Structural Geology & Resources 2022
16 October 2022

Mineral systems as chemical reactors with no mathematics

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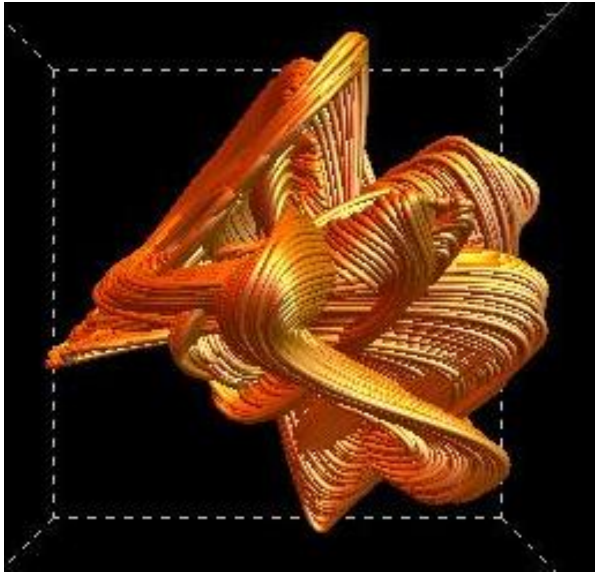
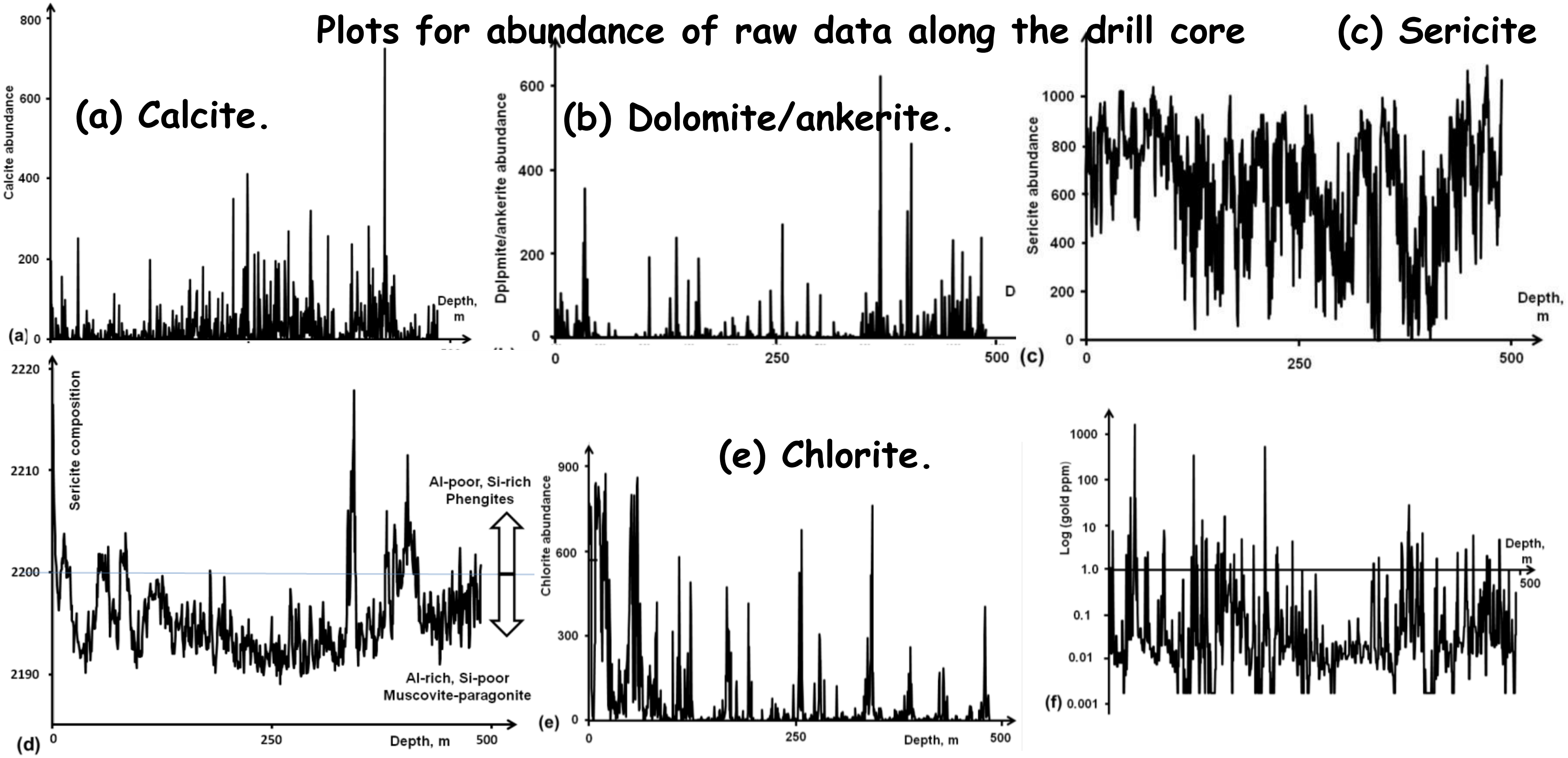
Fingerprint for a mineralising system



Session 5. 15:15 – 16:15

The example of Sunrise Dam

Plots for abundance of raw data along the drill core



(a) Calcite.

(b) Dolomite/ankerite.

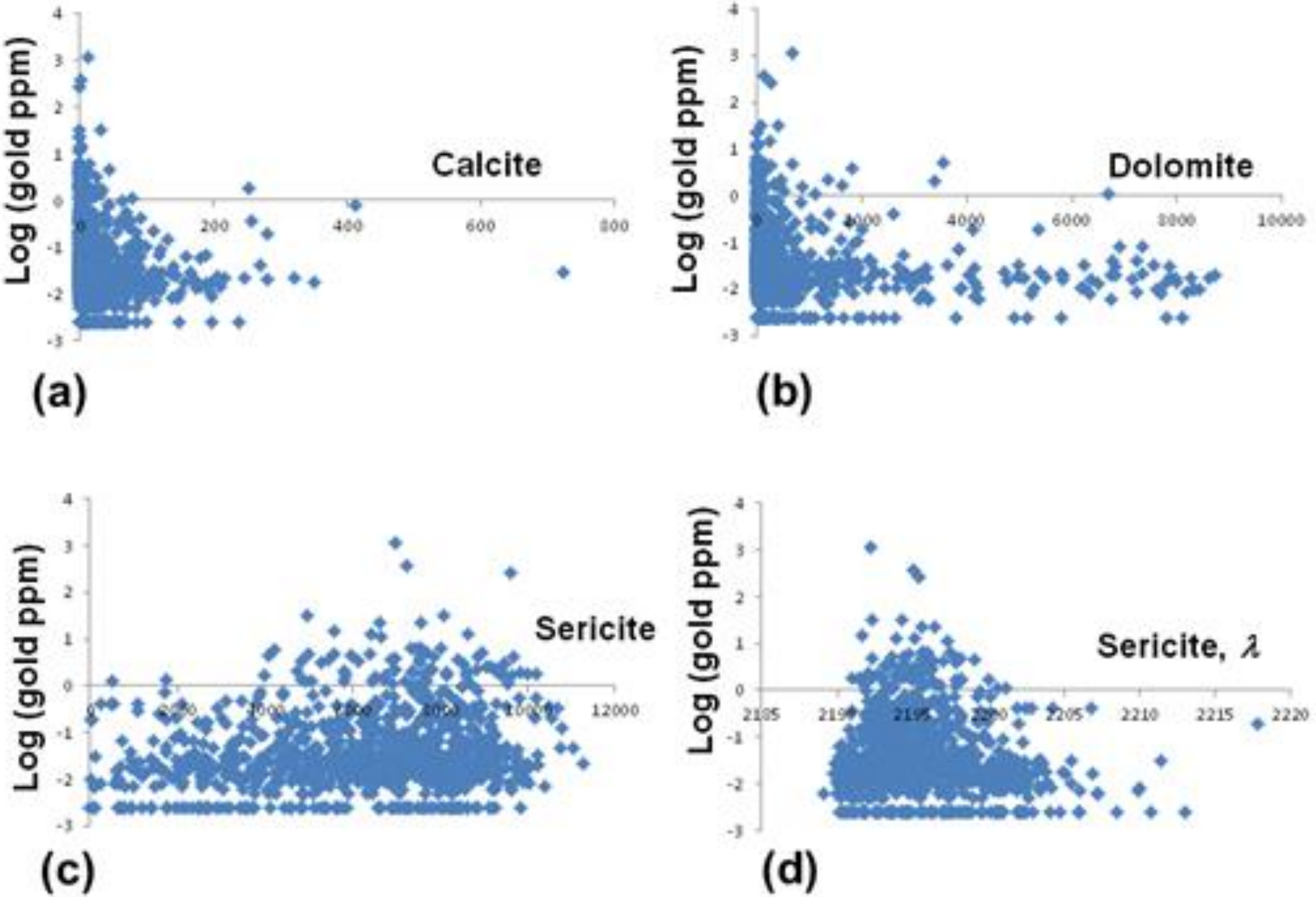
(c) Sericite

(d) Sericite composition. Vertical axis is IR absorption wavelength in nano-metres.

(e) Chlorite.

(f) Logarithm of gold concentration in ppm by weight.

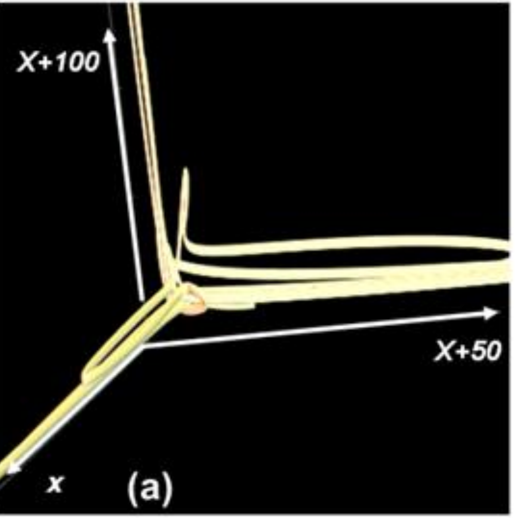
Plots of the log(gold) signal against other signals

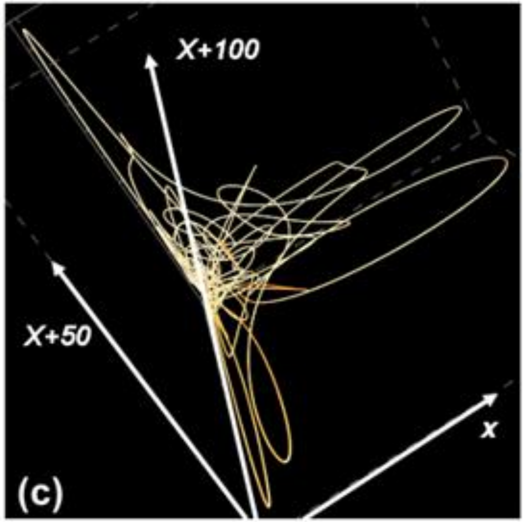


Cross correlation between signals.

	Dolomite	Log-gold	Sericite	Calcite	Chlorite	Sericite composition
Dolomite	1					
Log-gold	0.193	1				
Sericite	0.018	0.169	1			
Calcite	0.026	-0.088	-0.082	1		
Chlorite	-0.039	0.013	0.138	-0.060	1	
Sericite composition	-0.022	-0.096	-0.228	0.064	-0.024	1

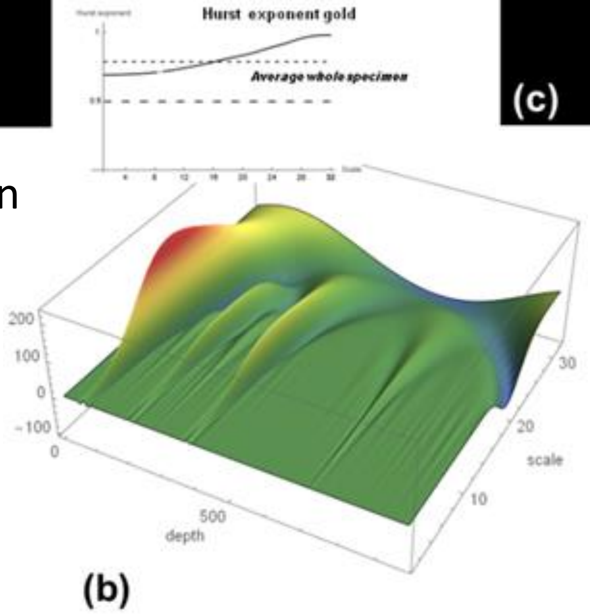
Three dimensional projections of attractors after application of low pass filter.

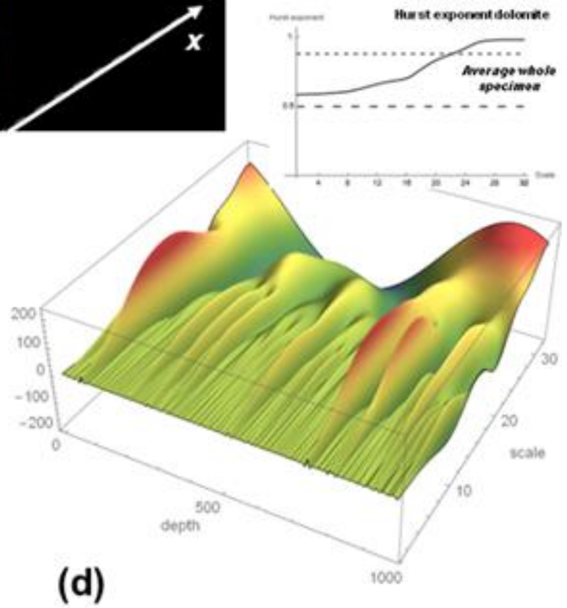




dolomite/ankerite abundance

raw gold concentration





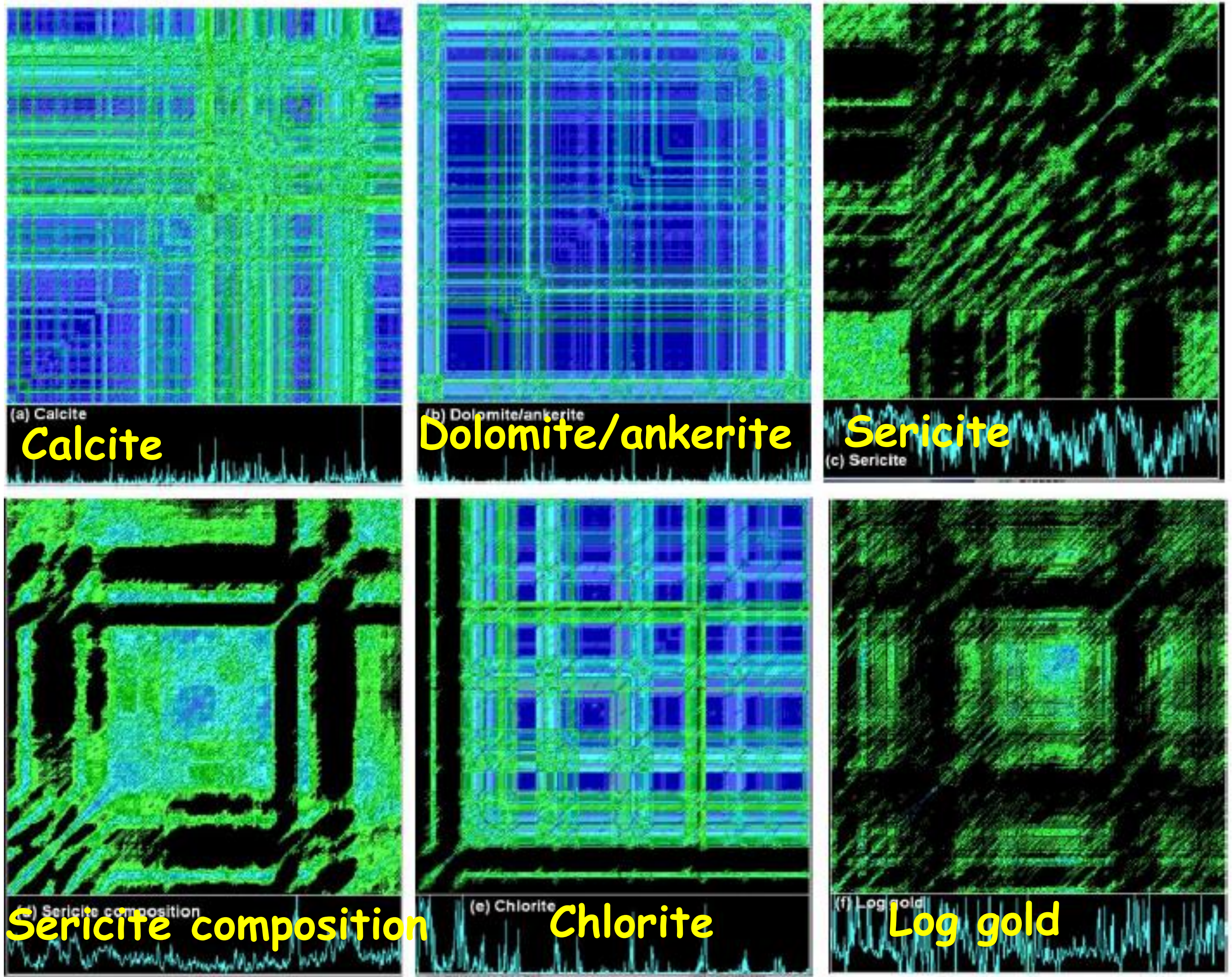
A recurrence plot identifies recurrences at different parts of the same signal on the one attractor.

Recurrence plots

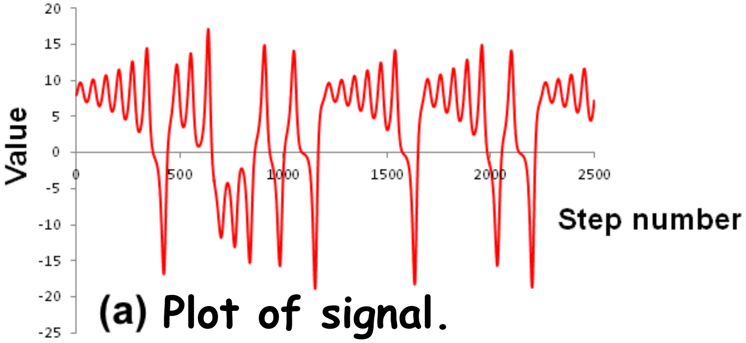
(a) Calcite.
(b) Dolomite/ankerite.
(c) Sericite
(d) Sericite composition.
(e) Chlorite.
(f) Log gold concentration in ppm by weight.

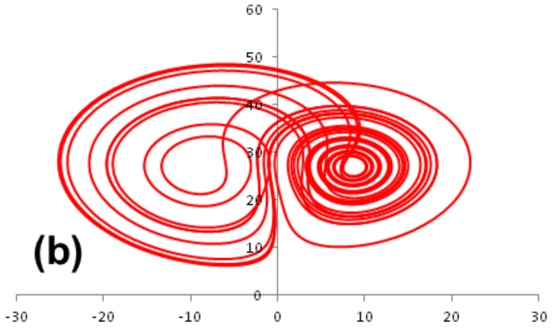
embedding dimension 10 delay 5.

Black - near zero recurrence
blue colours - high recurrence;
green - intermediate.

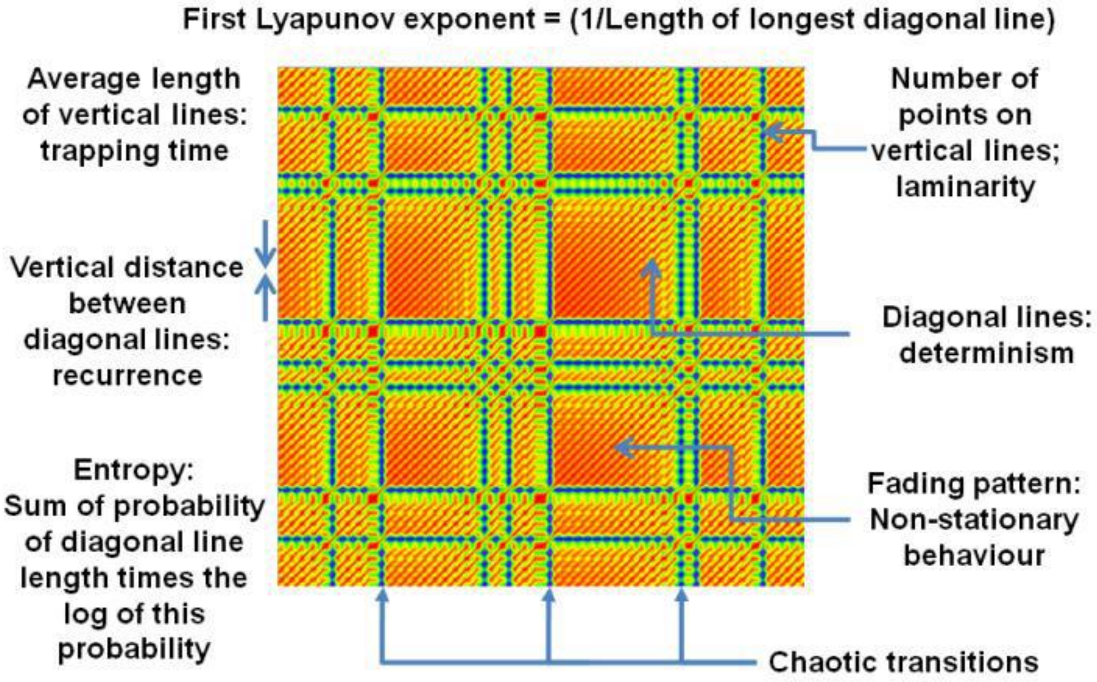


Recurrence measures based on the Lorentz system





Attractor for the system. Trajectories cross in this diagram because it is a projection from 3D into 2D.



A recurrence plot for the Lorentz attractor showing the significance of some of the recurrence quantification analysis measures and of other features of the plot.

RQA measure	Calcite	Dolomite/ ankerite	Sericite	Sericite composition	Chlorite	Log (gold ppm)
% recurrence	88.5	85.7	11.1	48	70	11.2
% determinism	99.1	95.2	63.1	96	98.5	55.2
dmax	413	542	186	640	262	137
entropy	2.0	2.2	1.9	3.5	2.4	1.5
trend	7.6	10.1	3.7	-4.1	58.3	10.6
%laminarity	99.2	96.4	73.5	97	98.9	74.8
vmax	411	411	122	411	251	128
trap time	12.7	12.2	4.3	16.1	25.1	4.3

A cross recurrence plot:

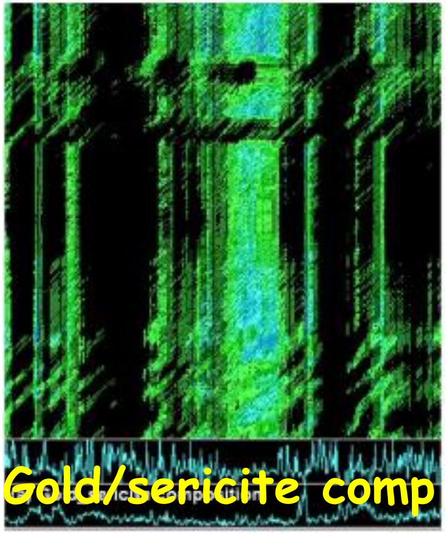
* identifies recurrences at neighbouring places in phase space for two different signals.

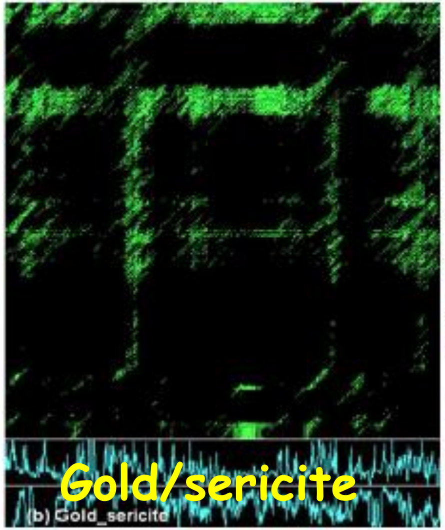
* identifies those places where a state in one system recurs in the other.

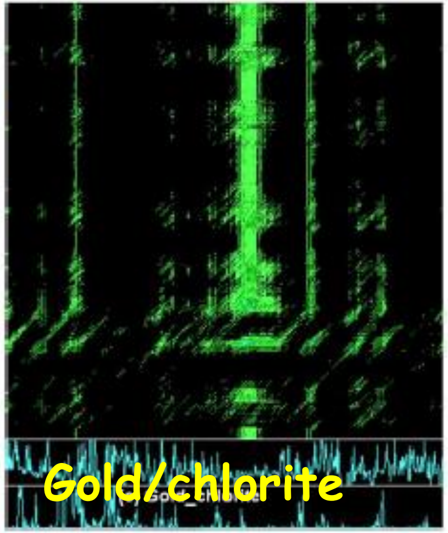
If the phase space trajectories visit different regions of the phase space, the cross recurrence plot tends to sparse.

Simultaneous occurrence of similar states produces dense plots.

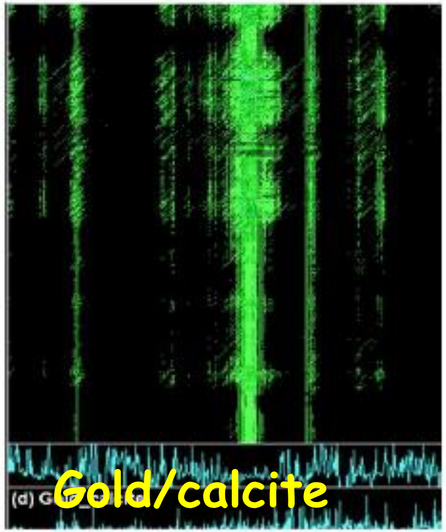
Cross recurrence plots.

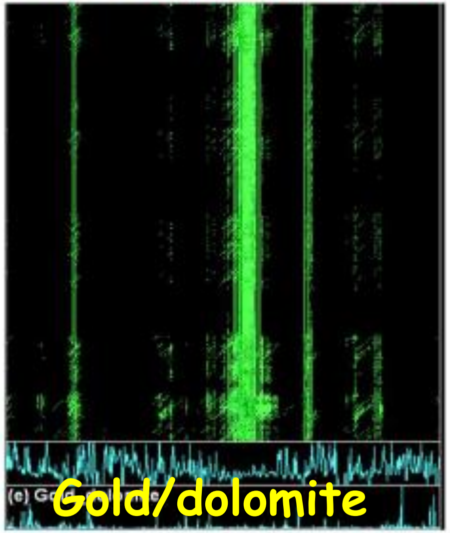






(a) Gold/sericite composition.
(b) Gold/sericite.
(c) Gold/chlorite.
(d) Gold/calcite.
(e) Gold/dolomite-ankerite.





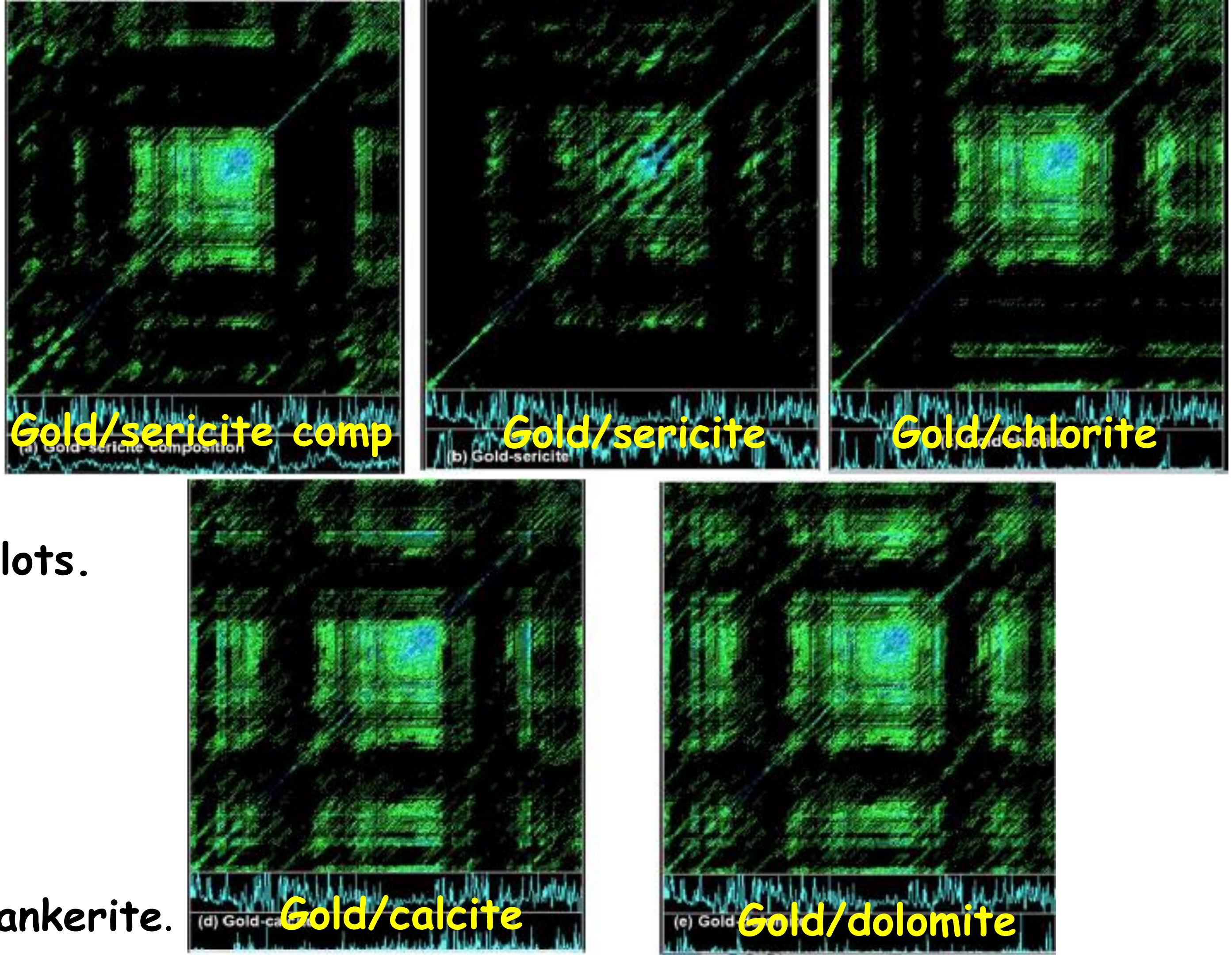
Cross recurrence analysis shows

strong spatial correlations of gold with carbonates

&

weaker correlations with phengitic micas and chlorite.

Joint recurrence plots portray the probability that two systems recur simultaneously in the neighbourhood of a formerly visited point in their respective phase spaces.

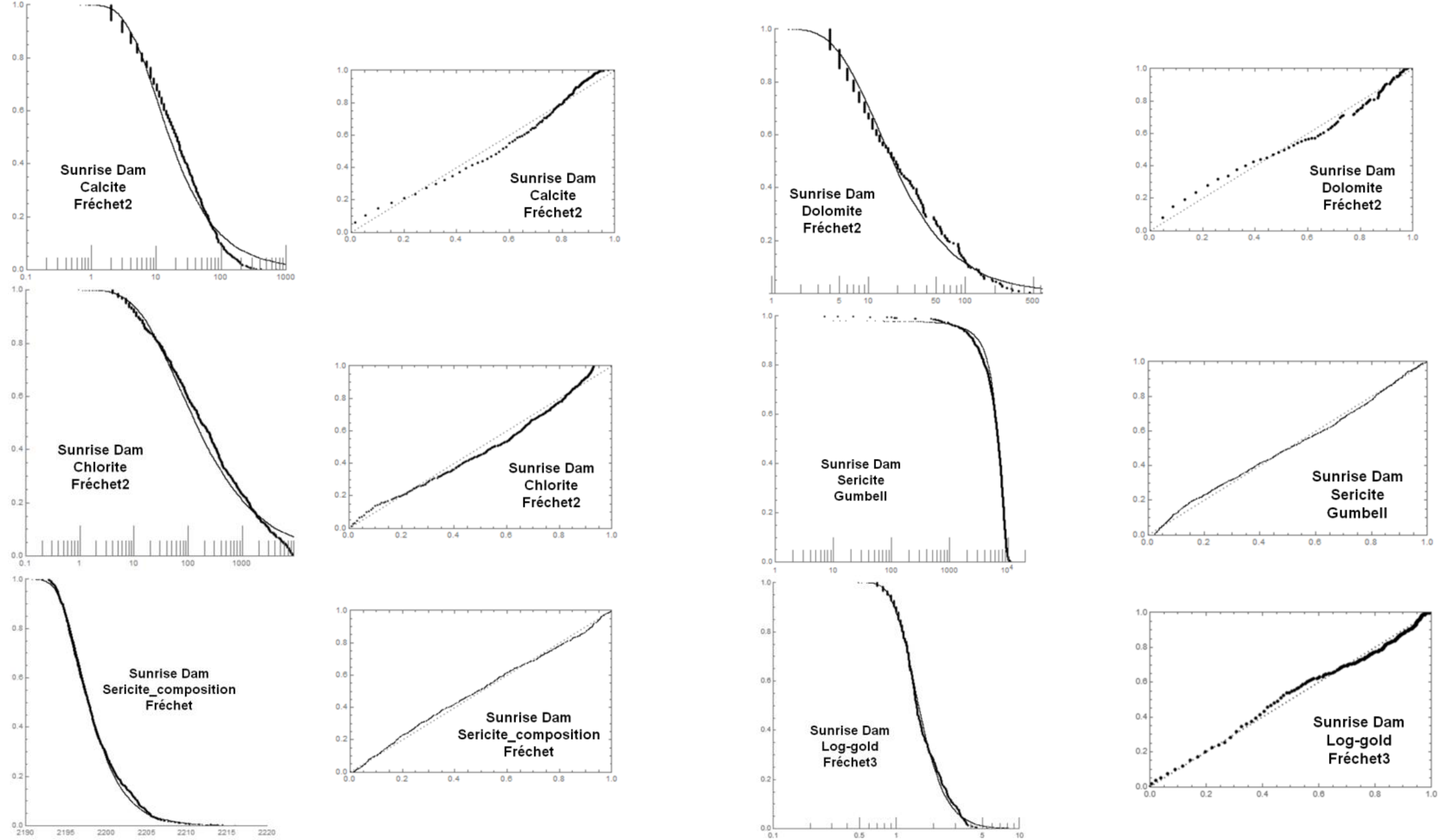


Joint recurrence plots.

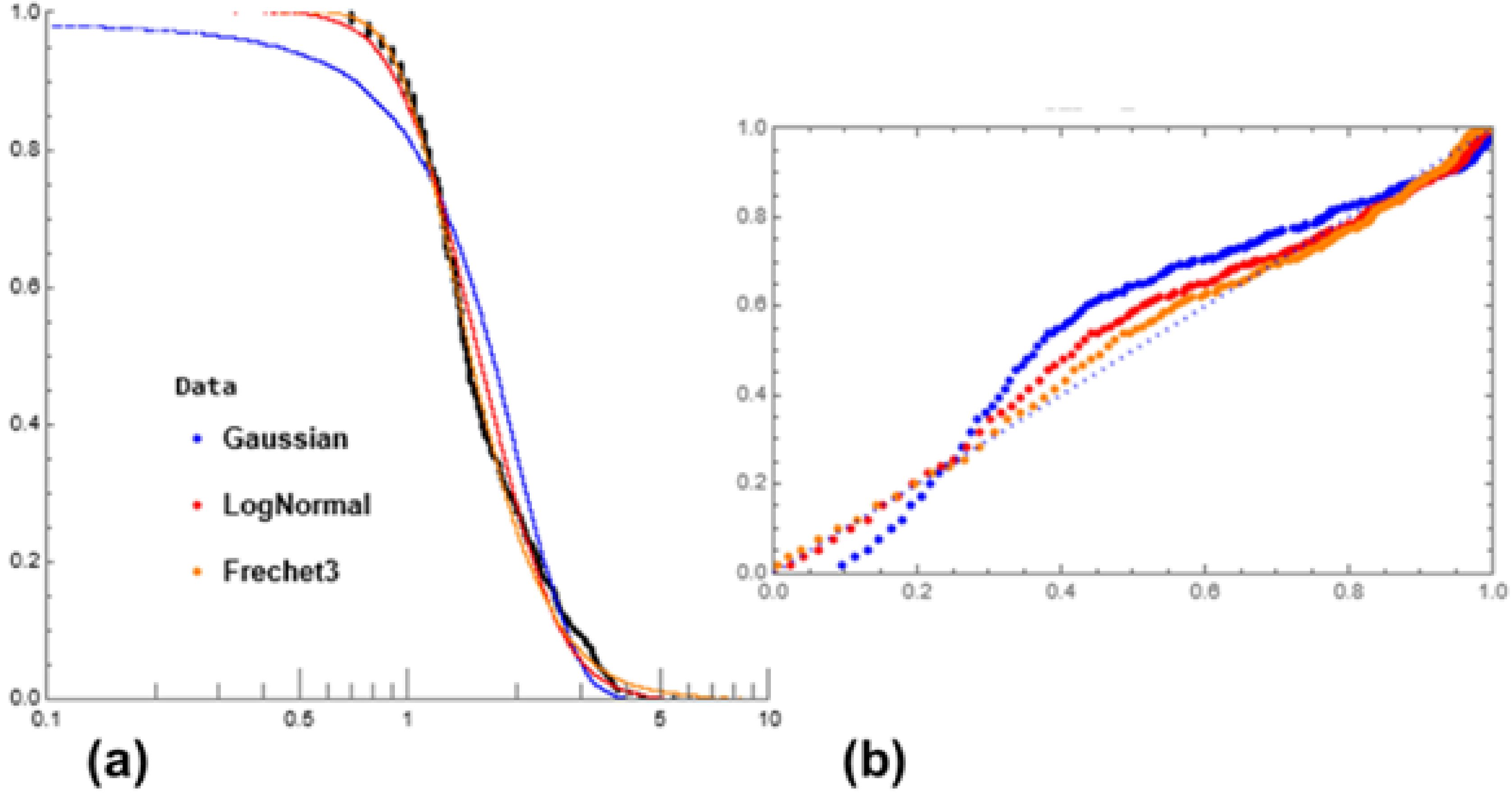
(a) Gold/sericite composition.
(b) Gold/sericite.
(c) Gold/chlorite.
(d) Gold/calcite.
(e) Gold/dolomite-ankerite.

Joint recurrence analysis reveals that all part of the system are part of the same dynamical attractor and hence parts of the same physical-chemical system.

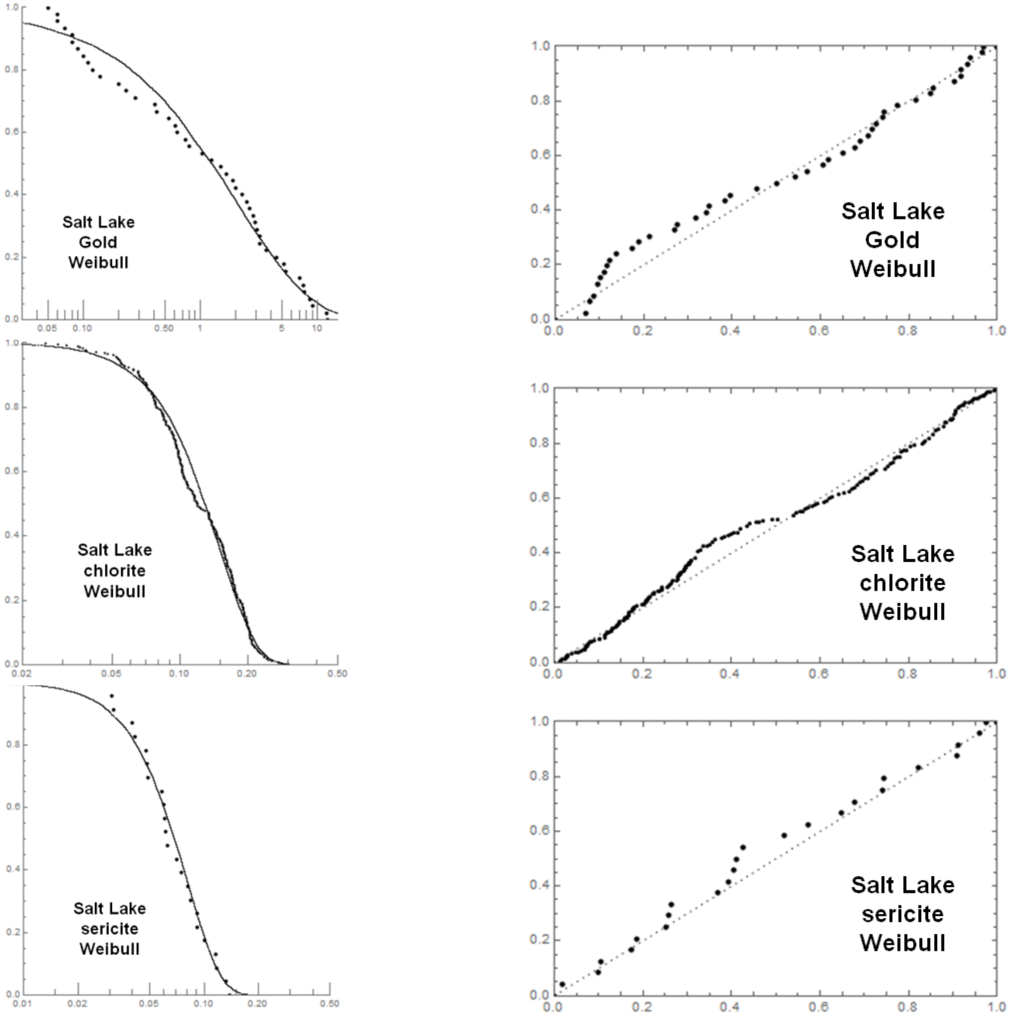
Probability distributions for calcite, dolomite, chlorite, sericite, sericite composition and log-gold



Comparisons between best fit Gaussian, log-normal and Fréchet3 distributions for log(gold)

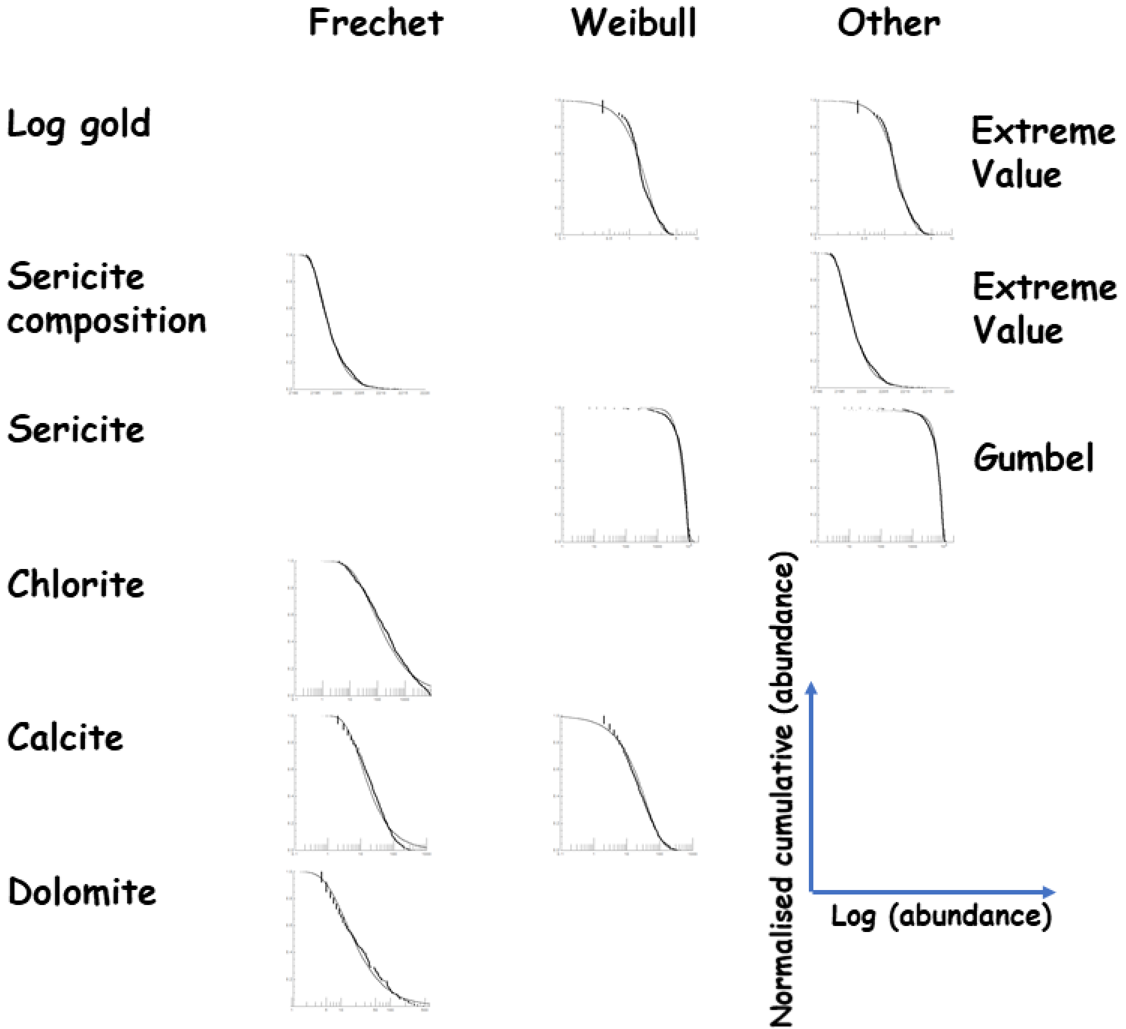


Probability distributions for log(gold), chlorite and sericite from the Salt Lake deposit, Yilgarn.

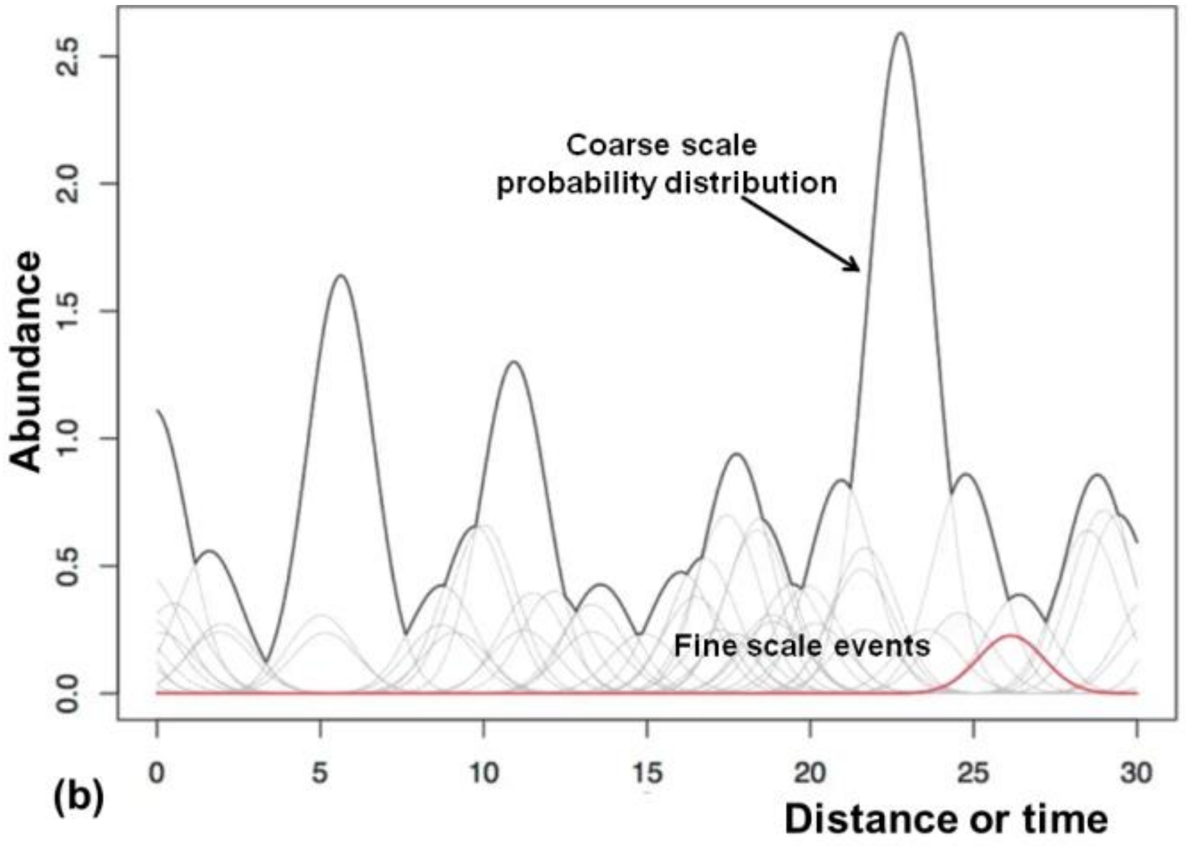


The data are best fit by the specialized Extreme Value distributions including Frechet, Weibull and Gumbel.

The data are less well fit by the heavy tail distributions of Pareto, Cauchy, Levy, and the long & heavy tailed Log Normal distribution.



These estimated distributions for the data arise from the underlying thermodynamics for the system.

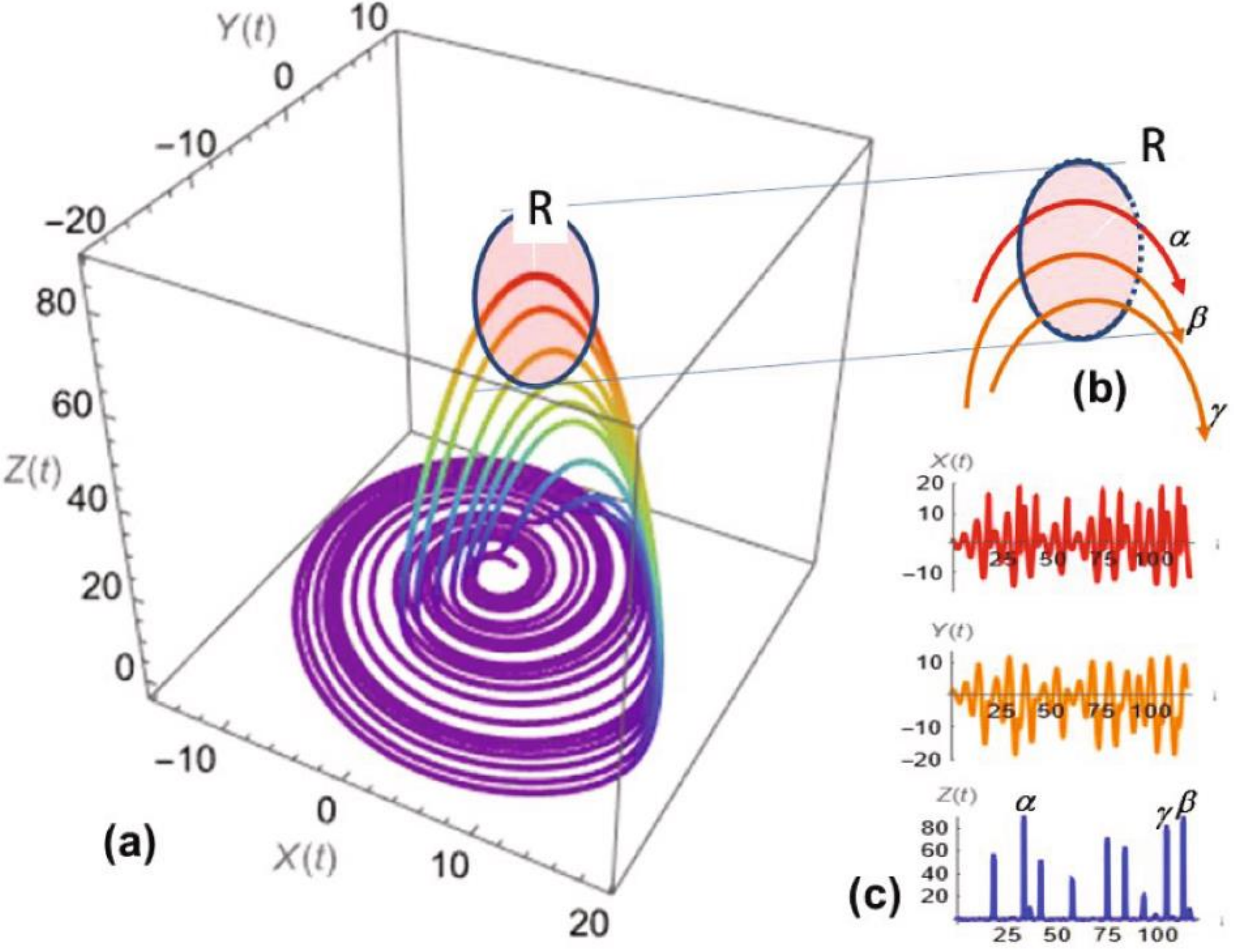


Aggregation of fine scale events (shown in grey) to form a coarse scale distribution of abundances (in black). The red trace shows an instantaneous fine scale event, From Davison and Huser (2015, Animation 6).

The nonlinear analysis highlights that the essential characteristic of the incoming fluid is that it has a chemical composition capable of strong chemical reaction with the host rocks.

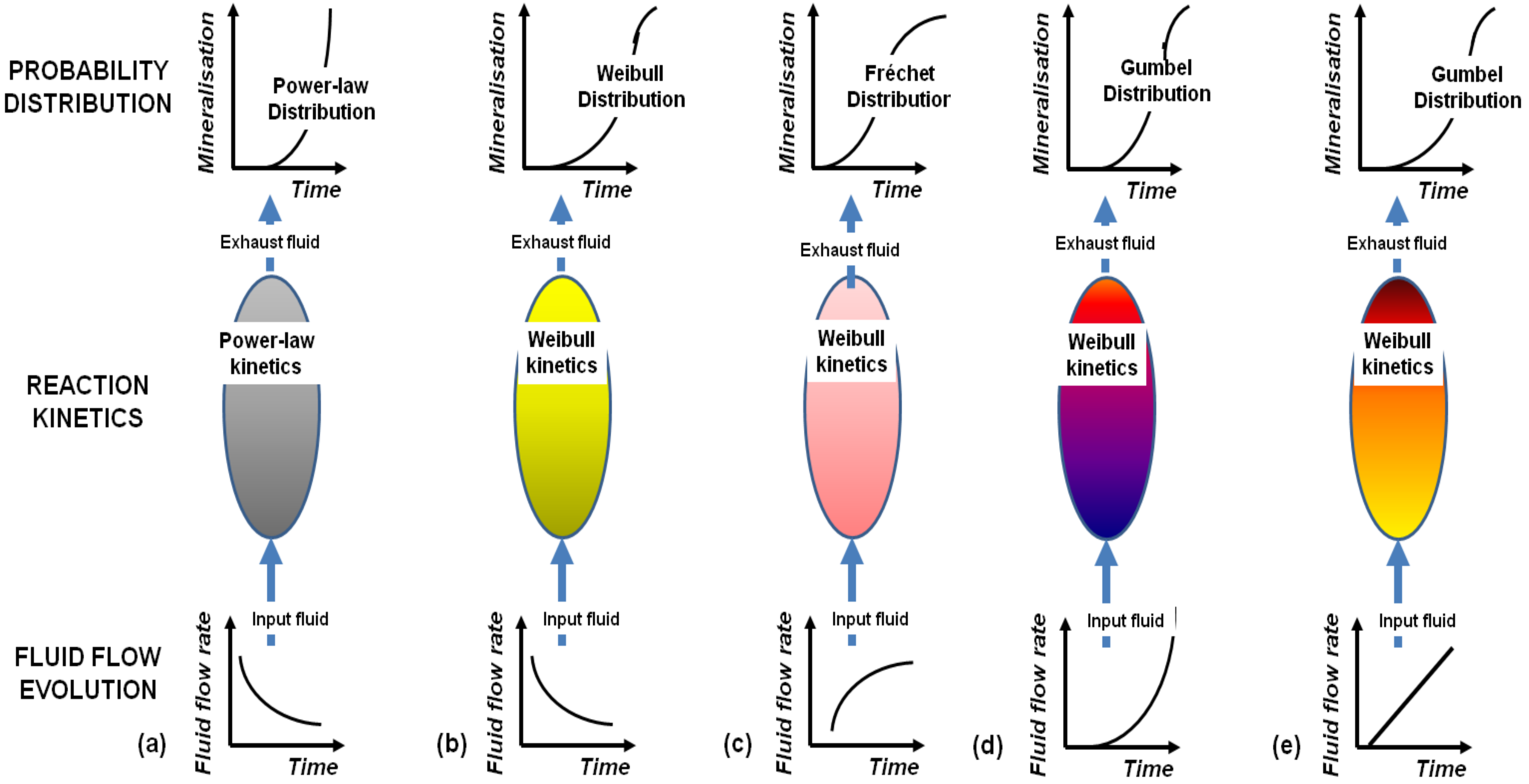
The presence of gold in solution is of course necessary but incidental to the operation of the system.

The chemical reactions with the host rocks are strongly exothermic and generate a varying Eh-pH environment responsible for gold deposition.



The concept of recurrence.
(a) Shows the attractor for the Rossler system (Sprott, 2003). This represents the reaction between three chemical compounds, *X*, *Y* and *Z*. Since the attractor for a non-random system does not occupy all of phase space the system repeatedly passes close to a former state on the attractor as it evolves. Here the trajectories of the system pass through states within the red ellipse, R.
In (b) some of these trajectories are shown and labelled α, β, γ. (c). The evolution of the concentrations of the compounds *X*, *Y* and *Z*. The recurrence is marked by α, β, γ in the evolution of *Z*.
The smaller peaks in (c, lower) are outside the tolerance set by the ellipse in (a).
One way of quantifying how closely a given state is repeated as the system evolves is to use recurrence plots.

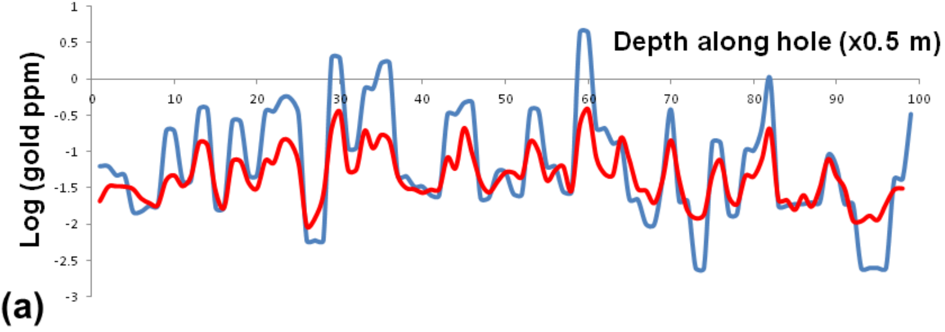
- Autocatalytic reactions associated with quartz and carbonate deposition control pH variations responsible for gold deposition.
- The heat generated by such reactions drives the deposition of quartz and carbonates and, again incidentally, gold, in such a way that all reaction/deposition processes (including oscillations in Eh/pH) are strongly correlated comprising a unified, coupled dynamical system.

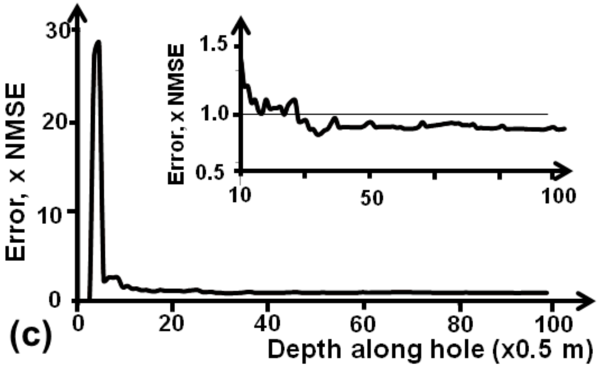


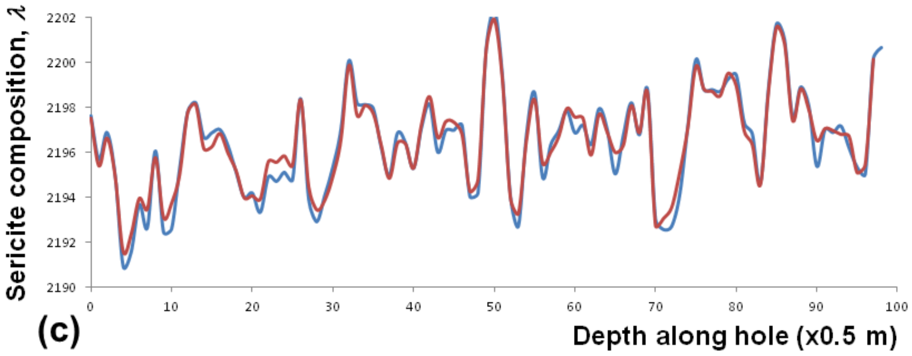
Controls on endowment

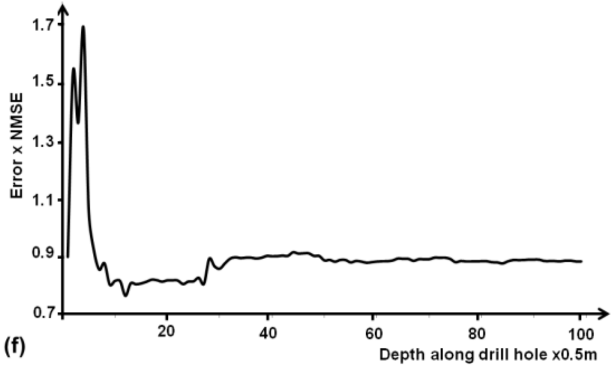
Does this help us predict?

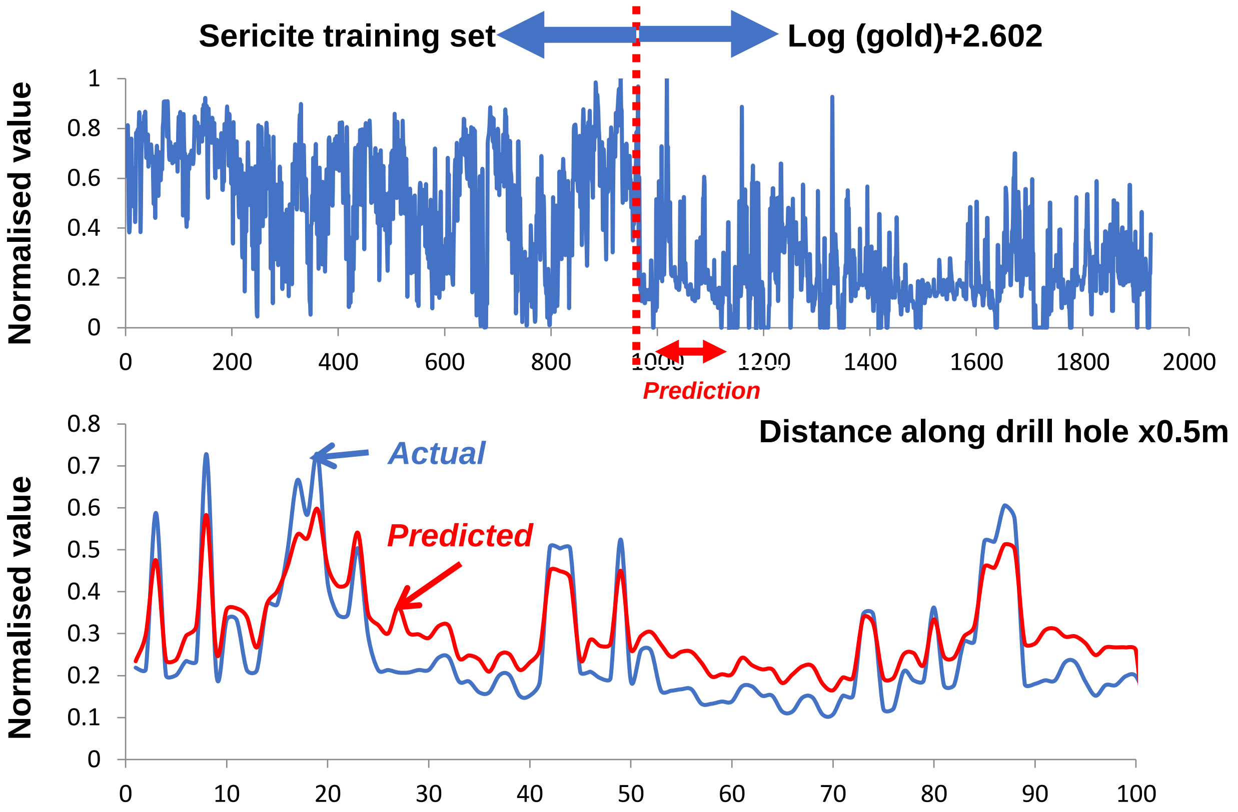
Nonlinear prediction of log(gold) and sericite composition signals



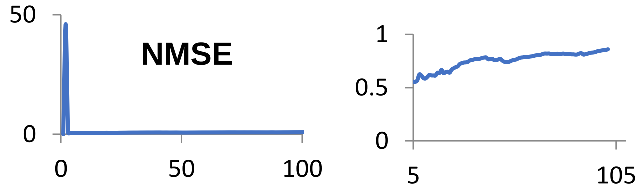


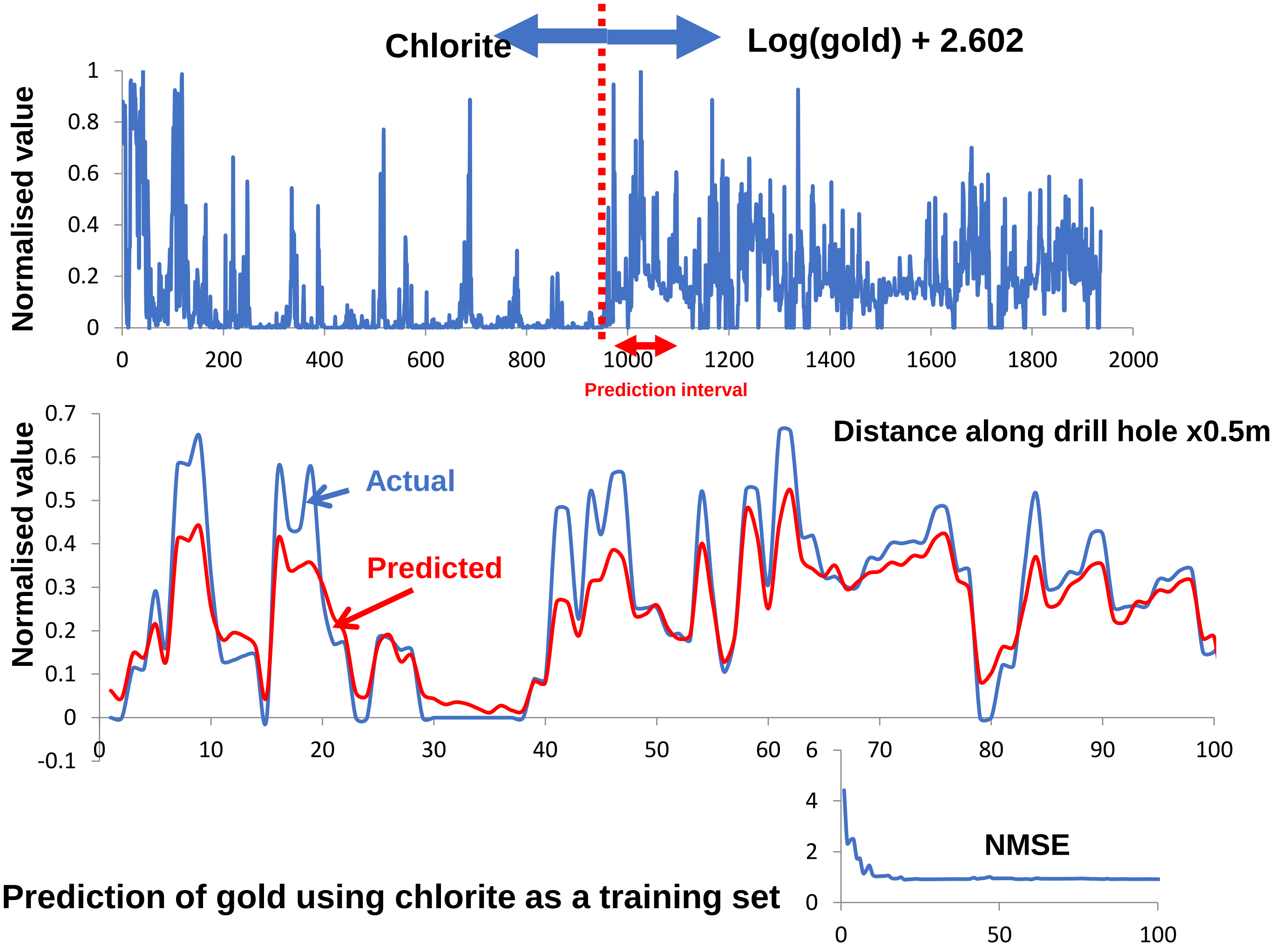




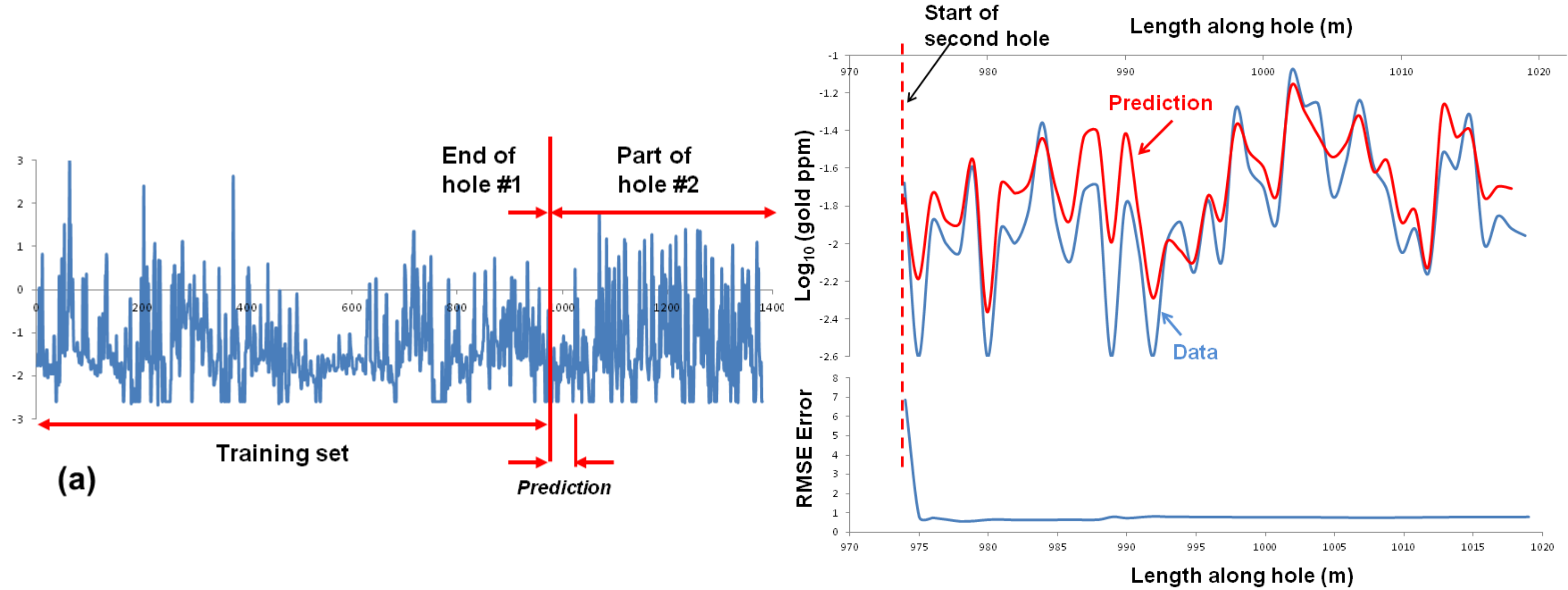


Prediction of gold using sericite as a training set

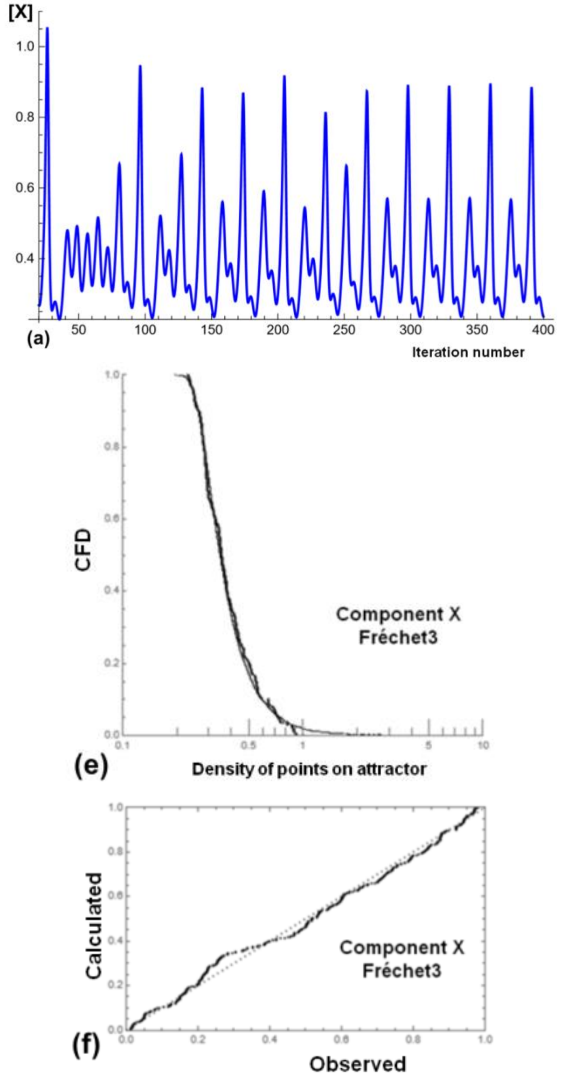


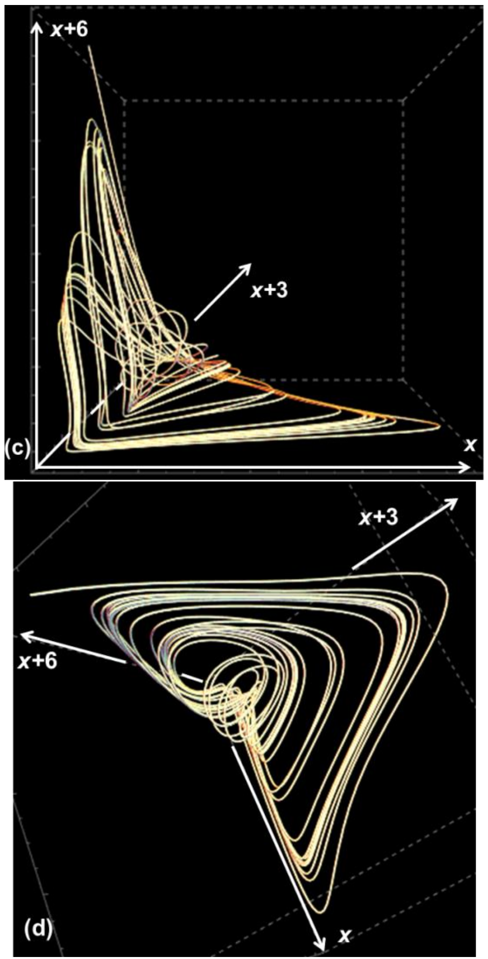


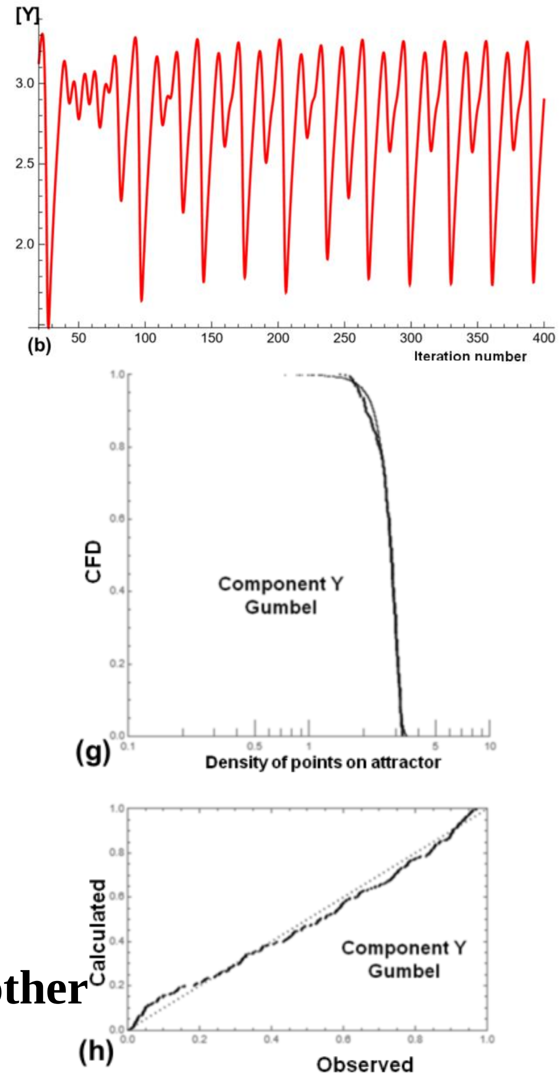
Prediction of gold using chlorite as a training set



Nonlinear prediction between two drill holes.
(a) Data with training and prediction intervals marked. The training is done in one drill hole and the prediction in an adjacent hole. (b) Prediction and error.







The Brusselator system coupled to another reaction that is periodic

Conclusions

The apparently irregular data sets of mineral composition and abundance from the Sunrise Dam orogenic gold system are indeed the result of deterministic processes operating within a nonlinear dynamical system.

The deposition process for gold is strongly correlated with those for the carbonates and that the reactions involving sericite and chlorite provide a background chemical/thermal environment for gold/carbonate deposition.

The cumulative probability distributions observed are direct reflections of the growth kinetics of the mineralising system in that nonlinear growth kinetics for nucleation-growth-extinction systems frequently lead to Generalised Extreme Value probability distributions.

There is a suggestion that low endowment systems may be characterised by Weibull distributions for gold whereas highly endowed systems are characterised by Fréchet distributions for gold.