Controlled growth of mollusc shells: Quantitative Crystallographic Texture Analysis input

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Overlook

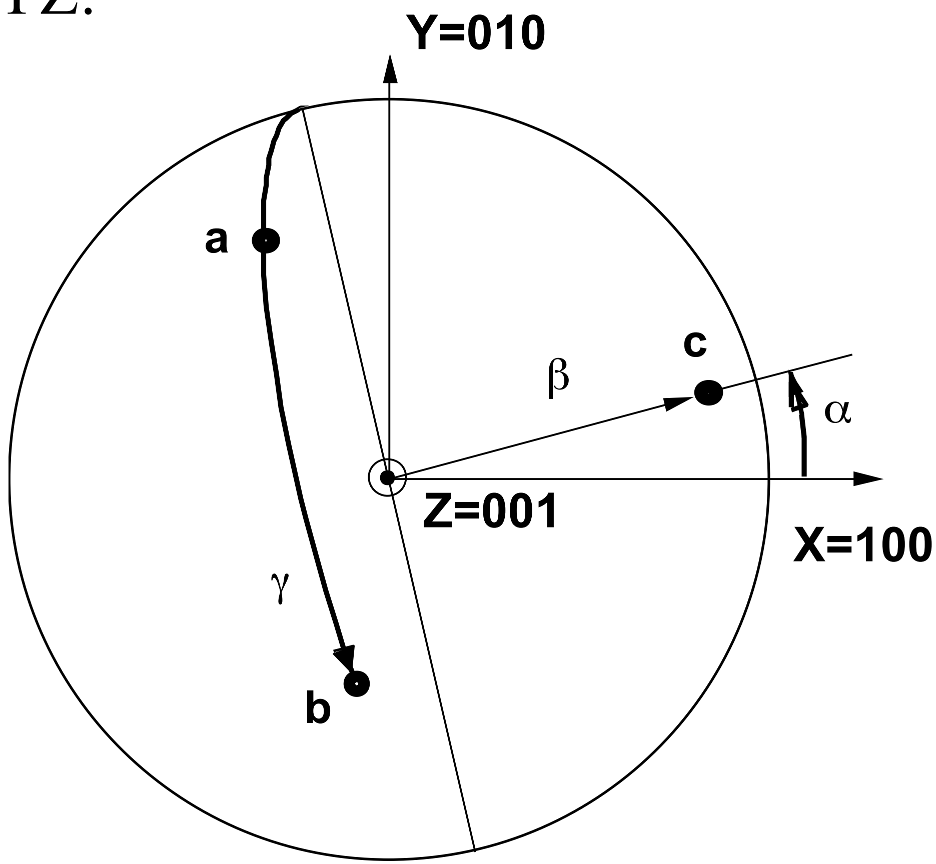
- Generality on QTA by diffraction
- Complex growth of layers: microstructure versus texture
- **a**- and **c**-axes patterns of aragonitic layers, twinning
- QTA: global versus local probes
- QTA and Mollusc's Phylogeny
- QTA and calcitic fossils
- QTA and Mollusc's prothaetics
- QTA and mechanical behaviour

Generality on QTA from diffraction

We measure pole figures P_{hkl}, statistical representation of crystallite orientation in a sample frame XYZ:

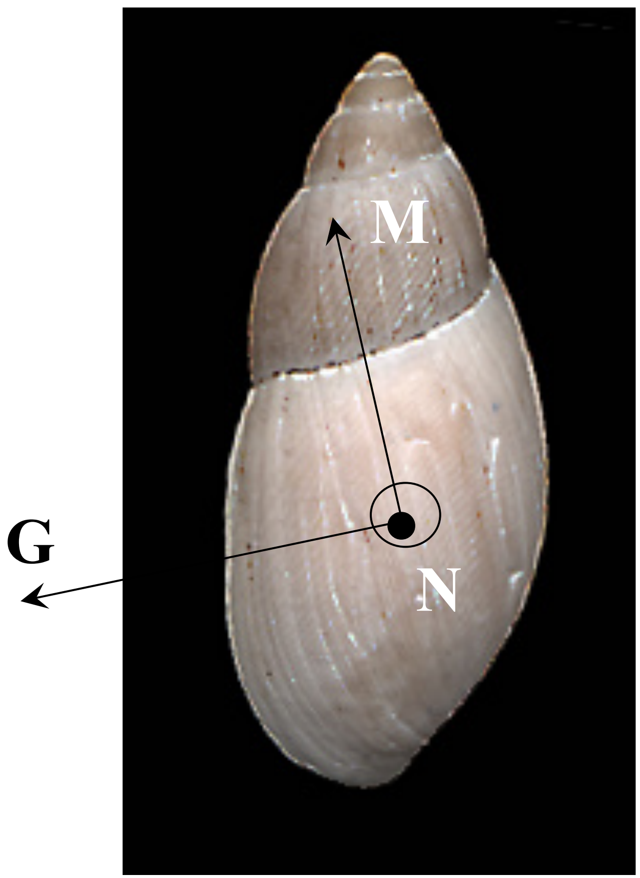
$$\frac{dV}{V} = \frac{1}{4\pi} P_{hkl} \sin\beta \, d\beta \, d\alpha$$

{α,β,γ} three Euler angles, γ accessed by refinement of the Orientation Distribution Function (ODF)

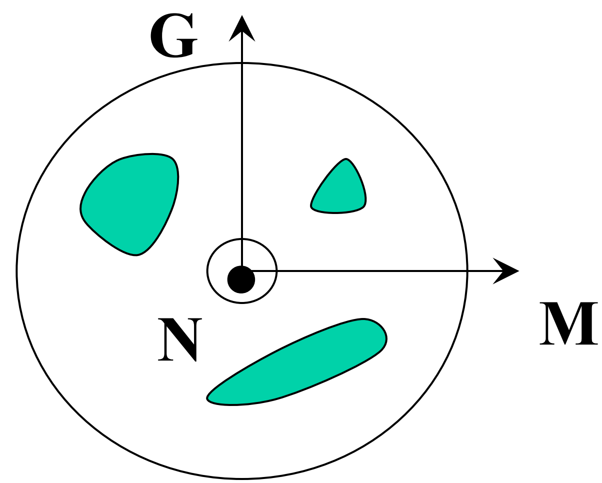


Example for one single crystallite:

Reference frame in mollusc shells

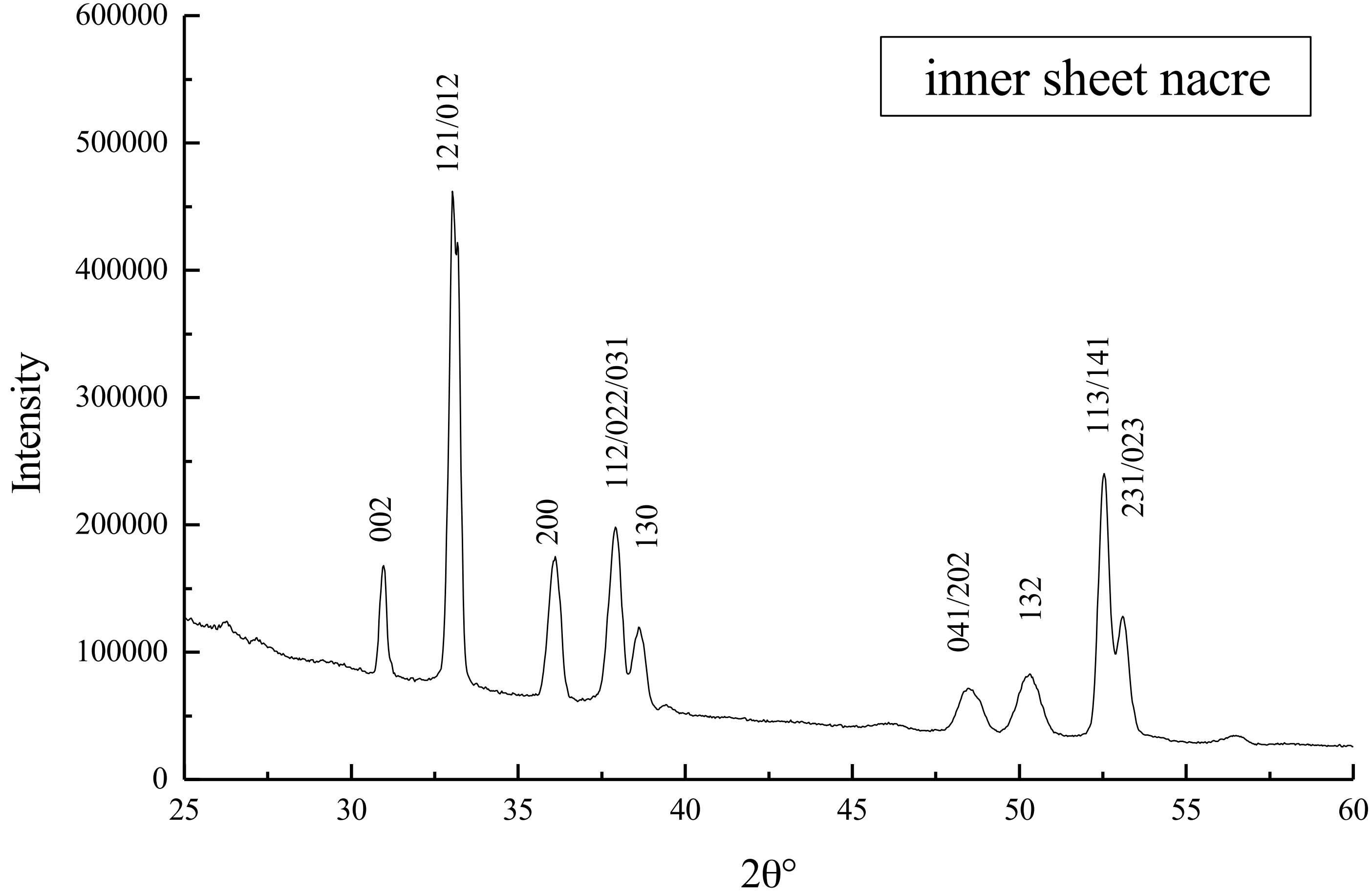


- Crystal: $CaCO_3$, aragonite (Pmcn) or calcite ($R\bar{3}c$), for thousands of crystallites:

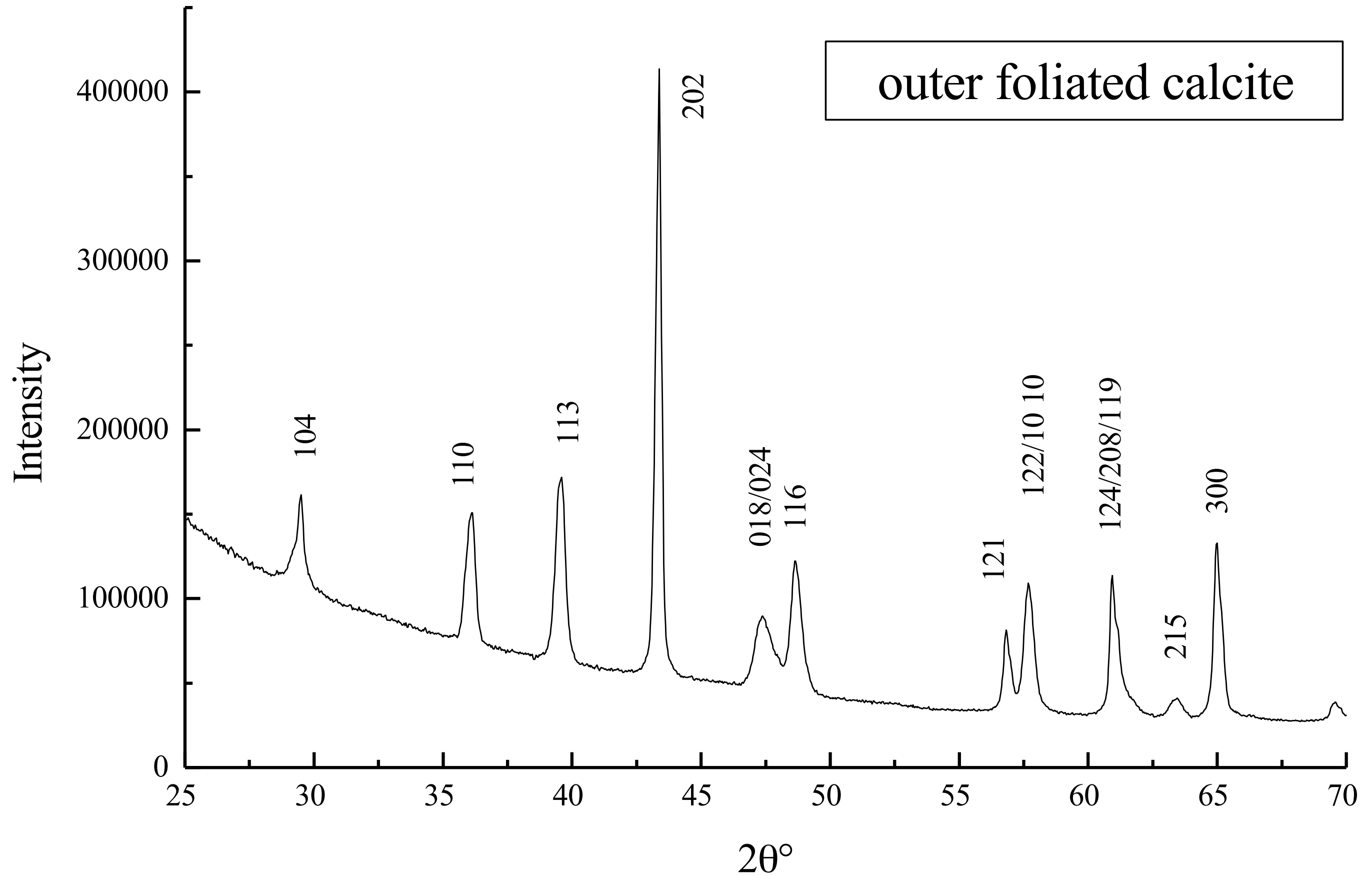


Typical x-ray diffraction pattern

Mytilus edulis (common mussel)

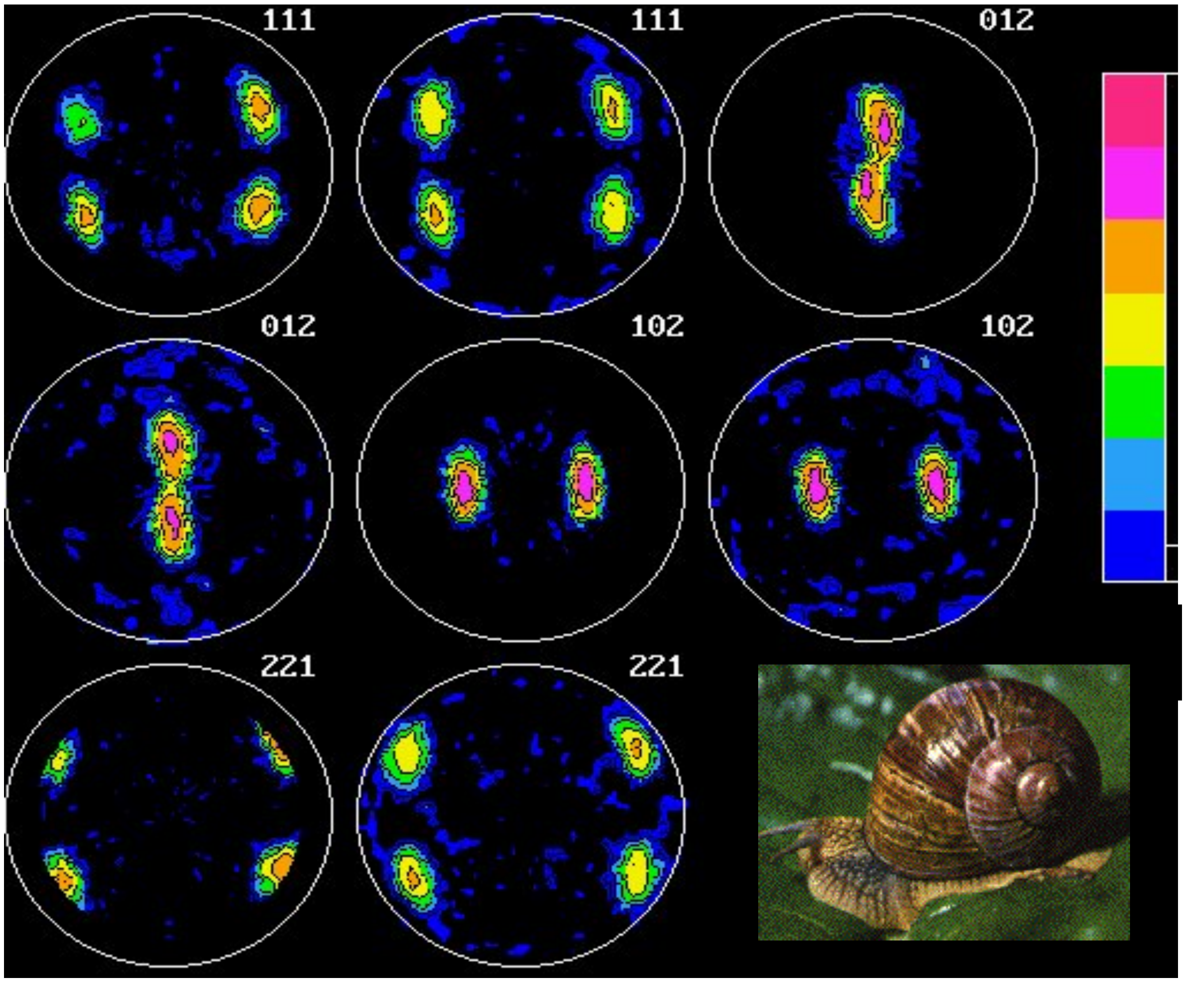


Crassostrea gigas (common oyster)



Measured for around 1000 sample orientations, using x-rays, neutrons or electrons, depending on the desired probed volume

ODF-reliability (x-rays: point detector): *Helix pomatia*
(Burgundy land snail: Outer com. crossed lamellar)

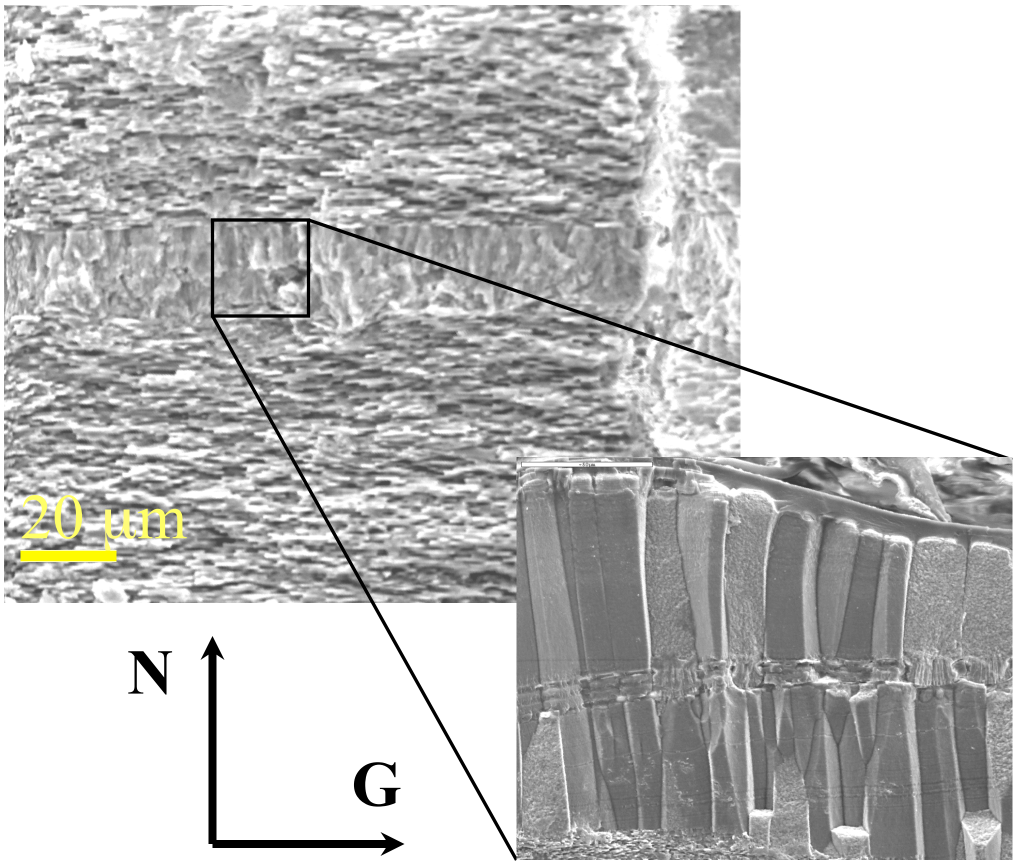


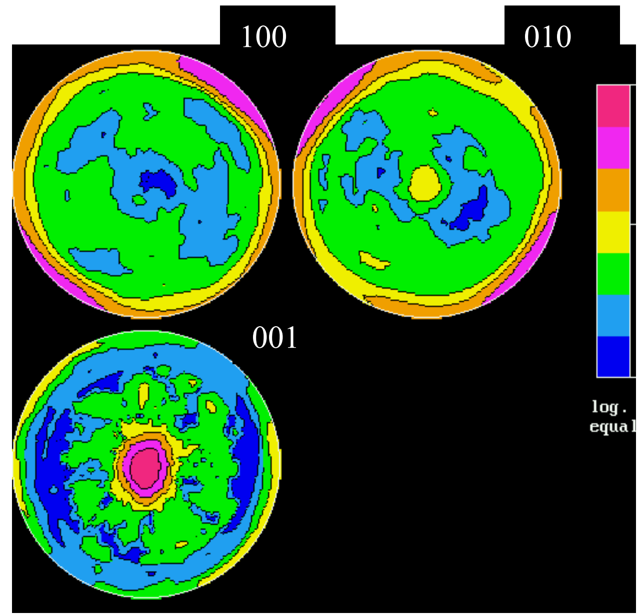
Complex growth of shell layers: microstructure versus texture

Microstructure versus texture

Inner sheet nacre of *Anodonta cygnea* (river mussel):

no intra-mineral epitaxy



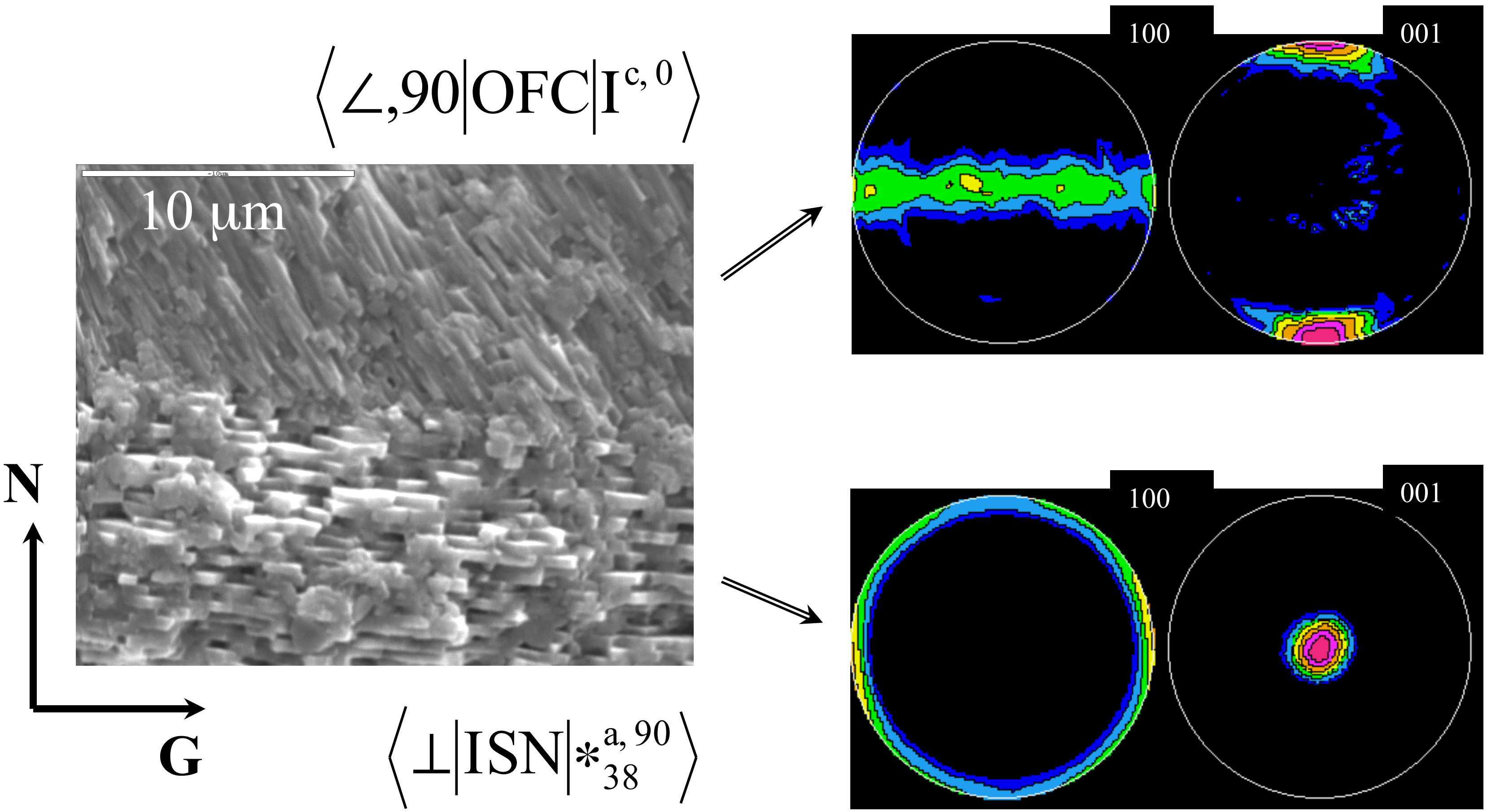


$$\left\langle \perp \middle| \mathrm{ISN} \middle| *^{a,\,-45}_{25} \right\rangle$$

Microstructure versus texture

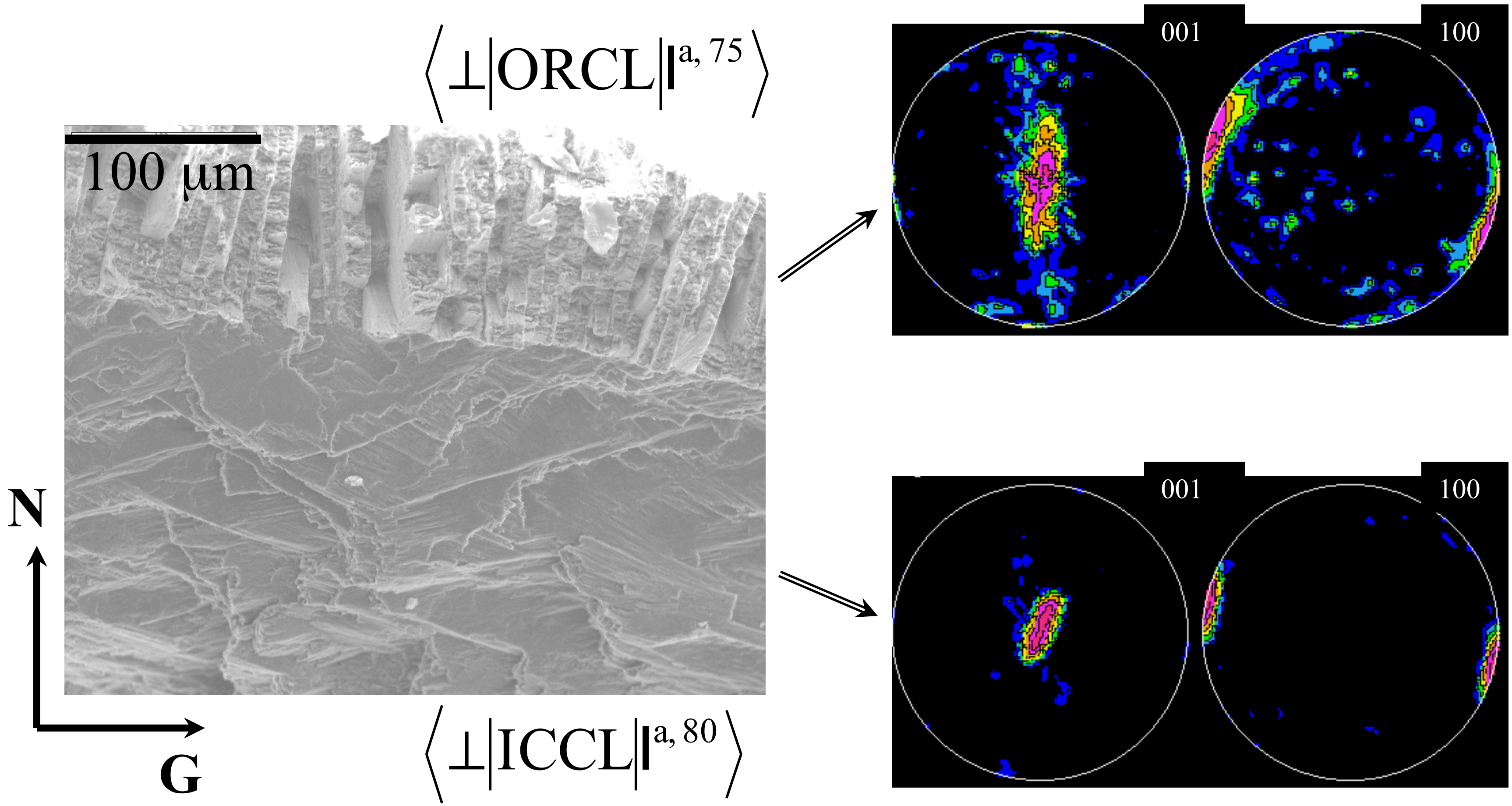
Bathymodiolus thermophilus (-2400m deep mussel):

no inter-mineral epitaxy



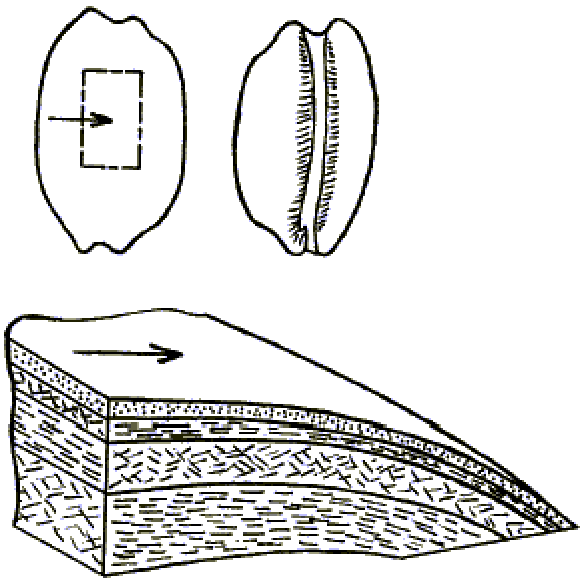
Microstructure versus texture

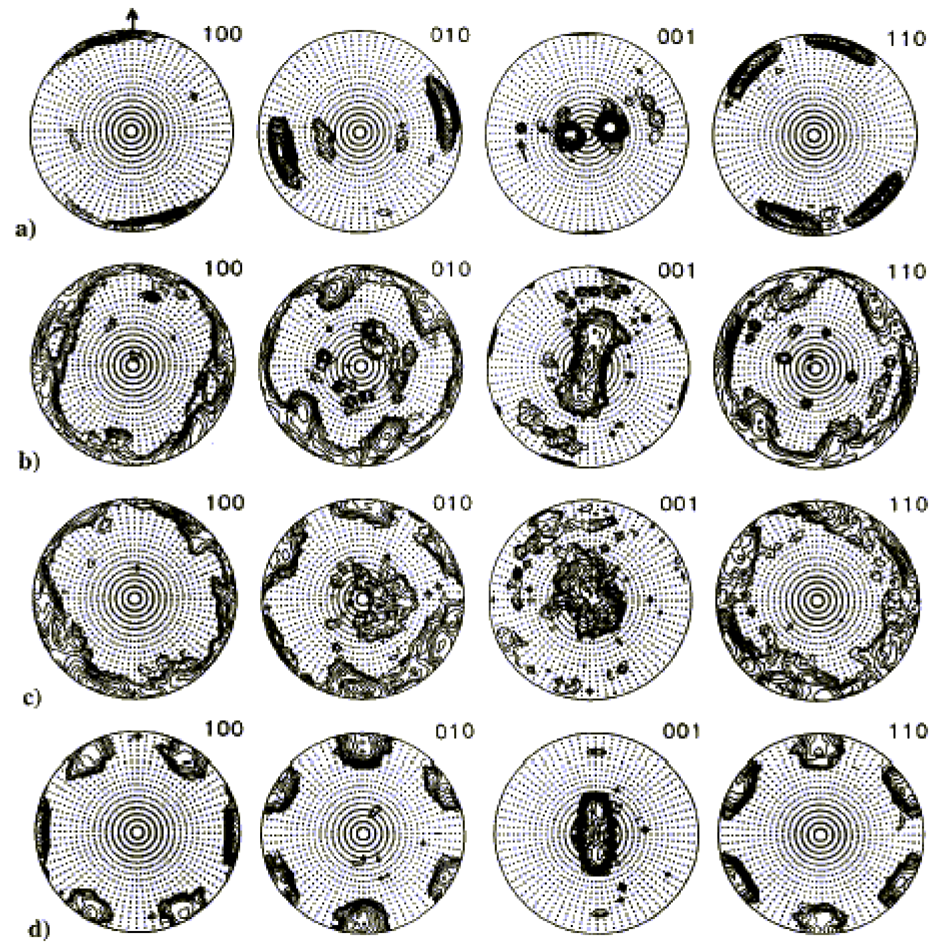
Euglandina sp.: different crystallite shapes, close orientations !



Microstructure versus texture

Inner sheet nacre of *Cypraea testudinaria* (cowry):
no inter-layer epitaxy

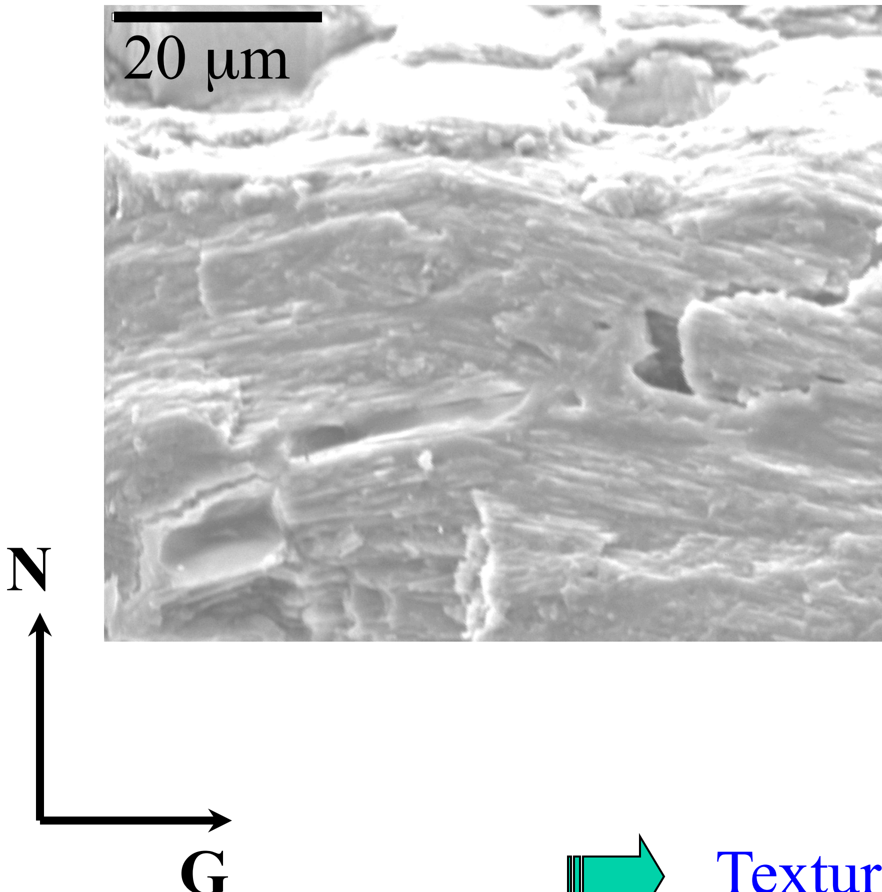


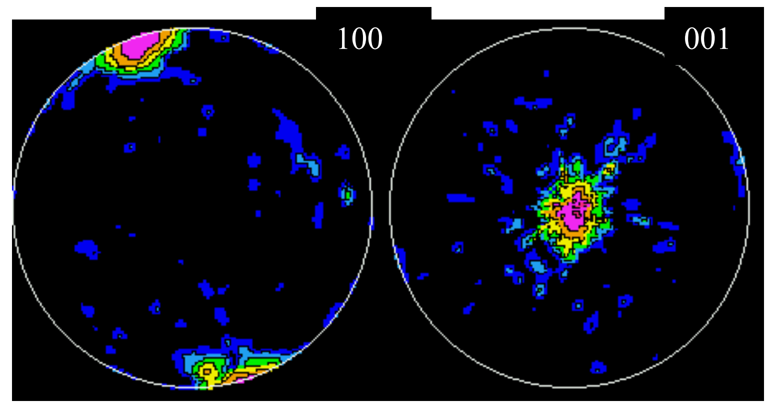


Organically driven growth

Microstructure versus texture

Cyclophorus woodianus: different crystal orientations look like single crystal from diffraction !





$\langle \perp | \mathrm{IRCL} | \mathbf{l}^{a,\,20} \rangle$

Texture parameters may deserve phylogenic analysis

a- and **c**-axes patterns of aragonitic layers, twinning

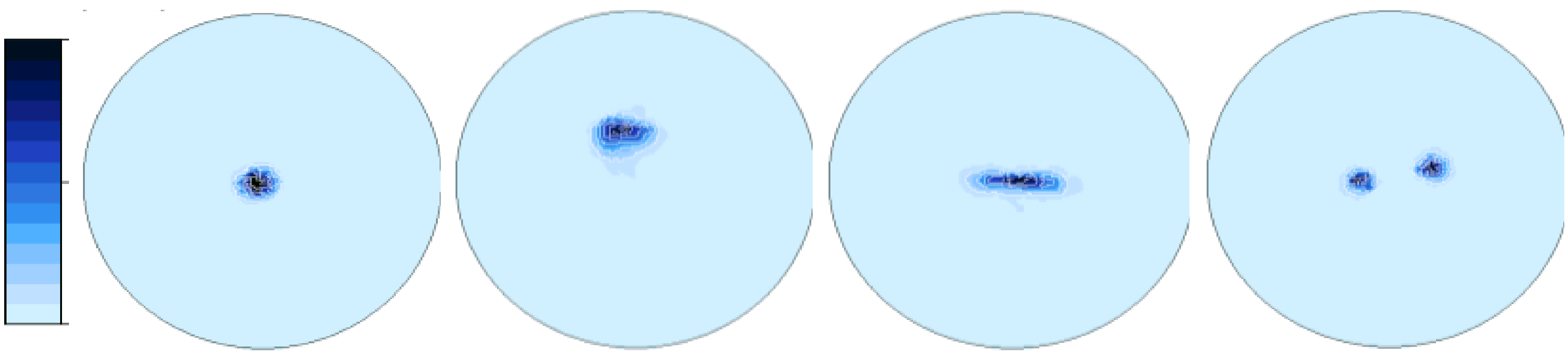
c-axes texture patterns

Pinctada maxima
ISN
"gold pearl oyster"

Nerita polita
ICCL
"polished nerite"

Fragum fragum
ICCL
"cockle"

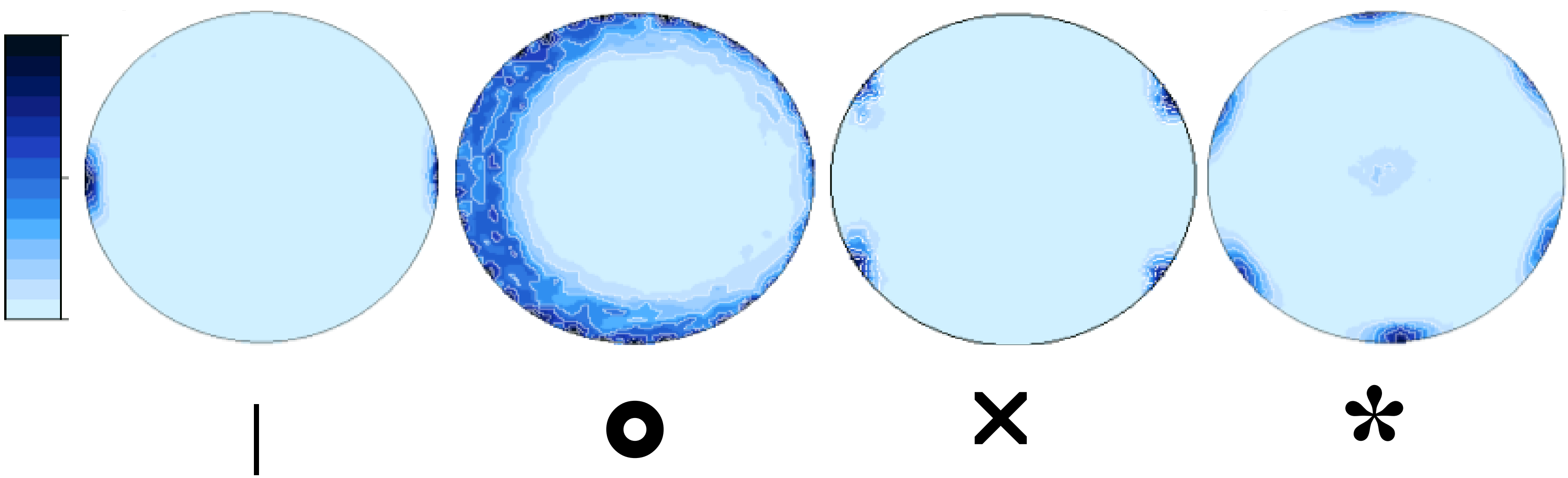
Cypraea testudinaria
ICCL
"turtle cowry"



⊥ ∠ ∀ ∨

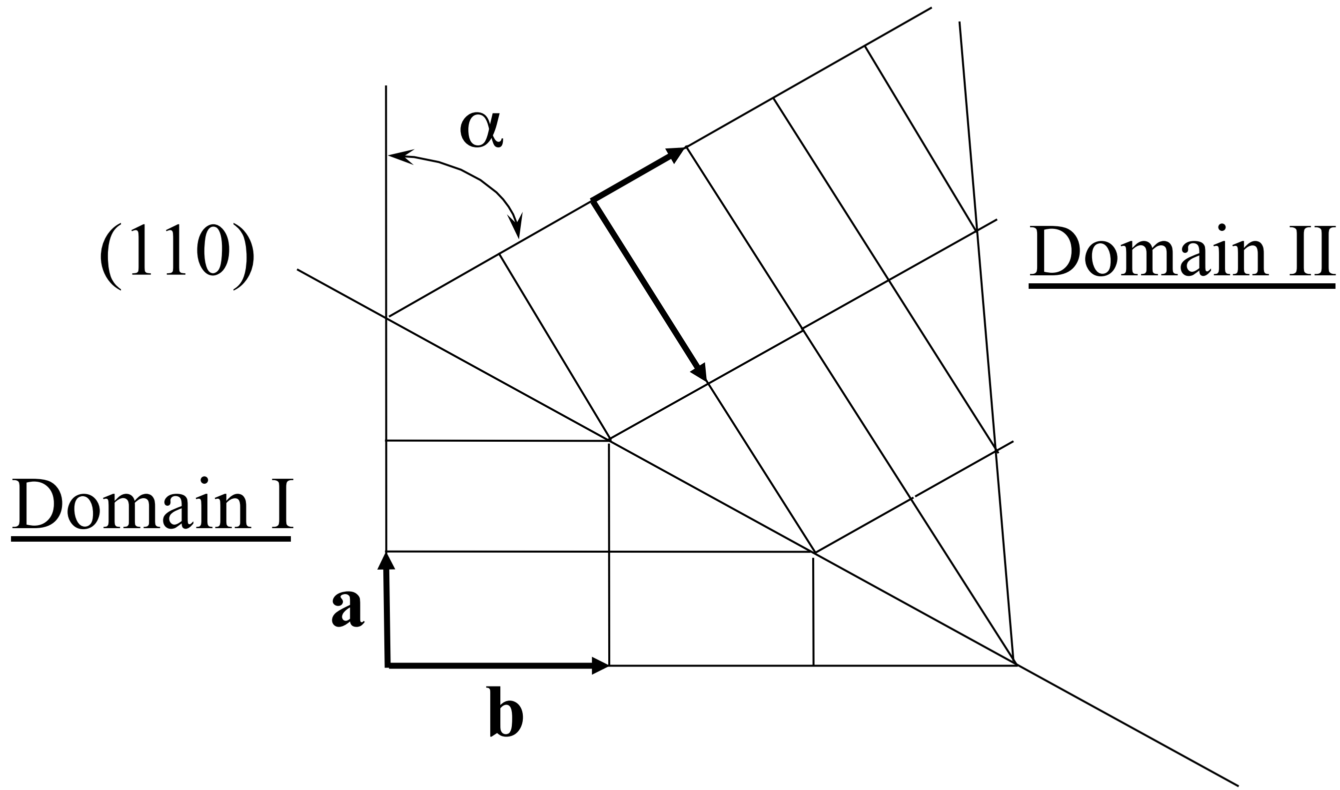
a-axes texture patterns

Helix pomatia	*Tectus niloticus*	*Conus leopardus*	*Nautilus pompilius*
OCCL	ICN	ICCL	ICN
“burgundy land snail”	“commercial top shell”	“leopard cone”	“new caledonia nautilus”



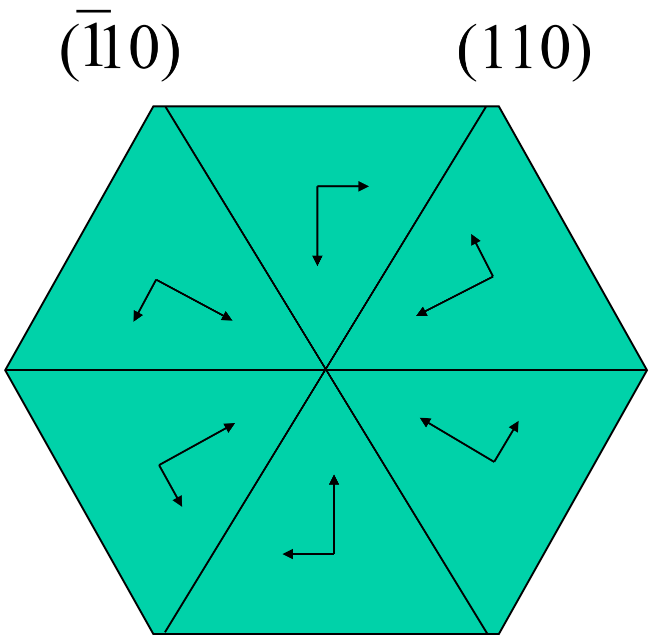
Chateigner, Hedegaard, Wenk, J. Struct. Geol. ***22*** *(2000) 1723-1735*

Twinning in aragonite ...

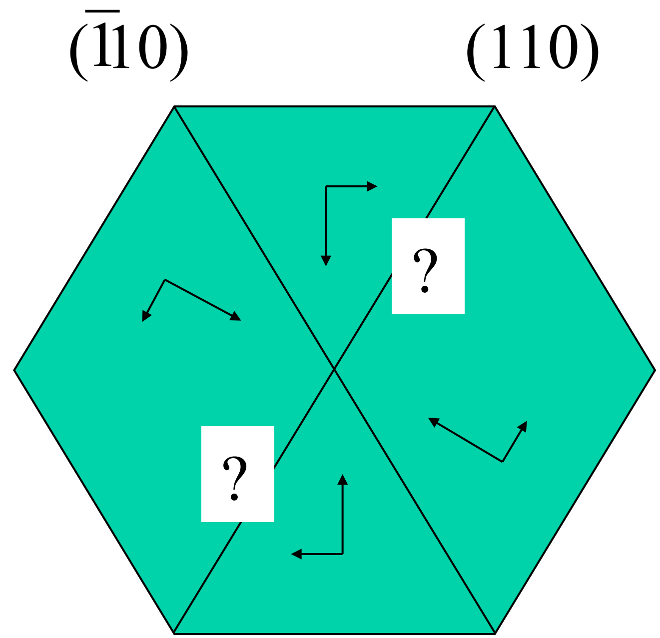


$$\alpha = 2 \arctan(a/b) = 63.8°$$

… forms nacre platelets …

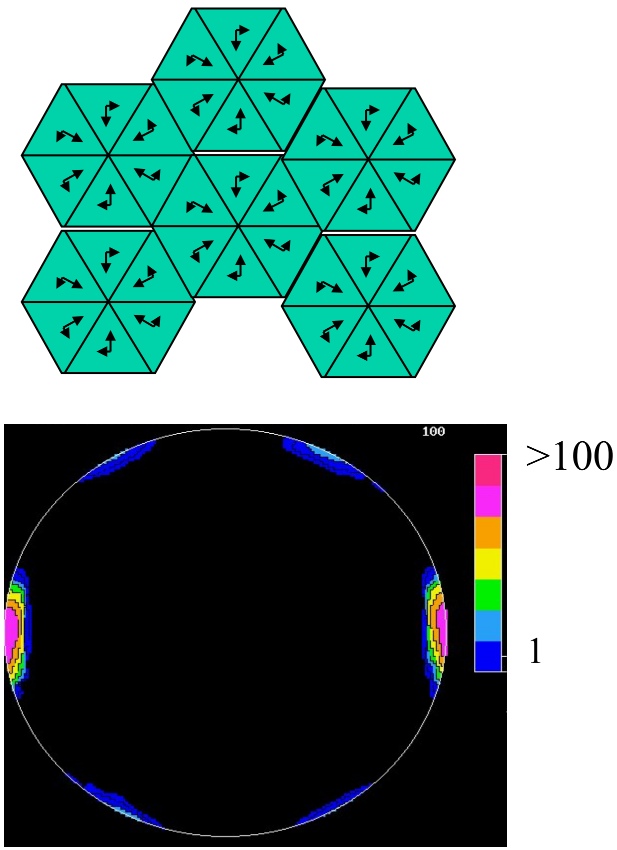


Bragg, 1937

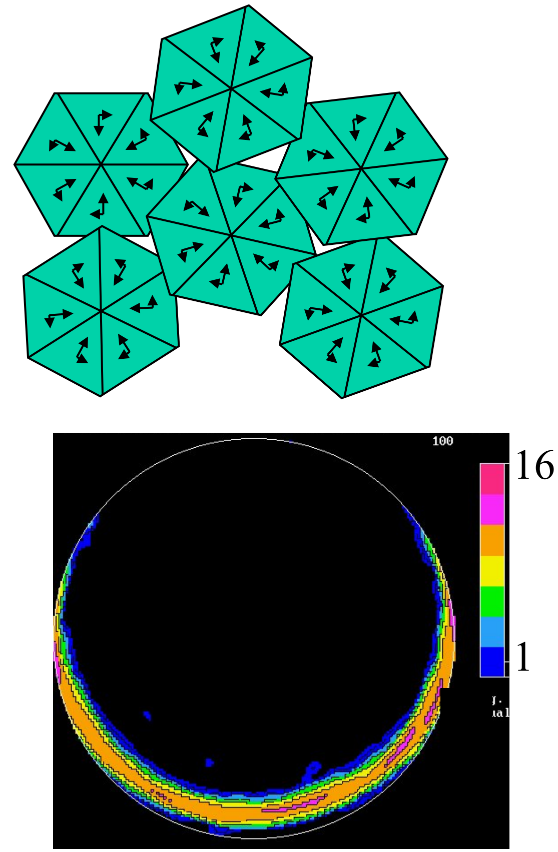


Mutvei, 1980

… that rearrange ...



Pinctada margaritifera
(black pearl oyster)

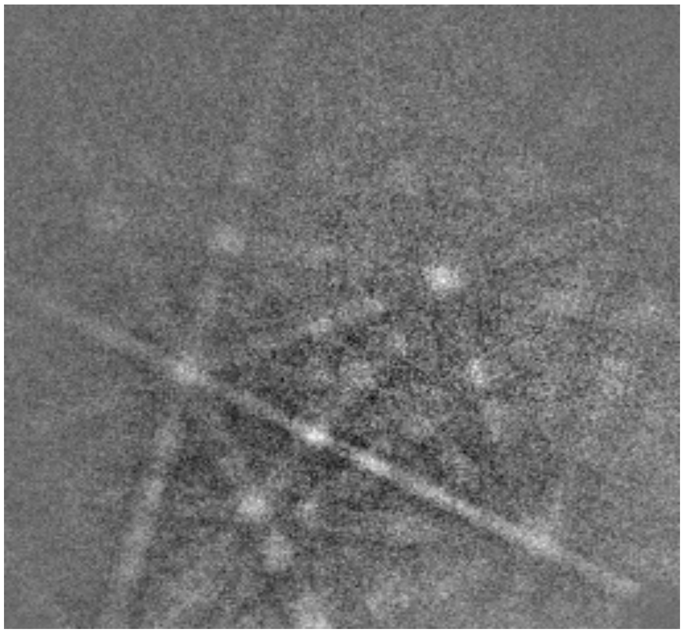


Haliotis cracherodi
(black abalone)

QTA: global versus local probes

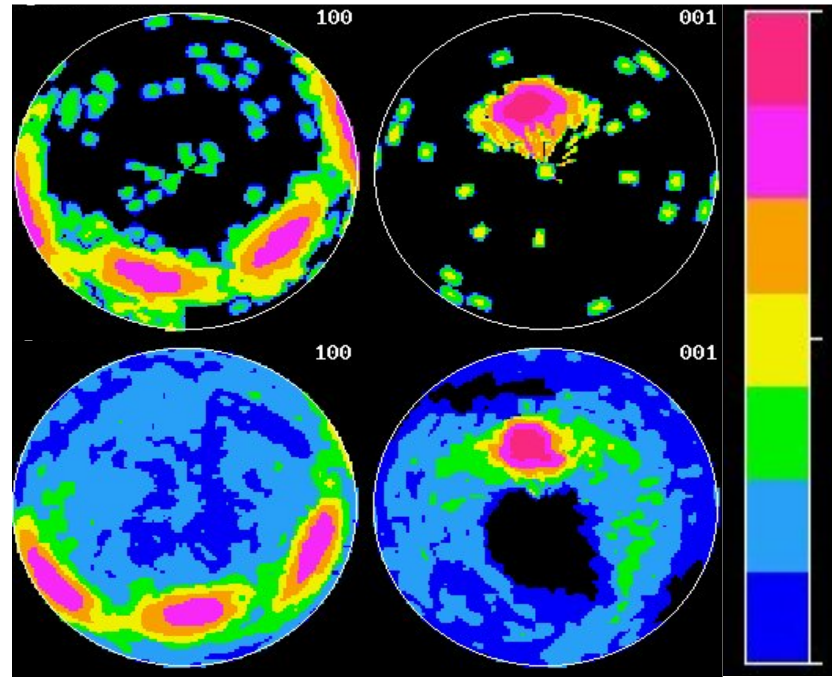
Neutrons or x-rays: global approach
Electrons: local, like with EBSD

Crassostrea gigas (common oyster: Inner foliated calcite)



Kikuchi diagrams

Electrons



x-rays

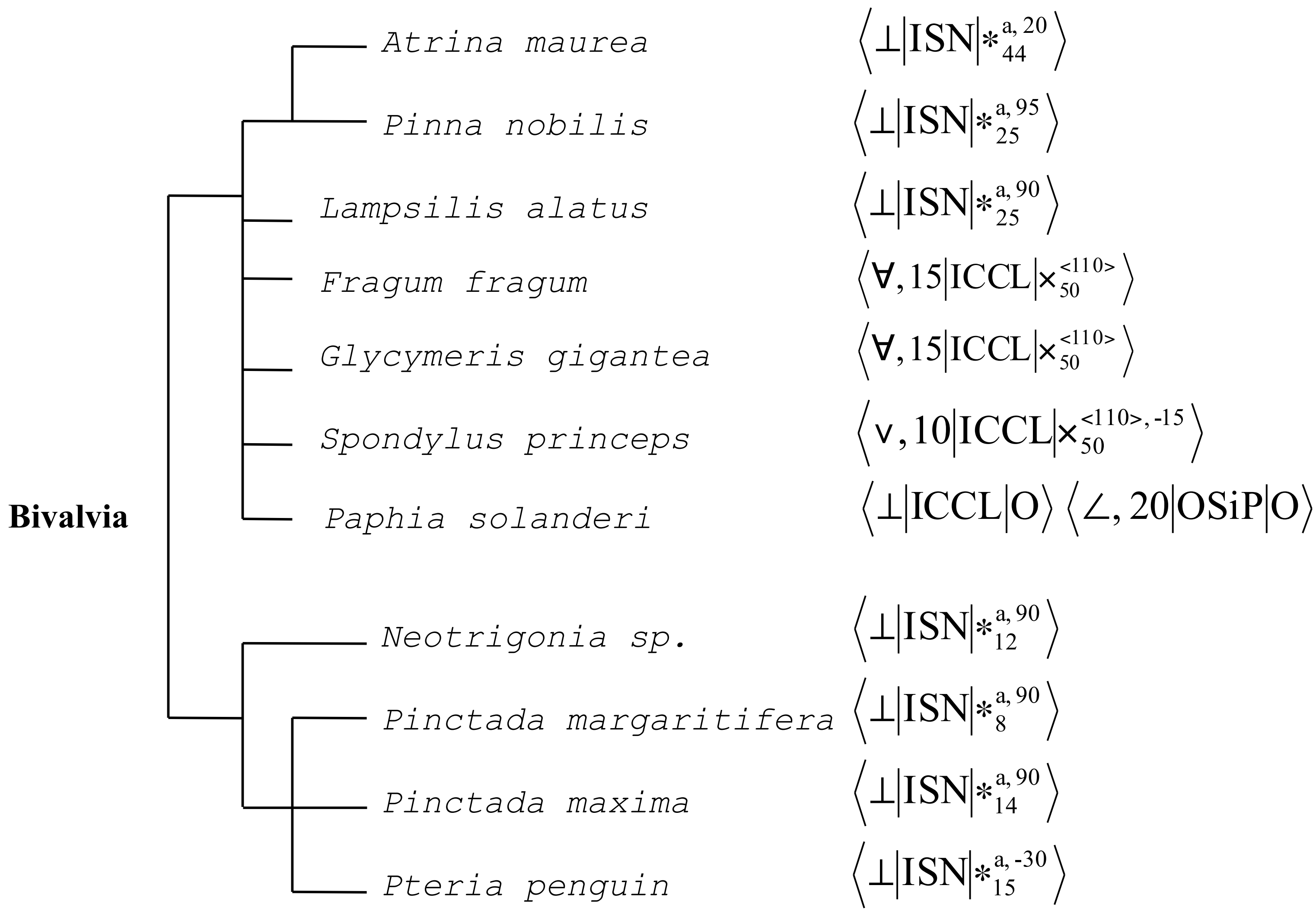
Global analysis is coherent with local ones like synchrotron microfocus x-rays *(Aizenberg, J. et al. (1996) Connective Tissue Research* ***34(4),*** *255-261)*

QTA and Mollusc's Phylogeny

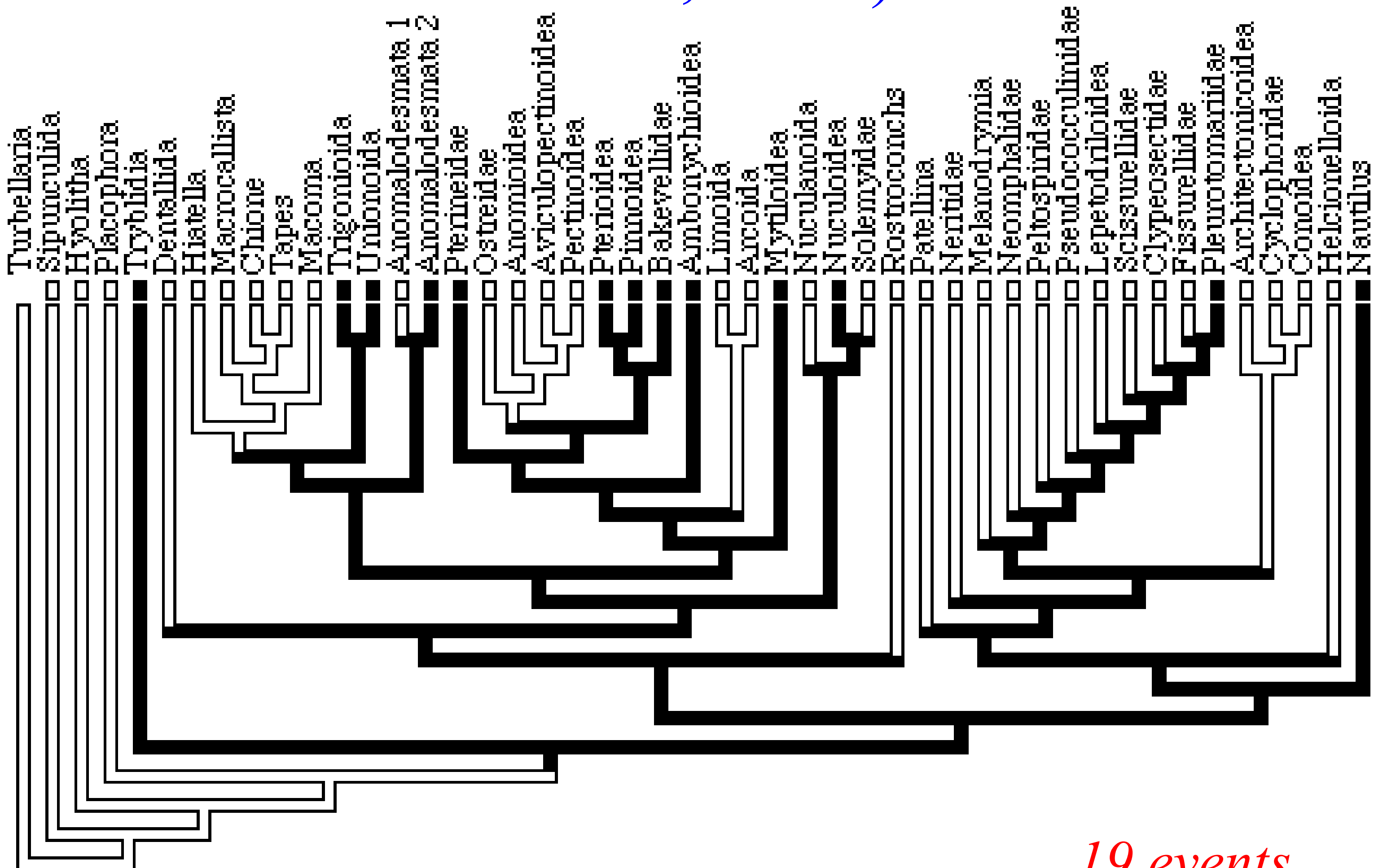
From 70 mollusc species (gastropods, bivalves and cephalopods), around 150 layers studied

In collaboration with C. Hedegaard (*DGB Aarhus, Denmark*) and H.-R. Wenk (DEPS Berkeley, *USA*)

Closely related species, close textural characters, but significant variations: textural parameters can serve character analysis

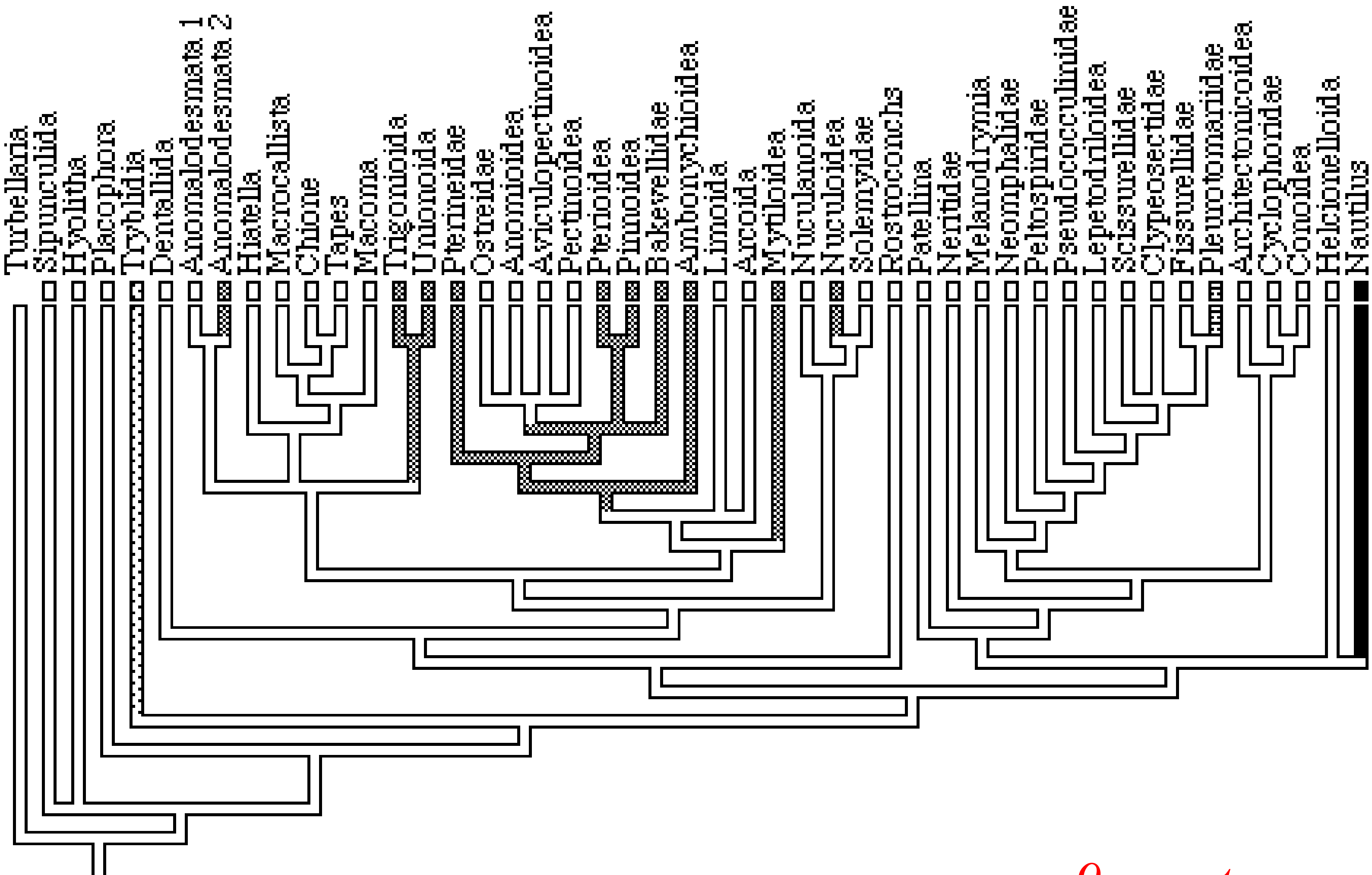


Phylogenic interest: nacre = ancestral (Carter & Clarck, 1985)



19 events

nacre not ancestral

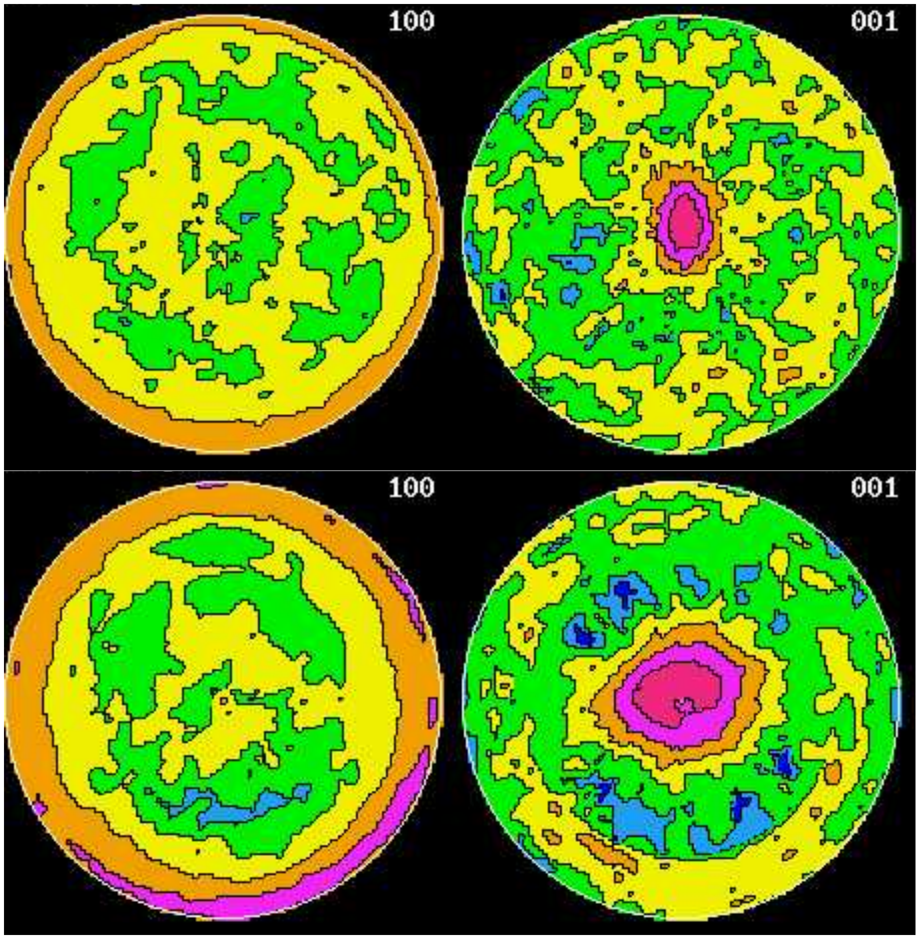


9 events

QTA and calcitic fossils

In collaboration with L. Harper (*DESC Cambridge, UK*) and M. Morales (*LERMAT-ENSICAEN, France*)

Pinnoid and Pterioid prismatic layers

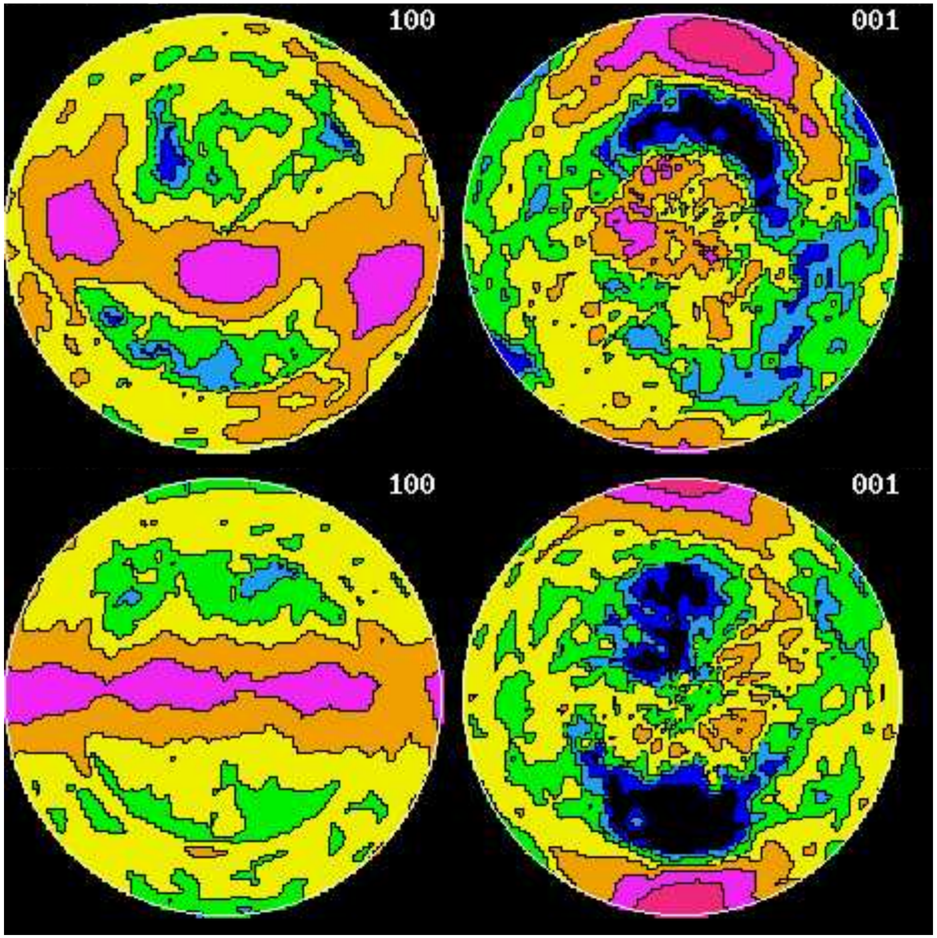


Pinna nobilis

c-axes // N
a-axes at random

Pteria penguin

Mussels prismatic layers



Mytilus edulis

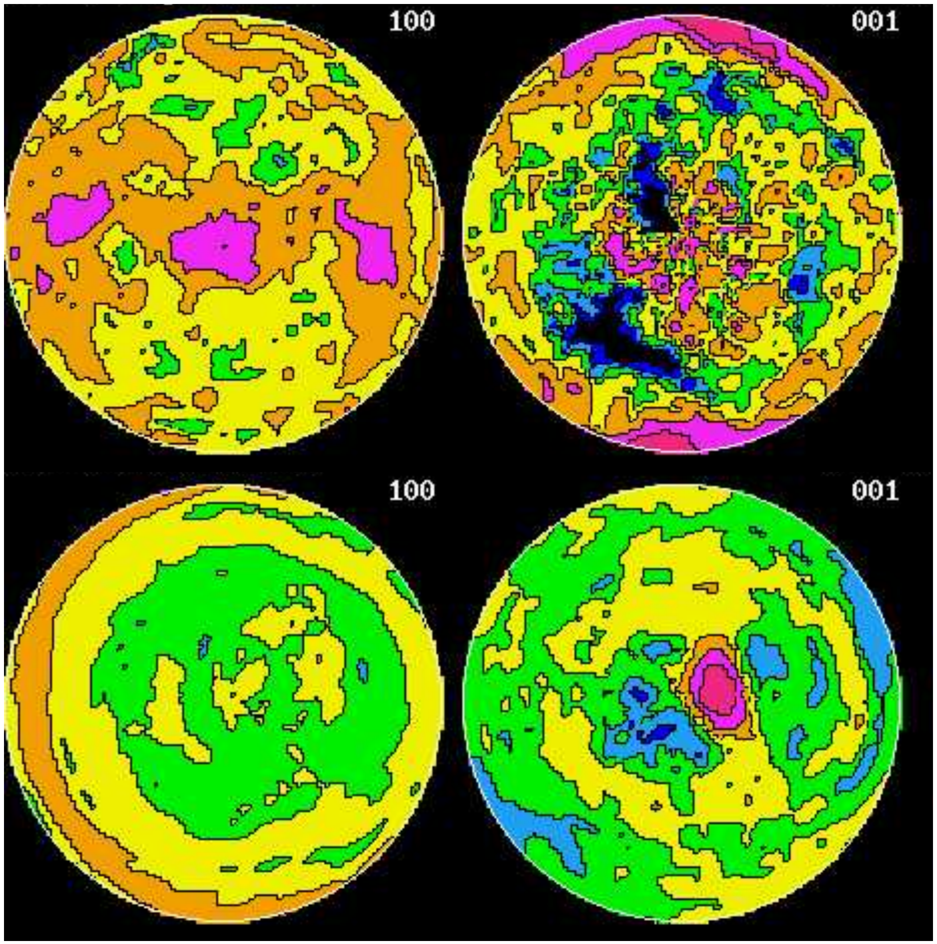
c-axes ∠ N

a-axes single-crystal like

c-axes ⊥ N, // G

Bathymodiolus thermophilus

Scallop and trichite prismatic layers



Amussium parpiraceum
(scallop)

c-axes ⊥ N, // G
a-axes single-crystal like

Trichites
(fossil)

c-axes ∠ N
a-axes random

Texture Analysis results

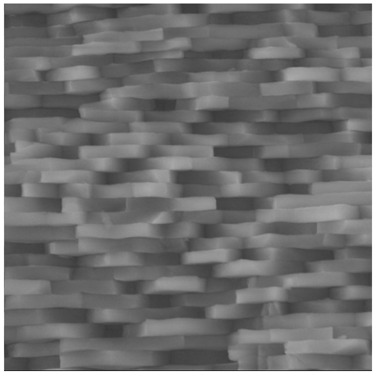
	Layer type	ODF Max (mrd)	ODF min (mrd)	RP0 (%)	RP1 (%)	c-axis	a-axis	{001} Max (mrd)	F^2 (mrd^2)	- S
Pinna nobilis	OP	303	0	50	29	// N	random	68	29	2.3
Pteria penguin	OP	84	0	29	15	// N	random	31	13	1.9
Amussium parpiraceum	OP	330	0	53	33	// G	<110> // M	20	31	2.6
Bathymodiolus thermophilus	OP	63	0	25	18	// G	// M	27	13	1.9
Mytilus edulis	OP	207	0	41	25	75° from N	<110> // M	23	21	2.2
Trichites	P	390	0	52	28	15° from N	random	56	41	2.2
Crassostrea gigas	IF	908	0	45	31	35° from N	// M	>100	329	5.1

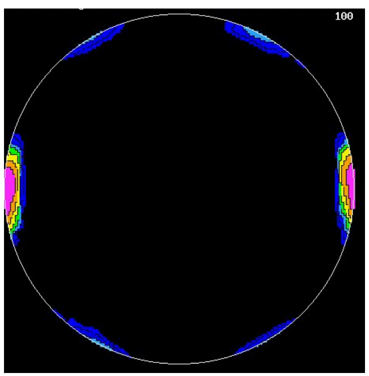
No DNA is available on fossils like in Trichites, but Trichite's textural parameters are close to the ones of *pinnoids* or *pterioids*: interesting for the classification of extinct species c

*Chateigner, Morales, Harper, Materials Science Forum, **408-412**, 2002, 1687-1692*

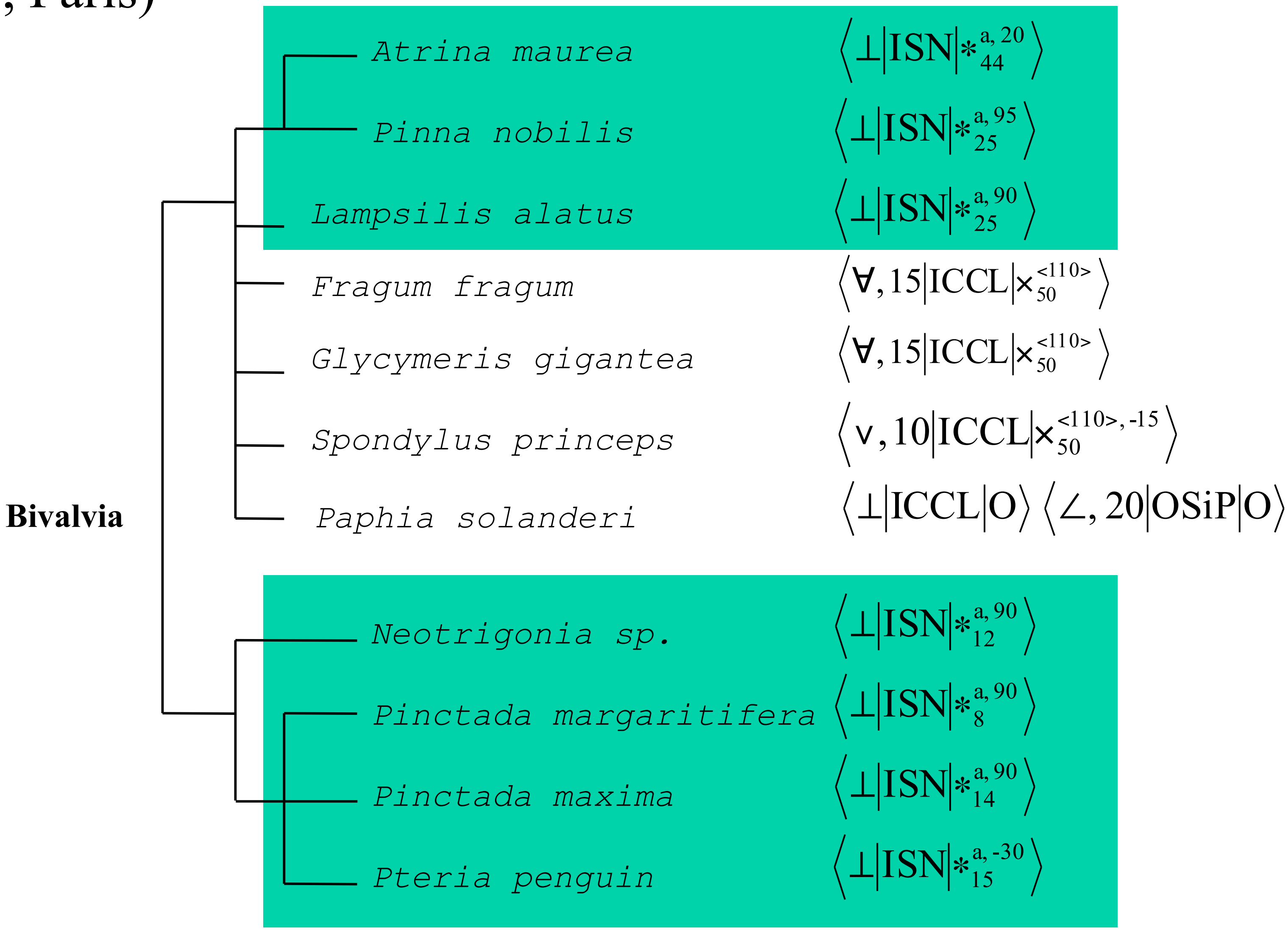
QTA and Mollusc's prothaetics

Pinctada margaritifera and *P. maxima* nacres:
Bio-compatible and bio-inductive layers for rabbit bones (E. Lopez (MNHN, Paris)





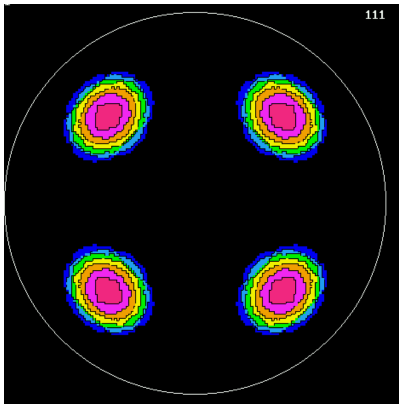
P. Margaritifera



QTA and mechanical behaviour

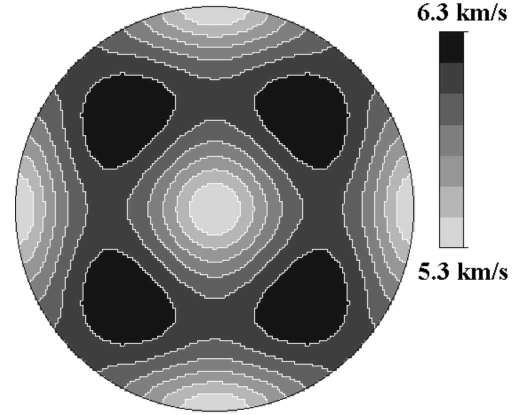
C_{ijkl} (Gpa)

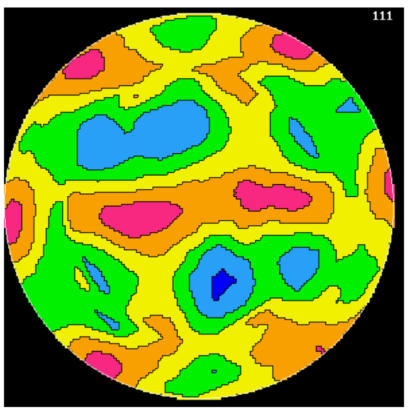
P waves



Single crystal (Gpa)

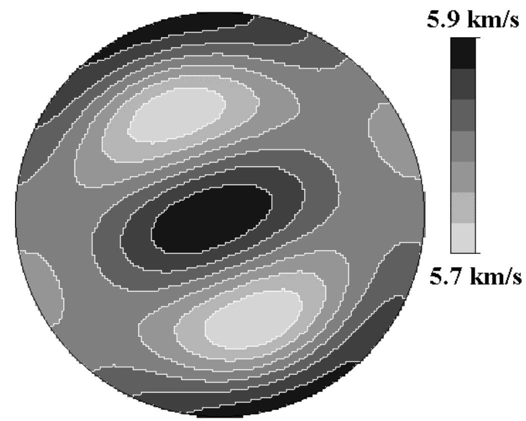
251	151	151			
151	251	151			
151	151	251			
			123		
				123	
					123





CoNi alloy

298	127	126	-0.	0.	-2
127	305	118	0.	0.	-1
126	118	307	-0.	-0.	3
-0.	0.	-0	78	2.8	0.
0.	0.	-0	2	85	-0.
-2	-1	3	0.	-0.	86



QTA + Simulation
Geometric Mean

Some conclusions

- Shells exhibit a large variety of texture patterns, in their aragonite and calcite layers
- Textural parameters are similar for close species, different for distant species, they confirm organically driven growth and refute mineral epitaxy
- Texture and microstructure analyses give non-redundant information in shells
- "Texture" characters can be relevant for classification and phylogenetic interpretation, either for living or extinct species
- Texture may serve as a tool to predict bio-compatible species, and mechanical behaviours of shells