Effect of specific surface area on cube counting fractal dimension of 3D pore structures of model sands: NMR micro-imaging study

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Diverse macroscopic properties of earth materials and porous media depend on their mircroscopic scale (from Å to mm) local structures [1, 2]. Fractal dimension of porous media allows us to link microscopic arrangements of constituent particles and their macroscopic properties such as permeability. As most of the studies for fractal dimension and the related properties of porous media have utilized 2D images (e.g. [3, 4]), despite the importance and applications, cube counting fractal dimensin (D_{cc}) of 3D pore structure and its relation with specific surface area in porous materials have not been systematically studied. Here, we explore the effect of specific surface area on 3D network and D_{cc} of pore structure of model sands composed of glass beads and silica gel using NMR micro-imaging to gain better insights into relationship among pore structure, fractal dimension, and the corresponding hydrologic properties.

D_{cc} analysis shows that even pore structures without self-similarity follow the power law within the upper and lower cutoff lengths, and D_{cc} increases from 2.5~2.6 to approximately 3.0 with increasing specific surface area from 2.5 to 9.6 mm^2/mm^3, with the data also showing that D_{cc} of pore network apparently increases with increasing porosity at constant specific surface area. The 3D micro-imaging data for the model porous networks show that the specific surface area increases from 2.5 to 9.6 mm^2/mm^3 with increasing porosity and permeability from 0.21 to 0.38, and from 11.6 to 892.3 D (Darcy), respectively. Those properties are relatively well explained with the Kozeny-Carman equation. The current results, together with analysis for natural sandstones with self-similarity show that D_{cc} is highly correlated with specific surface area, and thus, can be a controlling parameter of the permeability.

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Conservative tracers of oxygen fugacity in basalts and their mantle source regions

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Oxygen fugacity is an intensive parameter used to describe the chemical activity of O_2 in a given system and used as a proxy for the electrochemical redox potential between the different valence states of an element associated with a specific site in a given phase. Oxygen fugacity controls the speciation of redox-sensitive metals and volcanic gases and is hence important for understanding ore formation and the composition of the atmosphere. Arcs are the least understood tectonic environments in terms of fO_2. This is where altered materials from the Earth's surface are subducted back into the mantle and where magmas and volatiles are released back to the surface and atmosphere. Arc lavas are generally more oxidized than mid-ocean ridge basalts (MORBs) as evidenced by the higher Fe^{3+}/Fe_T ratios of arc lavas (>0.1 and up to 0.6) compared to MORBs (0.1-0.2). Expressed in terms of $\log_{10}$ deviations from a reference buffer (fayalite-magnetite-quartz, 'FMQ') arc lavas have fO_2s from FMQ to FMQ+4, whereas MORBs have fO_2s of FMQ-1 to FMQ+1, that is, arc lavas are up to 4-5 orders of magnitude higher in fO_2 than MORBs. The prevailing paradigm is that the high fO_2 of arc lavas reflects an oxidized mantle. This view is driven by the perception that material being subducted is oxidized so that the mantle wedge also becomes oxidized due to infiltration of oxidized slab-derived fluids or melts.

However, debate still persists because the Fe oxidation states of primary arc magmas and sub-arc mantle have not yet been directly determined. Here, we show that Zn/Fe_T ($Fe_T = Fe^{2+} + Fe^{3+}$) is a robust redox-sensitive element ratio that retains a memory of the valence state of Fe in primary arc basalts. During mantle melting, Fe^{2+} and homovalent Zn^{2+} behave identically, but because Fe^{3+} is more incompatible than Fe^{2+}, melts generated at high oxygen fugacity have low Zn/Fe_T. Primitive island arc basalts are found to have identical Zn/Fe_T as mid-ocean ridge basalts, indicating that their Fe oxidation states are also similar. This, combined with studies of V/Sc, V/Ga, and Fe isotopes, implies that the oxygen fugacity of arc mantle is similar to the rest of the upper mantle hence, the higher oxidation states of arc lavas may be related to shallow-level differentiation processes. However, reconciling these observations with the apparent correlations between Fe oxidation state and water in arc lavas remains a challenge.