GeoMap: Understanding Geological Structure from Remote Sensing Data

All Lab Lecture February 25, 2004

Exploration Systems Autonomy Section 367

Data Understanding Systems Group

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The GeoMap Initiative

▪MSSS/JPL/NASA MOC image

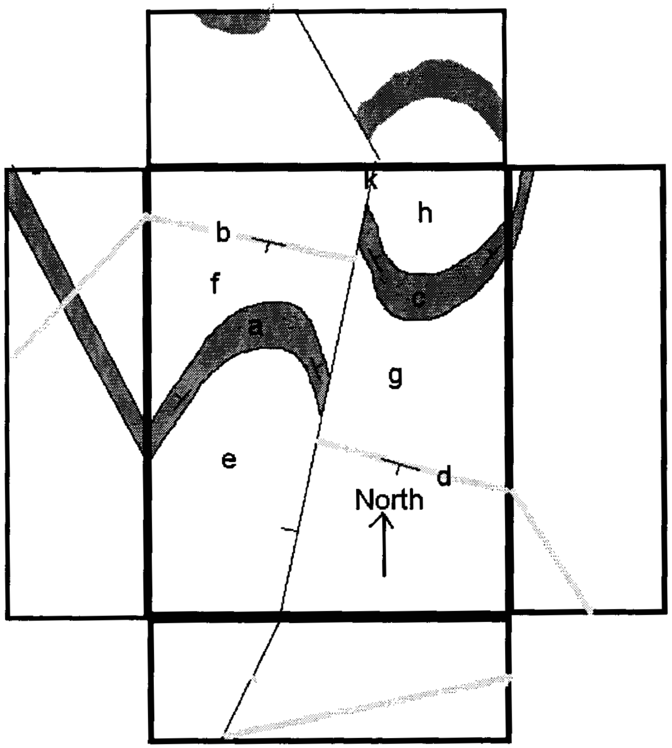
- We want a 4D geological model of Mars, Earth, and other solid bodies.
- We have (and are now collecting) much relevant data.
- We just need an automated way to extract the desired knowledge.

GeoMap Benefits

▪Granite Peak Geologic Map and cross section

- **Mars**:
  - Aid site selection
  - Interpretation of in-situ missions in context of a much more complete background understanding.
  - Ease of integration and comparison of new data with existing data
- **Earth:**
  - Understand and protect our home planet

GeoMap Solution



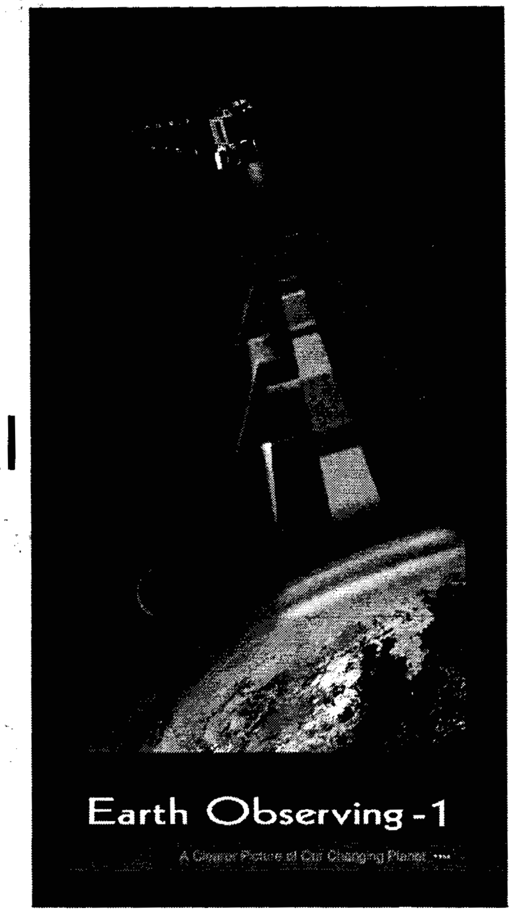
- Ingest high-resolution image, hyperspectral, topographic, and in-situ data
- Identify lithologic units based on clustering of texture and mineralogy
- Recognize patterns in lithologic units.
- Interpret these patterns in terms of 3D structure
- Infer a relative chronology of events to create 3D structure
- Enter into a database

Outline of the rest of the talk

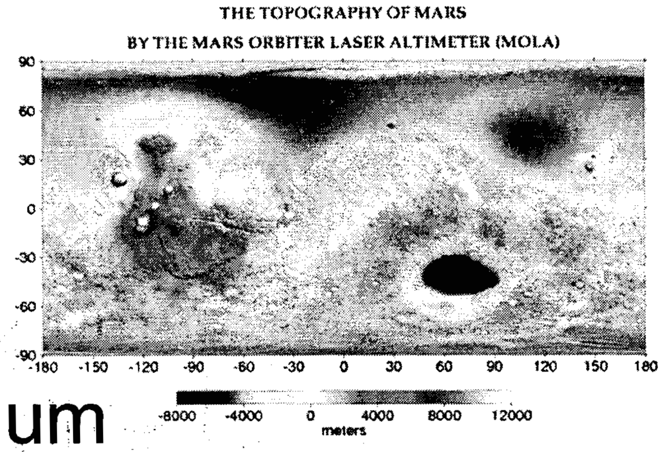
- Review remote sensing data
- Demonstrate plausibility of identifying lithologic units based on mineralogy and texture
- Digital Geologic Map Data Model
- Demonstrate how to infer 4D from 2D by hand
  - Review prior art
  - Proposed Parameterized Stochastic Grammar approach

Existing data - Earth

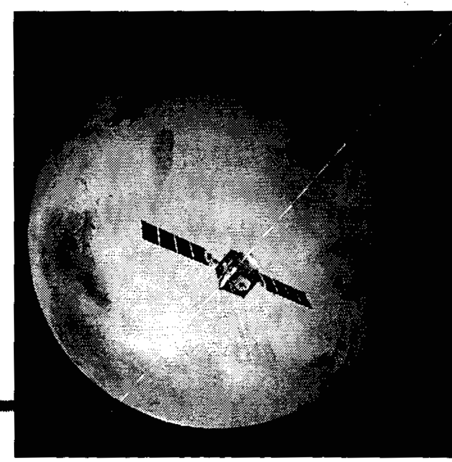
- HYPERION - EO1, 30 m pixel, Mineral ID, 220 bands 0.4-2.5 um
- ASTER – Terra, 14 bands, 0.5-12 um
- AVIRIS & HYDICE – Airborne Visible Infrared Imaging Spectrometer
- SRTM – 30 m pixel topography
- Ikonos – sub-meter pixel, visible
- Landsat – 30 m pixel 8 bands
- Others …



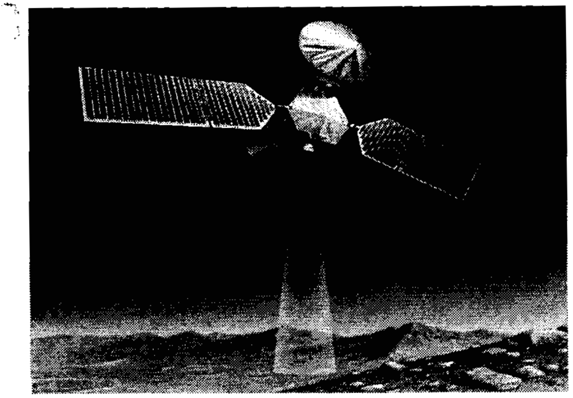
Existing data - Mars



- MOLA - MGS
- TES – MGS 3 km pixel, 6-50 um
- MOC – 1 m pixel
- THEMIS – Mars Odessy, 15 bands
- MARSIS – Mars Express, several Km sub-surface radar
- OMEGA – Mars Express, 100m mineral mapping spectrometer

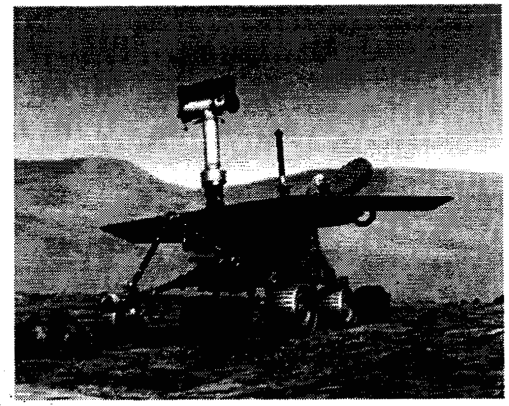


Future MRO mission



- HiRISE – MRO 0.25-0.5 m pixel, stereo, visible
- CRISM – MRO mineral ID spectrometer, 0.4-4 um, 560 bands, 18 m pixel
- SHARAD – MRO Up to 1 km sub-surface, 15 m vertical resolution, 0.3-3 km pixel

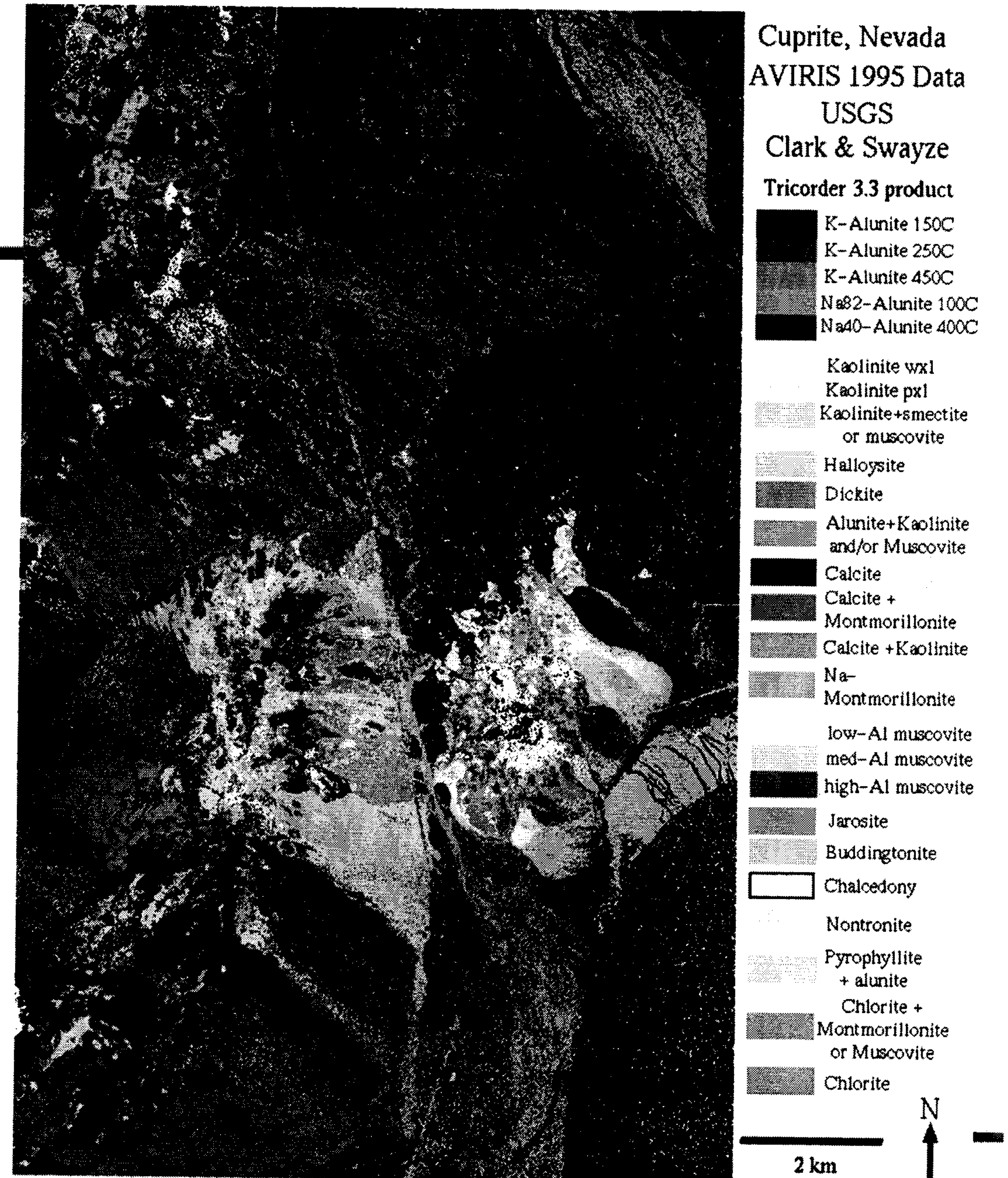
Complementary data



- Some observations are easy on the surface:
  - Small scale nature of a contact
  - Cliffs
- Some observations are easy from orbit:
  - Large scale morphology and context
    - Note: Spectral data from orbit can be sensitive to crystal/grain size

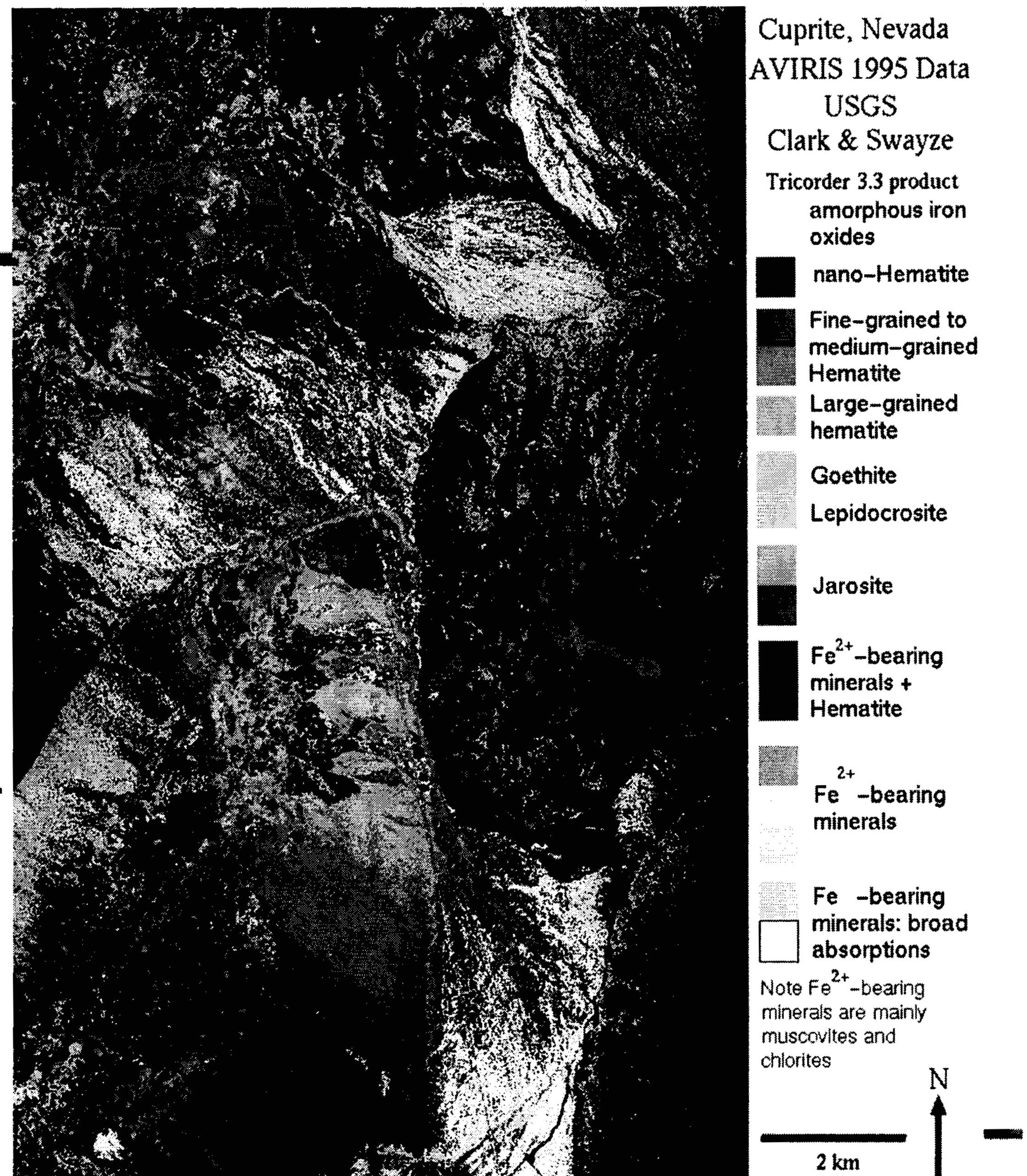
Mineral ID

- AVIRIS (Airborne Visible-Infrared Imaging Spectrometer)
- Processed to identify OH-, CO3-, and SO4- minerals



Mineral ID

- AVIRIS (Airborne Visible-Infrared Imaging Spectrometer)
- Processed to identify Fe2+, Fe3+ minerals

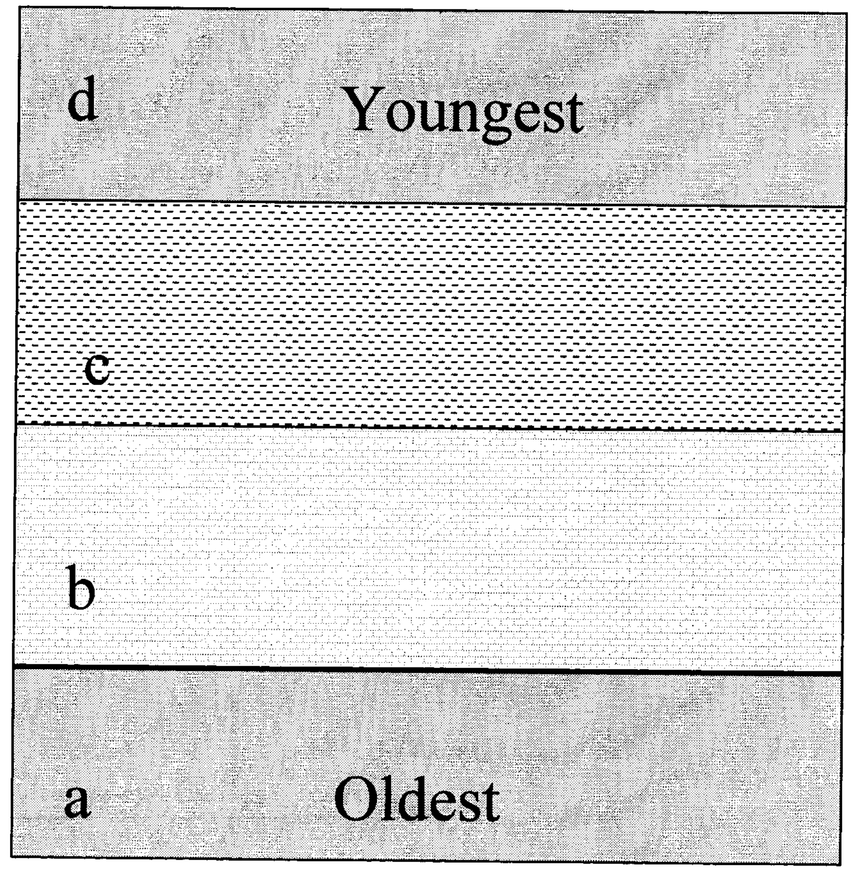


Digital Geological Data Model

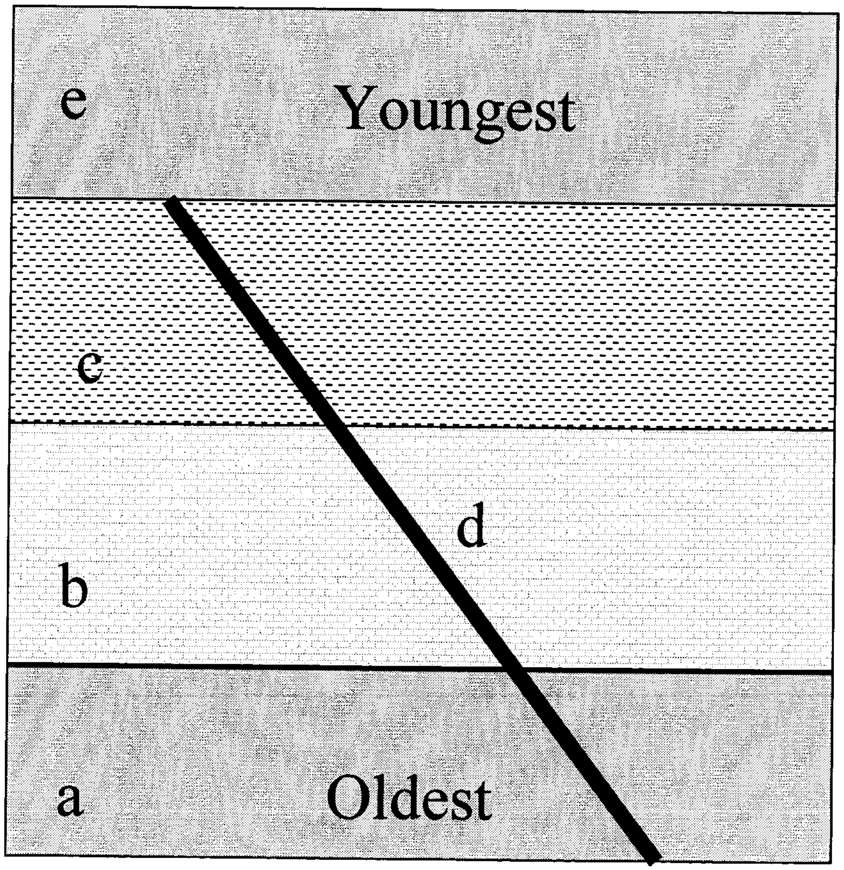
- Under development by State Geologists and USGS
- Digital Data Model for building a database containing the information in a Geological Map

4D from 2D

- In geology, time and space are closely linked by the “Principle of Superposition”
  - First stated by Steno in 1669
- Younger sediments overlie older sediments unless the strata have been overturned.

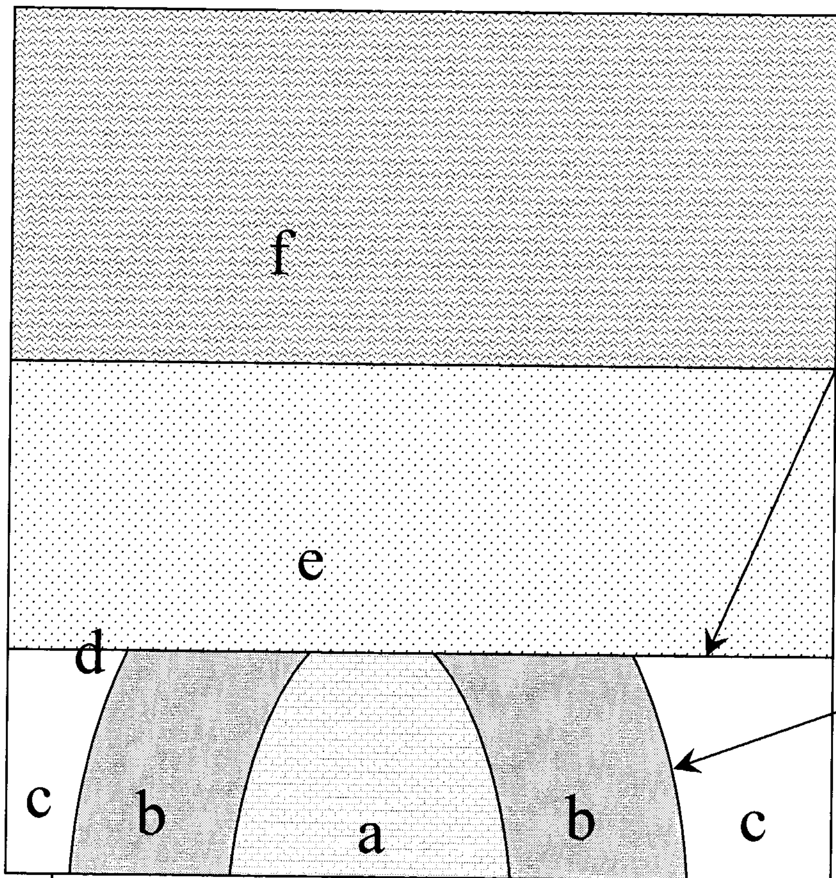


Corollaries 1



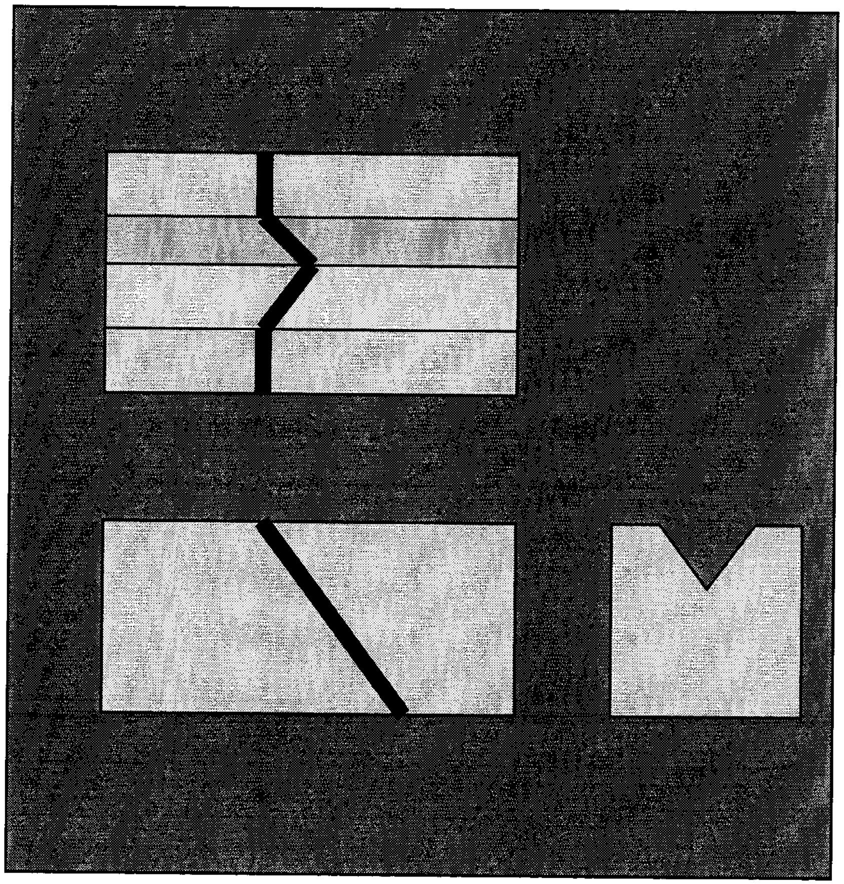
- Cross-cutting relationships
  - Younger events (rock units) cut across older events (rock units)
- Inclusion
  - Inclusions in sedimentary or igneous rocks are older than the surrounding rock unit

Corollaries 2



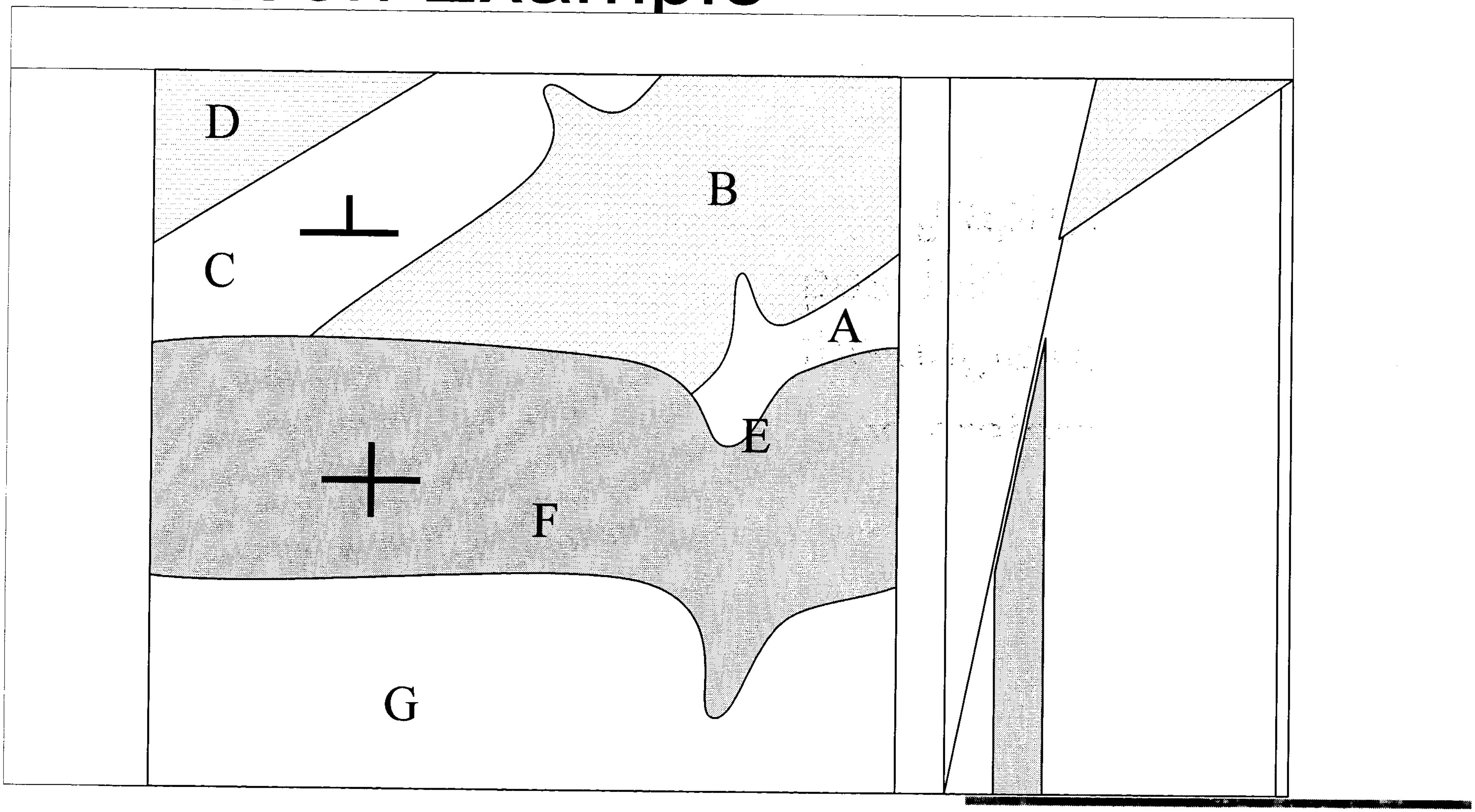
- Unconformities
  - An unconformity (erosional surface) is younger than the truncated rocks and older than overlying rocks
- Deformation

Orientation of contacts: The Three point problem

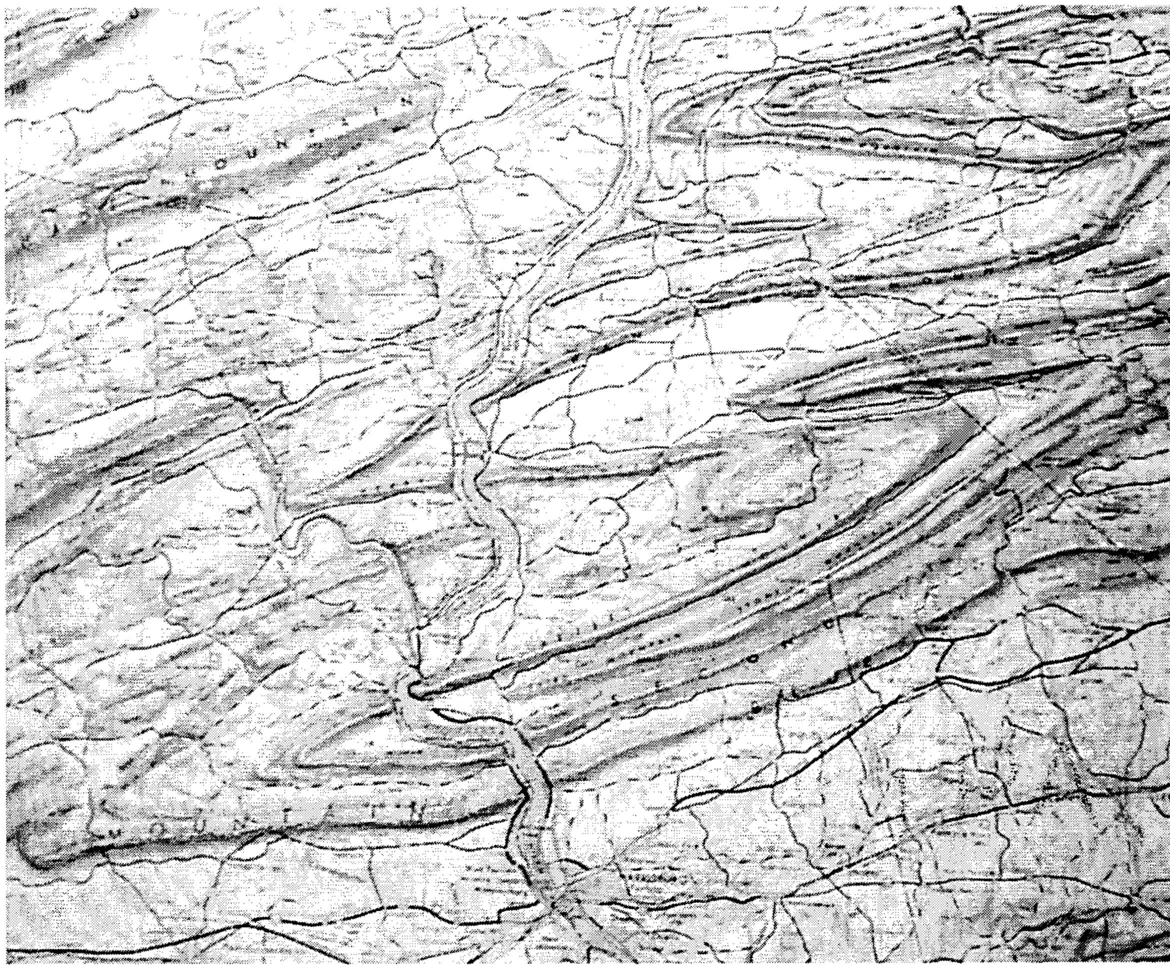


- Given a dipping boundary, and some topography, it is possible to work out the angle of the dip.
- Also craters can be thought of as "boreholes"

Cartoon Example



Example: Harrisburg PA



Example – Matrix Manipulation to Infer Chronology

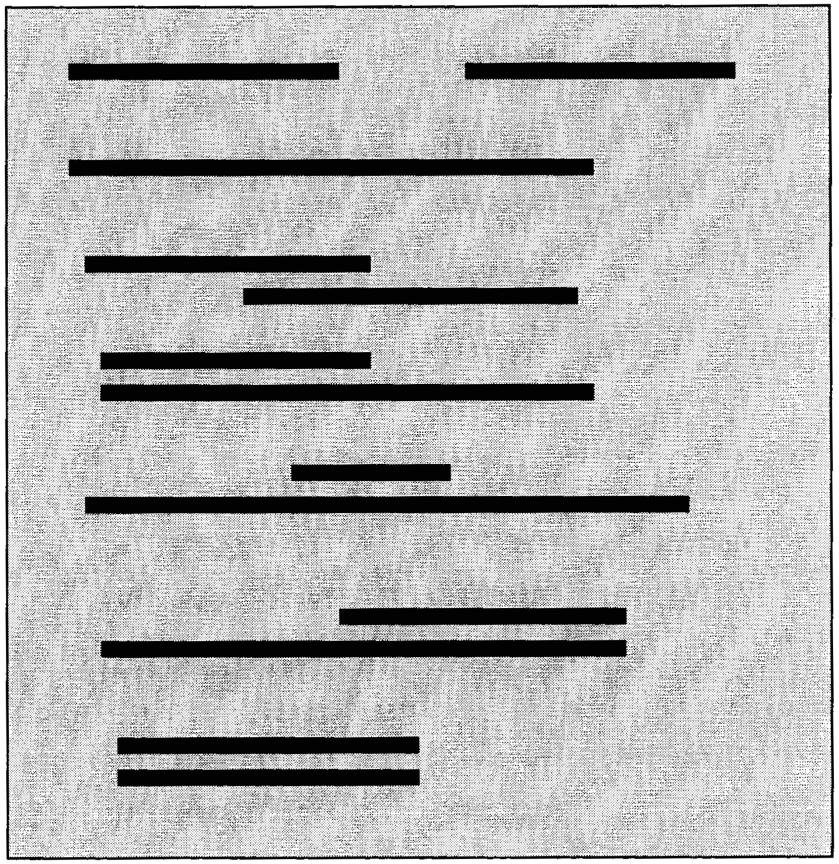
	A	C	E	B	G	F	D
A				2			
C							3
E						5	
B		1					
G						2	
F				1	4		
D			8				

	A	B	C	D	E	F	G
A		2	X	X	X	X	X
B			1	X	X	X	X
C				3	X	X	X
D					8	X	X
E						5	X
F		1					4
G							

Caveats of Matrix Manipulation

- Needs extension to handle the concept of "during"
- Chronology is often not unique
  - This is unavoidable since the information in the lithic record may not be complete.

Geological time concepts (after Ady 1993)



- A before B; B after A
- A meets B; B met-by A
- A overlaps B; B overlaped-by A
- A starts B; B started-by A
- A during B; B contains A
- A finishes B; B finished-by A
- A equals B

Geological time concepts

Erosion introduces gaps

Simultaneous events

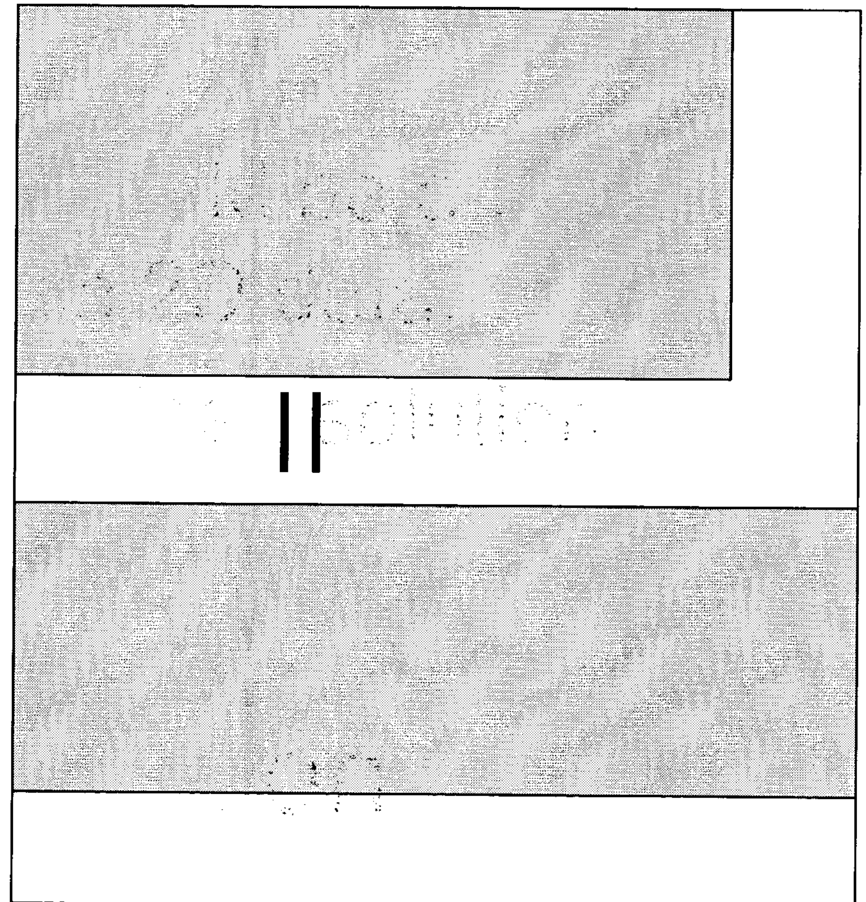
Finite duration events

Frequently under-constrained

- Erosion removes part of the record of the history written in the rocks
- Sub-surface structure could be arbitrarily complex and still match 2D data.
- There is usually a “simplest” solution consistent with the data

Balanced Cross-section

- Deformed strata (folded and faulted) should occupy the same volume as they did in their original un-deformed state.
- Humans are not good at this – computers are.



Stochastic Grammar

- Origin in natural language analysis
- Break down a sentence into sub-elements
  - Non-terminals – (eg noun-phrase, verb-phrase)
  - Terminals
- Relationships between elements may be probability rules, binary decision trees, or other
- Relationships between elements build up interpretation

Grammar using a sentence

- The boy hit a ball.
- <sentence> → <noun-phrase> <verb-phrase>
- <noun-phrase> → <article><modified-noun>
- <verb-phrase> → <verb> <noun-phrase>
- <modified-noun> → <adjective><modified-noun>
- <article> → a | the
- <noun> → boy | ball
- <verb> → hit

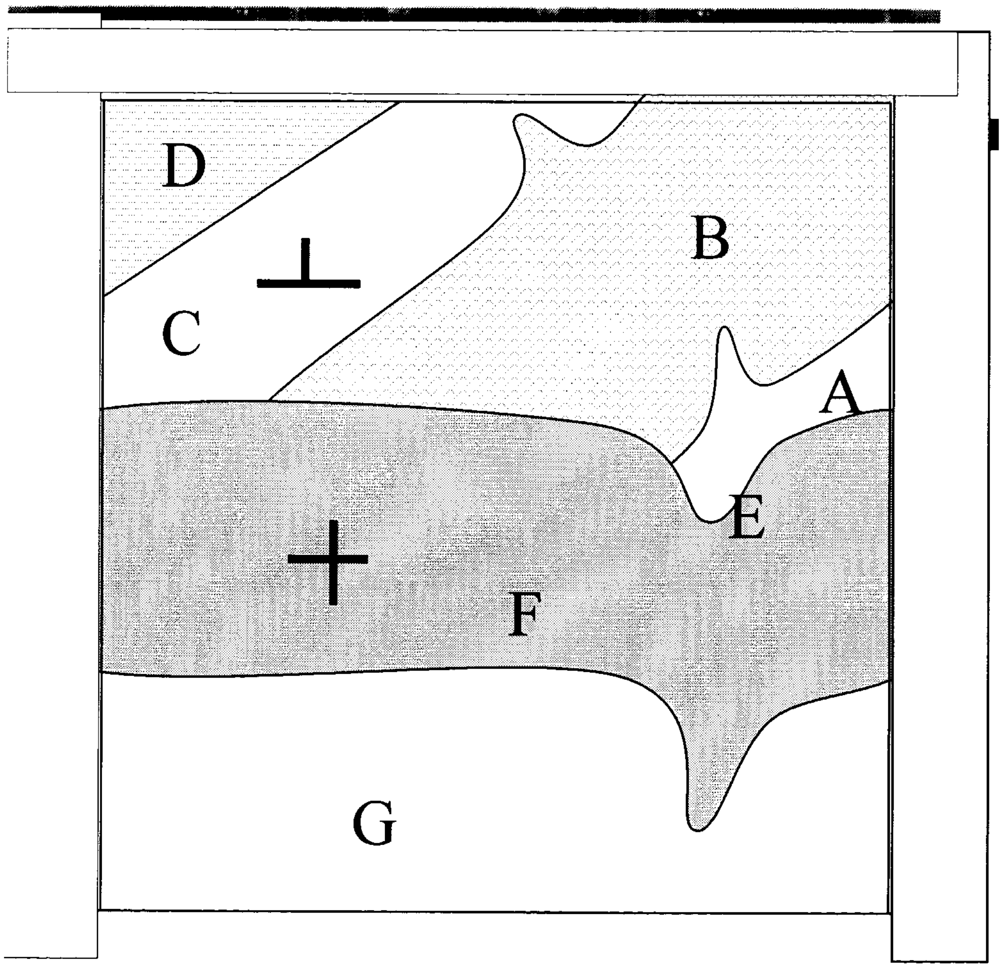
Geological Grammar building blocks

- <submergent phrase> Sequence going from sediment with pebbles in it through sandstone to mudstone
- <volcanic intrusive phrase> Igneous rocks surrounded by non-igneous. Surrounding rock contains minerals altered by hydrothermal fluids.
- Existing models are 1 dimensional. We will need to generalize to 3 spatial dimensions and time.

Roadmap: Grammar

- Phase 1: Develop a Stochastic Grammar to infer the sub-surface structure and chronology of events from an annotated map or image. Will involve extension of Stochastic Grammar concept to deal with notions of 3D spatial relationships, orientation, and chronology.

Roadmap: Annotated image



- Phase 2: Adapt and extend software to identify lithologic units, estimate their orientation, and annotate the image.

Roadmap: Integration

- Phase 3: Integrate the results of Phase 1 and 2 to produce a prototype system ingesting raw image data, and producing a geologic map with 4D interpretation stored in a Digital Geologic Map Data Model database

Roadmap: Production

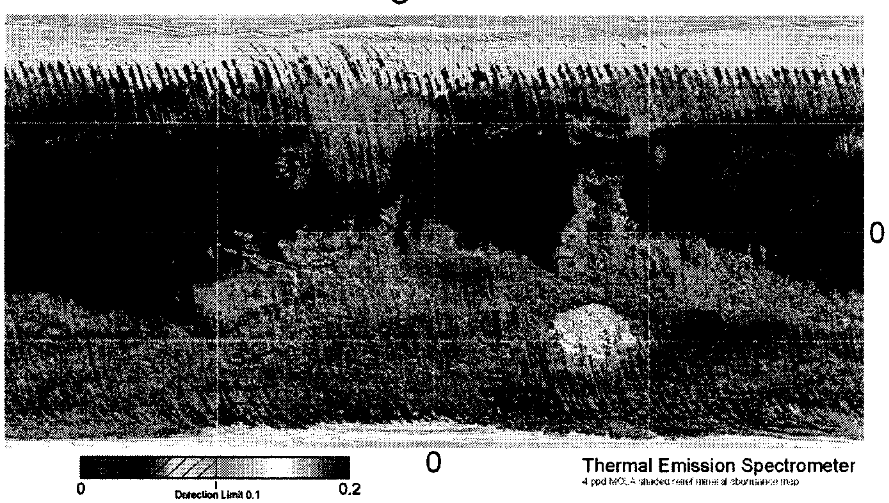
Akna Montes mountain belt, Venus, http://nssdc.gsfc.nasa.gov/imgcat/html/object_page/mgn_c160n291_1.html

- Phase 4: Refine the system to be a production system and apply it to global data for Mars, Earth, and other solid planetary bodies.

Summary

- There is enough data to "cut our teeth"
- We are soon to have much more data
- We can do mineralogy with remote sensing data
- There are

Plagioclase



Principle of Superposition

- "Both the most obvious, unnecessary, uninteresting and intellectually insulting of considerations, and also the most subtle as it relates time and space and essentially derives the time sequence from the space order" (Harland 1978)

Corollaries 3

- Physical continuity
- Metamorphism

Algorithm for inferring time order of events from 2D map (Burns 1976)

- Construct a matrix in which each bed is represented once on the rows and columns.
- Wherever a time relationship between two beds is known, make an entry in the matrix such that row is older than column.
- Triangularize the matrix by transposition of columns. Inability to triangularize indicates inconsistent information.
- Can then "fill in" much of rest of matrix

Example using stratigraphic sequence (Duane, 2001???)