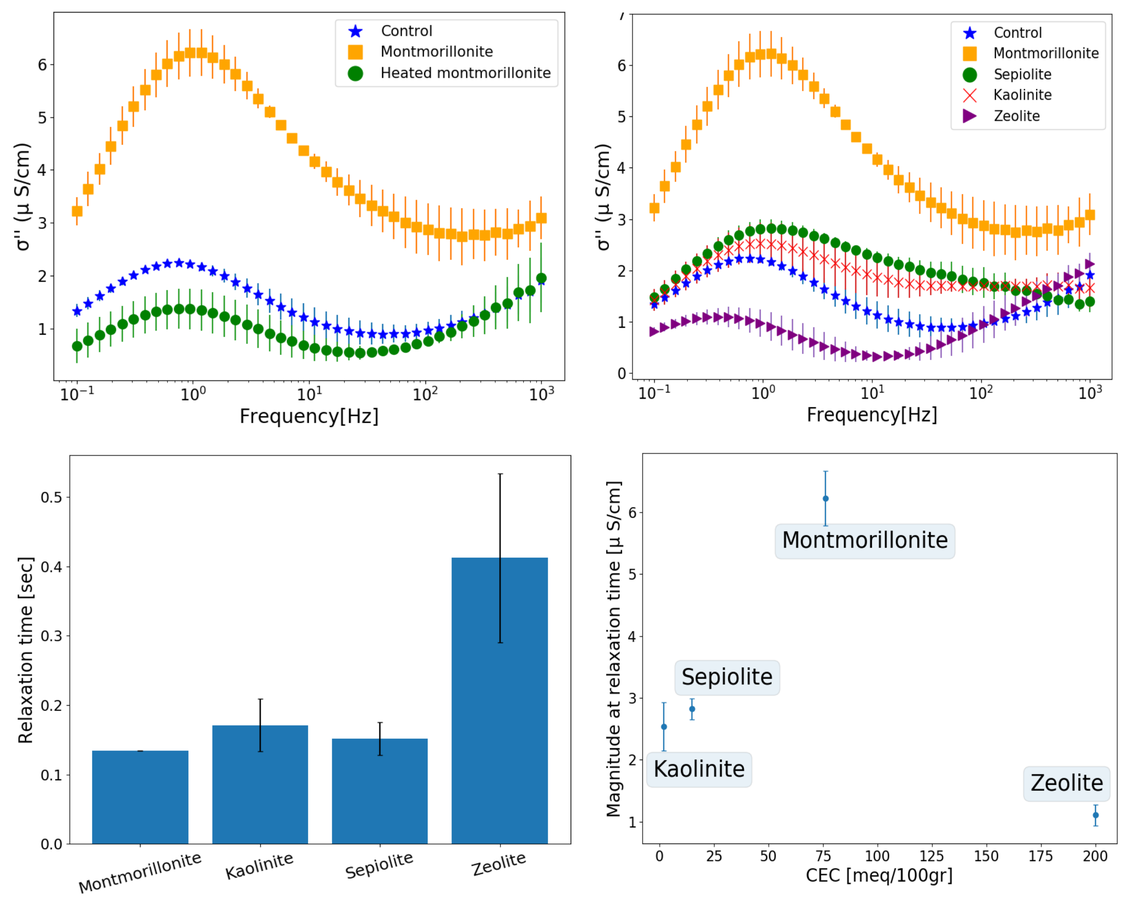
Mineral	Montmorillonite	Heated montmorillonite (800°c)	Kaolinite	Sepiolite	Zeolite
CEC [meq/100gr]	76	~10	2	15	~200

SEM Results



(a) Zeolite
(b) Montmorillonite
(c) Kaolinite
(d) Sepiolite
(e) Silica grain with montmorillonite
(f) Silica grain with zeolite

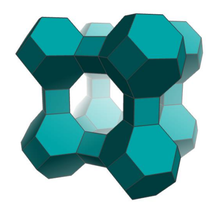
Electrical Experiment Results



- Heated montmorillonite with lower CEC value shows a decrease in SIP signature compared to untreated montmorillonite.
- Higher CEC values correspond to higher polarization, except for the zeolite treatment.
- The zeolite treatment has the highest relaxation time.

Discussion

- CEC is a physicochemical property that affects the SIP signature. The positive correlation between CEC and SIP signature is not always maintained.
- The low polarization of the zeolite treatment can be explained by its unique structure. It has a network of interconnected tunnels and pores (on a micron scale). The movement of the ions in the pores is limited, lowering polarization.
- The SIP method was found to be sensitive to mineral structure and can be used in the future for monitoring changes in structure processes.



Zeolite particle structure

Montmorillonite plate structure