Clay Minerals and Italy – the Nannobacterial Connection

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This work is dedicated to F. Leo Lynch, a brilliant clay mineralogist who died in 2009. During Leo's Ph.D. dissertation on oil reservoir sandstones in the South Texas subsurface, the first hints of nannobacterial precipitation of clay minerals were identified. (Lynch, 1994; Folk, Lynch & Rasbury, 1994). Leo grew up in Passaic, New Jersey; his Irish father died early and Leo was raised by his mother and her two sisters, all immigrants from Sicily. Leo got his B.S. in Geology from Tufts University and his M.S. from Dartmouth where he worked under R.C. Reynolds, who got him interested in clays.

Leo came to Houston to work in the clay minerals Lab of Shell under Dave Pevear and in 1987 came to the University of Texas for his Ph.D. Here, in addition to his studies, he was the star comedian of the annual student spoof of faculty, under the name of "Claynac." In 1995 we went to Italy and worked mainly in Sicily, collecting volcanic rocks to document how they altered in contact with sea water. After seeing his maternal ancestors' hometown of Vallelunga, he could see why they came to America! The X-ray work on Italian clays was in its infancy when Leo left to teach at Mississippi State, but preliminary data revealed an inchoate, nannobacterially-formed mess of proto-clays with varying amounts of Al, Fe and K that cannot decide what clay minerals to form when they grow up. His untimely death left this work incomplete. However, the SEM work we did together should have important implications for the putative biological precipitation of clay minerals. Our mineral "identifications" are based largely on morphology, but with some preliminary x-ray control. Some data has been formally presented:

Folk, Robert L., Lynch, F. L. & Rasbury, E. T. (1994). Evidence for Bacterial Precipitation of Clay Minerals upon Sand Grains, in soils, and in the Subsurface. *Geological Society of America Abstracts with Programs*, 26(7), A-508.

Folk, R. L. & Lynch, F. L. (1997). The Possible Role of Nannobacteria (Dwarf Bacteria) in Clay-Mineral Diagenesis and the importance of careful sample preparation. *Journal of Sedimentary Research*, 67, 583-589.

Lynch, F. L. (1994). The Effects of Depositional Environment and Formation Water Chemistry on the Diagenesis of Frio Formation (Oligocene) Sandstones and Shales, Aransas, Nueces, and San Patricio Counties, Texas. *Ph.D. Dissertation at University of Texas (unpublished),* 304.

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On the island of Vulcano a pahoehoe flow is attacked by sea water, and these are pictures of the altered surfaces. Fig. 1 shows two sizes of organisms. Larger nannobacteria, about 0.25 micron, seem to form conjoined pairs. Smaller nannobacteria, about 40 nm, cover most of the surface. Fig. 2, abundant nannobacteria, about 0.1 micron, form chains and in the middle spell out "OK" to show that we are right! This is not a doctored photo. Fig. 3, spheroids made of honeycomb-textured clay (perhaps smectite) perch on a carpet of ~50 nm nannobacterial cells. Fig. 4, larger balls made of radiating 40 nm cells perch on a carpet of 40 nm cells covering an altering olivine. Fig. 5 shows a fresh break, unaltered, with a mass of nannobacteria ready to attack “Over the Top!”

On the beach at Vulcano we found one scoria pebble which contained its own amazing little universe. Each vesicle in the scoria seemed to have its own assemblage of wonders...here are a few. Fig. 6 chains of nannobacteria on edge of probable smectite flakes. Fig. 7 shows zeolite rods and 10-15 micron balls of clay (one caterpillar-shaped mass). Fig. 8, flabby bags of honeycomb smectite, we don't know the reason for this! Fig. 9, a long cylinder of honeycomb smectite and a fraction of a micron away, big balls studded with chlorite. What kind of nannogeochemistry is this!? Fig. 10-12, a vesicle interior showing walls of this vesicle covered with smectite, and with larger elliptical balls of chlorite blades (colored green). Fig. 10, the chlorite balls are exactly the same size and shape as “big” bacteria. The flakes of chlorite are planar ellipses...as if the “big” bacterial body was a watermelon and you cut it in random directions with a machete, and chlorite then filled in the cuts. If this isn't a mineralogical miracle, (pseudomorphing a bacterial body with chlorite) then I don't know what is! Fig. 11 shows a different field, with iron oxide prongs colored brown. Fig. 12, the chlorite blades are ~30nm thick, and seem to be made of merged 30 nm balls. Iron oxide prongs with round ends are at the bottom.

On the island of Ischia, the main clay is a pale green color and it seems to be a mixture of several clays with varying amounts of Fe and K, including celadonite. It occurs in a tuff that was altered by seawater. Fig. 13 shows balls of about 50 nm merging into sheets. Fig. 14 and 15 reveal lovely chains of 50 nm nannobacterial balls on a zeolite crystal. Fig. 15 is very similar to nannobacterial chains that NASA revealed on Mars in 1996. Fig. 16 shows a surface with isolated 50 nm balls. In Fig. 17, 40 nm balls occur on the edges of thin clay sheets, much as in the illite pictured by Lynch (1994, fig. 6.5) and Folk and Lynch (1997, fig. 1 & 2). Fig. 18 is an etched zeolite in which tiny nannobacterial bodies have been exhumed. And a strong etch (10% HCl, 2 ½ days) shows abundant balls and sheets.

Acireale, Sicily lies at the foot of Mt. Etna and we sampled where a prehistoric lava flow was now being bathed by sea water. Fig. 19 shows Dr. Lynch sampling the altered rock. Fig. 20 is a lower power view showing chlorite rosettes coating cavity walls. Fig. 21 shows the chlorite flakes with a staphylococcus-like colony of 80 nm nannobacteria. Fig. 22 is an extreme closeup showing that the chlorite flakes are really made of pancake-stacked sheets about 30 nm thick, edges marked by sausage-shaped nannobacteria. The size of the nannobacterial cells predestined the thickness of the sheets, as is the situation with Texas kaolins (Folk, McBride & Yancey 2012).

Fig. 23 and 24 show a progression of chlorite flakes as they are created by nannobacteria. Fig. 23 shows isolated round cells 40 nm thick with a few “worms” of the same thickness. The background chlorite flake shows the hamburger patty structure. In Fig. 24 the worms are more abundant – biology anyone? In Fig. 25 the underlying chlorite sheet is covered with 25 nm balls, slightly larger than the 20 nm balls that have coalesced to make the upper sheet, in which they tend to occur in lines parallel with one flake edge. Fig. 26 is the “Golden Spike” photo. It shows single elliptical cells (about 25 x 35 nm) that aggregate into parallel chains (bottom of photo) and finally, in the underlying flake, into a layer of almost irresolvable balls with straight, crystalline-looking flake edges. This is the origin of the “hamburger patty” texture. But the Eureka point is reached when the sheets of chlorite are seen edge-on, where it is evident they are made up of a monolayer of balls – each sheet is one ball 30 nm thick, which shows that the sheets of chlorite are indeed being created by the layer of nannobacterial cells – just as in East Texas kaolins.

Honeycomb-structured smectite coating detrital grains has been a mystery in many sandstones described in literature. Fig. 27 may indicate a solution. Clay (perhaps smectite) starts as random worms on an altered mineral surface. If these would then initiate formation of flakes, you might get a honeycomb-like appearance, each worm growing tall “sails,” so to speak. The underlying altered mineral also shows hamburger patty texture. All in all, Acireale rocks have a lot of stories to tell.

A final example is from an outcrop of limonitically-weathered tuff from the north flank of Monte Vico at Viterbo, Italy. Fig. 28 is a freshlybroken piece of of ignimbrite. The fracture we made is clean and smooth; along a microcrack of natural origin there is a swarm of 70 nm nannobacteria, ready to start the weathering process. And Fig. 29 is a weathered soil sample from the same outcrop showing masses of 65-100 nm nannobacteria on biotite flakes that have sharp edges and smooth faces and seem to have not been altered.

These remarkable photos should go far in demonstrating a biological – specifically a nannobacterial – origin for many clay minerals. The hope is that professional clay mineralogists will cooperate with biologists and determine if we are right or wrong, and perhaps come up with alternate hypotheses. Buona fortuna!

Communications processing science by Nicole Raney, who put this all on the computer – grazie mille!...Robert L. Folk, December 2012.

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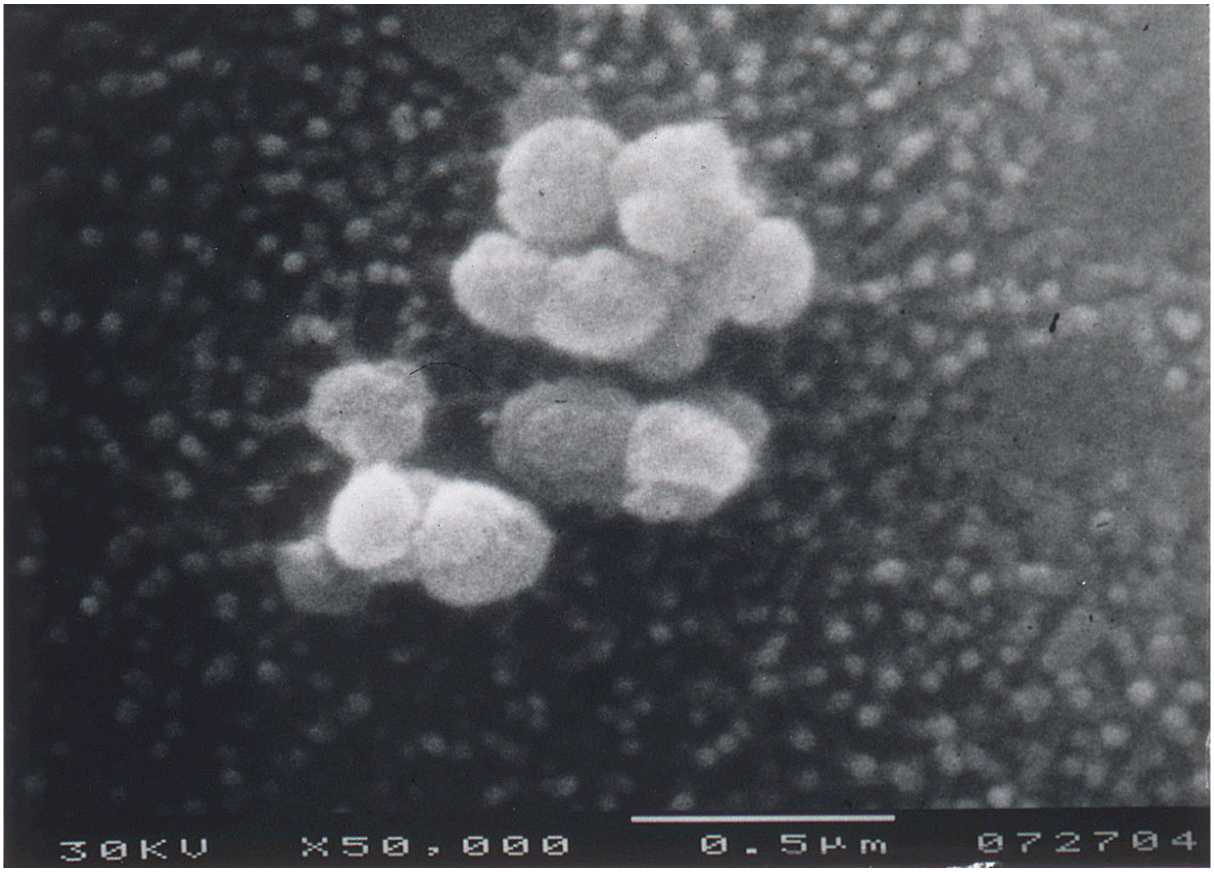


Fig. 1

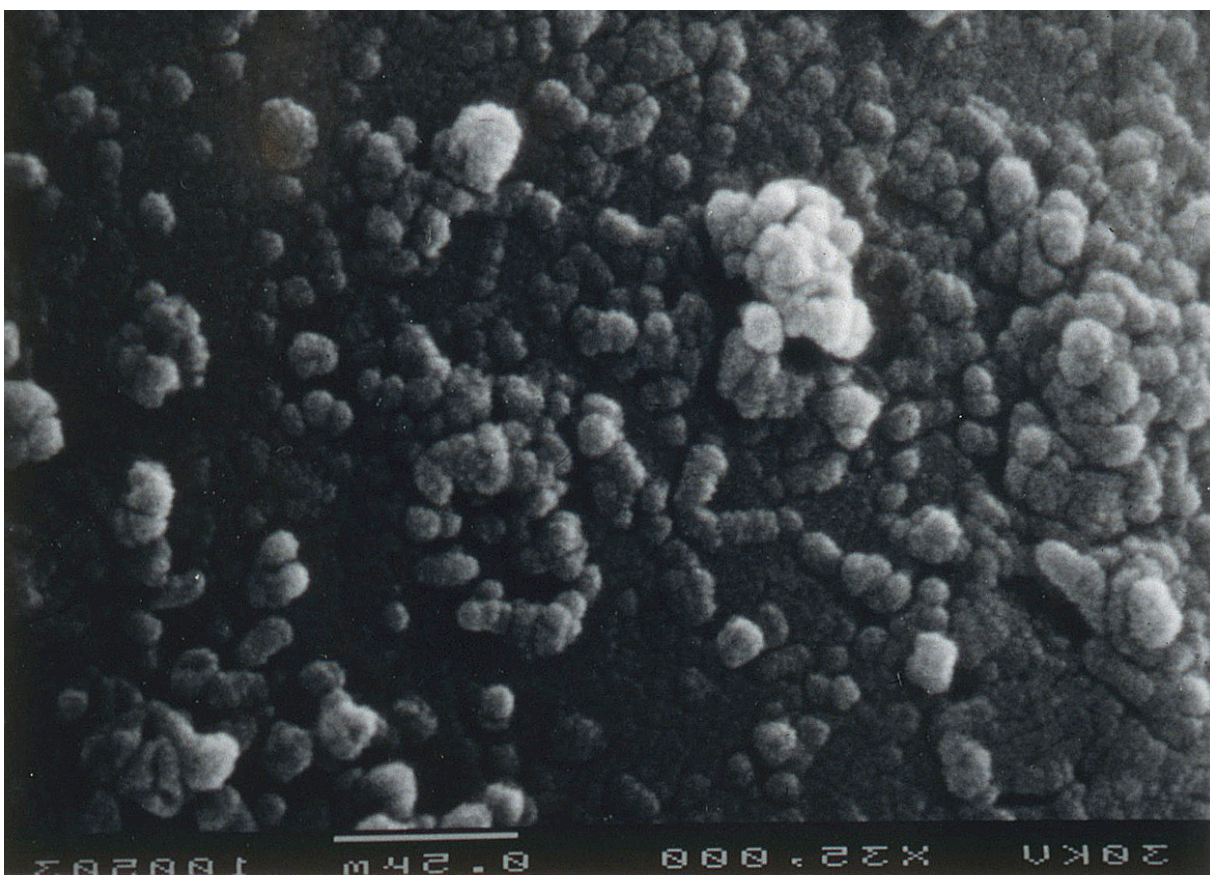
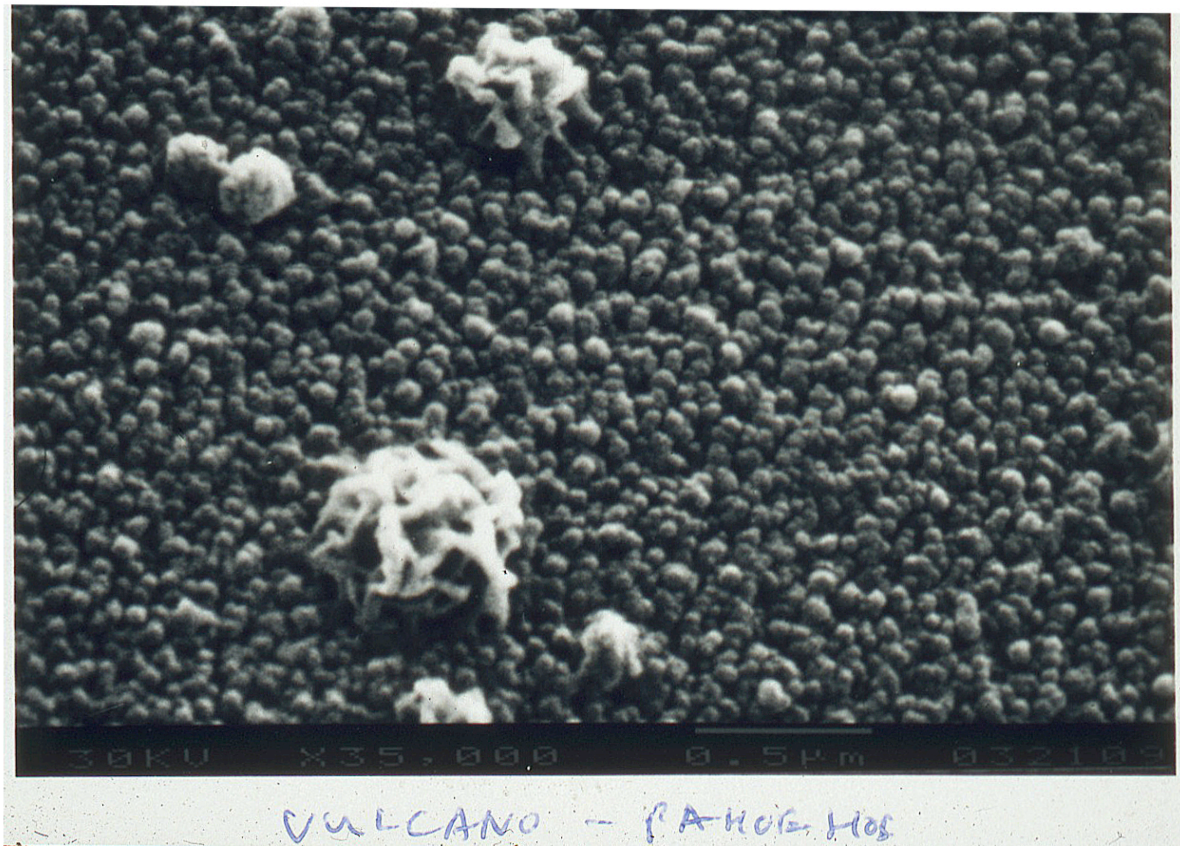
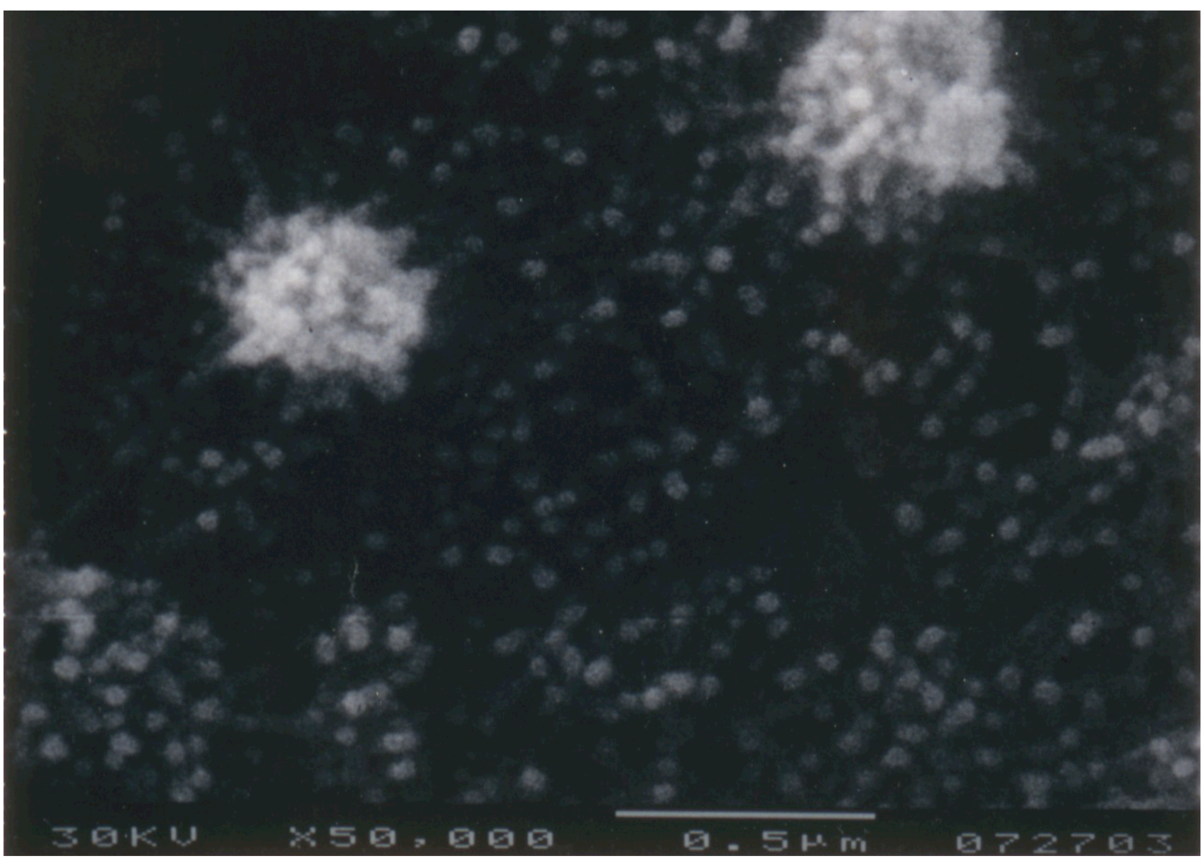


Fig. 2



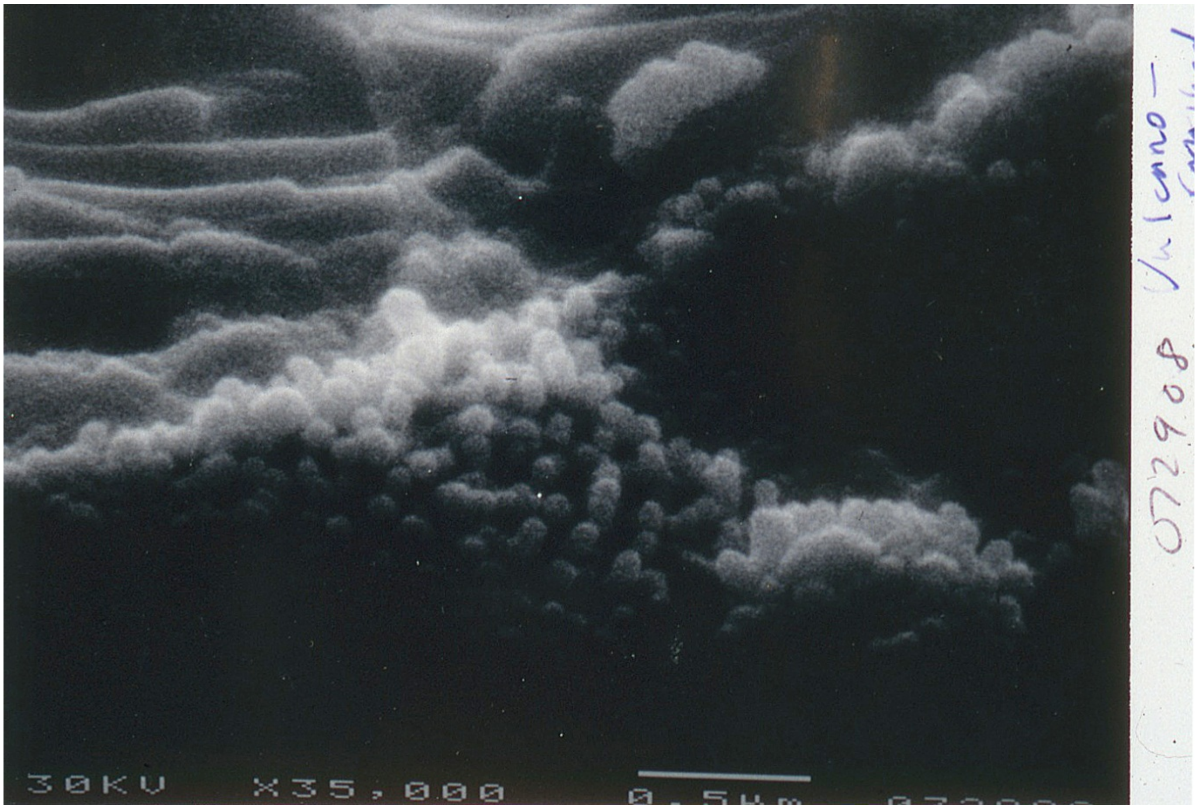
30KV X35,000 0.5μm 032103
VULCANO - PAHOEHOE

Fig. 3



30KV X50,000 0.5μm 072703

Fig. 4



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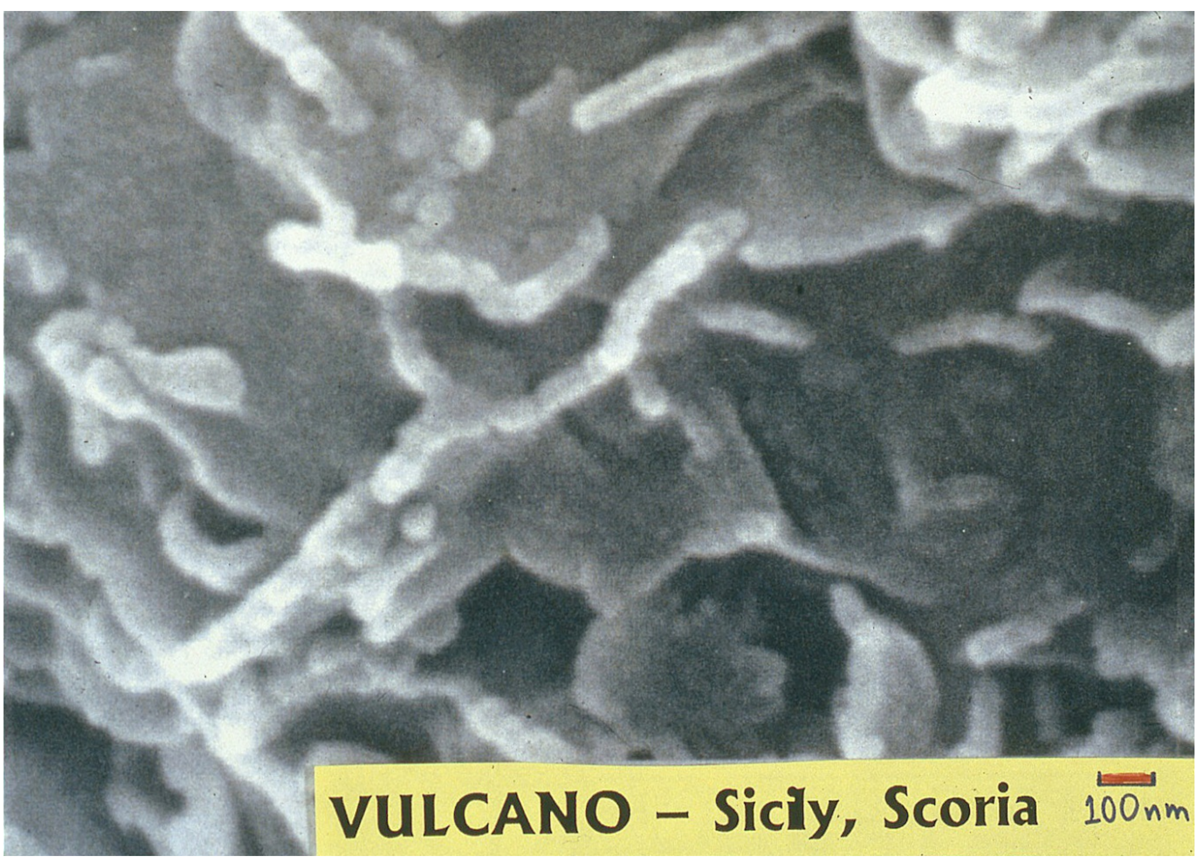

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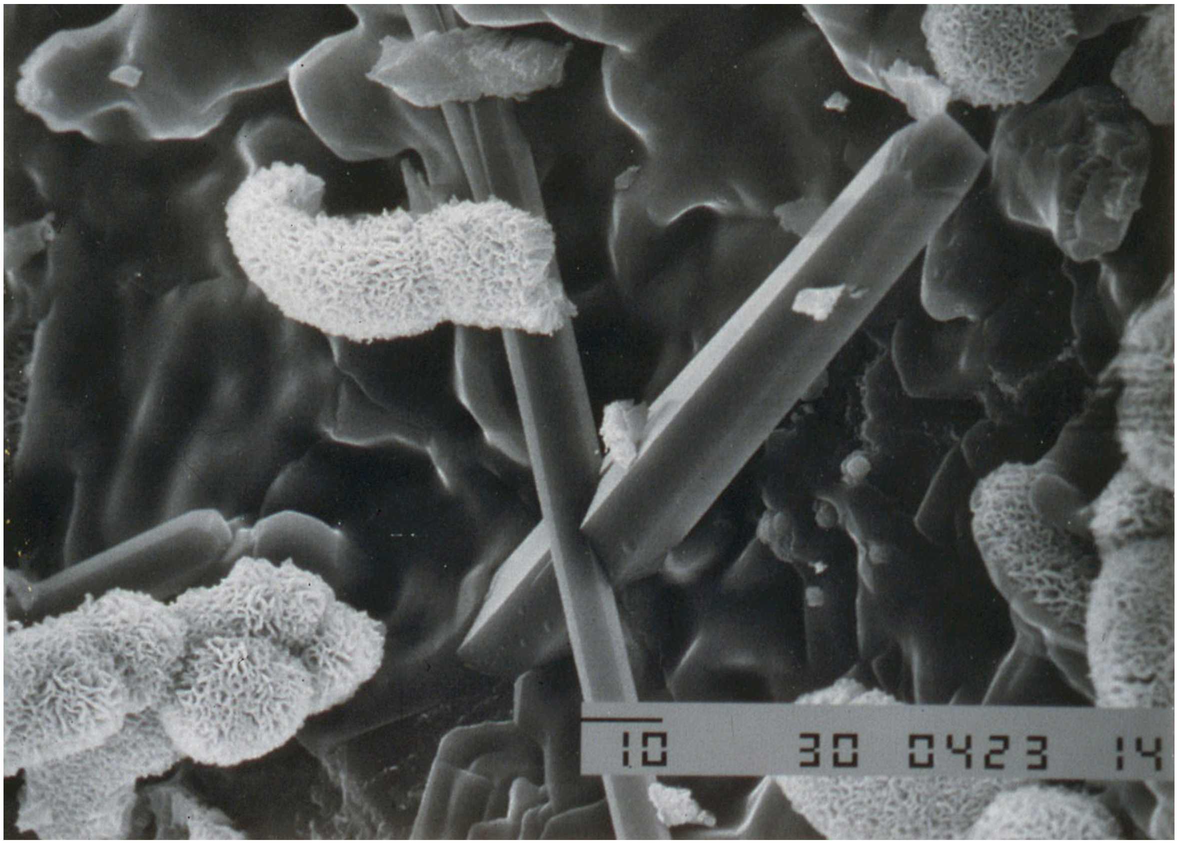

10 30 0423 14

Fig. 7

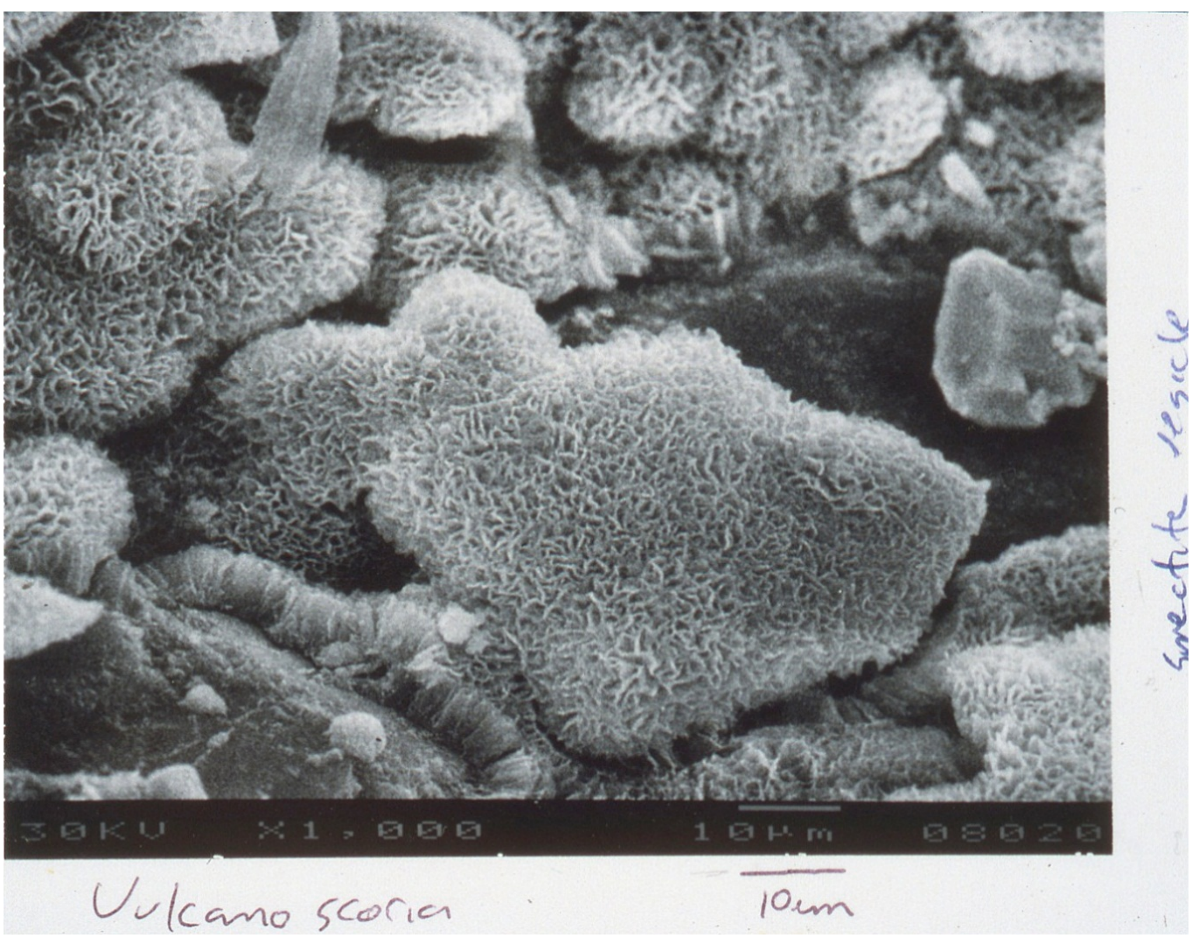

30KV X1,000 10µm 08020
Vulcano scoria
10um
smectite vesicle

Fig. 8

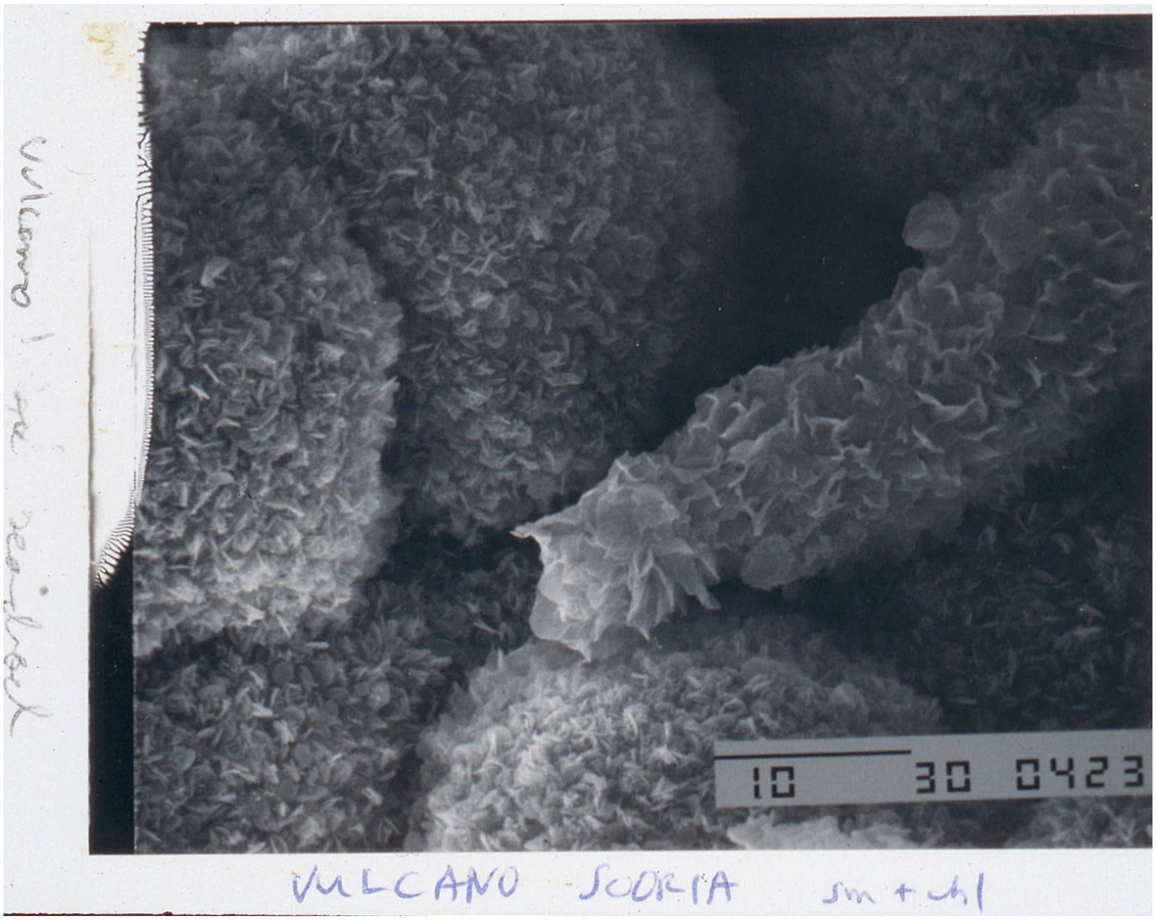


Fig. 9

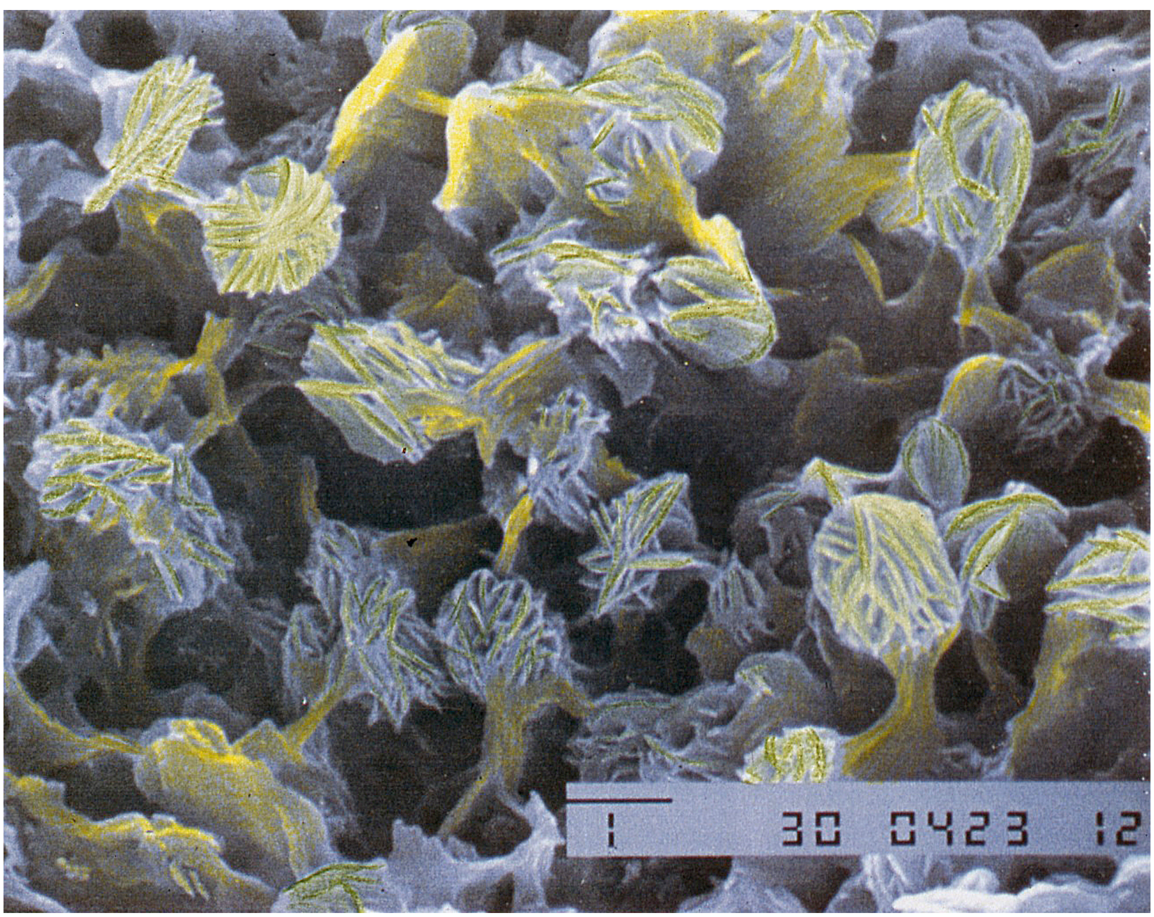


Fig. 10

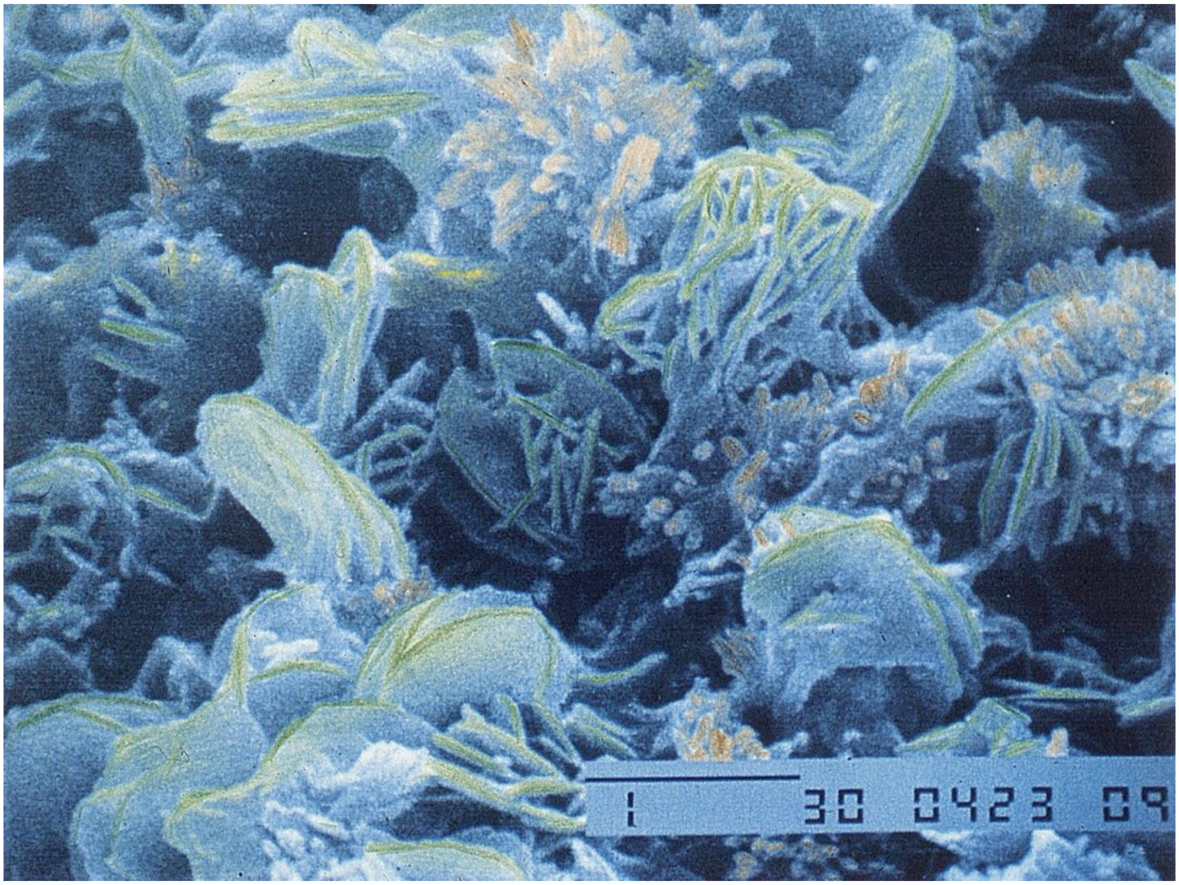


Fig. 11

Fig. 12

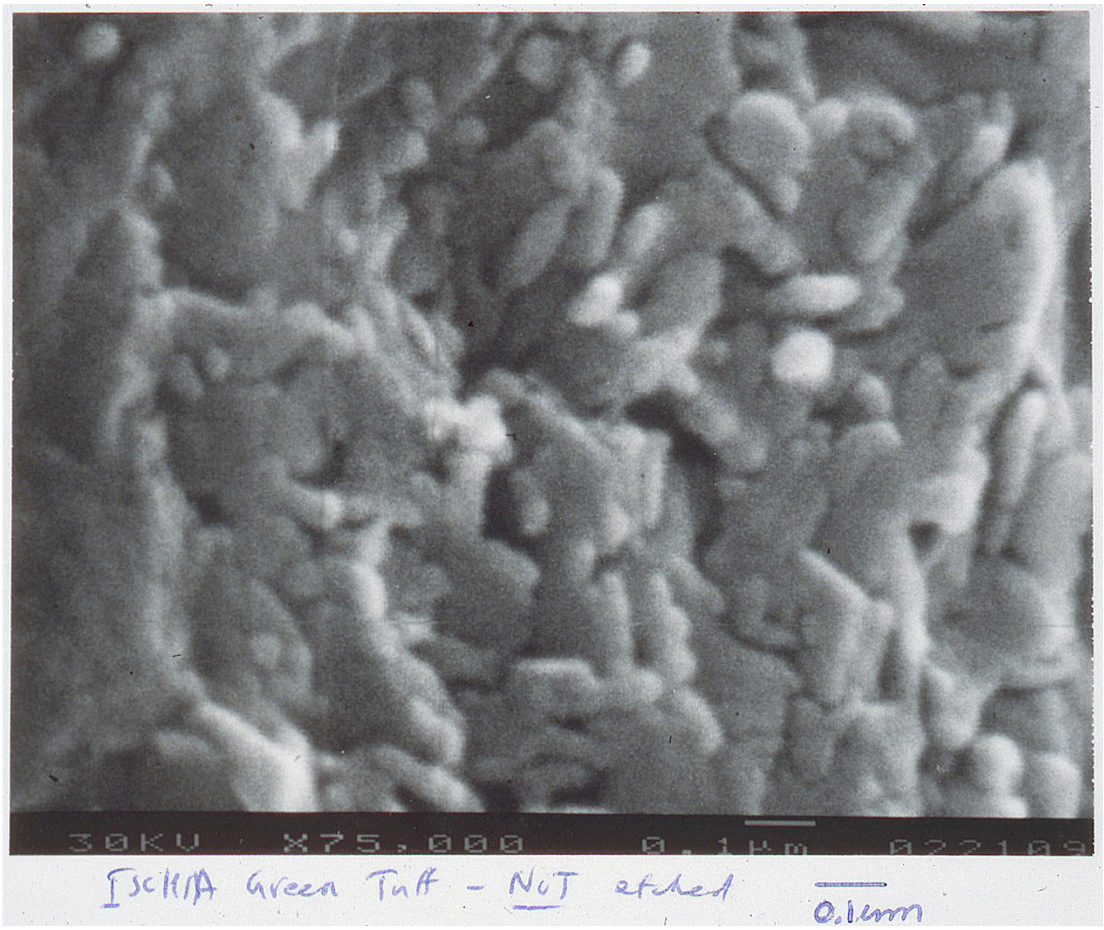

30KV X75,000 0.1µm 022109
ISCHIA Green Tuff - NOT etched
0.1µm

Fig. 13

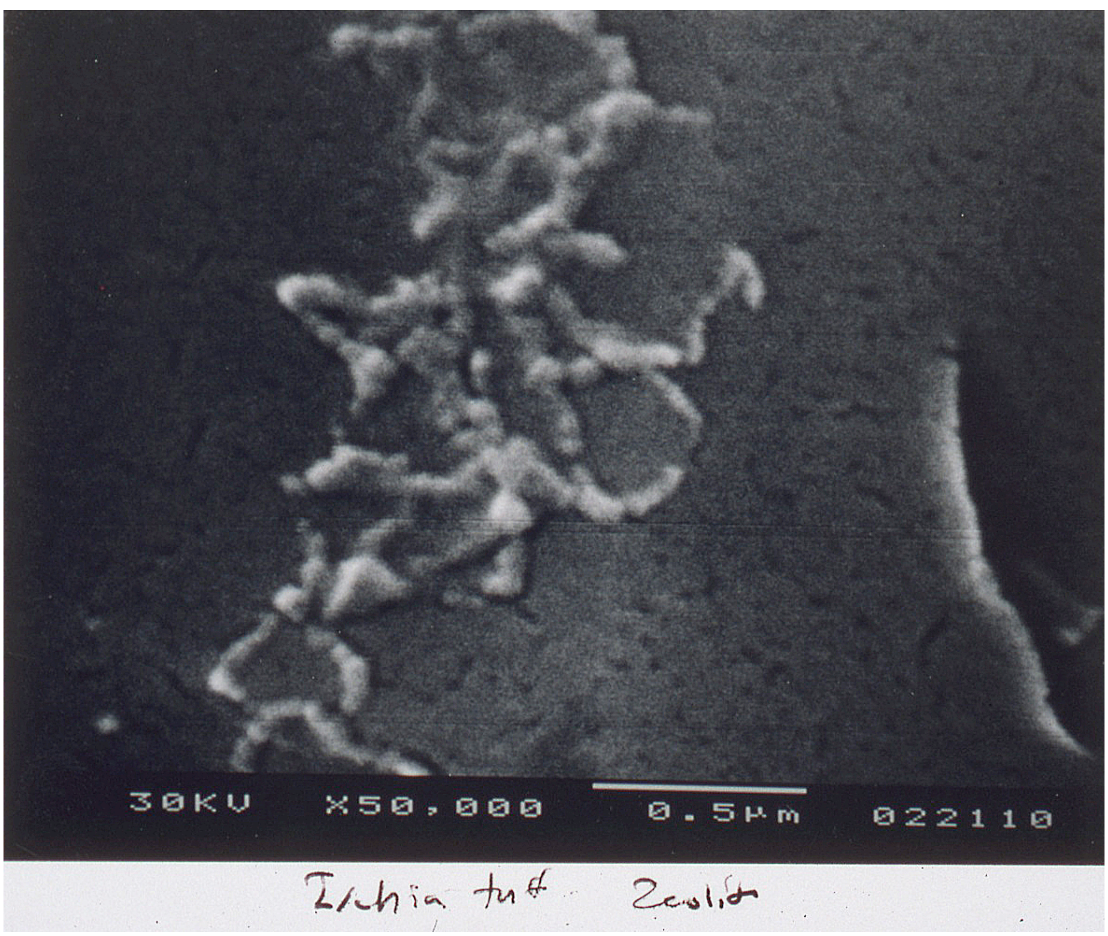

30KV X50,000 0.5µm 022110
Ischia tuff Zeolite

Fig. 14

Fig. 15

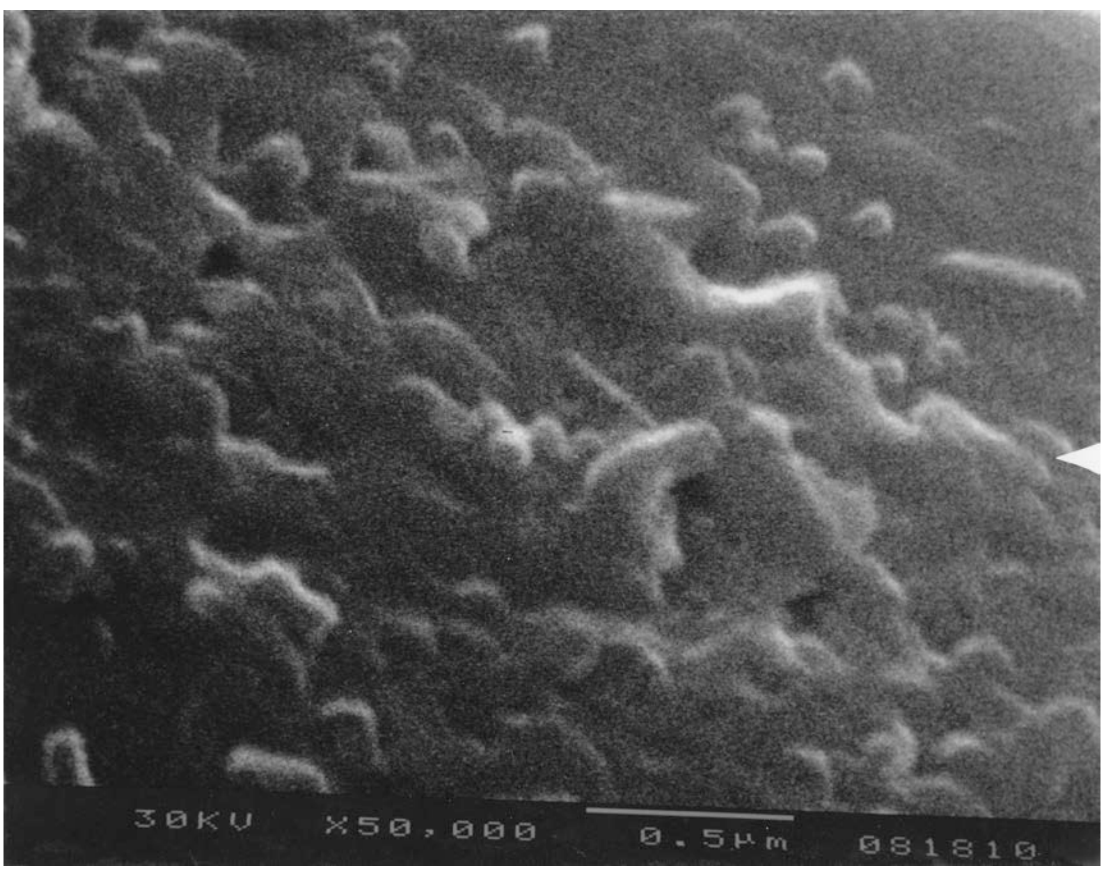


Fig. 16

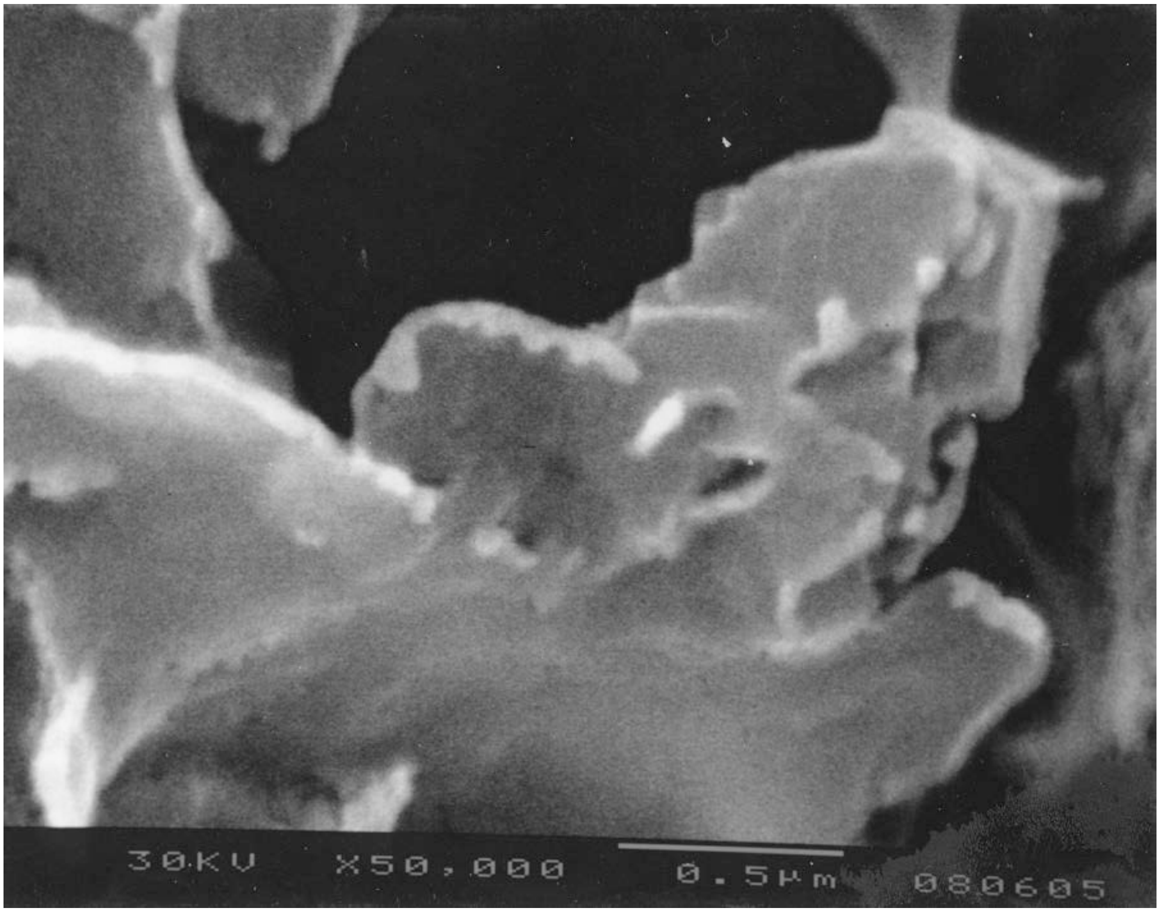


Fig. 17

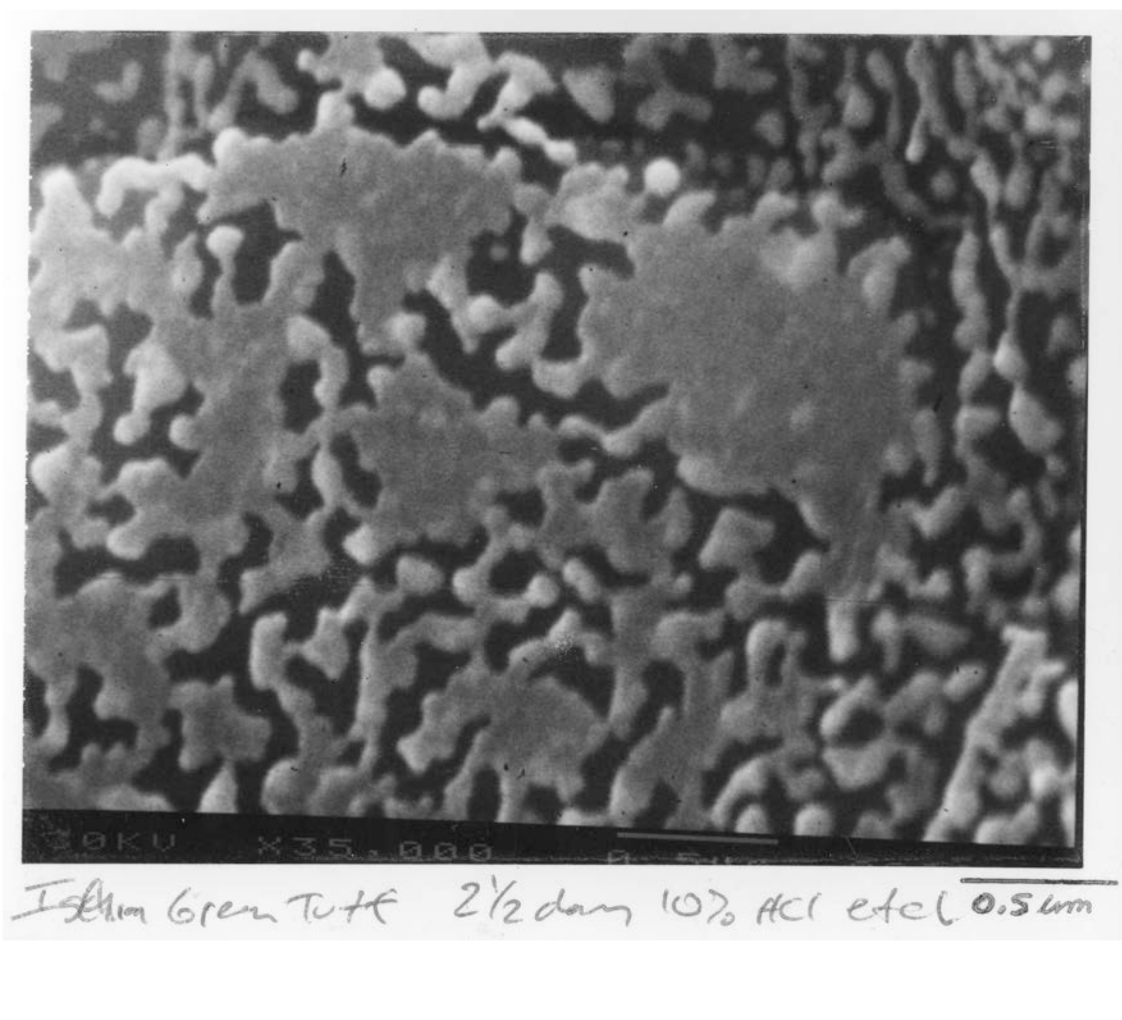


Fig. 18

Fig. 19

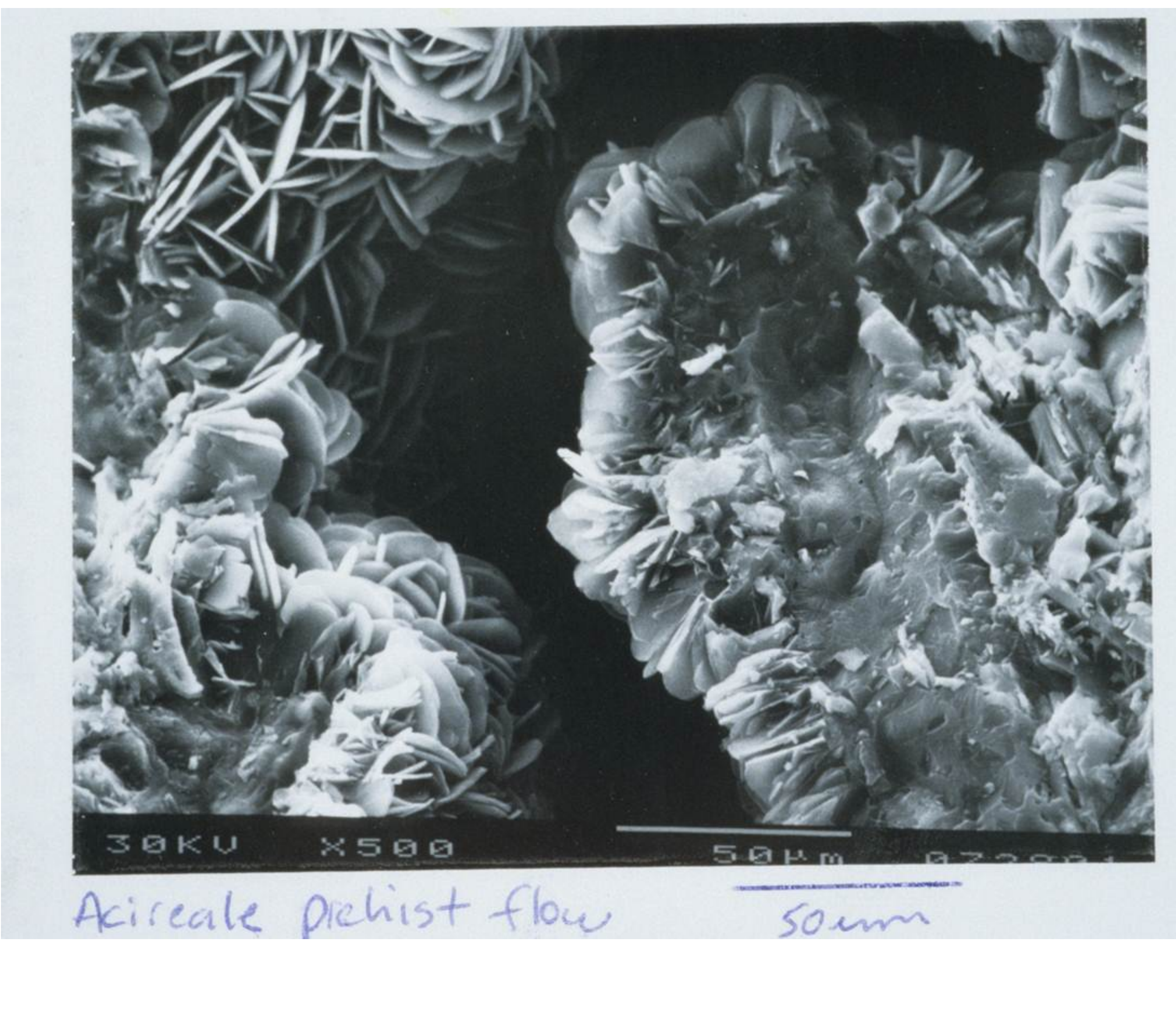


Fig. 20


ACIREALE, Sicily
300 nm
Mt. Etna lava flow – chlorite flakes

Fig. 21

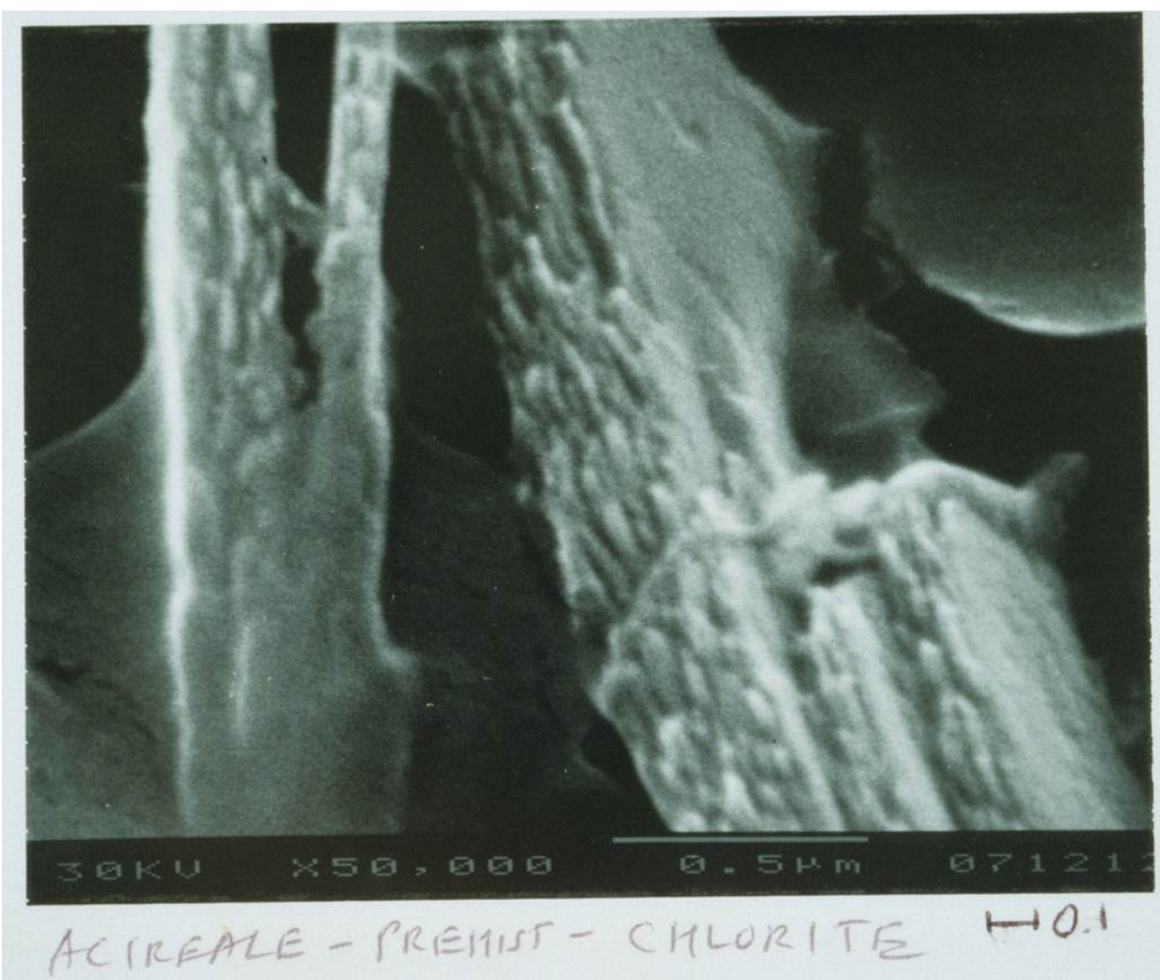
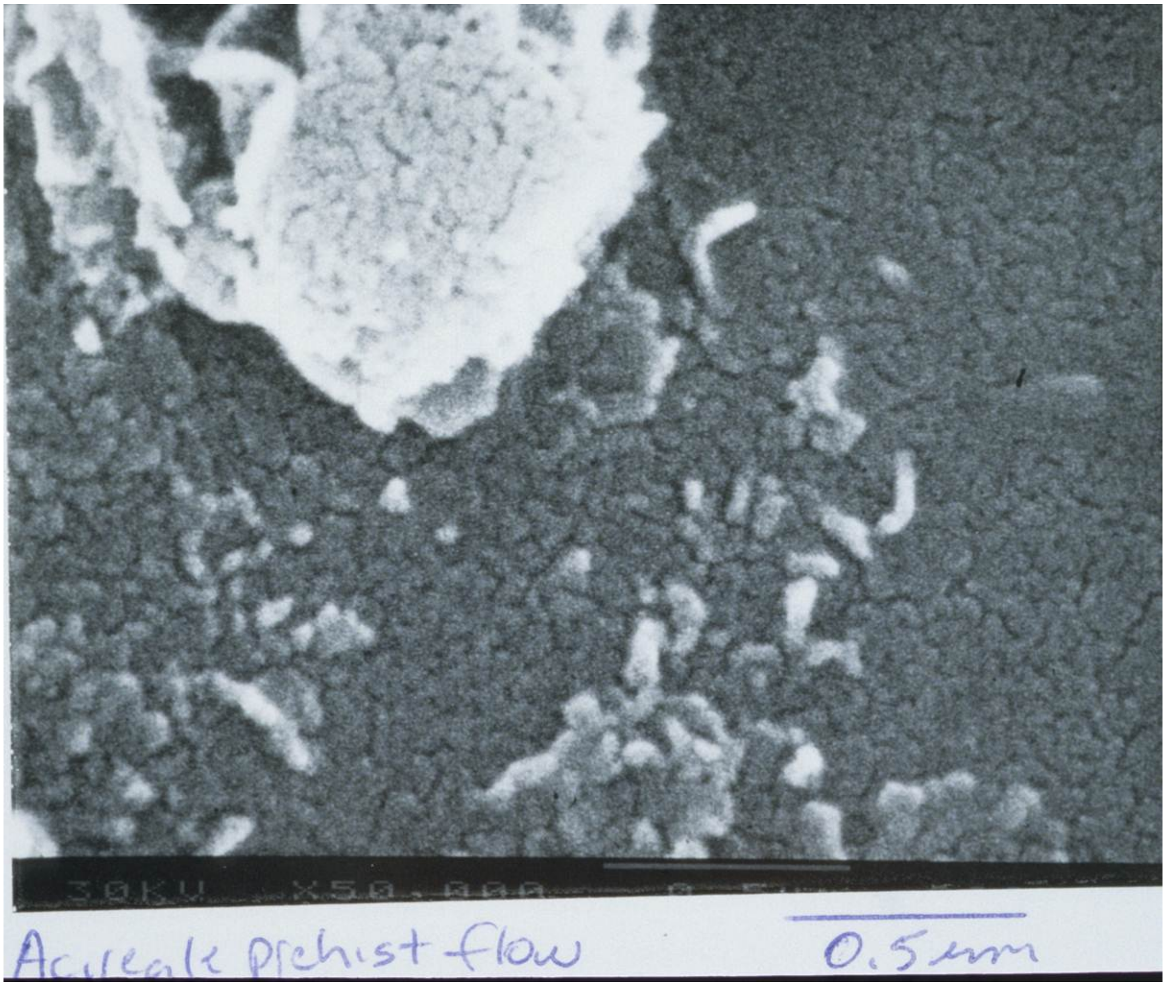
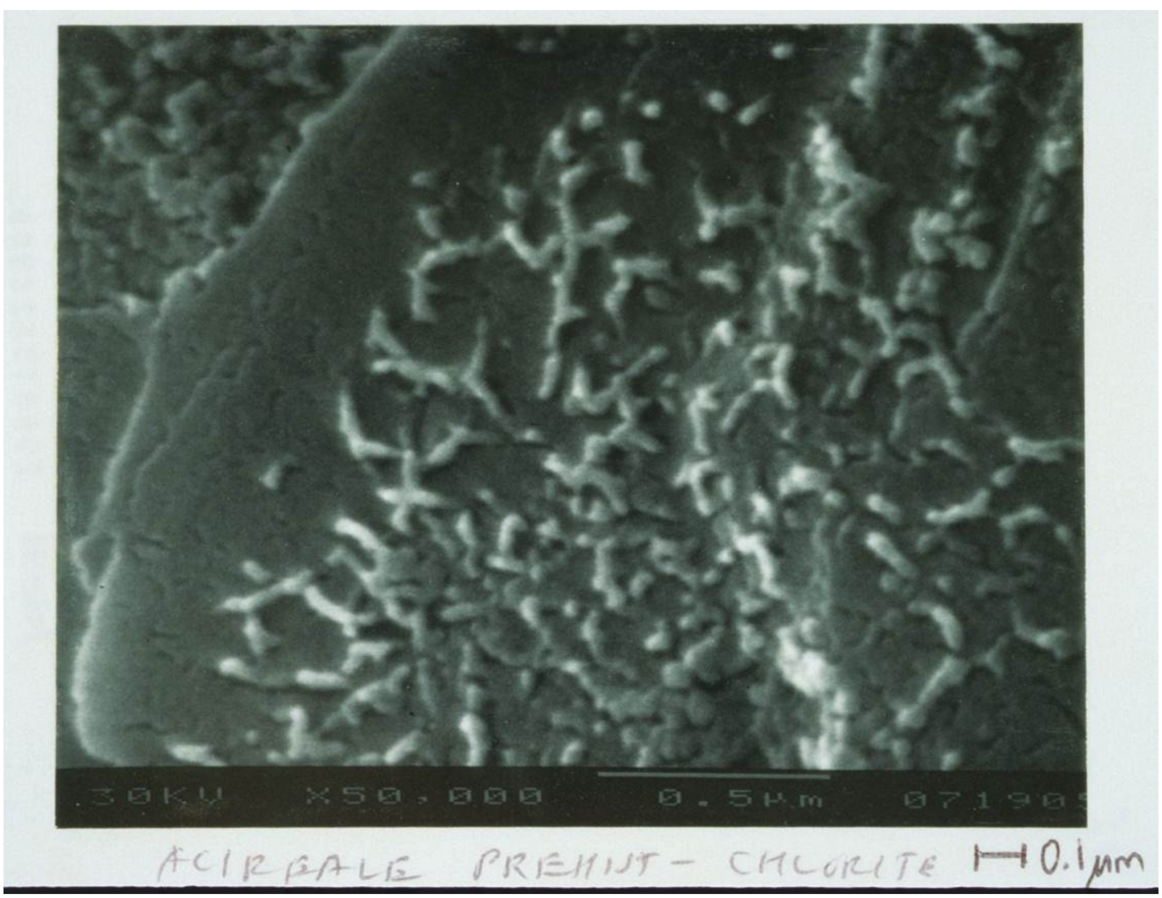

30KV X50,000 0.5µm
ACIREALE - PREMIST - CHLORITE
0.1

Fig. 22


30KV X50,000
Acireale prehist flow
0.5 um
Fig. 23


30KV X50,000 0.5μm
ACIREALE PREHIST - CHLORITE
0.1 μm
Fig. 24

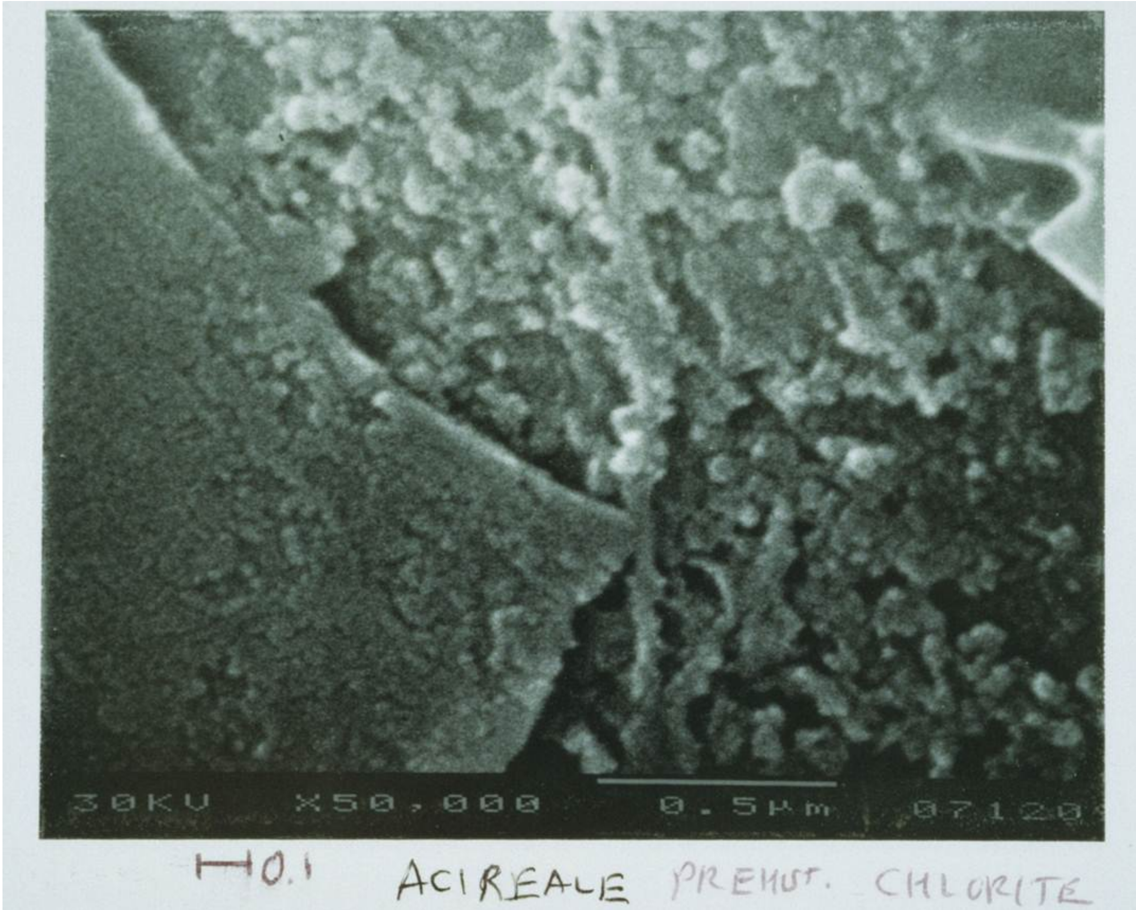

30KV X50,000 0.5µm
H0.1 ACIREALE PREHST. CHLORITE

Fig. 25

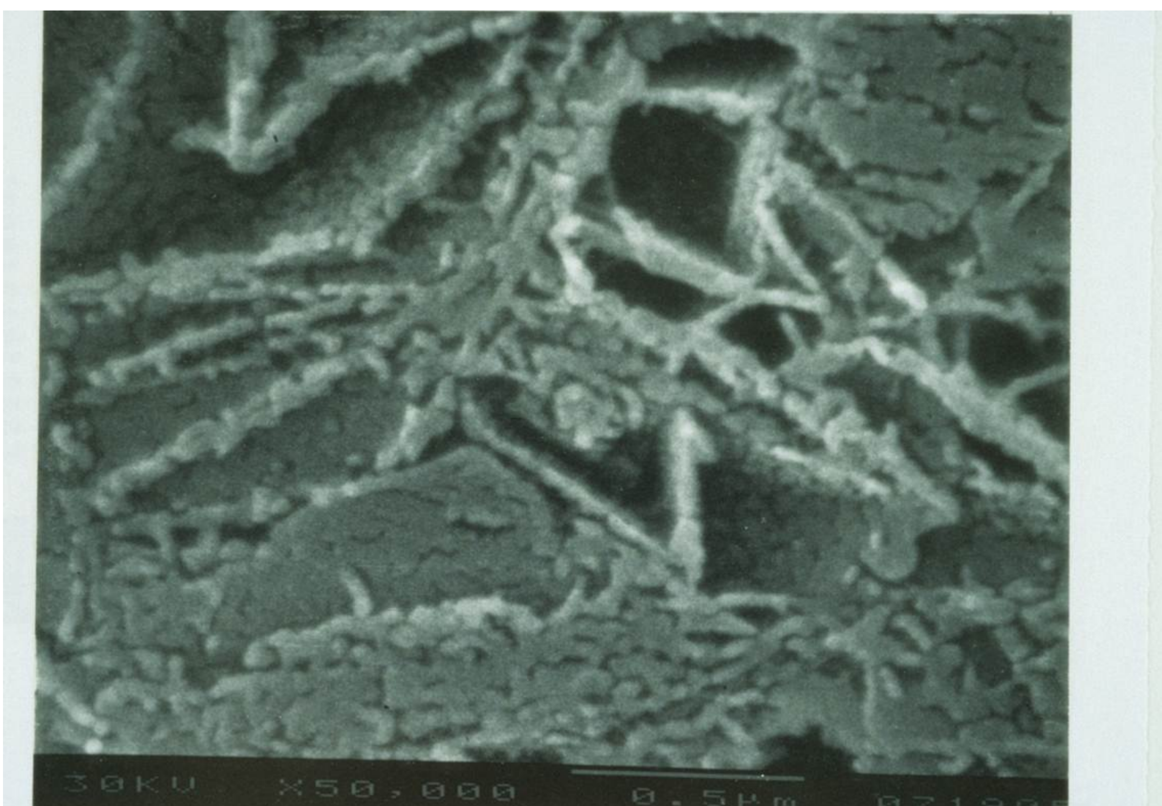

30KV X50,000 0.5µm
ACIREALE PREMIST - CHLORITE H 0.1µm

Fig. 26

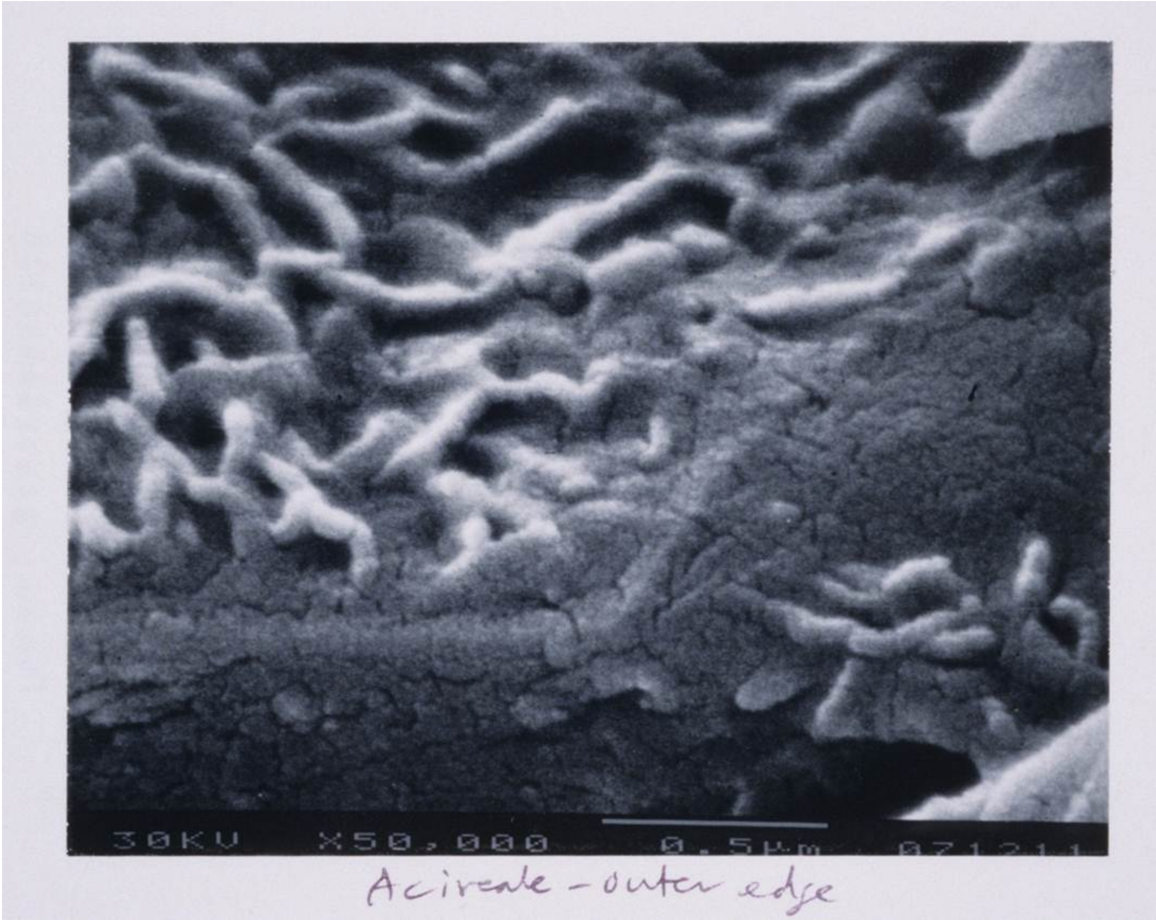

30KV X50,000 0.5μm
Acireale - outer edge

Fig. 27

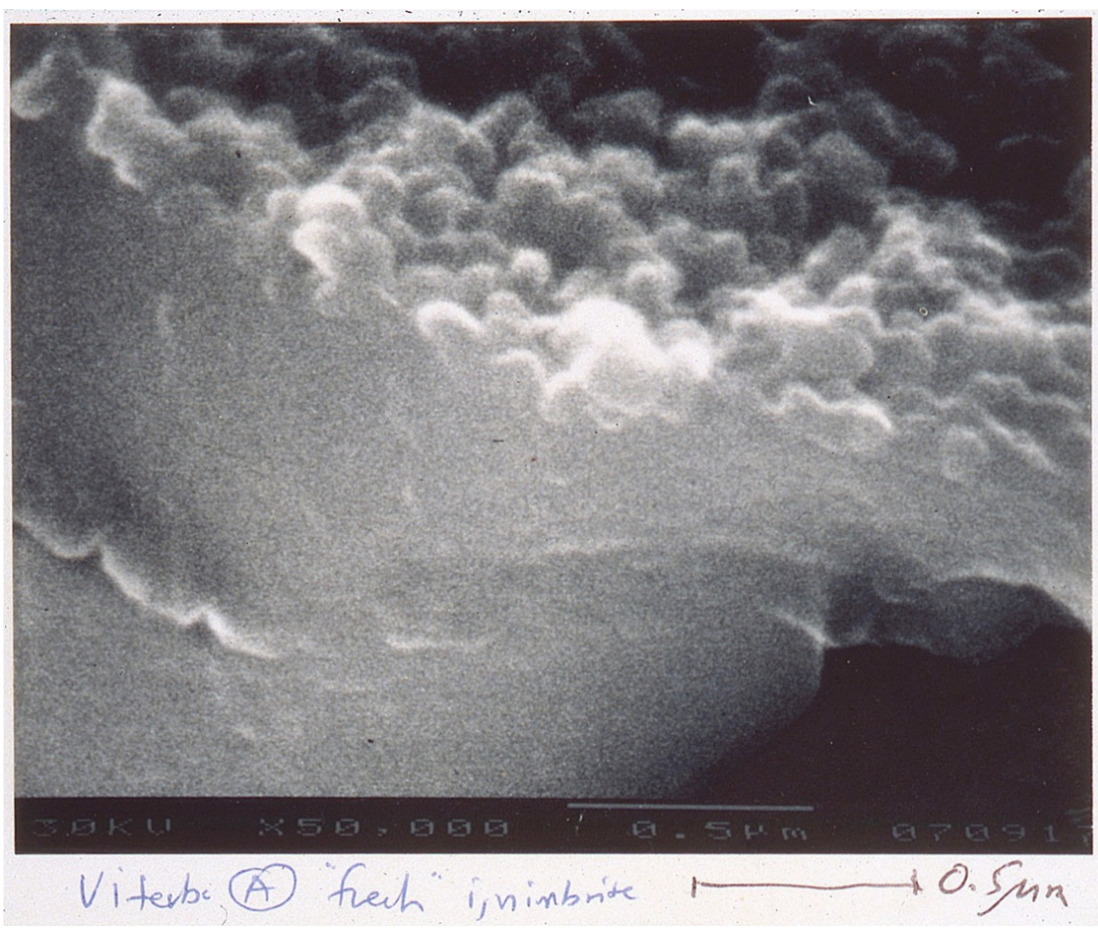

30KV X50,000 0.5μm
Viterbo (A) "fresh" ignimbrite
0.5μm

Fig. 28

Fig. 29