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# Tribological Contacts

## Fundamental Phenomena and Practical Applications

*Course Leader*

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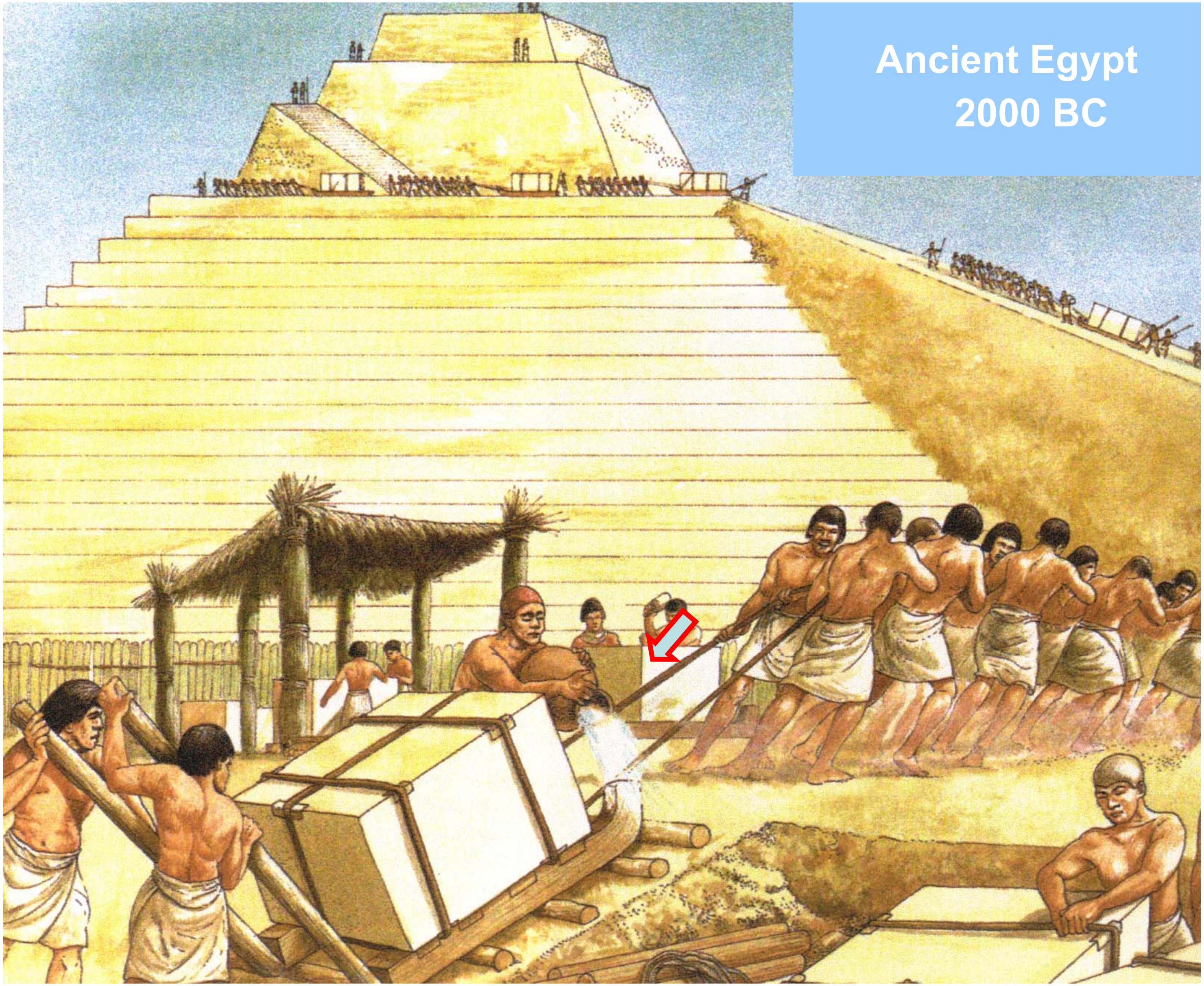
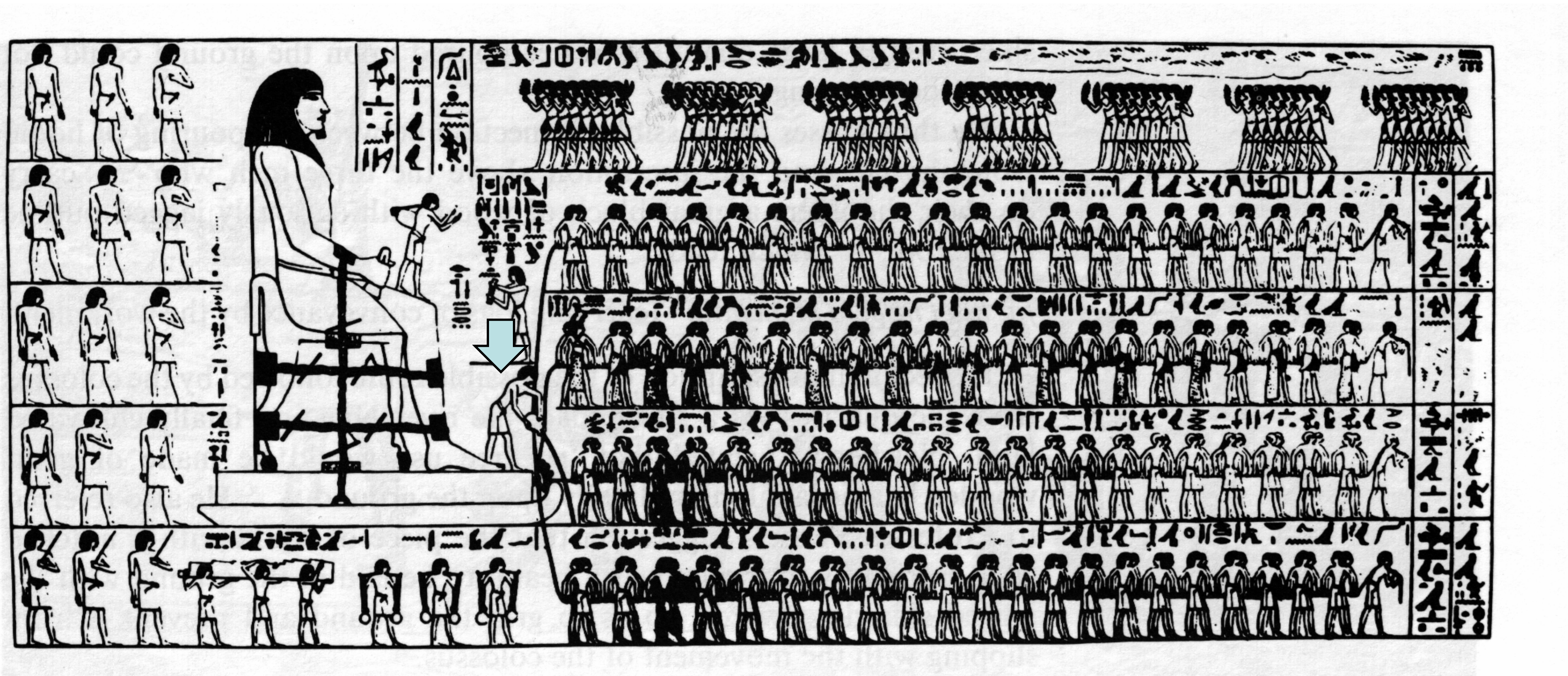
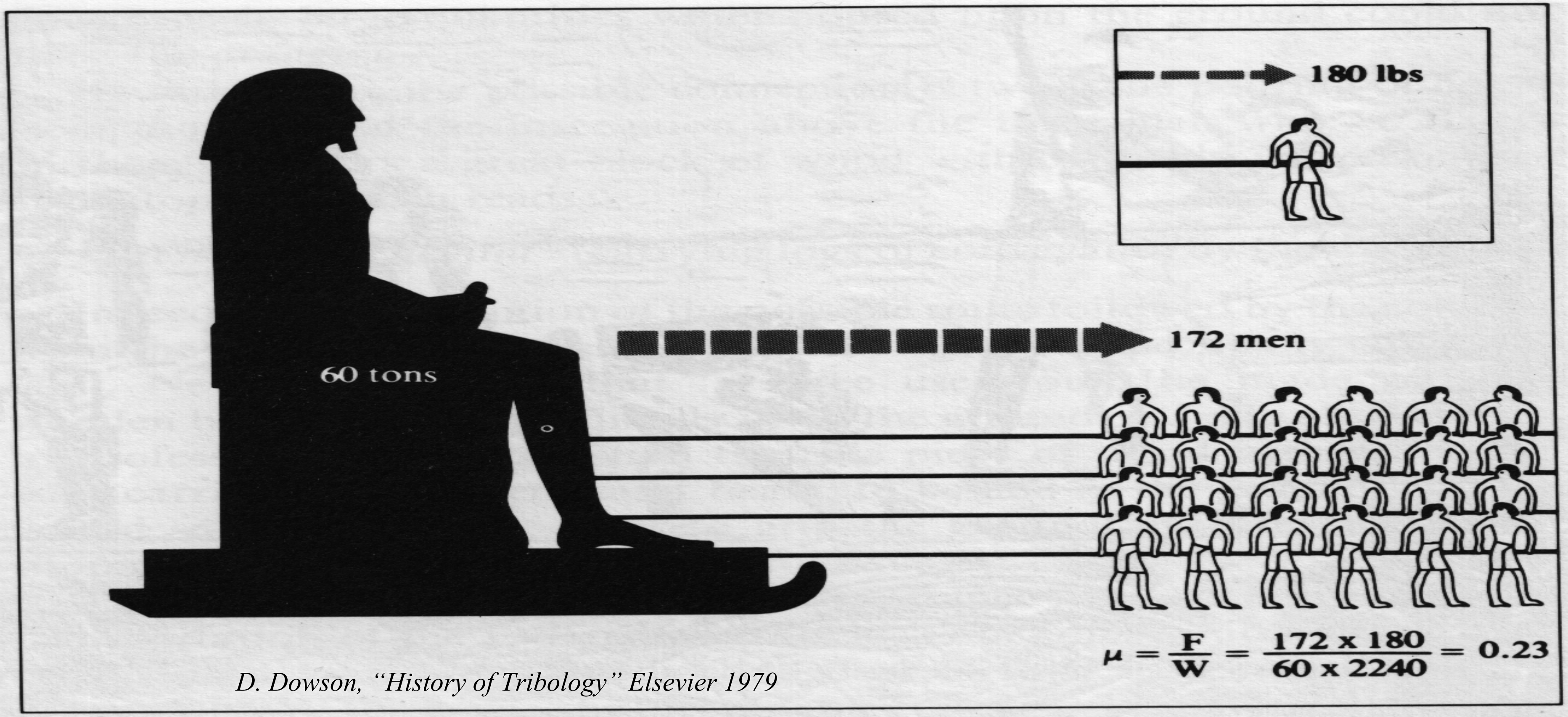
# *Chapter 1*
# Historical Perspective



# *Transporting an Egyptian Colossus*



***Source: Painting from a Grotto at El-Bersheh***
***Source: Duncan Dowson, History of Tribology , Elsevier, 1979***




*Bowden and Tabor, "Friction and Lubrication of Solids-Part I" Oxford 1950*

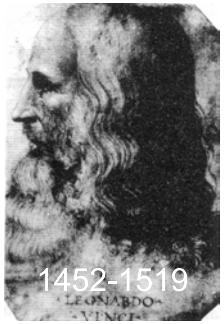
**•The coefficient of friction, μ, for hard wood sliding on wet/moist wood is 0.2**

**•The coefficient of friction of wood-on-wood in dry condition is 0.45-0.50**

**In ancient Egypt, about 100, 000 men were employed each year to transport massive objects.**

**Without a lubricant, 200, 000 for a state in 2000 BC can be large expense even if the monarchs fed them only one meal and paid no wages!!!**

# Significant Milestones in Recorded History



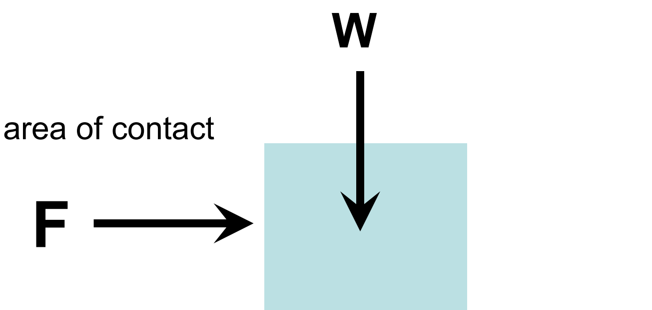

## Leonardo da Vinci (quotes from his note books)

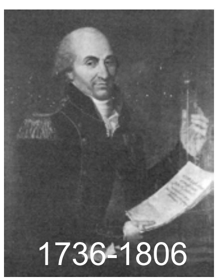
The very rapid friction of two thick bodies produces fire
That thing which is entirely consumed by the long movement of its friction will have part of it consumed at the beginning of the movement
Friction is independent of contact area
Friction resistance of a body is about ¼ of its weight

1663-1705

## Guillaume Amontons (Unaware of da Vinci's recorded observations)

First t publish the two laws of friction:
Friction force is proportional to normal force
Magnitude of friction force does not depend on the apparent area of contact




## Charles Augustin Coulomb

Verified the two laws of friction, and added the third law.
Friction force is independent of velocity once motion starts


## Heinrich Rudolph Hertz

His most famous work on contact stresses and deformation is the basis upon which so many tribological concepts rest

# Fortieth Birth Anniversary of the Phrase *"Tribology"*

Peter Jost, CBE

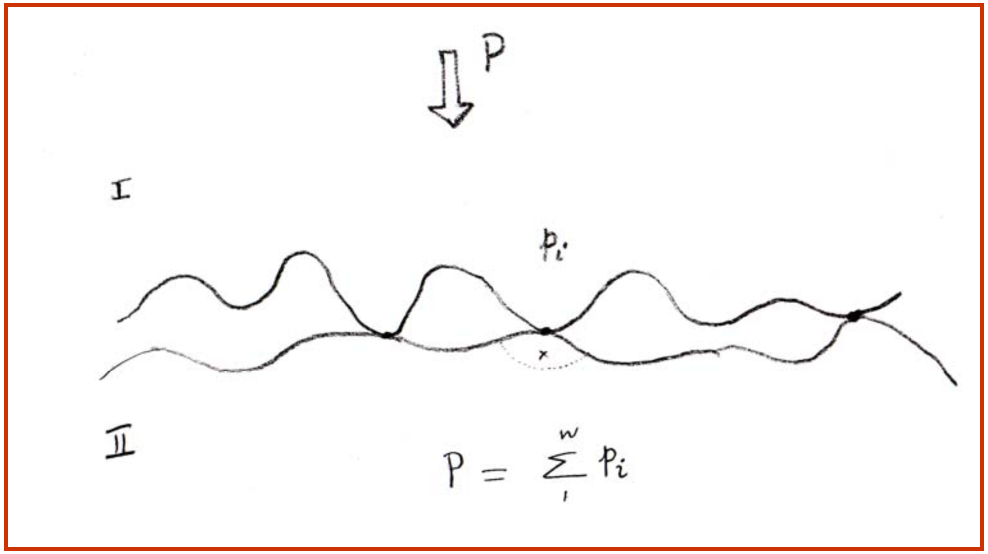
Methods by which financial savings could be made through improved tribological practice in UK industry. The percentages represent proportions of the total annual saving, which was estimated at £515 million (at 1965 prices) (from UK Department of Education and Science, Lubrication (Tribology): Education and Research, HMSO, 1966)

| | |
|---|---|
| Reduction in energy consumption from lower friction | 5% |
| Reduction in manpower | 2% |
| Savings in lubricant costs | 2% |
| Savings in maintenance and replacement costs | 45% |
| Savings in losses resulting from breakdowns | 22% |
| Savings in investment through greater availability and higher efficency | 4% |
| Savings in investment through increased life of plant | 20% |

British Government Report published on 9 March 1966

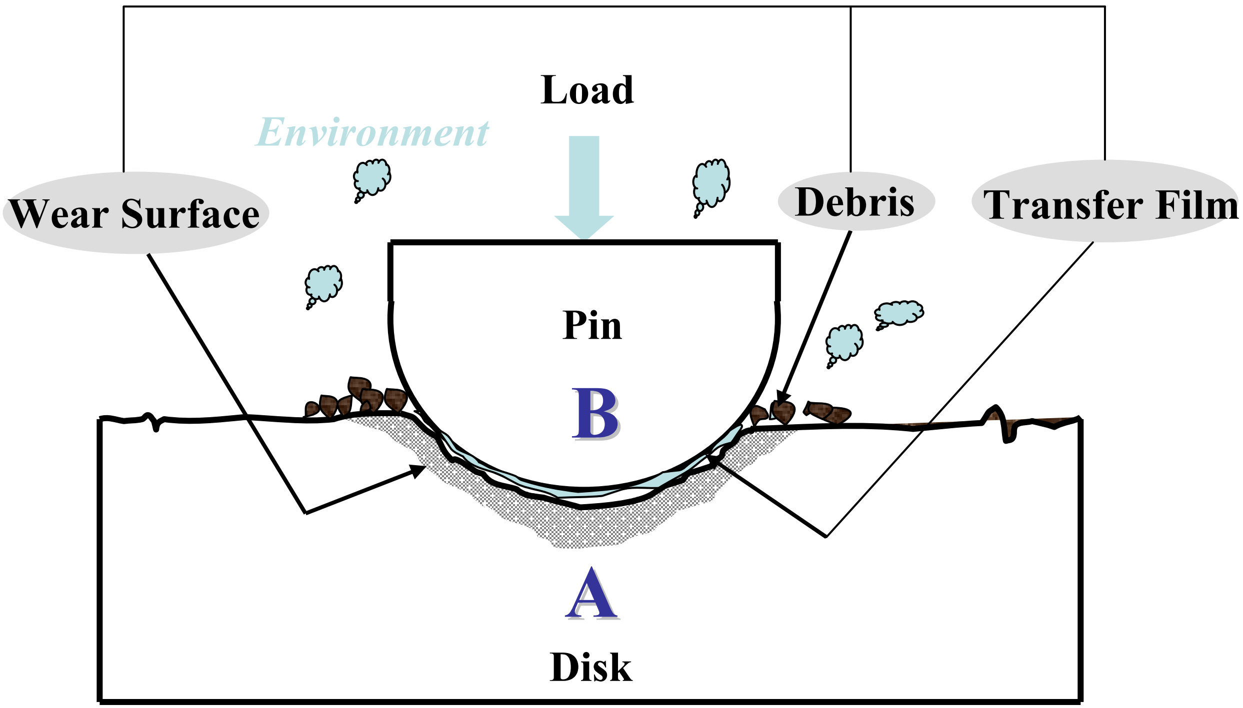
After much consideration, the concept was defined as being "the science of interacting surfaces in relative motion and associated practices" (later amended to associated subjects and practices), and after consultation with the *Editor of the Oxford Dictionary*, given the name "Tribology", based on the Greek "Tribos" (rubbing)

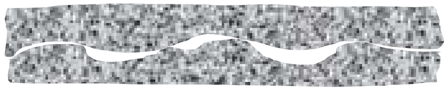
# Recognize the limitations of the laws of friction



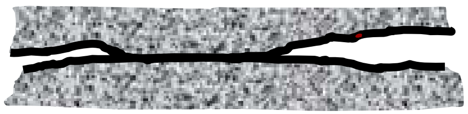

- Engineering surfaces are not atomically flat
- Contact will be at asperity level
- Friction increases (Hertzian) contact stress
- Surface composition typically differs from the bulk
- Sliding contact results:
  - Plastic deformation
  - Diffusion
  - Fracture initiation
  - Tribochemistry and Environmental reactions

# Tribology is a systems property; Tribochemical reactions play a crucial role in determining the performance and reliability

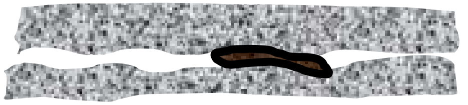


Mechanical Interlocking (Surface Morphology)



Adhesion



Debris Entrapment

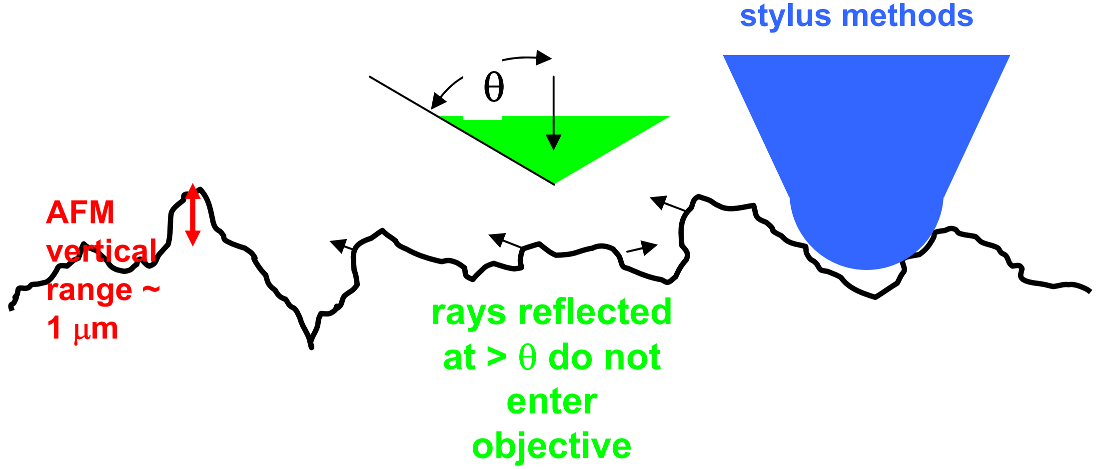
# Metallic Friction and Stick Slip

# Chapter 3

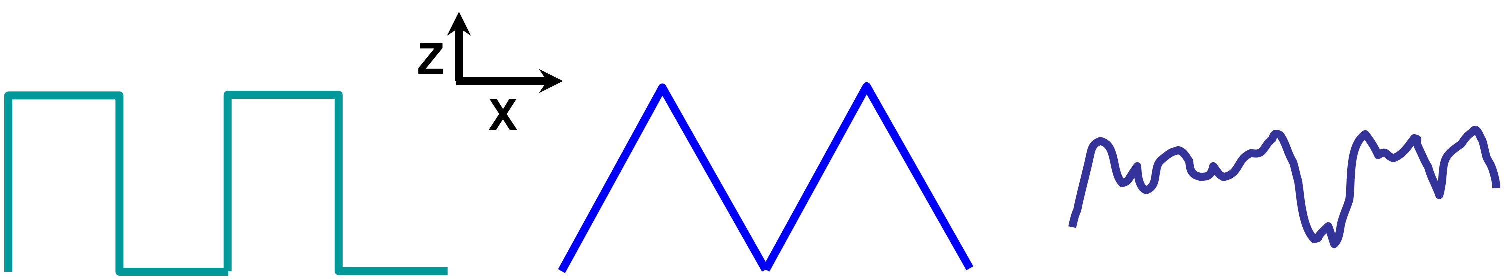
## Wear and Abrasion

# Recognize the limitations in surface topographical analyses

Stylus
Optical
AFM




| | | |
|---|---|---|
| **average roughness** | $R_a = \frac{1}{L}\int_0^L \lvert z(x)\rvert dx$ | **average deviation from profile mean line** |
| **r.m.s. roughness** | $R_q^2 = \frac{1}{L}\int_0^L z^2(x) dx$ | **root mean square deviation from mean line** |




The line profiles above can have the same Ra or Rq

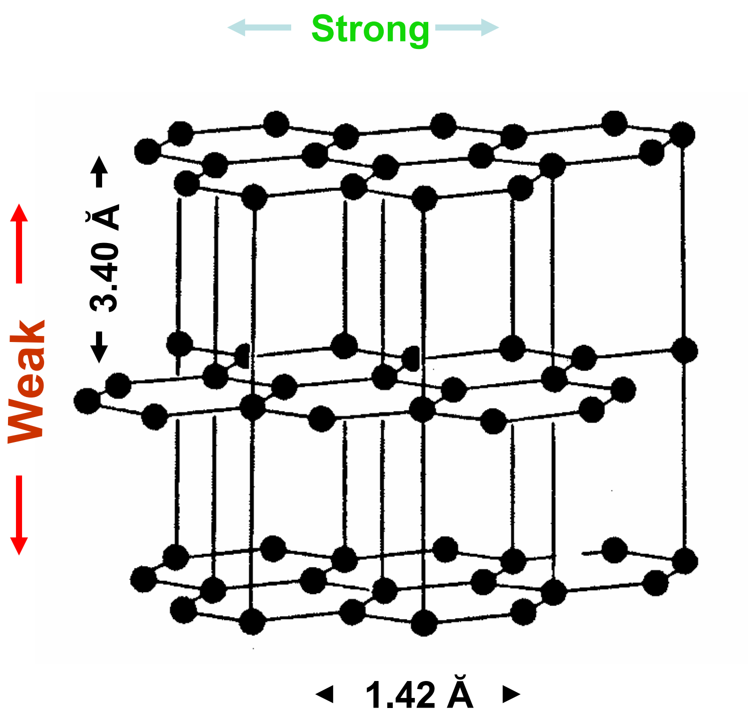
# Comparison of Surface Topographical Techniques

| Method | Quantitative information | Three-dimensional data | Resolution (nm) | | On-line measurement capability | Limitations |
|---|---|---|---|---|---|---|
| | | | Spatial | Vertical | | |
| Stylus instrument | Yes | Yes | 15-100 | 0.1-1 | No | Contact type can damage the sample, slow measurement speed in 3D mapping |
| Optical methods | | | | | | |
| Specular reflection | No | No | 105-106 | 0.1-1 | Yes | Semiquantitative |
| Diffuse reflection (scattering) | Limited | Yes | 105-106 | 0.1-1 | Yes | Smooth surfaces (<100 nm) |
| Optical interference | Yes | Yes | 500-1000 | 0.1-1 | No | |
| Scanning tunneling microscopy | Yes | Yes | 0.2 | 0.02 | No | Requires a conducting surface; scans small areas |
| Atomic force microscopy | Yes | Yes | 0.2-1 | 0.02 | No | Scans small areas |
| Fluid/electrical | No | No | | | Yes | Semiquantiative |
| Electron microscopy | Yes | Yes | 5 | 50 | No | Expensive instrumentation, tedious, limited data, requires a conducting surface, scans small areas |

# Materials Science of Solid Lubricants

- Carbon based materials (Graphite, DLC)
- Transition metal-dichalcogenides ($MoS_2$, $WS_2$)
- PTFE-based materials

# Lubrication by graphite



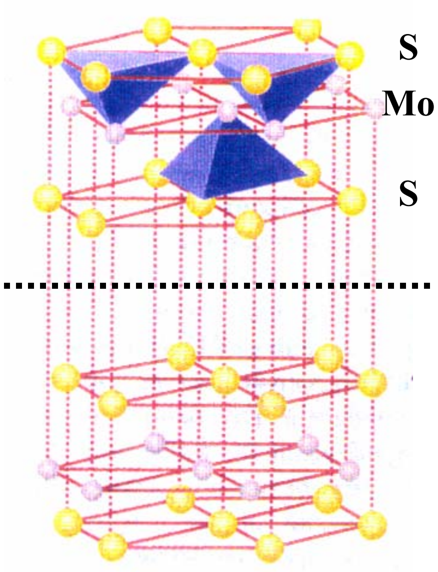

**Graphite**

Element C (four valence electrons) can exist in different allotropic forms

- $sp^2$ bonding configuration (crystalline graphite as shown in the right): basal planes held with strong covalent bonds, while the planes are held with weak Van der Waals forces. This gives rise to interlamellar mechanical weakness. Other $sp^2$ kinds include: carbon-carbon composites, unhydrogenated carbon, etc.
- sp3 bonding in diamond
- Hydrogenated carbon with various degrees of $sp^2/sp^3$ bond ratios that are commonly known as diamond-like carbon.

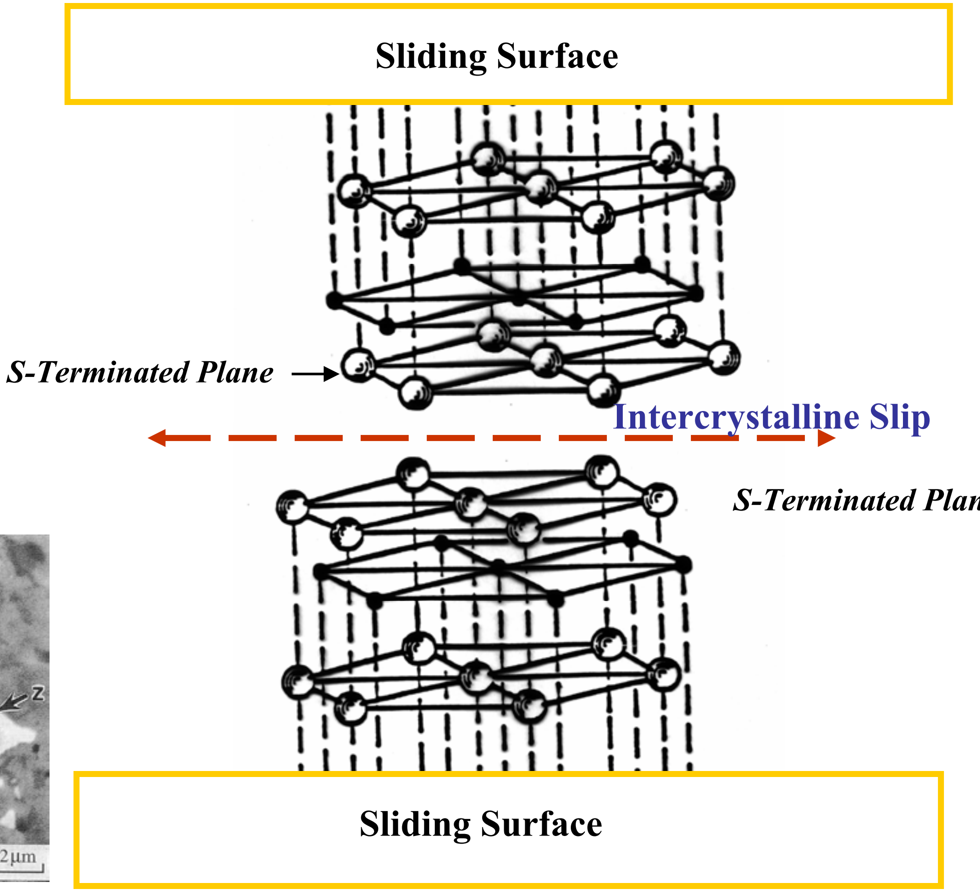
Graphite needs moisture or adsorbed gases in the environment (>100 ppm) (they either act as intercalants, or passivate the dangling covalent bonds) to lubricate.
In vacuum, graphite exhibits high friction and wear—a phenomenon known as "dusting", first observed in the late 1930's when graphite brushes in aircrafts experienced accelerated wear at high altitudes.

# Lubrication by transition metal dichalcogenides ($MoS_2$, $WS_2$)

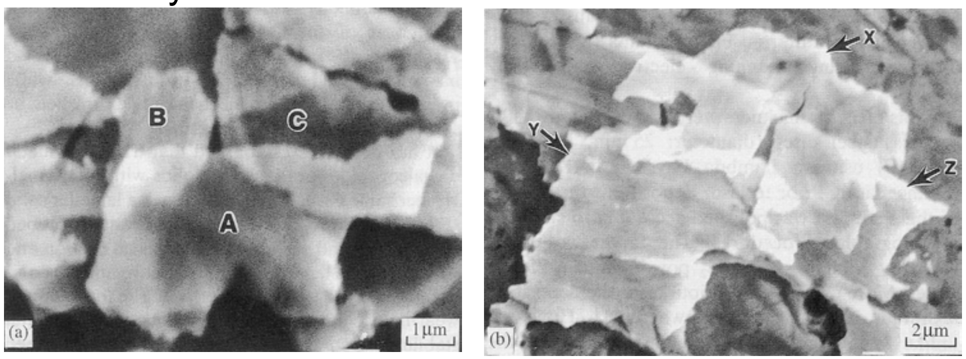



**Mo/W Disulfide**

Extremely low COF (0.01-0.05) and long wear life (millions of wear cycles for a micron thick $MoS_2$ film), **but only in dry environments**.

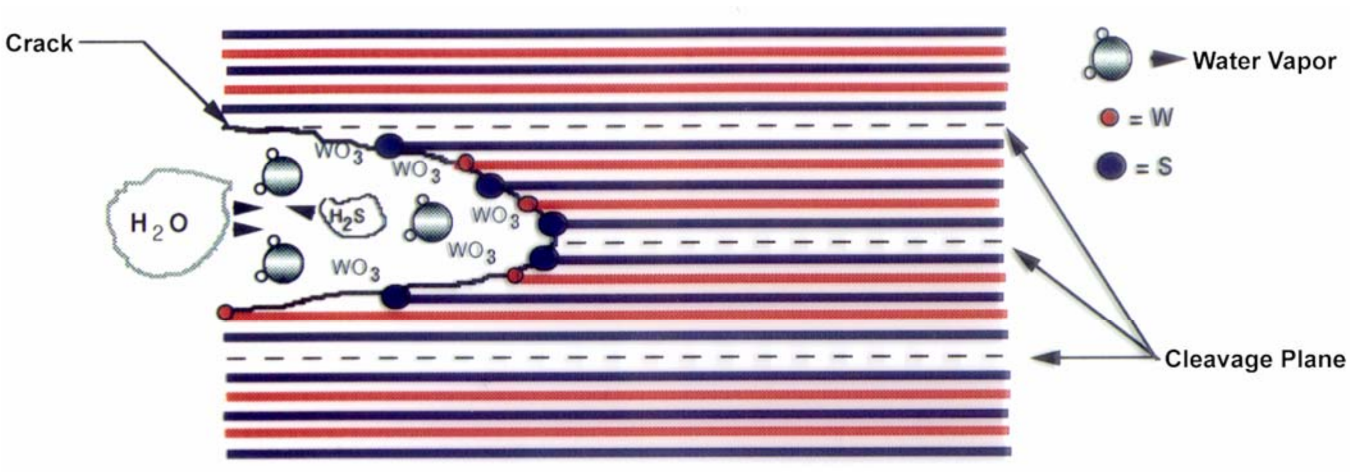


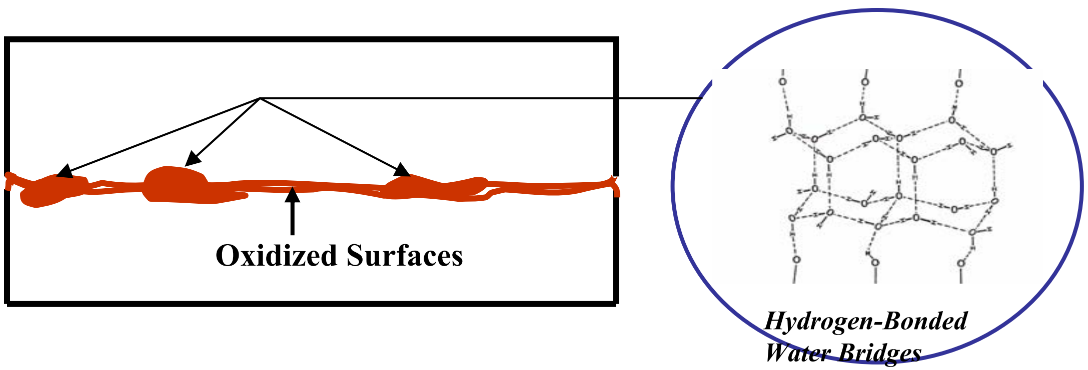

They form thin transfer films on the counterface

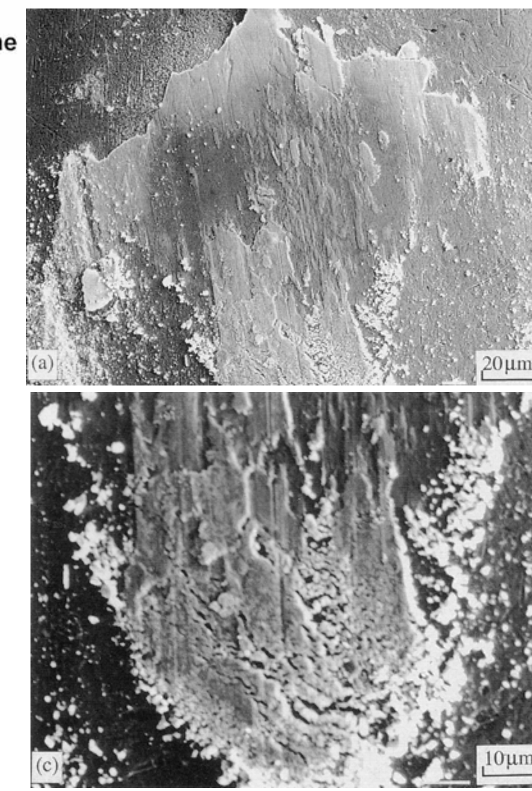



S. V. Prasad and J. S. Zabinski, *J. Mater. Sci. Lett*. 12 (1993) 1413-1415

# Oxidize in humid environments, losing their ability to lubricate



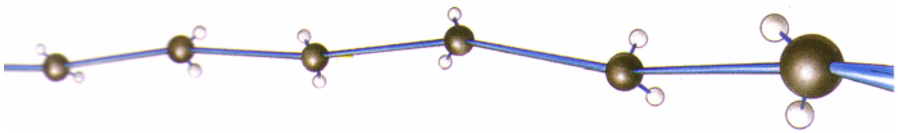



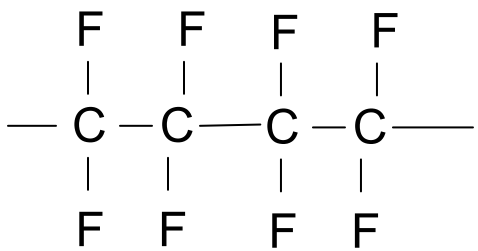

Typical transfer films ($WS_2$) in humid air

S. V. Prasad, J. S. Zabinski and N. T. McDevitt, *Tribology Transactions*, 38 (1995) 57-62

# Lubrication by PTFE



PTFE



- Polytetrafluoroethylene (PTFE) is a well known for its lubricating behavior:
  - No unsaturated bonds, not easily polarized
  - No cross-linking
  - Low intermolecular cohesion
- PTFE functions by transfer film mechanism, like graphite and $MoS_2$.

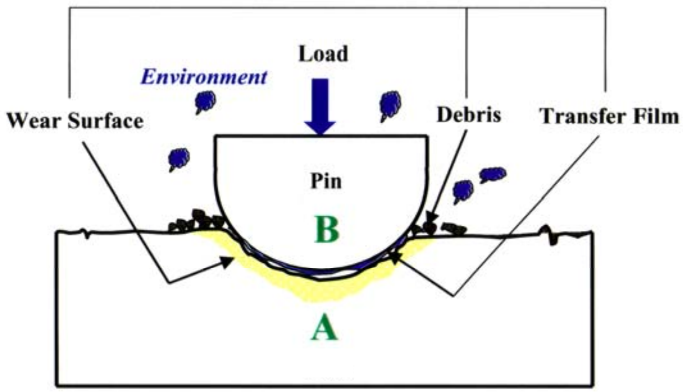
- Pure PTFE has unacceptable amounts of wear
  - (Fillers provide significant improvement in wear resistance for a little sacrifice in COF)
- PTFE loses its antifriction property if:
  - The roughness of the counterface is high (>1mm)
  - Sliding speed is too high
  - Bulk temperature is too high or too low (glass transition or dissociation temperatures)

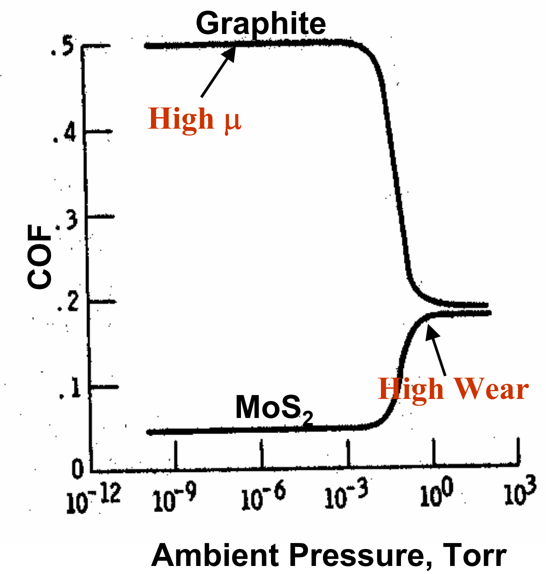
Uses

- PTFE is used as a matrix in a self-lubricating composite
- Fibers and powder are also used as solid lubricant fillers in composites for antifriction applications

# Summary: No material can act as a solid lubricant in all environments and under all operating conditions

Solid lubricants function by forming soft third-body films on sliding surface: Shear accommodation




- Environmental effects
- Load
- Speed
- Temperature
- High wear (e.g. pure PTFE)