# Instrumented Indentation

Introduction, Overview, and Elastic Contact Mechanics

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ME 482: Experimental Tissue Mechanics

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# mechanical tests, including instrumented indentation, enhance our sense of touch

"Instrumented indentation testing is a technique for measuring the mechanical properties of materials. It is a development of traditional hardness tests such as Brinell, Rockwell, Vickers, and Knoop. Instrumented indentation testing is similar to traditional hardness testing in that a hard indenter, usually diamond, is pressed into contact with the test material. However, traditional hardness testing yields only one measurement of deformation at one applied force, whereas during an instrumented indentation test, force and penetration are measured for the entire time that the indenter is in contact with the material. **Nearly all of the advantages of IIT derive from this continuous measurement of force and displacement."**

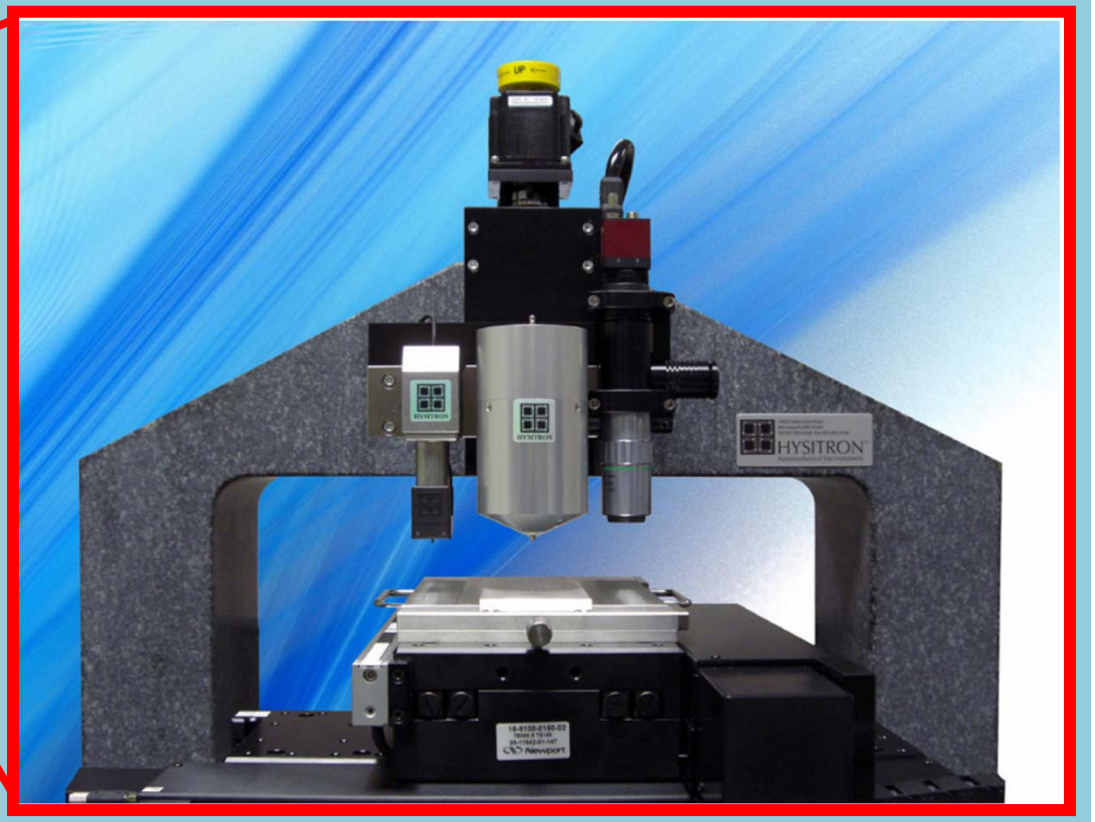
Hay, J.L., "Introduction to Instrumented Indentation Testing," *Experimental Techniques* ***33****(6), 66-72, 2009.*

# other names for instrumented indentation

- nanoindentation
  - the fact that we can get contact areas from load-displacement data facilitates small-scale testing.
- depth-sensing indentation
- continuous-recording indentation

# the hysitron triboindenter ti-950

www.hysitron.com

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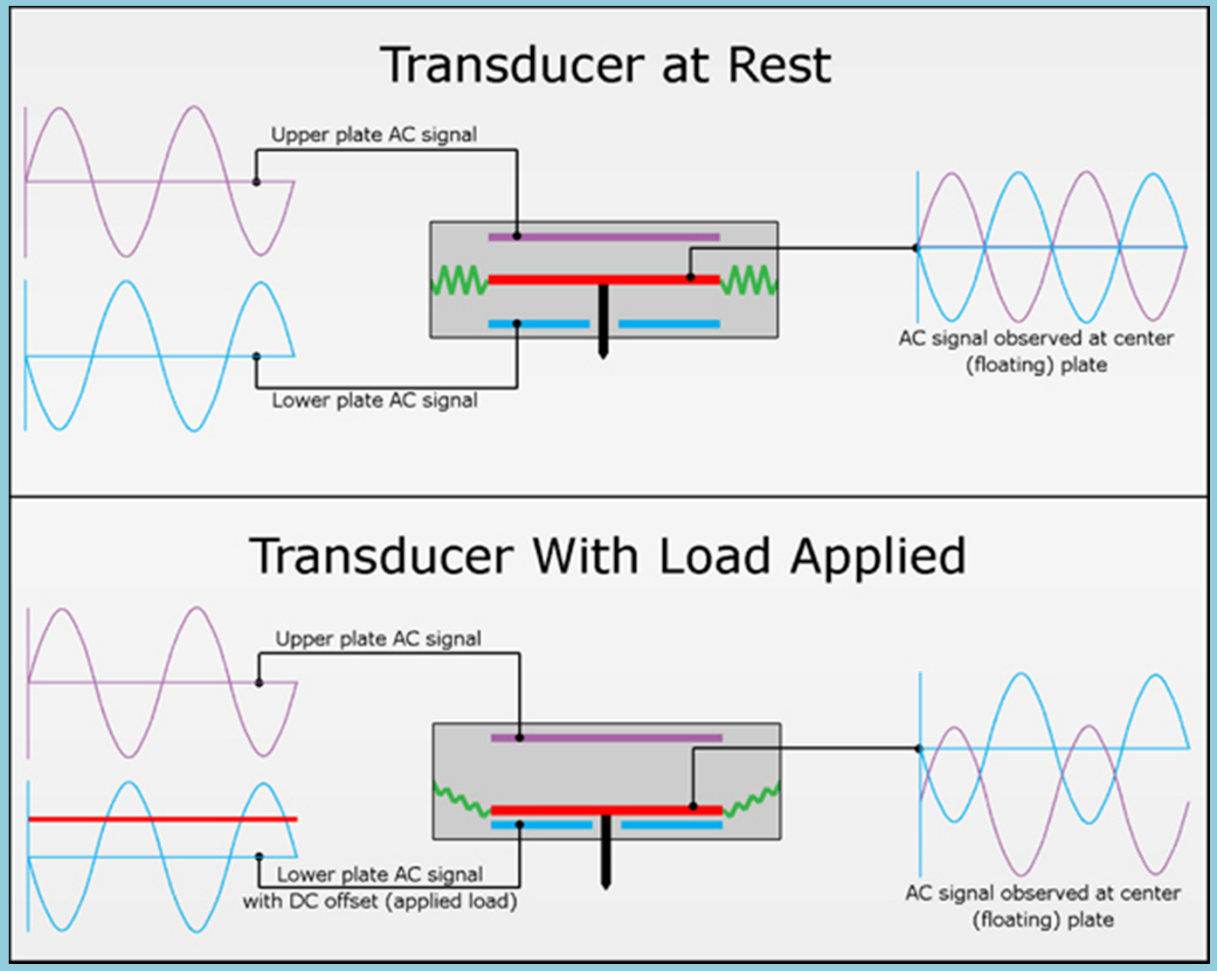
# hysitron's 3-plate capacitive transducer

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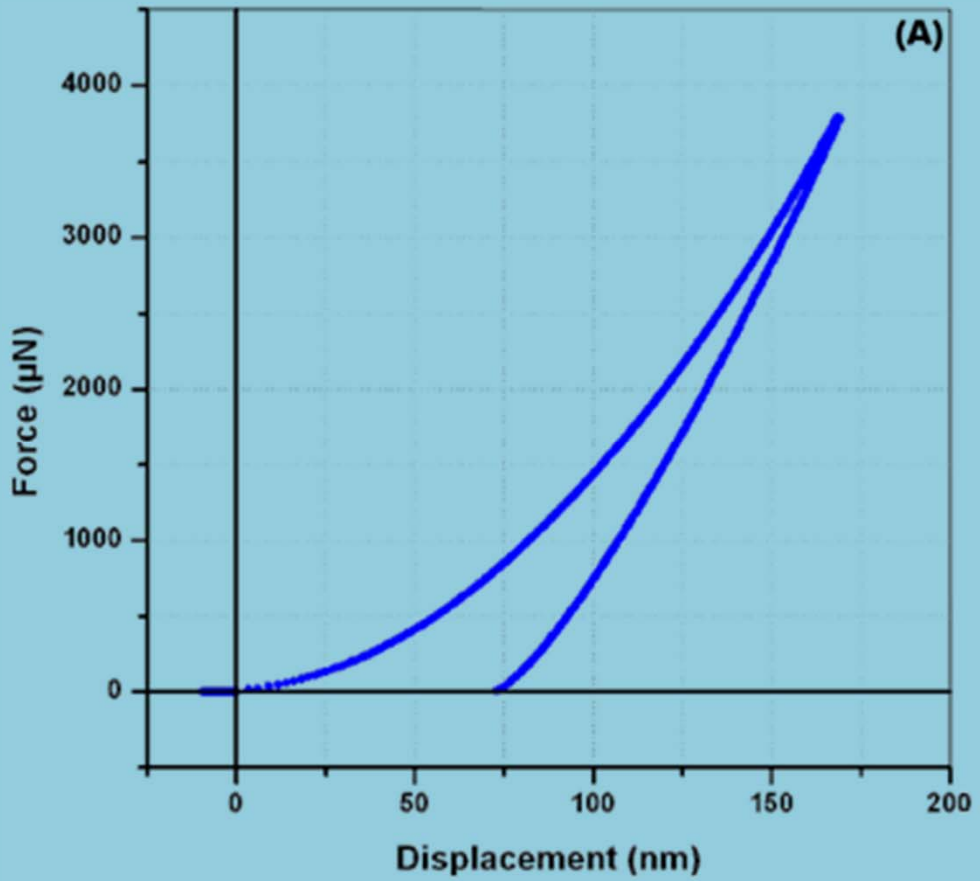
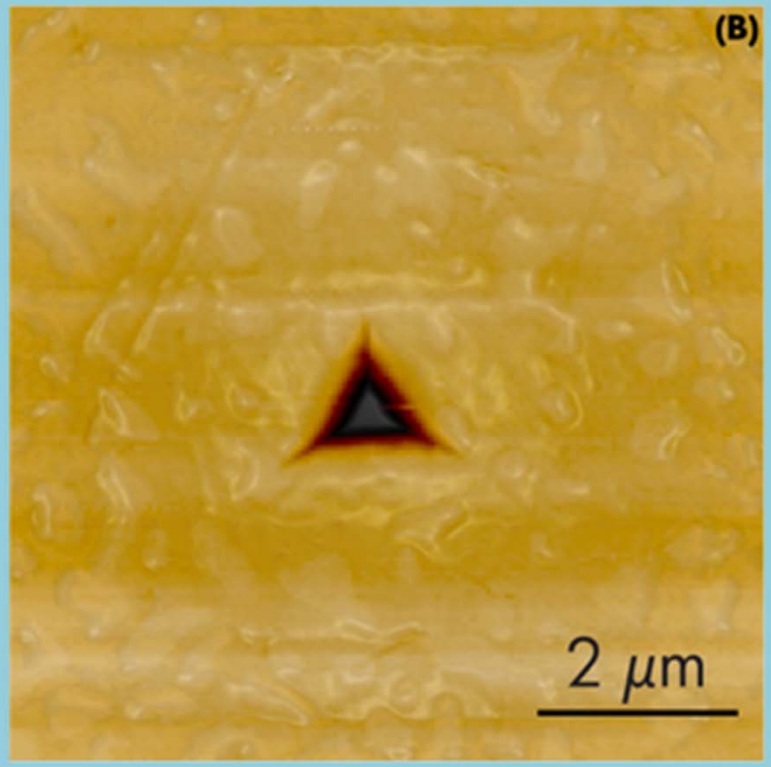
# instrumented indentation testing




Force versus displacement curve on fused quartz showing typical response of elastic-plastic material.




Resulting *in-situ* SPM image of quartz surface after quasistatic nanoindentation showing residual indent impress

# material properties acquired by indentation

- young's modulus.
- hardness
- complex modulus.
- strain-rate sensitivity.
- fracture toughness.

# young's modulus

young's modulus (E), also known as the tensile modulus, is a measure of the stiffness of an elastic material and is a quantity used to characterize materials. It is defined as the ratio of the uniaxial stress ($\sigma$) over the uniaxial strain ($\varepsilon$) in the range of stress in which Hooke's law holds. $\sigma = E\varepsilon$

# yield stress $(\sigma_y)$ and Hardness (H)

yield stress $(\sigma_y)$ is that value of uniaxial stress at which plastic (permanent) deformation ensues.

Hardness (H), generally defined for an indentation test as load divided by contact area, is a poor-man's quantification for yield stress. For metals, $H = C\sigma_y$.

# so why do we need instrumented indentation?

- small volumes of material.
- material behaves differently at small scales.
- heterogeneity
- testing simplicity.
- measured mechanical properties at small length scales may explain macroscale mechanical properties and enhance macroscale models of biological tissue.

# indentation is a more clinically relevant mode of testing?

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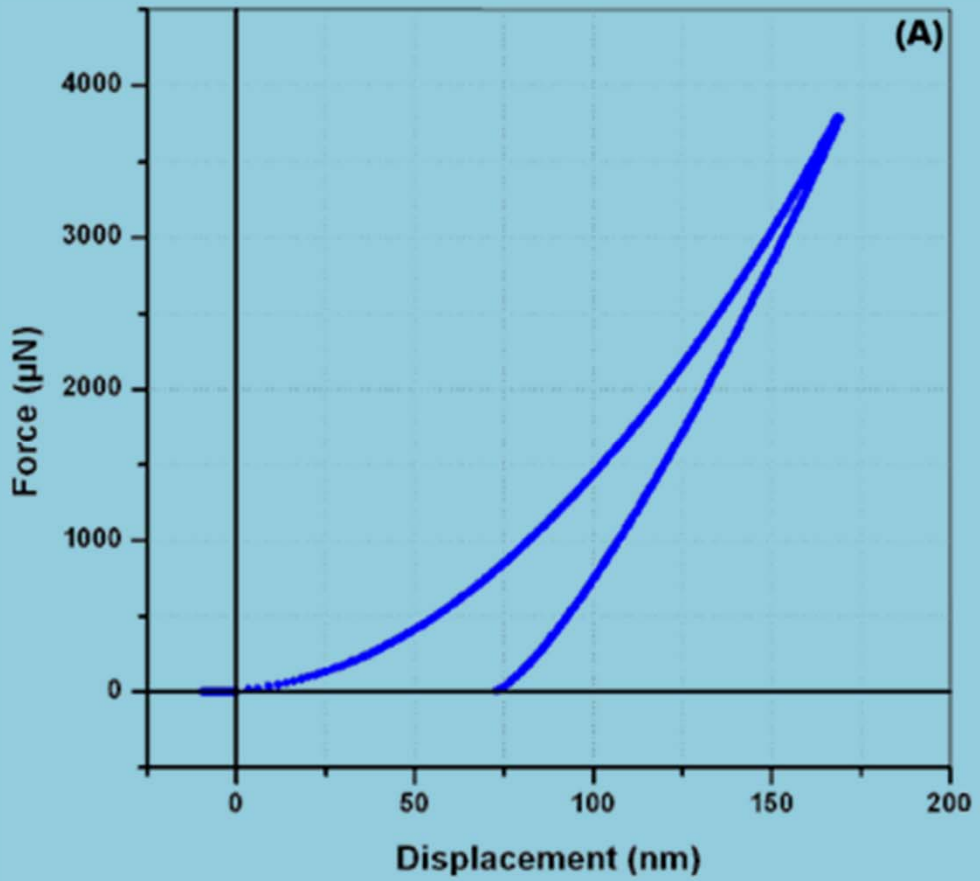
# summary of introduction and overview

- as a mechanical test, instrumented indentation complements (enhances and quantifies) our sense of touch.
- an instrumented indentation test comprises pressing a hard indenter into a test surface while continuously recording the contact force and displacement.
- elastic modulus and hardness can be obtained by an instrumented indentation test.
- relative to uniaxial compression or tensile testing, instrumented indentation has the advantage of being able to characterize small volumes.

# instrumented indentation testing

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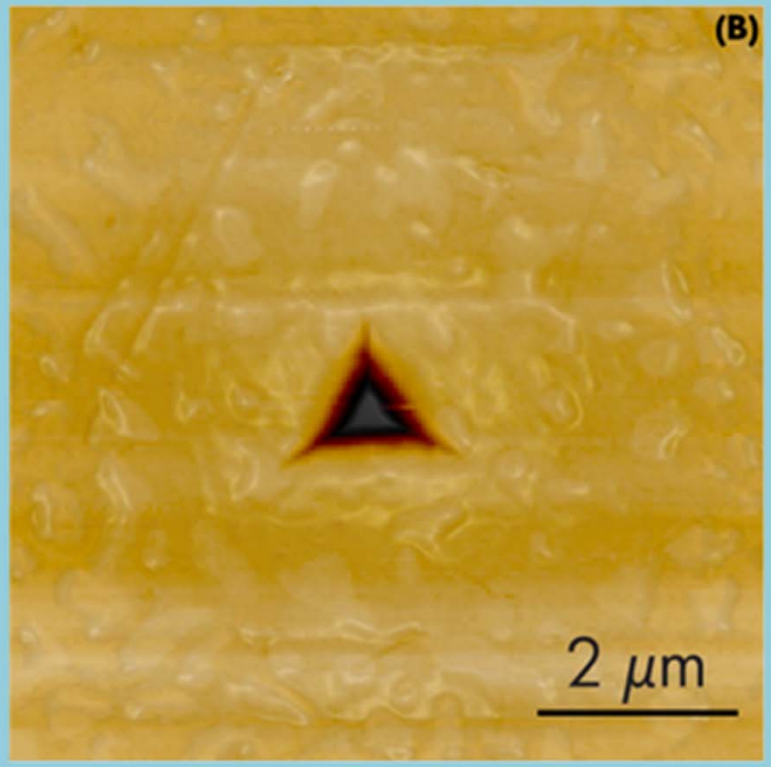
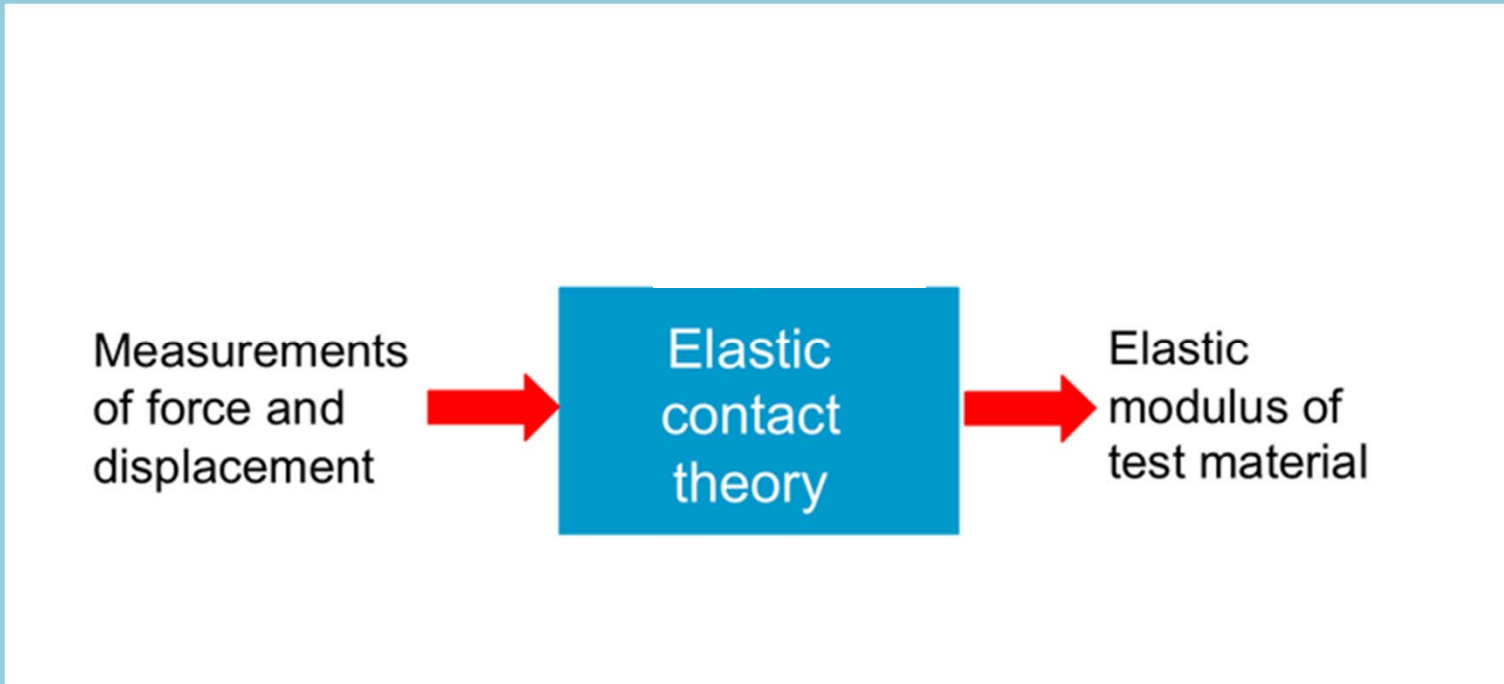



Resulting *in-situ* SPM image of quartz surface after quasistatic nanoindentation showing residual indent impress

# interpretation of indentation data




Elastic contact theory provides a rational relationship between:

- Force
- Displacement, and
- Elastic properties of a material.

Adapted from: J. Hay, Indentation University, Agilent Technologies, Sept. 2012

# schematic of impression during load

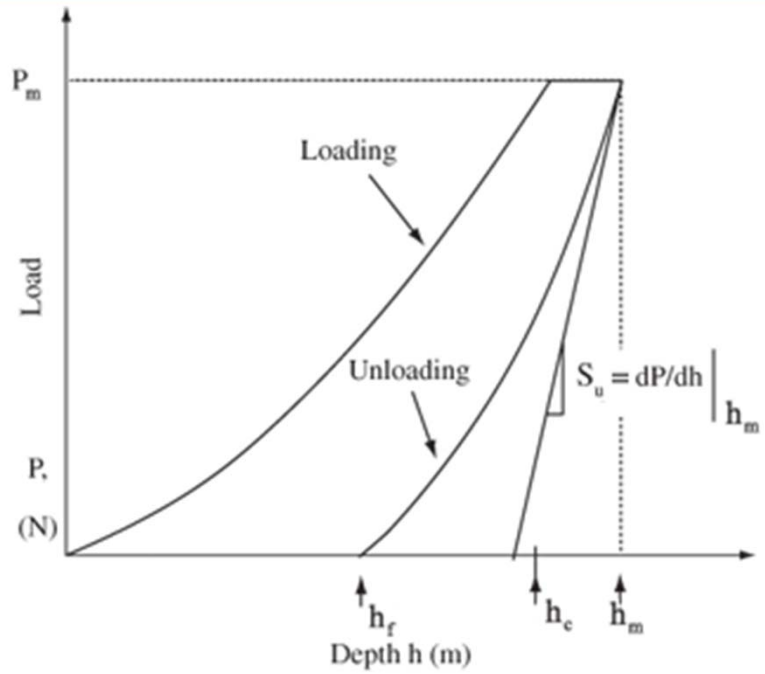



**Figure 1.** Schematic representation of indentation load-displacement data, showing the main parameters: $P_m$: peak indentation load; $h_m$ indenter displacement at peak load; $h_c$ contact depth; $h_f$ final depth of the contact impression after unload and $S_u$ initial unload stiffness[3].

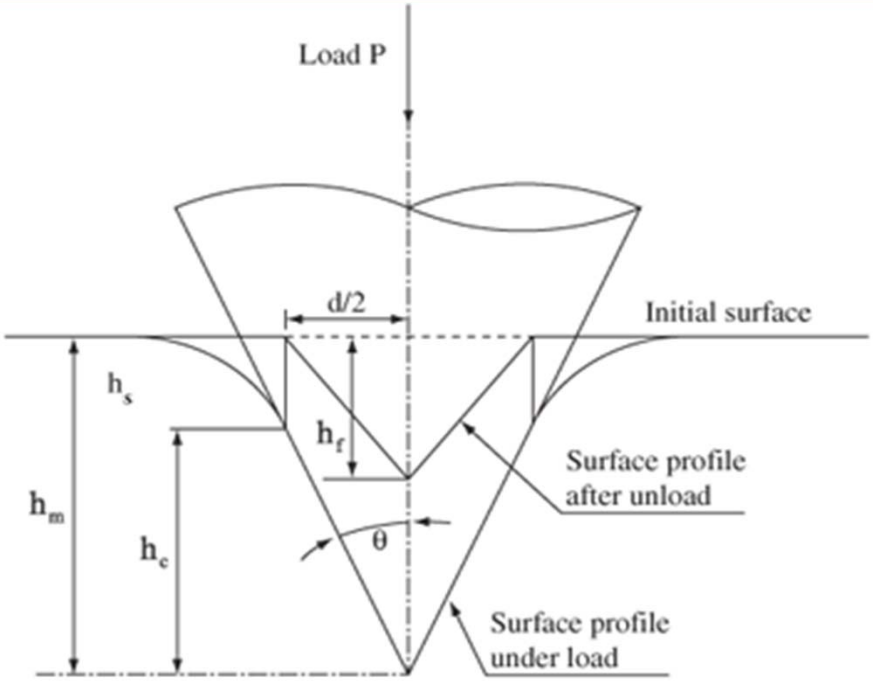



**Figure 2.** Schematic representation of the impression during load and impression left after unload, during a nanoindentation test[3]: $h_s$: distance form surface to the point of last contact between indenter and the specimen at maximum load; d: diagonal of contact.

# indenter geometries

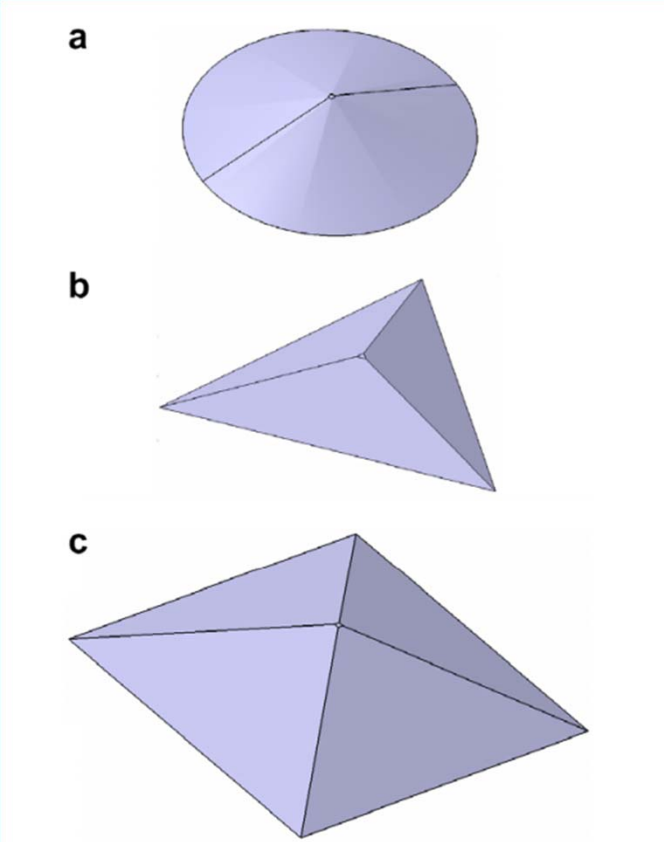



**Fig. 1.** Indenters geometry: (a) conical; (b) Berkovich; (c) Vickers.

N.A. Sakharova et al. / International Journal of Solids and Structures 46 (2009) 1095–1104

# sample prep for bone

minimizing the surface roughness

grind the surfaces with progressively finer grit size sand paper

polish using polishing clothes