emergent properties
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geometry, form and organization: landscape, river networks and the continental crust
credits

- arc priority area selection
- the $bci$ index
- prof leopold (very high on the all-time $bci$ list)
- the murray ‘back arc’ basin salinity crisis!
just what is erosion trying to do?
River networks and self-organization

Balcanoona Creek
Flinders Ranges, South Australia

reflecting not so simple system dynamics - ARC rest assured!
Fluvial landscapes

Unmistakable mosaics of channels and hillslopes!\(^2\)

\(^2\) reflecting efficient and inefficient transport modes, respectively
The wisdom of fluvial geomorphology

A myriad of scaling laws:

Horton: \[ \frac{n_w}{n_{w+1}} = R_n, \frac{\overline{X}_{w+1}}{\overline{X}_w} = R_x \]

Tokunaga: \[ \frac{T_{v+1}}{T_v} = R_T, T_v = T_1(R_T)^{v-1} \]

Hack: \[ l \propto a^h \]
Fractal character of fluvial landscapes

Just another description- so what?

In fact, an artifice arising from the interaction of various scale dependant processes (Chase, 1992)\(^3\) to make a kind of overall scale independency.

\[\text{such as incision and tectonics which roughen the landscape on the short- and long-range, respectively, and mass wastage and sedimentation which smooth the landscape on short- and long-wavelengths, respectively.}\]
Yes, but why networks?

‘The most probable river profiles approach the condition in which the downstream production of entropy per unit mass is constant.’

Leopold & Langbein (1962)

but what on earth is this thing geomorphic entropy
Optimal channel networks (OCN)

Optimal channel networks minimize overall energy expenditure\(^5\)


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at least when compared with other political systems

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Rodriguez-Iturbe et al. (1992)
Entropy and dissipative systems (1)

Irreversible thermodynamics produce entropy.

In the linear, near to equilibrium, irreversible region, entropy production $\sigma$ is given by the product of a flux and a force $^6$

\[ \sigma = X.F_i \]

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$^6$ strictly in the region that Onsagers’ reciprocity relations apply, as opposed to the far-from equilibrium irreversible region.
Entropy and dissipative systems (2)

For heat conduction:
the flux is the heat flow, $F_i = q$
and the force the inverse temperature gradient, $X = \nabla(1/T)$:

$$\sigma = q.\nabla(1/T) \propto \frac{1}{T^2} q.\nabla T$$
An example of entropy generation

\[ \sigma_H = \frac{\dot{Q}}{T_H}, \quad \sigma_L = \frac{\dot{Q}}{T_L} \]

\[ \sigma_{gen} = \sigma_L - \sigma_H \]

\[ \sigma_{gen} = \frac{1}{T_H T_L} \dot{Q} (T_H - T_L) \]

\[ \sigma_{gen} \propto \frac{1}{T^2} q \cdot \nabla T \]
The importance of entropy

‘The thermodynamics of close-to equilibrium systems .... evolves towards a stationary state characterized by a minimum entropy production compatible with the constraints imposed on the system.’

Entropy generation minimization (EGM)

EGM provides the **arrow of time** for non-equilibrium thermodynamics\(^7\)

...can we see what leopold & langbein were on about with the constant ‘*downstream production of entropy*’?

\(^7\) at least in the linear, near-to equilibrium region
Thermal landscapes?

The concept of entropy production in geomorphic systems is pretty weird, so how about **thermal landscapes**?

Do heat trees spontaneously arise from EGM principles?
Thermal landscape rules

As simple as a 2-stage algorithm with one rule:

- compute the temperature and entropy production fields with boundary conditions for irreversible heatflow.
- convert insulators (hillslopes) to conductors (channels) at points of maximum entropy production\(^8\).

\(^8\) consistent with the concept of a threshold for channel formation
Thermal landscape reality

Heat flow driven by boundary conditions and internal heat production. Channels progressively embedded according to EGM.
temperature field

entropy production rate

log\(_{10}\)(conductivity field)

heat flux

\(k_{\text{ratio}} = 106.0512\)

\(dd = 5.1\%\)
Some observations on EGM networks

Points of maximum \( \sigma_{gen} \) provide the most resistance to flow, and therefore experience the greatest ‘pressure’.

Channelization of the points of maximum \( \sigma_{gen} \) provides the best return (i.e., reduction in \( \bar{T} \)).
temperature field

entropy production rate

log_{10}(conductivity field)

k_{ratio} = 10^{3.0511}

heat flux

dd = 3.1\%
Effective networking - a modern guide to not so simple systems

Networks result from the thermodynamic optimization in systems with area (or volume) to point flow involving transport processes with contrasting efficiency\(^9\).
Heat trees are not rivers! but

river networks reflect a system-wide optimization of mass
transport between hillslopes and channels, limited by a
threshold for channel formation.
The continental crust: a really simple system?

Why is the crust so

- thick / thin?
- flat / rugged?
- strong / weak?
- stressed / unstressed?
- geochemically stratified / unstratified?
Why does it matter?

If the crust weren’t so weak then it couldn’t do this \(^{10}\)

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for the disbelievers, extension in continental interiors is the primary indication of intraplate tectonic activity in the modern Earth!
It does matter!

and if it couldn’t do that, could it do this?

*ipso facto,*

if continents were to strong for intraplate tectonics then plate tectonics would be different or even, possibly, not possible!¹¹

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disbelievers beware, let the true significance of intraplate tectonics be upon you!
On strength!

What controls strength of continental interiors?

- crustal thickness (probably)
- lithospheric thickness (certainly)
- the distribution of heat producing elements (absolutely)\(^2\)

\(^2\) I would say that, wouldn’t I
and stress!

What controls stress in continental interiors?  

- plate geography (plate boundaries)
- mantle - lithosphere coupling (dynamic topography)
- crustal thickness (potential energy)

and, for Dietmar, crustal architecture, even if it has a high BCI rating!
and the primary observation!

Continents are (just about) everywhere deforming!

Stable continental region seismic moment release equates to strain rates are of the order of $10^{-17}s^{-1}$ (0.6% of the Earth’s seismic moment release).

Is this just fortuitous, or is it that continents are somehow preconditioned to respond
Adelaideans be warned!

SE Australia is shortening at a rate of about 1 km per myr equating to a crustal thickening rate of 3.5 km/100 Ma!
so what is the connection between salinity and crustal self-organisation!