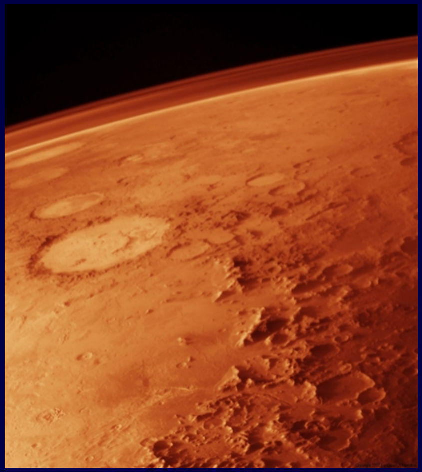
Zero-Valent Iron on Mars:

An Alternative Energy Source for Methanogens



Courtesy: NASA

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Methanogens – Good Model for Possible Subsurface Life on Mars

- Can grow in temperatures below 0 C (Reid *et al*., 2006)
- Can tolerate exposure to extremely low pressures (Altheide and Kral, 2008)
- Phylogenetically primitive

*Mars in a laboratory! →

Fe^0 on Mars

- Several large iron meteorites composed primarily of Fe^0 found on Mars' surface. (Schroder *et al*., 2008)

- Stony-irons containing substantial Fe^0 also found in what might be a strewn field. (Schroder *et al*., 2008)

Courtesy: NASA/CORNELL

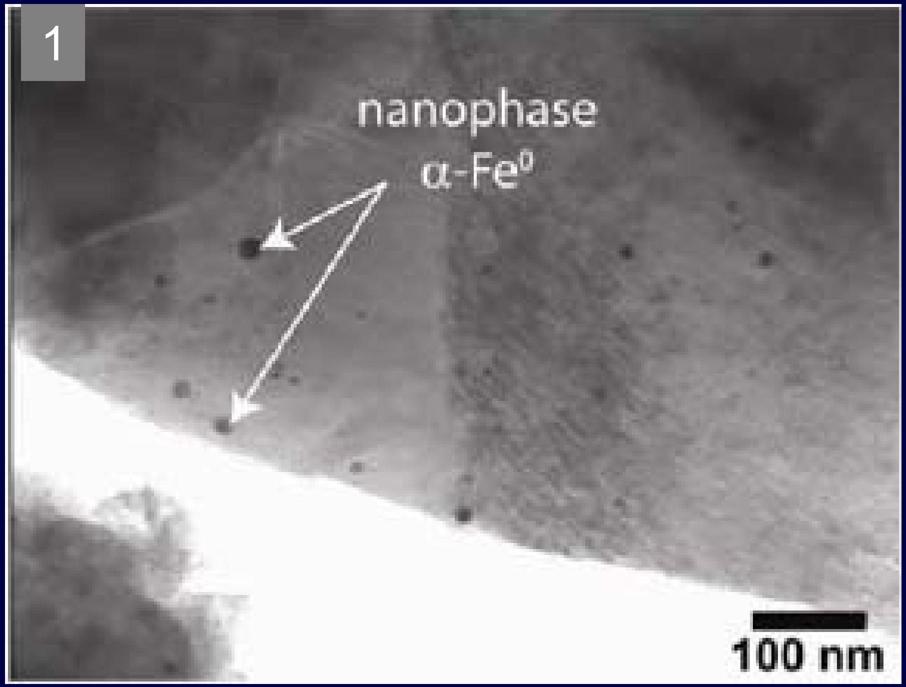
Micrometeorite Delivery

- Just like Earth, Mars is bombarded with meteoritic debris, much of it Fe^0.
  - Substantially thinner atmosphere increases the amount reaching the surface

- Flynn and McKay (1990) estimate as much as 29% of Martian soil from meteorites.
  - Up to 59,000 tons per year delivered to the surface

Shock-reduction from Impacts

- Impacts can lead to shock-reduction of iron-bearing minerals resulting in nanophase Fe^0.
- Numerous studies confirm Fe^0 in SNC meteorites. (e.g. Kurihara *et al*., 2009)
- This has been mimicked in the laboratory using JSC Mars-1 regolith simulant. (Moroz *et al*., 2009)



1) TEM image of NWA 2737 olivine. Small, dark (electron-dense) spherules are consistent with α-iron kamacite [after Treiman *et al*., 2007] (Pieters *et al*., 2008)

Fe^0 Source Summary

- Large meteorites deliver exogenous Fe^0
- Micrometeorites deliver exogenous Fe^0
- Large impactors generate and spread nanophase Fe^0 due to shock-reduction of iron-bearing minerals

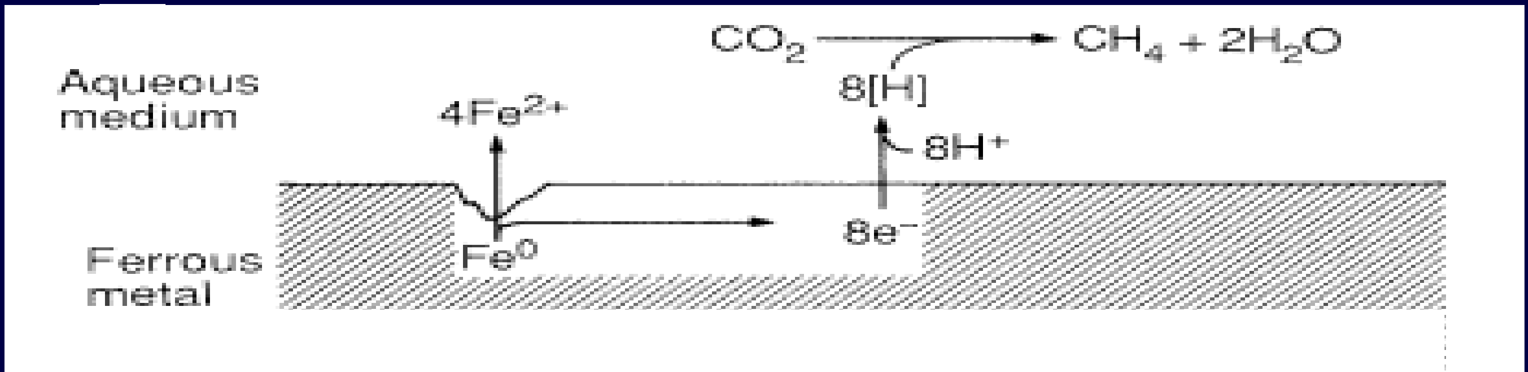
- May lead to substantial buildup of Fe^0 over time

Fe^0 Relationship to Methanogens

- Protons in solution can react with Fe^0 to produce H_2, but the reaction is not thermodynamically favorable.

$$4Fe^0 + 8H^+ \rightarrow 4Fe^{2+} + 4H_2 \qquad \Delta G^{0'} = +3.5\ \text{kJ}$$

- However, a sink for H_2 can drive the reaction.
- Daniels *et al*. (1987) show that methanogens in nutritive medium can utilize the H_2.



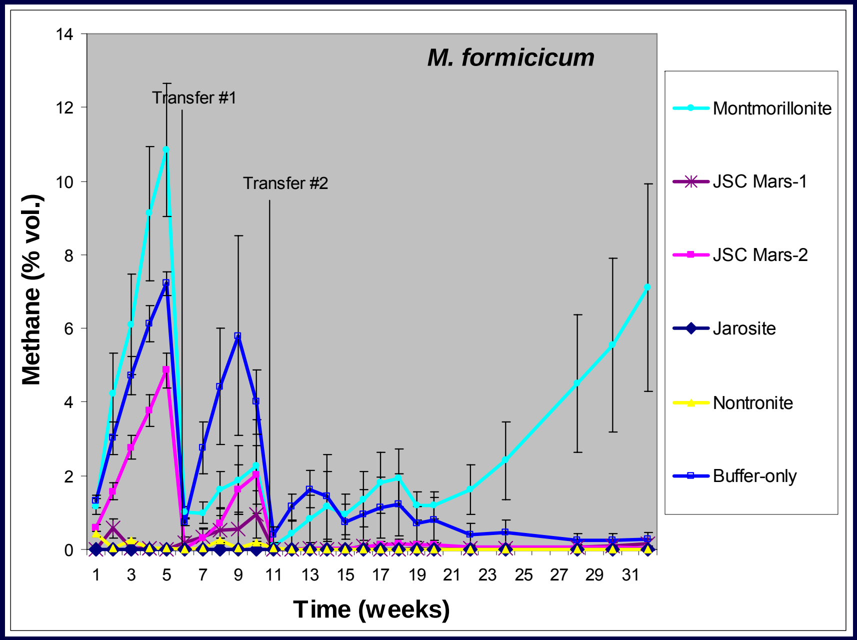
Daniels et al. (1987)

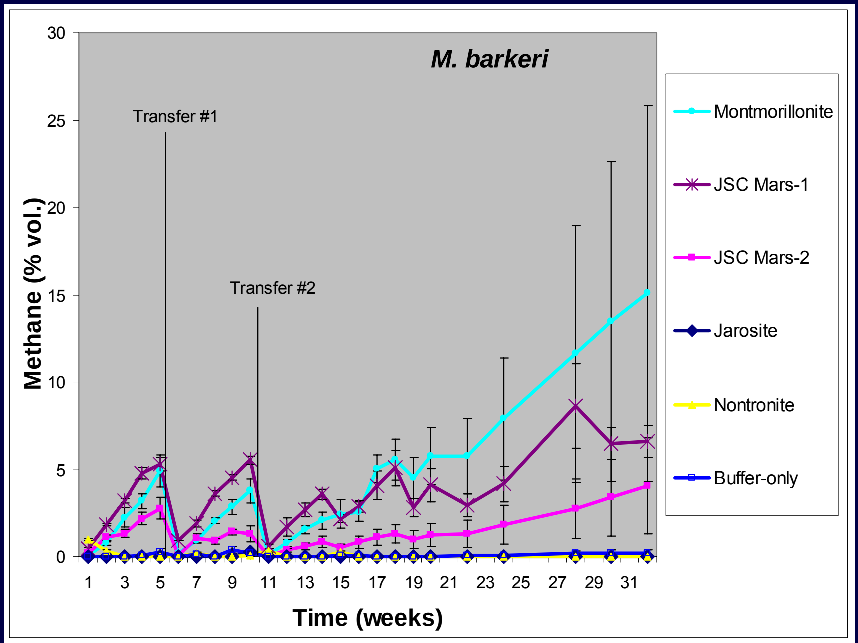
This Study:

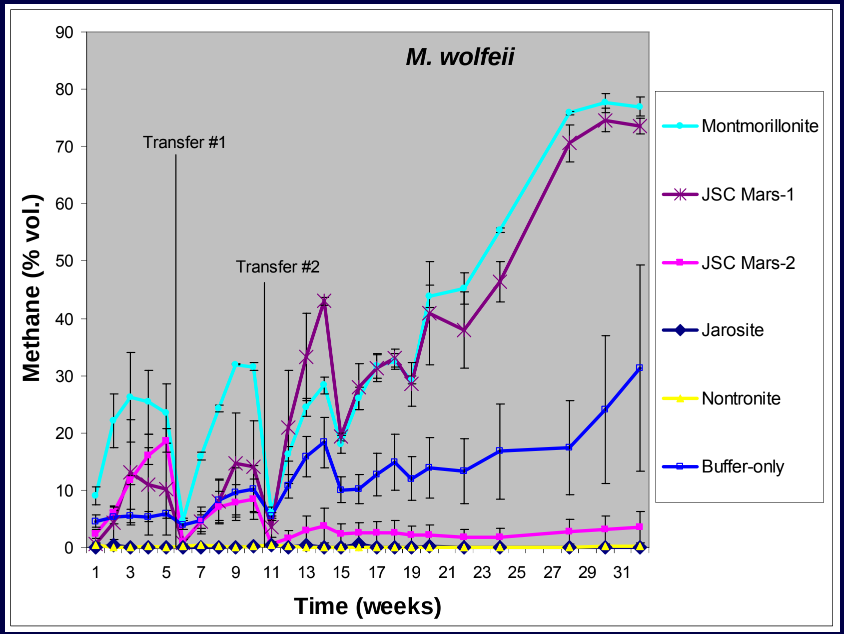
- Fe^0/any H^+ in solution (energy)
- Bicarbonate buffer/CO_2 (carbon/water)
- Montmorillonite clay (micronutrients)

- Does methanogenic metabolism take place in these Mars-relevant conditions?

*Why montmorillonite?

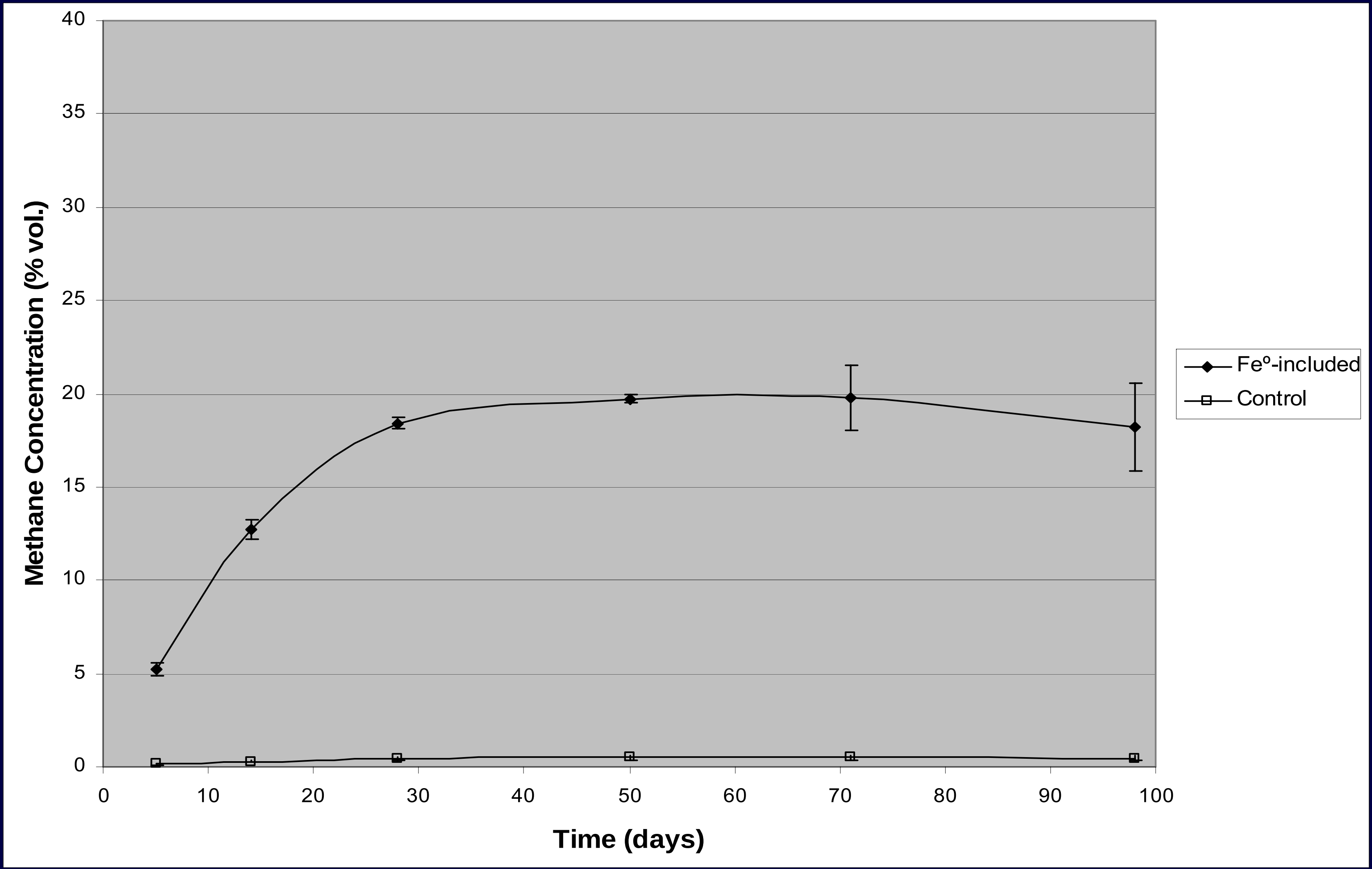






Montmorillonite clay can supply the micronutrient requirements of methanogens.

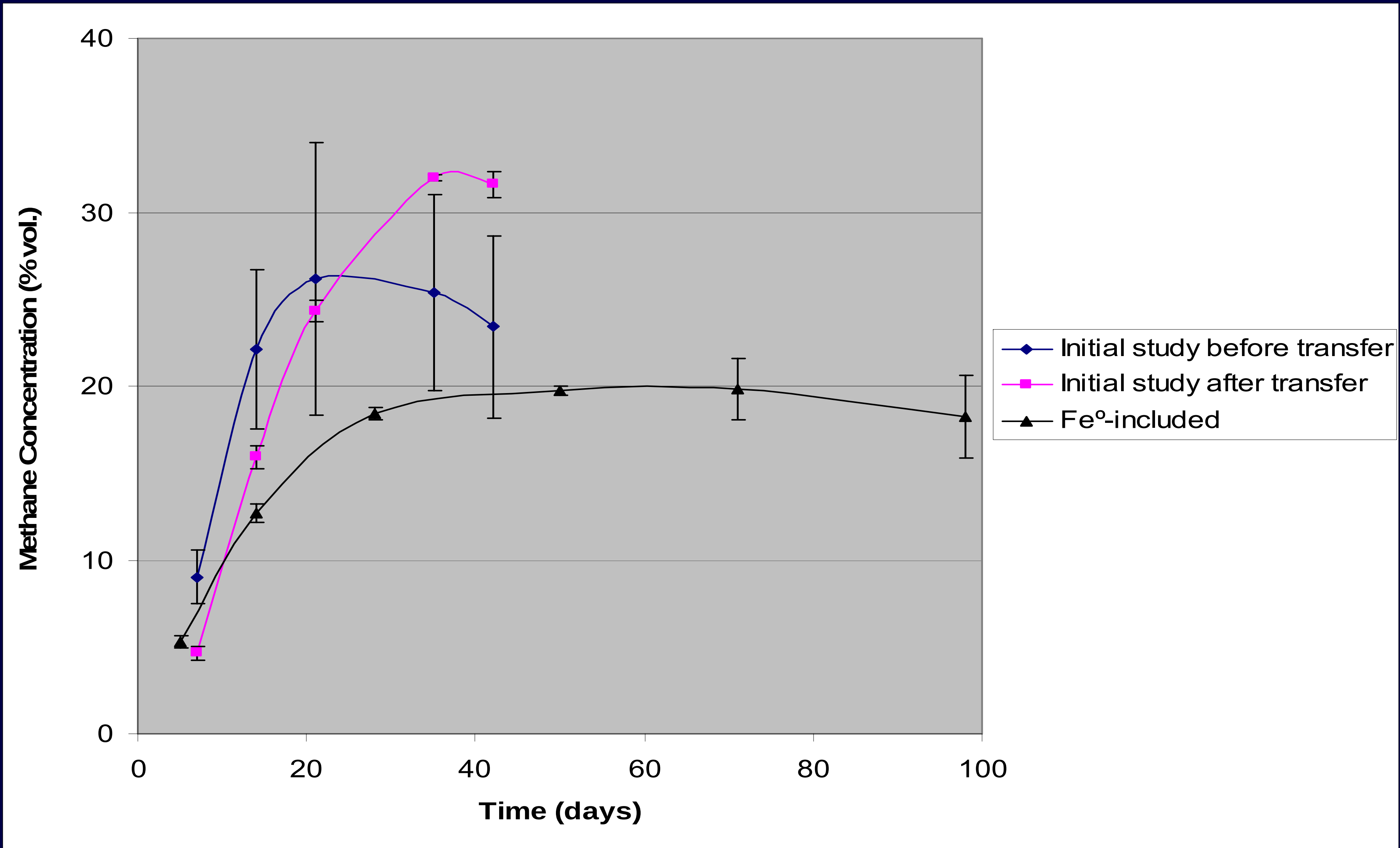
Results: Fe^0 vs. no H_2



Obvious oxidation to Fe^{3+}

*Is the darker color of the montmorillonite an indication of $Fe(OH)_2$?

Comparison to Previous Work



Concluding Remarks

- Fe^0 is available on Mars
- CO_2 is available on Mars
- Montmorillonite-like clays are available on Mars
- Given the right environmental conditions, these three materials can support methanogenic metabolism
- The temperature was not exactly Mars-relevant, BUT…