Mineralisation on Mars: Mechanisms & Terrestrial Analogues

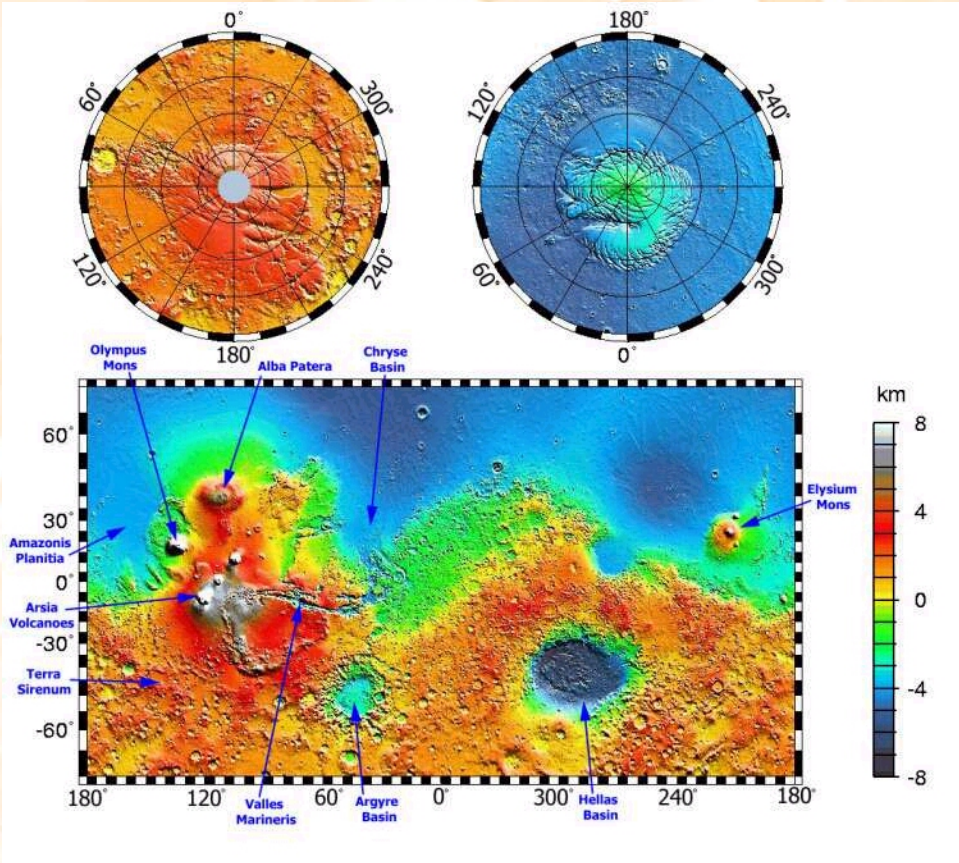
Michael D. West[1] & Jonathan D. A. Clarke[2]

[1]Research School of Physical Sciences & Engineering,
The Australian National University, Canberra

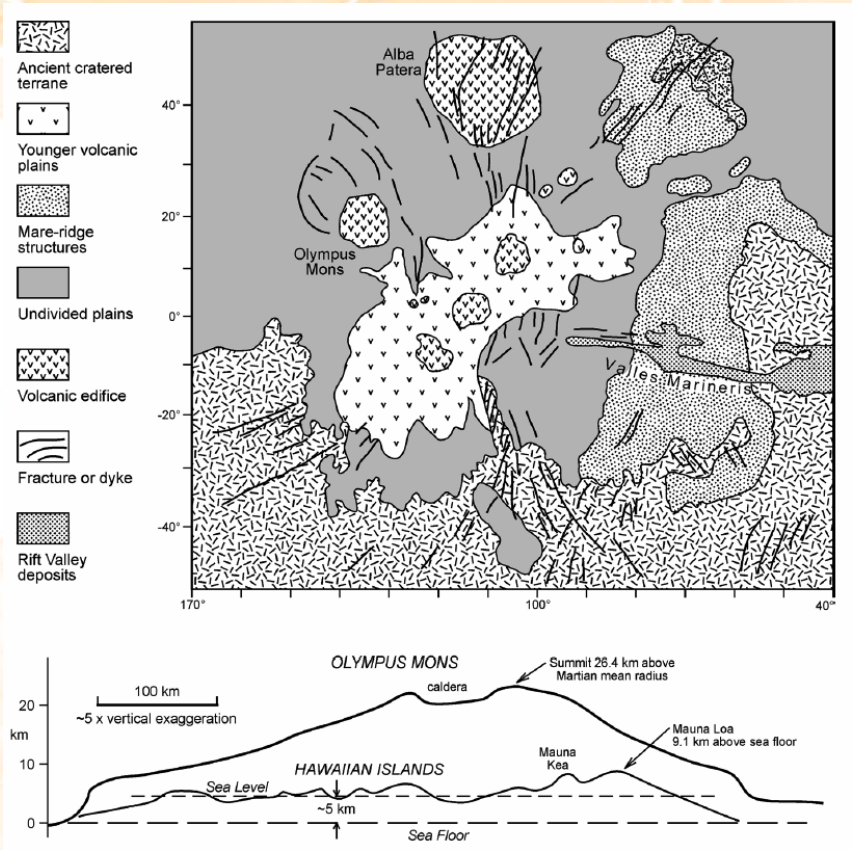
[2]Mars Society Australia & Australian Centre for Astrobiology,
Macquarie University, North Ryde

The Geology of Mars

- Northern smooth lowland plains
- Cratered highlands to the south
  - Rise 1-4 kms above lowlands
- Surfaced shaped by
  - rises
  - volcanoes
  - narrow grabens
  - fracture systems
  - channels
  - valley networks
  - impact craters
- Significant geological and tectonic activity has occurred in the past



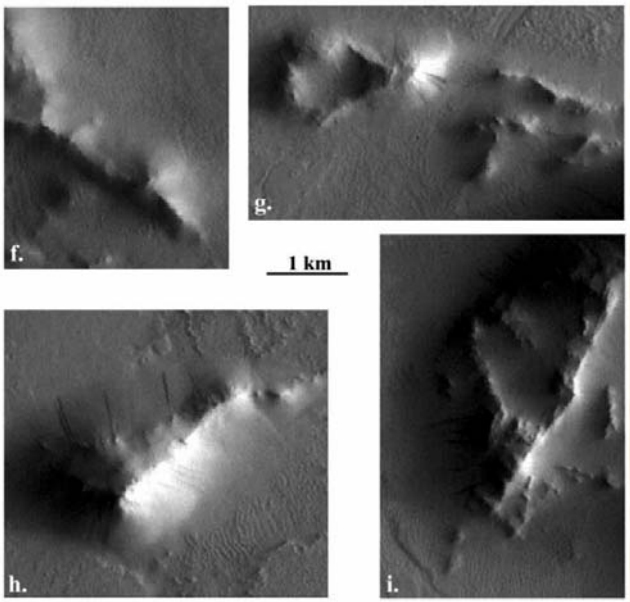
The Geology of Mars



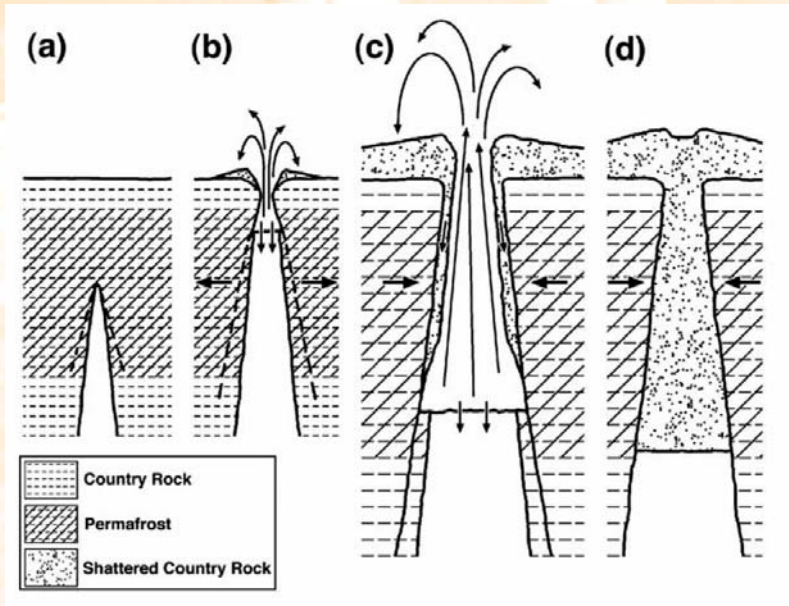
- Huge morphological structures
- Tharsis Rise
  - Covers 25% of surface
  - 4000 km wide
  - 10 km high
  - igneous province 6.5 x 10^6 km^2
  - mantle plume on one-plate lithosphere (e.g. African plate)
- Olympus Mons
  - 550 km diameter
  - 24 km high
  - largest volcano in Solar System
- Local topography is flat lying
  - crater walls, central uplifts & canyon edges are prime sites for mineral exploration - expose stratigraphy & mineralised zones

Mars Volcanism & Hydrothermal Deposits

- Cratering rates suggest recent to contemporary volcanism
- Incidences of hydrothermal activity are likely to be very high
  - in and around volcanoes, caldera floors, fractures & rift valleys
- Dyke intrusions into ice-rich regolith
  - explosive phreato-magmatic eruption of 2-3 minute duration!



MOC images of ridges on the northern flanks of Olympus Mons formed via explosive volcanism from Wilson et al, 2003



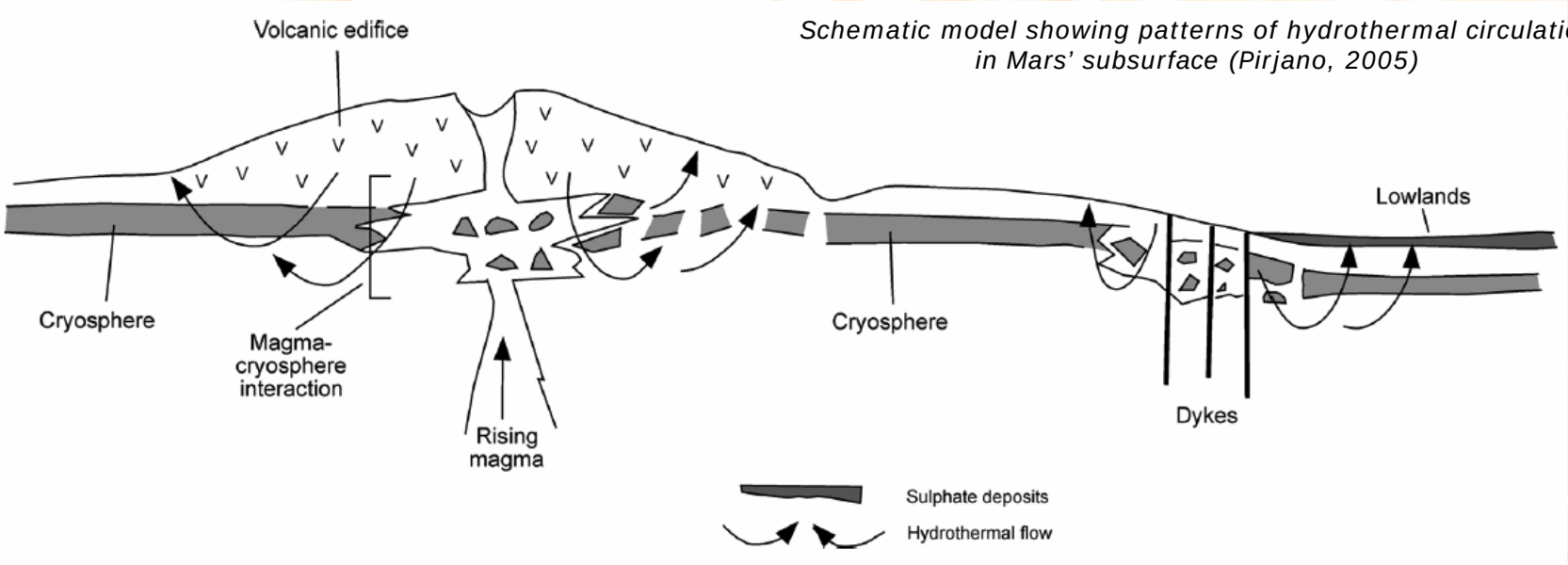
Dyke intrusion model from Wilson et al, 2003 a) before surface breakthrough b) shortly after surface breakthrough c) part way through eruption d) after activity ceases

Mars Volcanism & Hydrothermal Deposits

• Convective heat flux & dyke intrusions mobilise fluids capable of producing zones of mineralised hydrothermal alteration

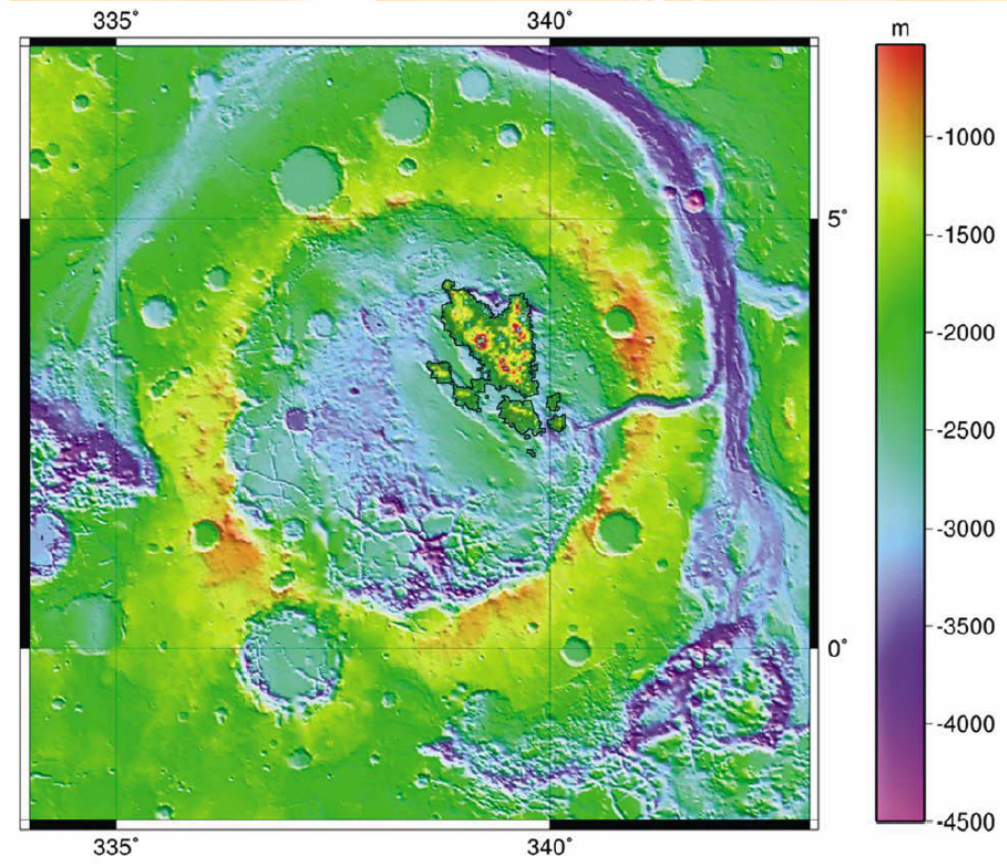
• May form mafic related volcanic hosted massive sulphide (VHMS) deposits
  – yield Cu, Zn, Pb, As, Ag & Au ores on Earth (Cyprus type deposits)
  – vein deposits of Ag, Au & Te possible in cracks, fissures & faults

• Sinter like deposits from sulphate rich fluids (H_2S & H_20 from cryosphere ice) discharged by rising magma or dykes



Schematic model showing patterns of hydrothermal circulation in Mars' subsurface (Pirjano, 2005)

Mars Volcanism & Hydrothermal Deposits

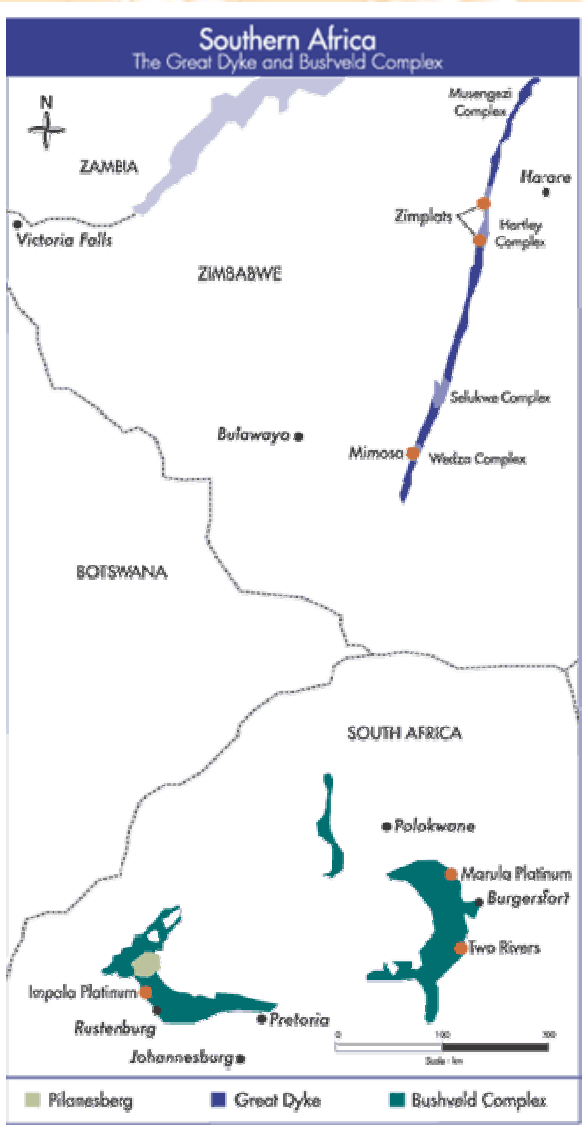


Aram Chaos topography with area enriched in coarse-grained crystalline hematite overlaid. Overlay is based on spectral signatures from TES (Catling, 2003)

- TES detection of coarse-grained crystalline hematite
- Heamatite deposits - Aram Chaos
  - melted ground ice OR groundwater expulsion into basin
  - driven by magmatic intrusions
- Analogous to massive specularite formation & metasomatism in Yukon, Canada
  - forced release of hydrothermal fluids

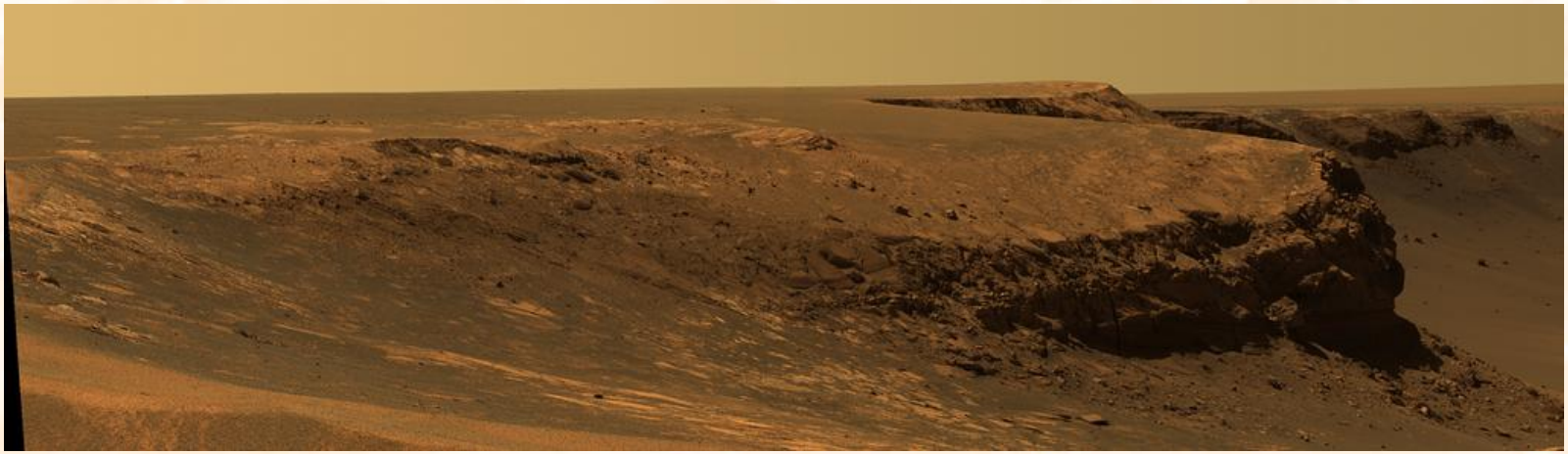
Large Igneous Provinces

- Martian volcanic flows ~ 1800 km
- Terrestrial LIPs linked to Ni-Cu-PGE deposits (Cu, Ni, Fe, Ti, Cr & PGEs)
- Bushveld intrusion, South Africa (2060 Ma)
  - Largest LIP, global supply of platinum & chrome
- Noril'sk deposit, Siberian Trap event (250 Ma)
  - 70% world's palladium
- Mafic dyke swarms around LIPs
  - 140 on Earth > 300 km long



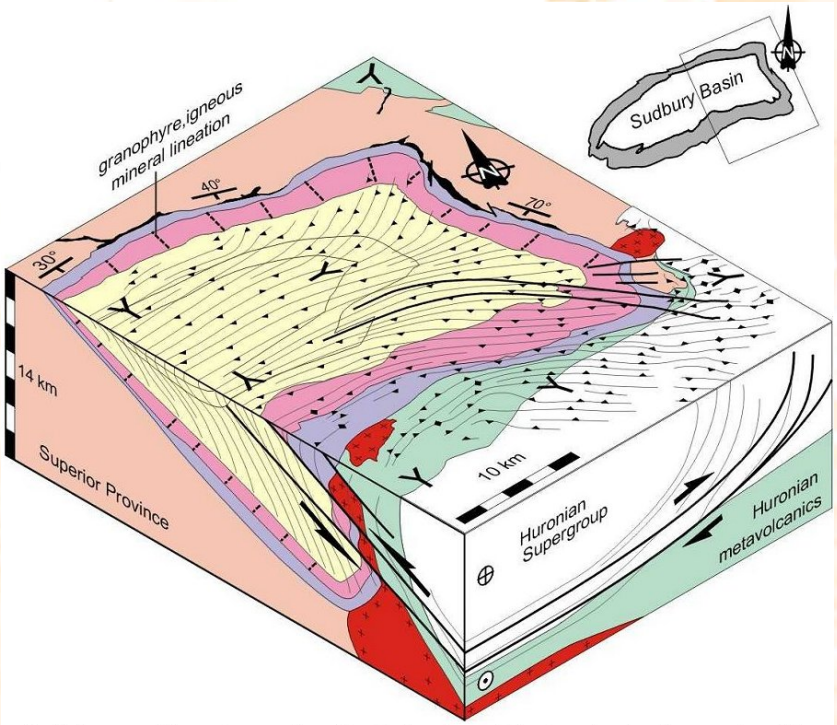
Impact Cratering

- Southern Mars - most heavily cratered areas in Solar System
- Large craters have lobate ejecta blankets suggesting target rocks saturated with H_20
- Elevate temperatures of local rock for long periods (100,000s yrs)
- Terrestrial impact related ores deposits are categorised as progenetic, syngenetic & epigenetic
- Progenetic - deposit exist prior to impact but modified as result
  - Canadian Carswell, economic U ores

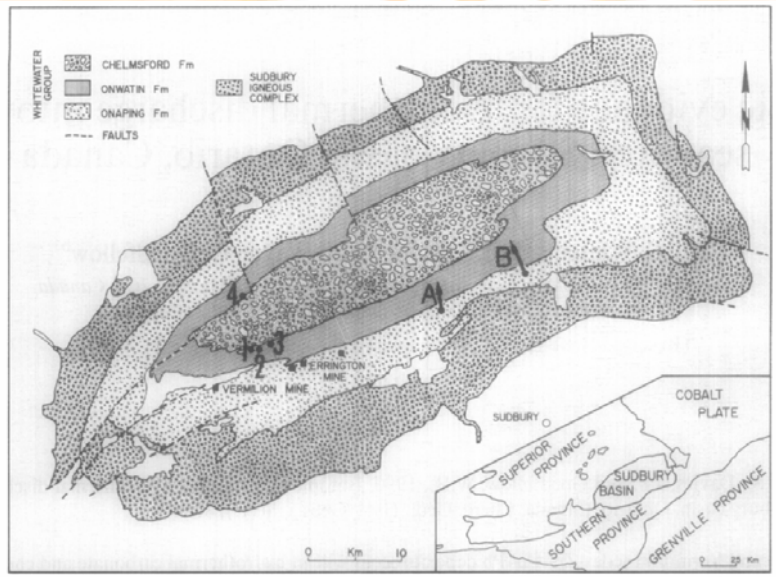


Impact Cratering

- Syngenetic - deposit formed as direct result of impact
  - Cu-Ni, PGE & diamond deposits
  - Sudbury Igneous Complex, Canada - one of world's largest nickel deposits
  - Kara & Popigai, Russia - impact derived diamonds (pre-existing carbon)

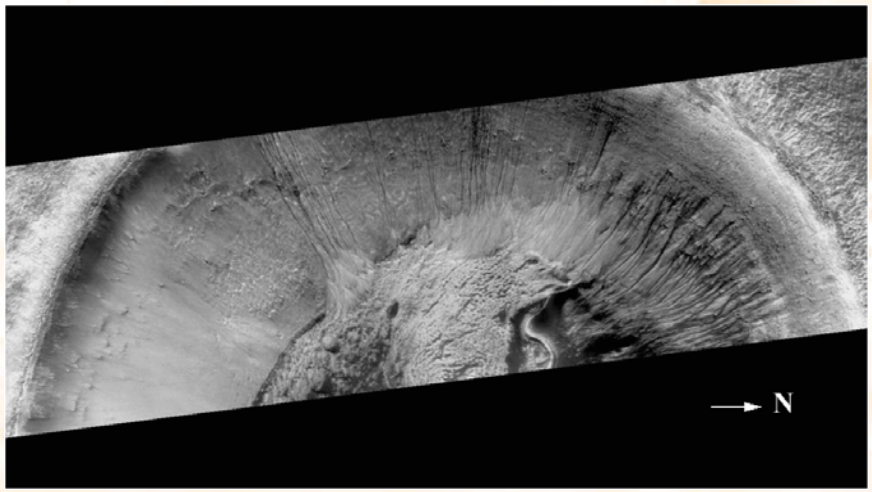


Block diagram of the eastern portion of the Sudbury Impact Structure showing the geometry of the Sudbury Igneous Complex (from Cowan et al., 1999) Lines with barbs are trajectories of ductile shape fabrics formed by post-impact orogenic deformation.

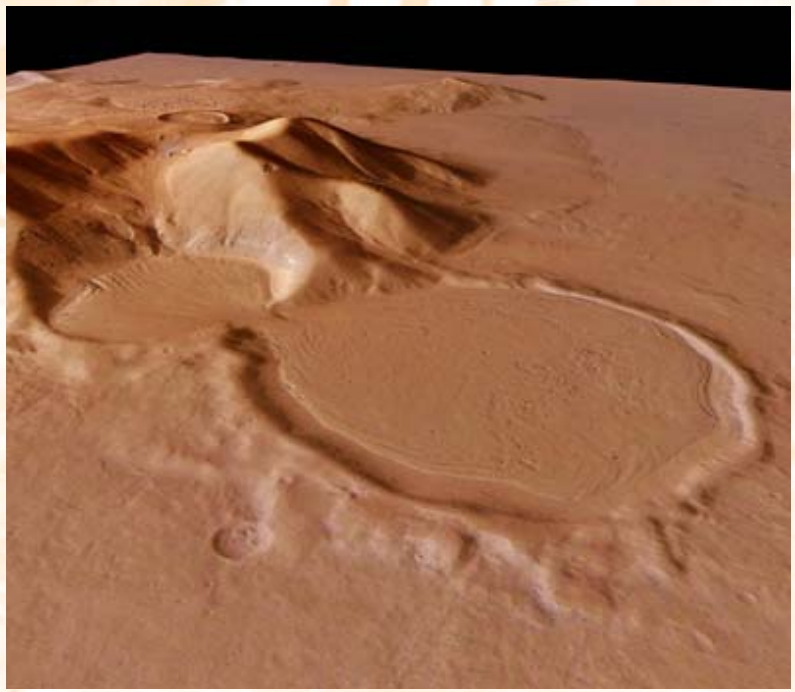


Impact Cratering

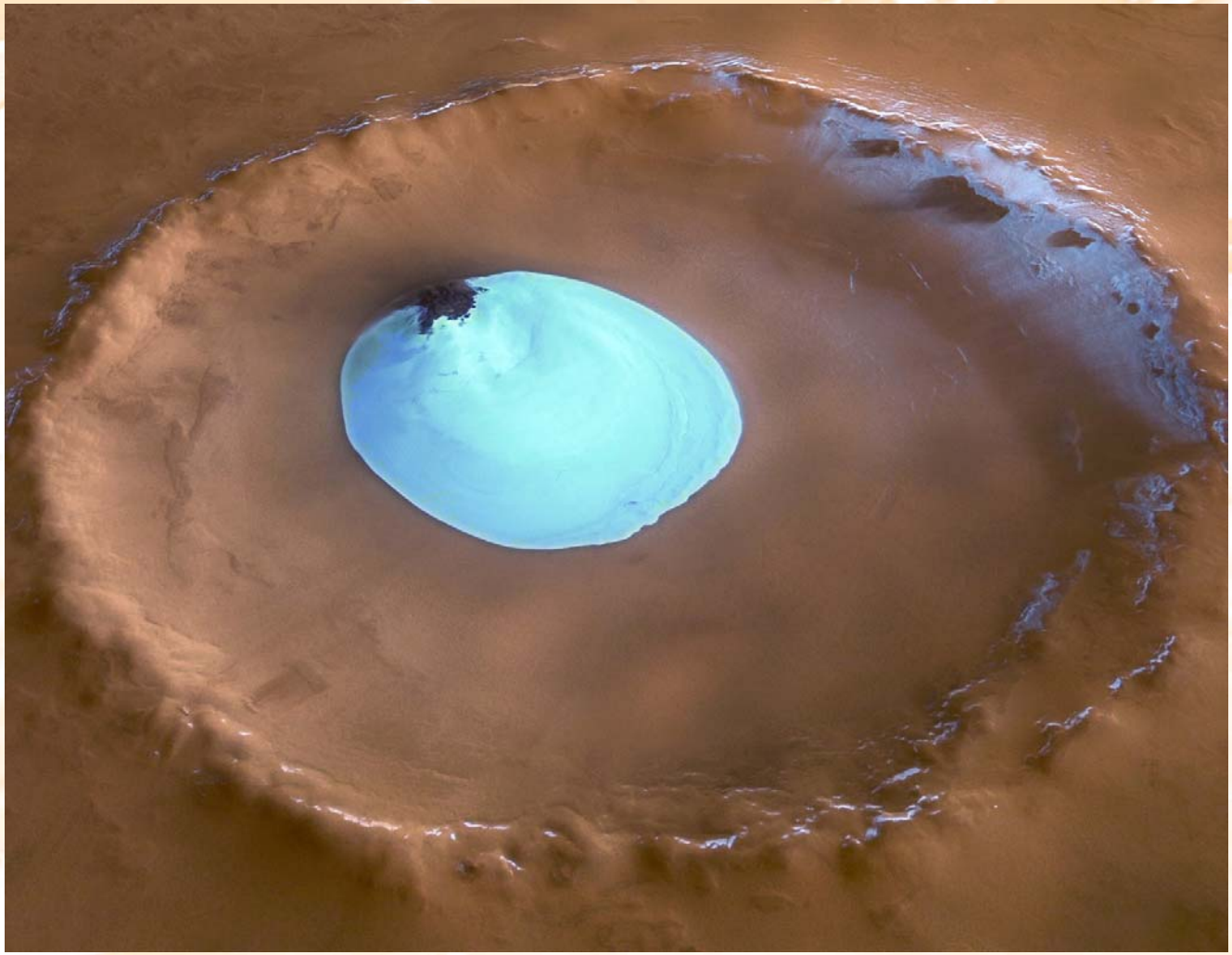
- Epigenetic - hydrothermal circulation caused by cooling impact melts or impact induced magmatic activity
  - – can occur at considerable distance from impact
  - – Cu, Zn Pb & Au vein-type mineralisation at Vermillion in Sudbury



System of gullies & aprons in 7 km diameter crater in Newton basin (MOC image)

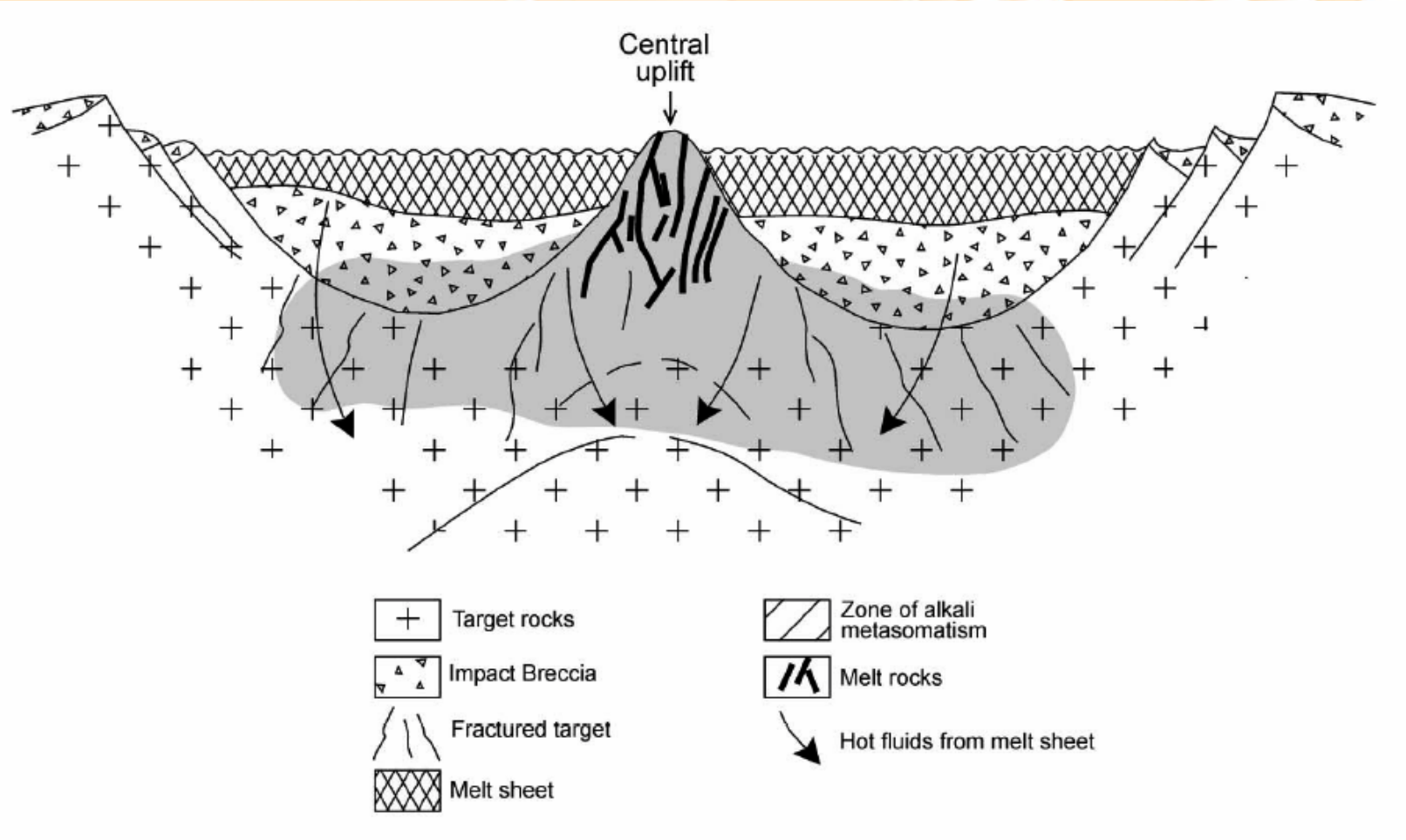


Impact Induced Hydrothermal Deposits



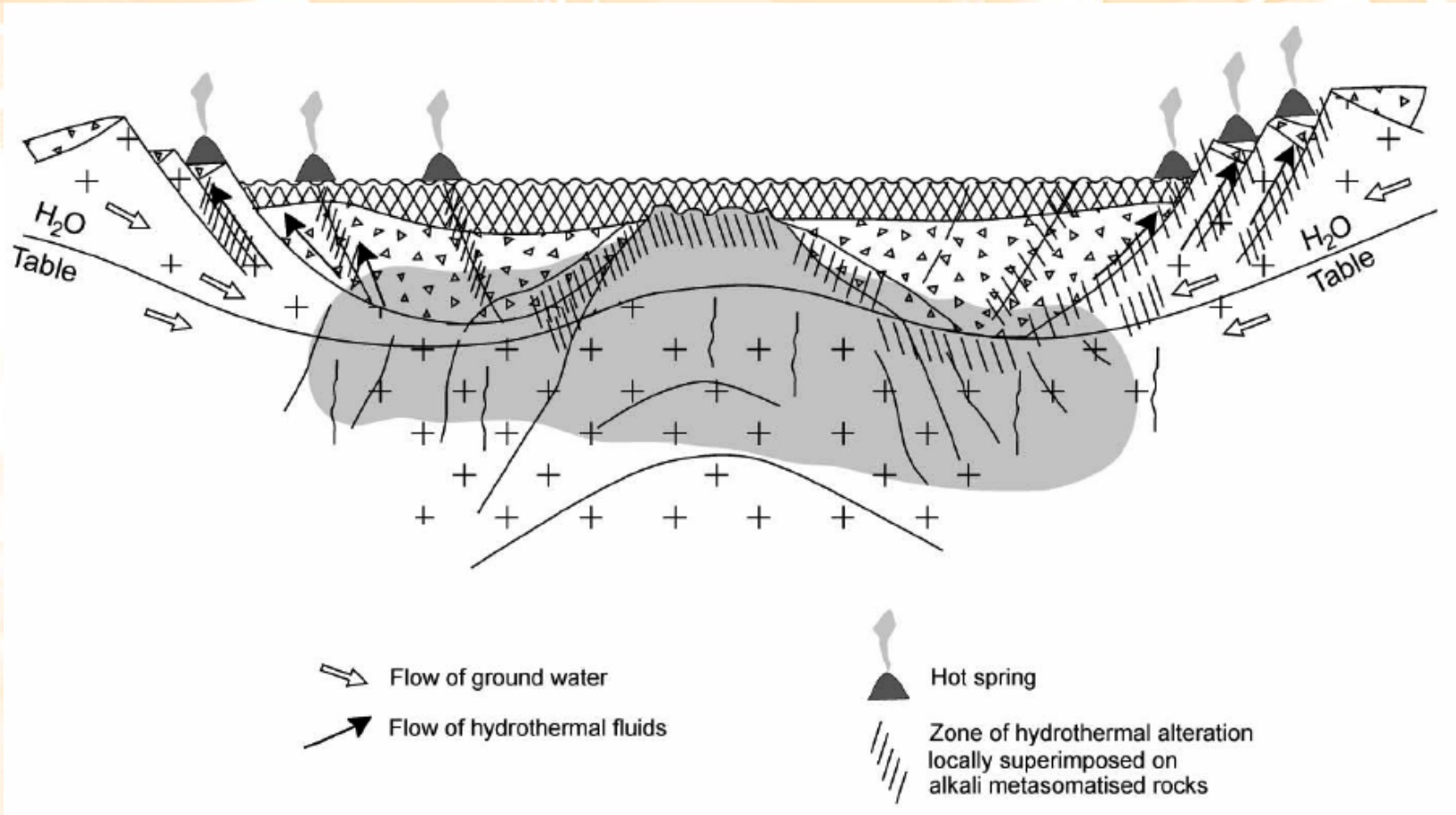
Water ice in an impact crater near the martian north pole (HSRC - Mars Express)

Impact Induced Hydrothermal Deposits



Stage 1 of hydrothermal fluid circulation in impact structure. Model proposed by Pirajno (2005)

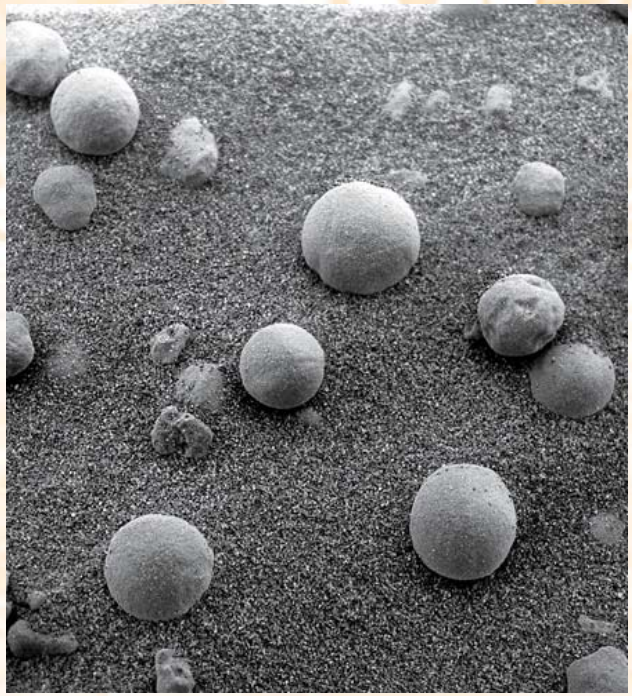
Impact Induced Hydrothermal Deposits



Stage 2 of hydrothermal fluid circulation in impact structure. Model proposed by Pirajno (2005)

Hematite Deposits

- 1/5 of weight soil and 16% abundance of rocks is Fe
- Hematite ‘blueberries’ are α - Fe_2-0_3, a common iron mineral
- Extraction with a simple vacuum cleaner!



Hematite ‘blueberries’ found by Opportunity rover (left) & close up taken with microscopic imager (right)

Mineral Sand Deposits

- Martian sands are primarily basalt derived TiO
  - rich in Ti & other rare elements
- Aeolian processes concentrate minerals in heavy sand layers
  - easily extractable from valley floors
  - Valles Marineris is ideal wind-sorter of particles

Deposits Unlikely on Mars

- Porphyry related Cu & Au
- Sediment hosted Pb, Zn & Au e.g. MacArthur River deposit
- Deposits of rare earth elements, phosphates, U, Th & Vl
- Al in form of bauxite
- Sedimentary ironstones
- Some of above require large supplies of water and/or biological activity

Conclusions

- Principal concentration & exposure methods are martian volcanism, LIPs and impact cratering
  - All can induce hydrothermal activity of various degrees
- Mineral sorting by eolian processes & hematite deposits are important
- Various deposit types are unlikely as past or present conditions on mars are not favourable
- Large scale mineral deposits on Mars are unlikely and difficult to locate
- At best subsistence mining for indigenous uses will be possible


Questions?