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Using Statistical Physics to Understand Relational Space: a case study from Mediterranean Prehistory

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This talk:

Explain how two different Aegean networks have been modelled:

1. EBA Cyclades (3000 – 2000 BCE)
   (Broodbank revisited)

2. MBA ‘Minoan’ Aegean (2000 – 1500 BCE)
   (our work – CK, TSE, RJR)

Issues:

1. How do we relate the mesoscopic to the macroscopic in island networks?

2. How do we incorporate a very patchy archaeological record in a robust way?

We shall see that:

- No universal network structure for island archipelagos

- Difference is one of hierarchy

  - reflects different marine technologies
  - shift from oar to sail
  - different distance scales

- mesoscopic* – intra-island (with qualification)
  macroscopic – inter-island

The Bronze Age Aegean

Globally: One large island (Crete), many small islands and mainlands make for a ‘heterogeneous’ whole

The Bronze Age Aegean

Locally: Many small habitable islands in a ‘homogeneous’ core – Cyclades

We have examined the consequences of assuming that

- EBA Cyclades:

  Macro-level is largely determined by the meso-level

- MBA ‘Minoan’ Aegean:

  Macro-level is approximately independent of the meso-level*

‘Island’ Networks

- Vertices/nodes - correlated to community/resources:

- Edges/links (directional) - ‘trade’ between sites

  - cultural transmission
  - reciprocity
  - exogamy
  - redistribution
  - storage
  - barter
  - Markets

1. EBA Cyclades form 'isolated' system – 'exchange network'

- mutually visible
  - accessible by oar
- agriculturally marginal
  - NOT self-sufficient
  - small populations

EBA Cyclades: Broodbank revisited

Meso-level connectivity between local nodes which determines the macroscopic 'exchange' network

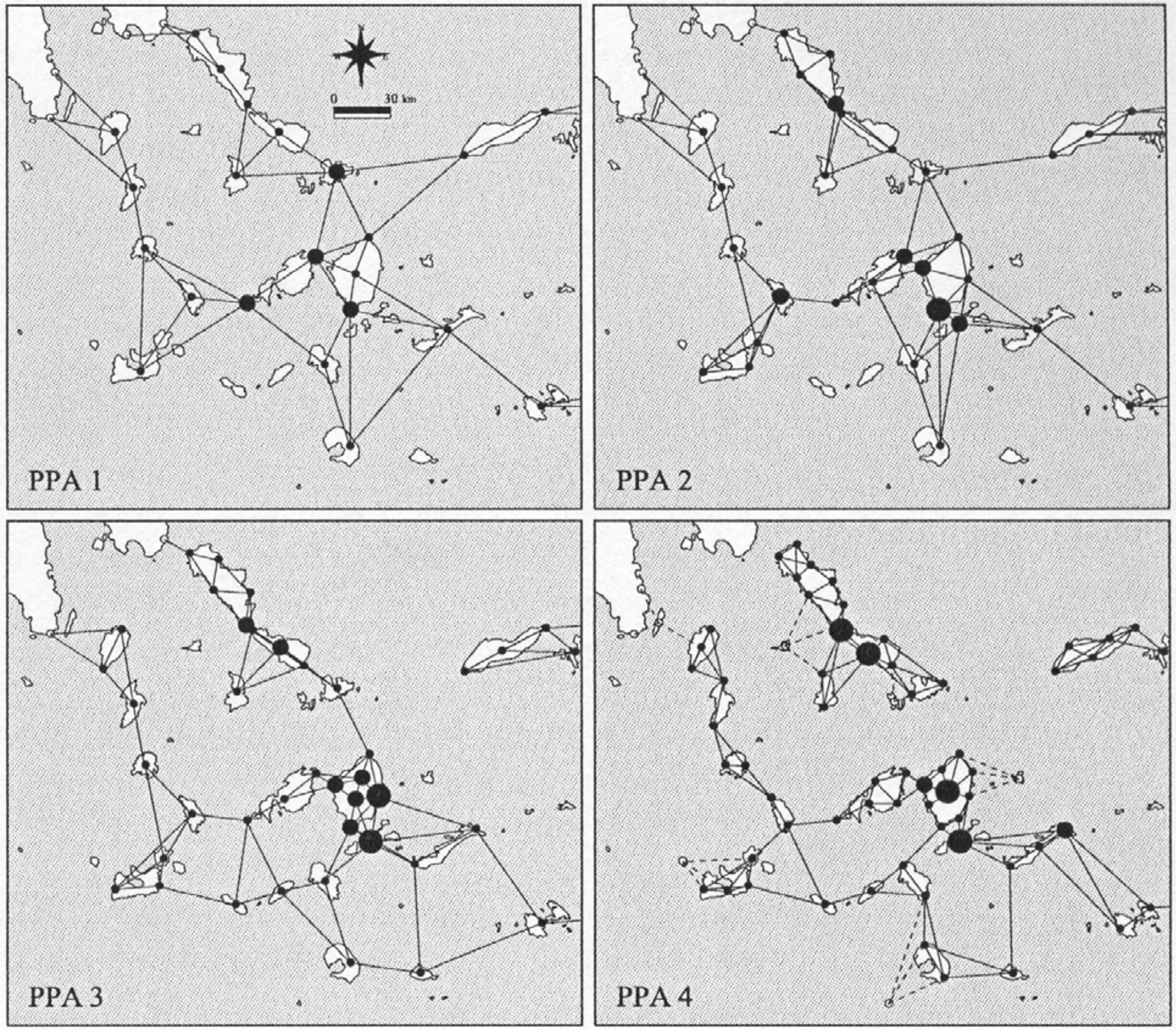


Fig. 75 Nodes of intense communication in the Cyclades as modelled by PPAs 1–4 (five and six linkages only).

EBA Cyclades: Broodbank revisited

Simple algorithm with exogenous evolution:

PPA

- Each node corresponds to the same unit of population/resource.

As total population increases the # of nodes increases

- Connect each node to three nearest neighbours

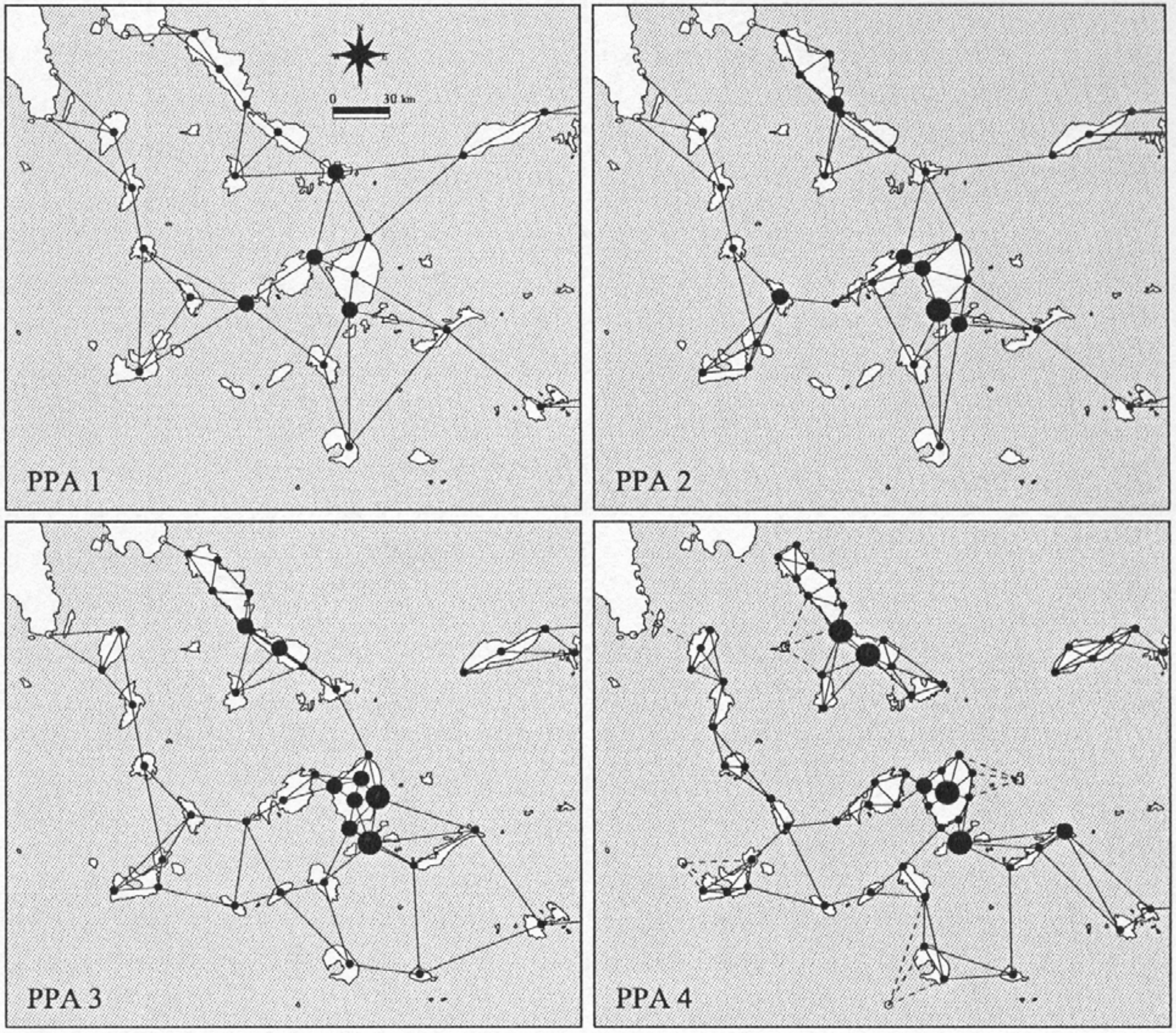


Fig. 75 Nodes of intense communication in the Cyclades as modelled by PPAs 1–4 (five and six linkages only).

EBA Cyclades: Broodbank revisited

Simple algorithm with exogenous evolution:

PPA

Communities need to interact for reasons of

- exogamy
- storage
- etc.

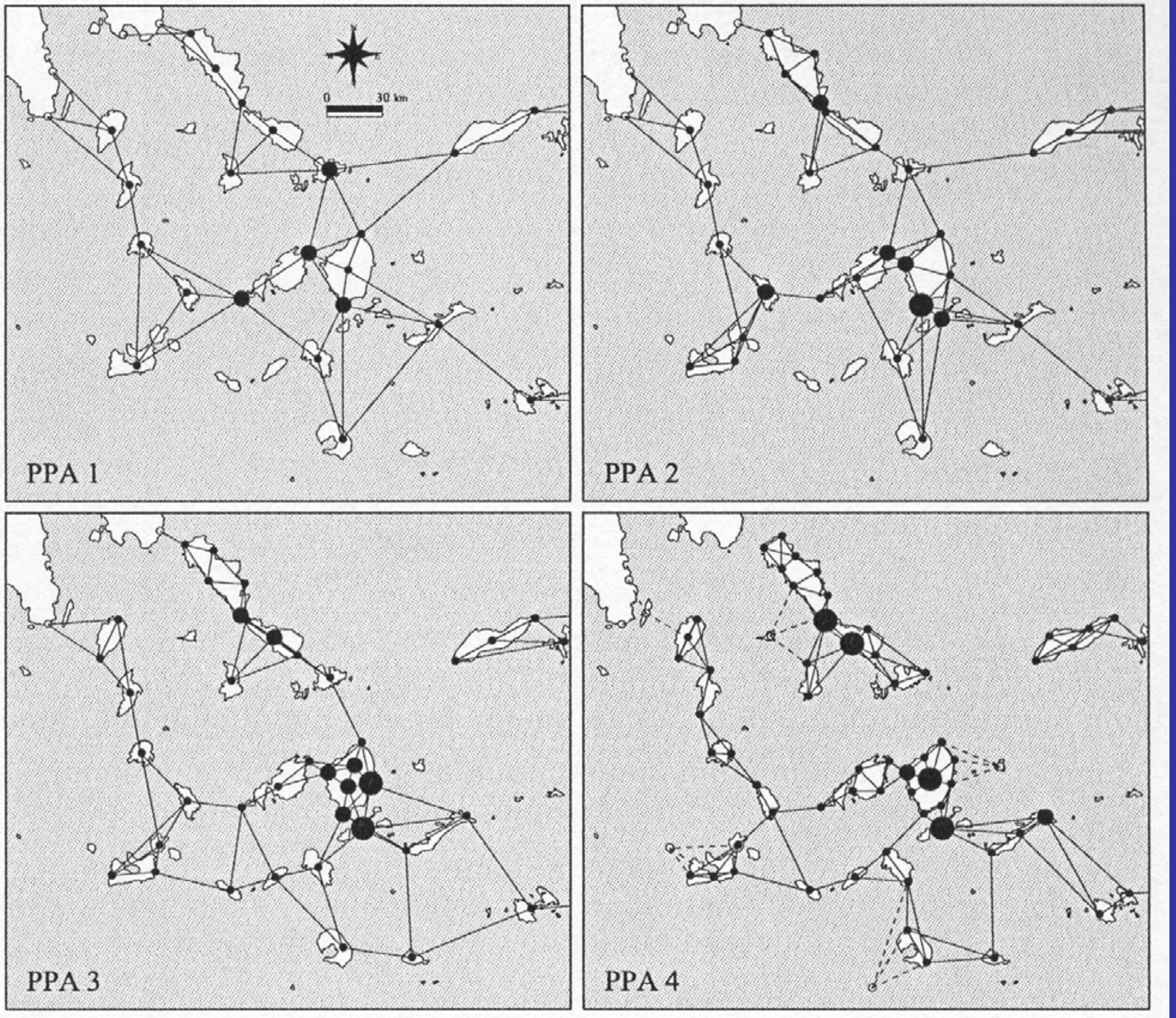


Fig. 75 Nodes of intense communication in the Cyclades as modelled by PPAs 1–4 (five and six linkages only).

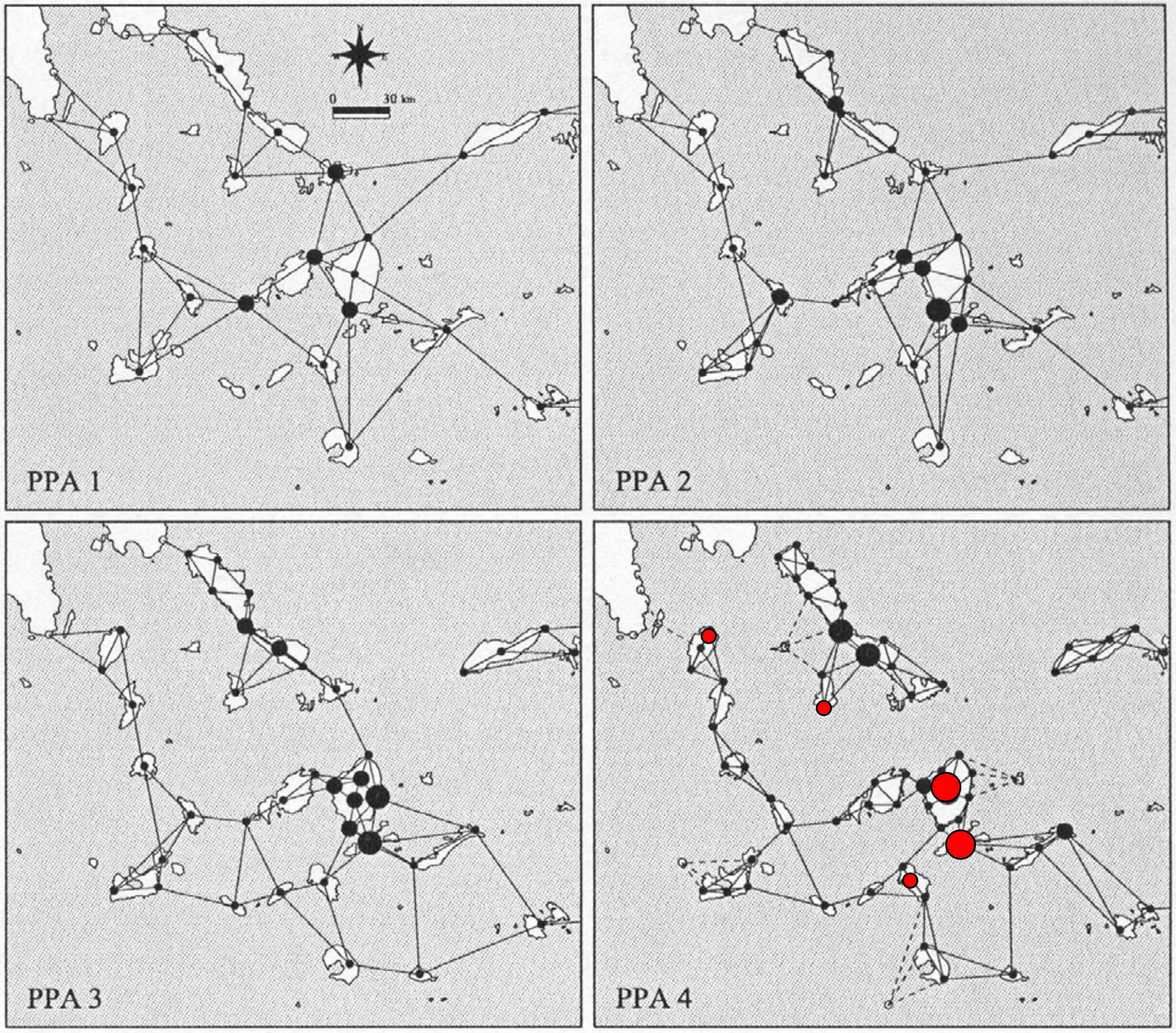
EBA Cyclades: Broodbank revisited

The bigger dots are those with > 4 links

These predict the EB II hubs of the network

Hits: Grotta-Aplomata
Daskaleio-Kavos

Misses: Skarkos
Chalandriani
Ayia Irini



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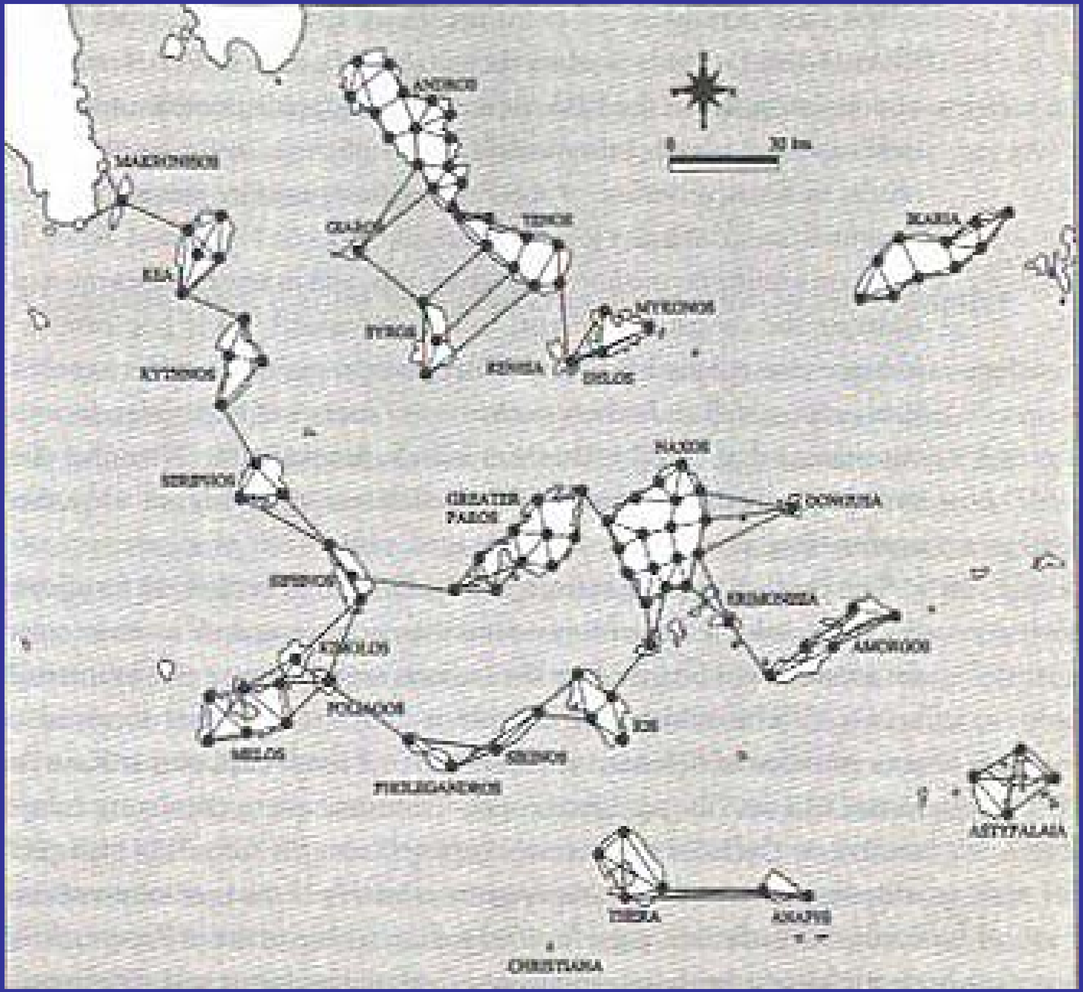
EBA Cyclades: Broodbank revisited

Note:

Nodes/vertices are only loosely related to archaeological record

Consequence of geometric axiom

That matters. Without that correlation conclusions depend critically on the axioms. Adjacent axioms do not give adjacent conclusions



EBA Cyclades: Broodbank revisited

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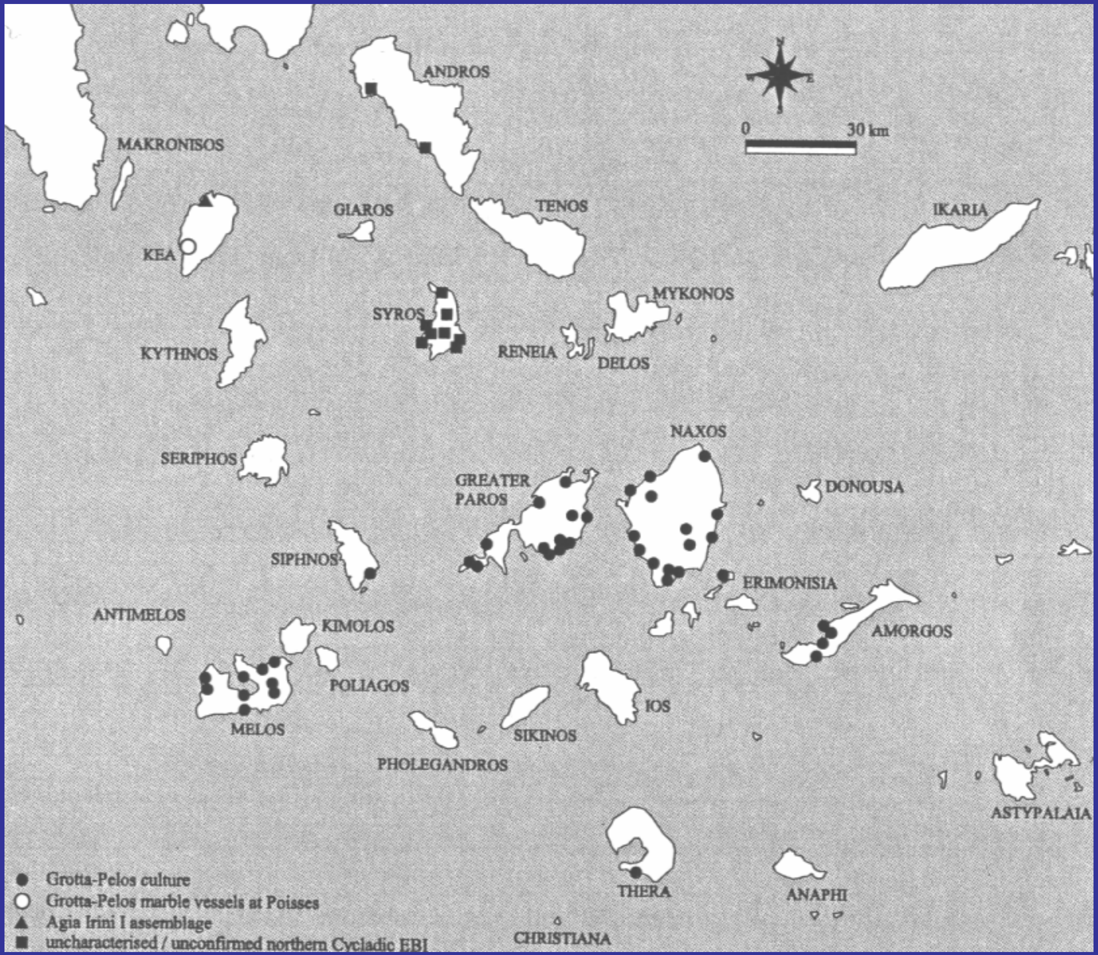
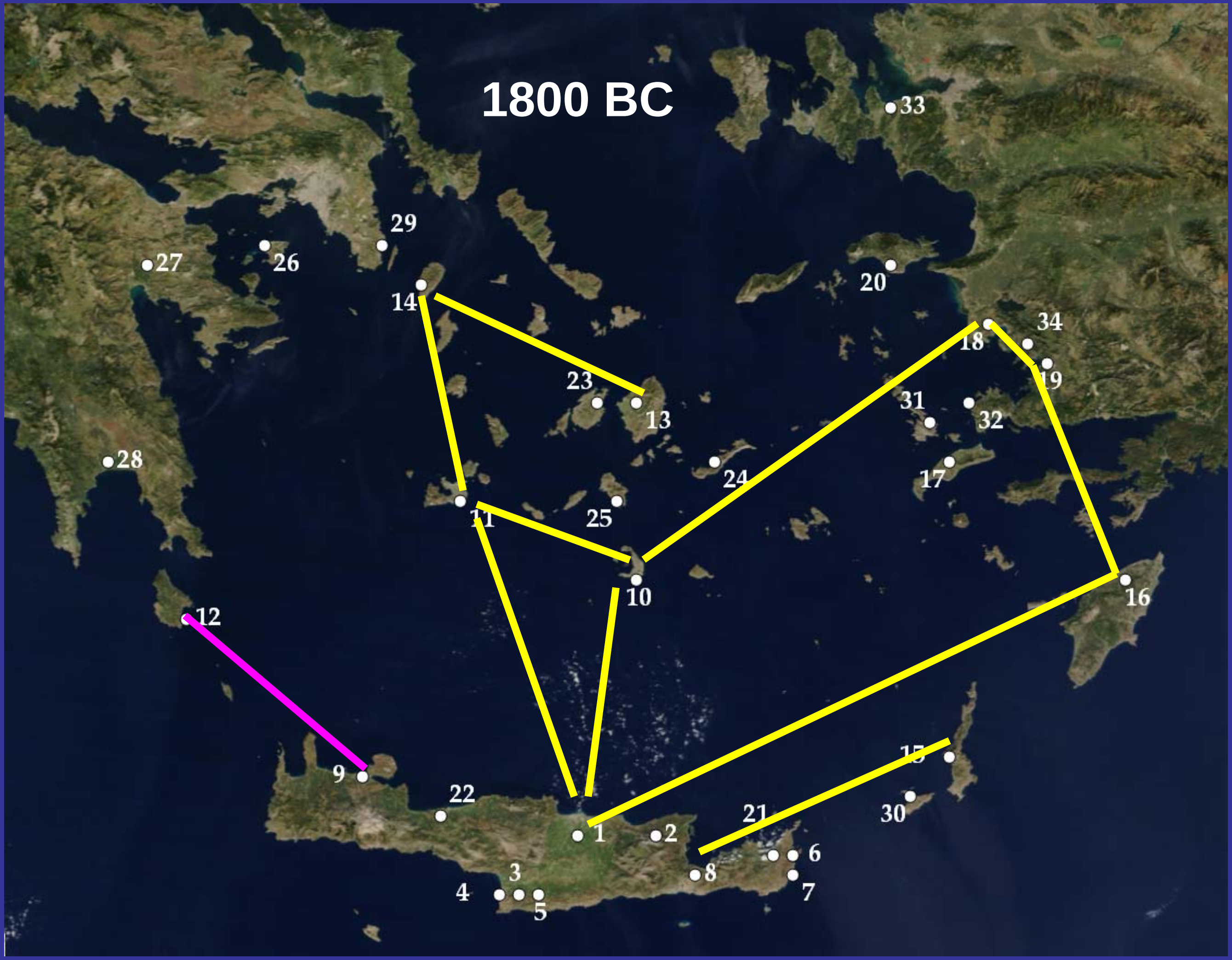


Rigid but not robust

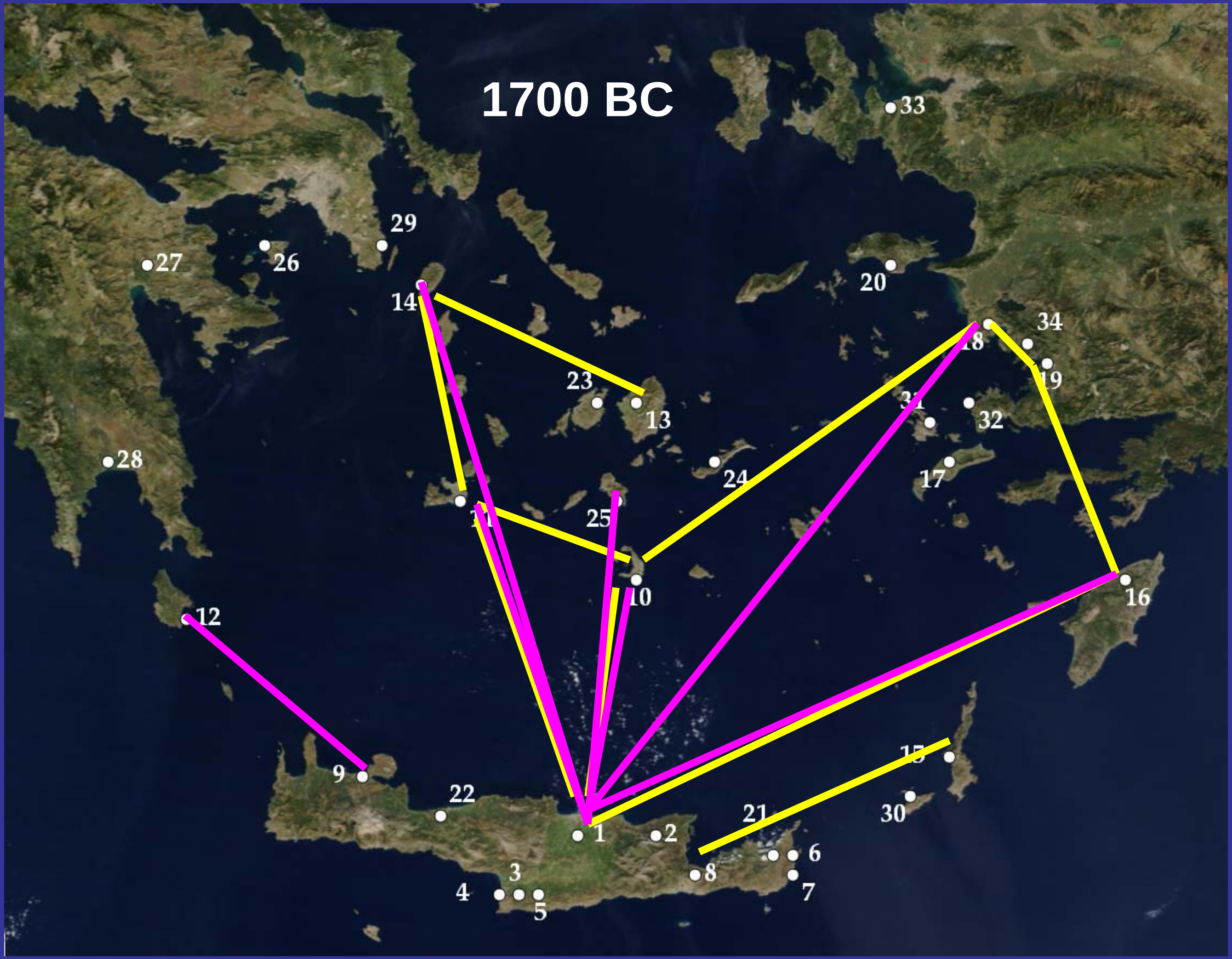
2. MBA southern Aegean c. 1800 BC
Scenario 1



= ‘contact’

= ‘colony’

2. MBA southern Aegean c. 1700 BC
Scenario 2



= ‘contact’

= ‘colony’

Agency: Optimisation of an ‘Energy/Cost’ function H

Introduce a ‘cost ‘ function

$$H = -\lambda E - \kappa I + j P + \mu T$$

that reflects the social and material costs and benefits of exploiting resources and maintaining exchanges

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Assumption:

Network adjusts to optimise benefits/ minimise costs

i.e. to minimise H

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Many local mimina are comparably optimum (~ 1000 dimensons)
Chosen by ‘volatility’

Statistically Panglossian

MBA Aegean

Assumption:

To a first approximation the network is not determined at Broodbank's meso-level of intra-island communities, but at the 'small - island' level

Island is the basic unit

Consequences

One site per island e.g. Naxos

BUT several sites for Crete and mainland

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Meso – level structure within blob

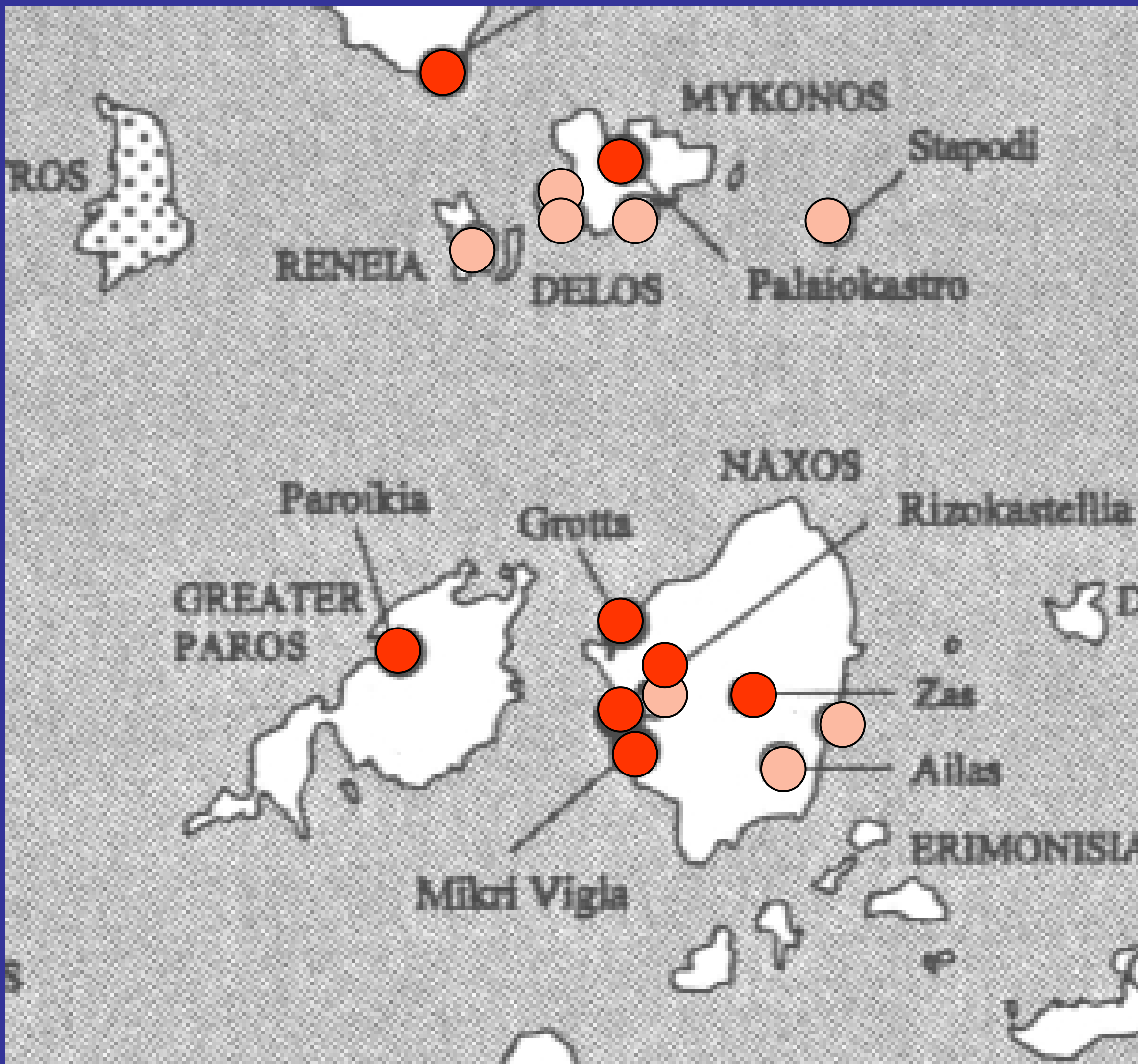
Consequences

One site per island e.g. Naxos

BUT several sites for Crete and mainland

As with EBA, no direct correspondence with detailed archaeological record

How do we understand the meso-level?



- major site
- limited or uncertain data
- unknown sites

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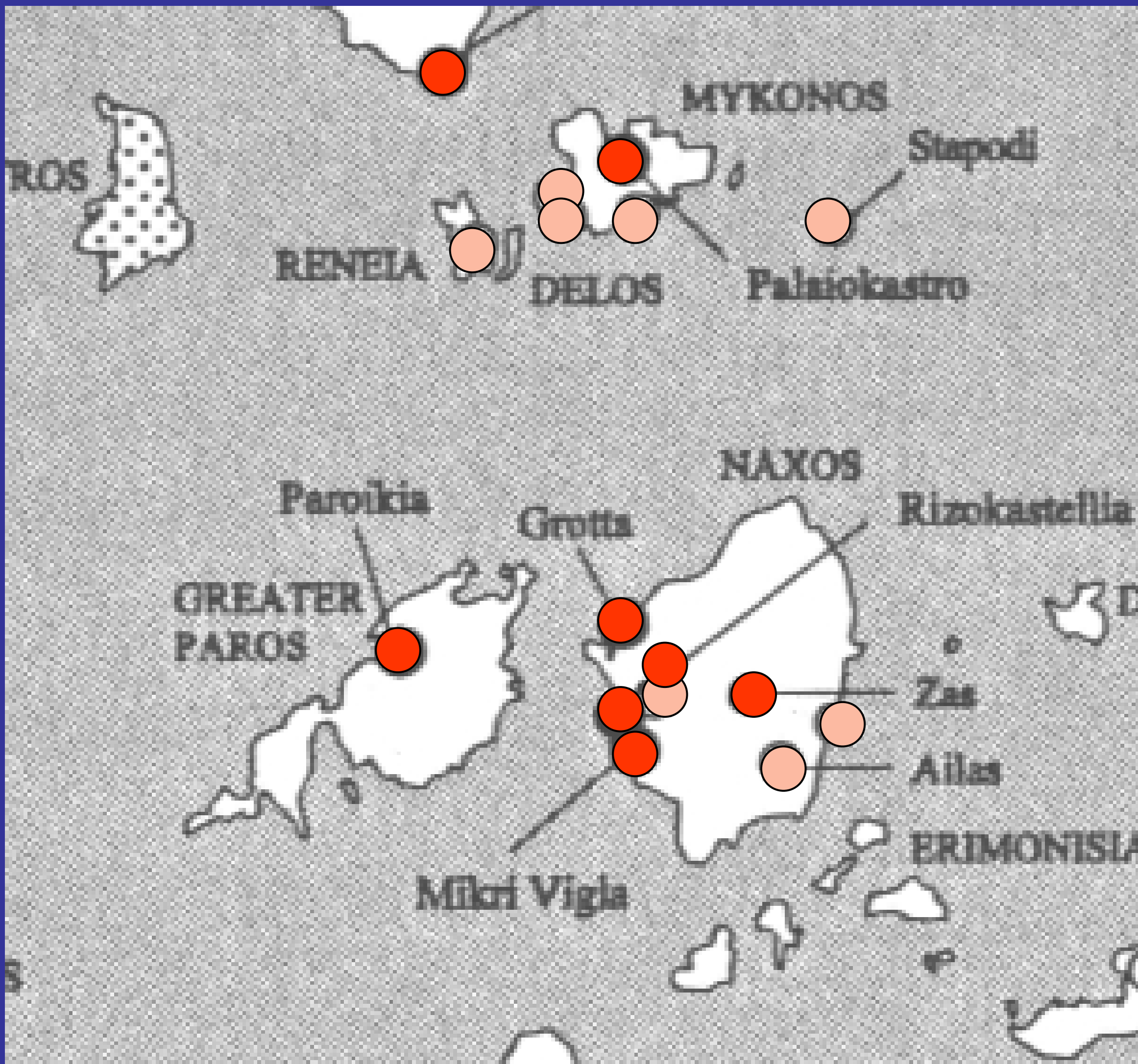

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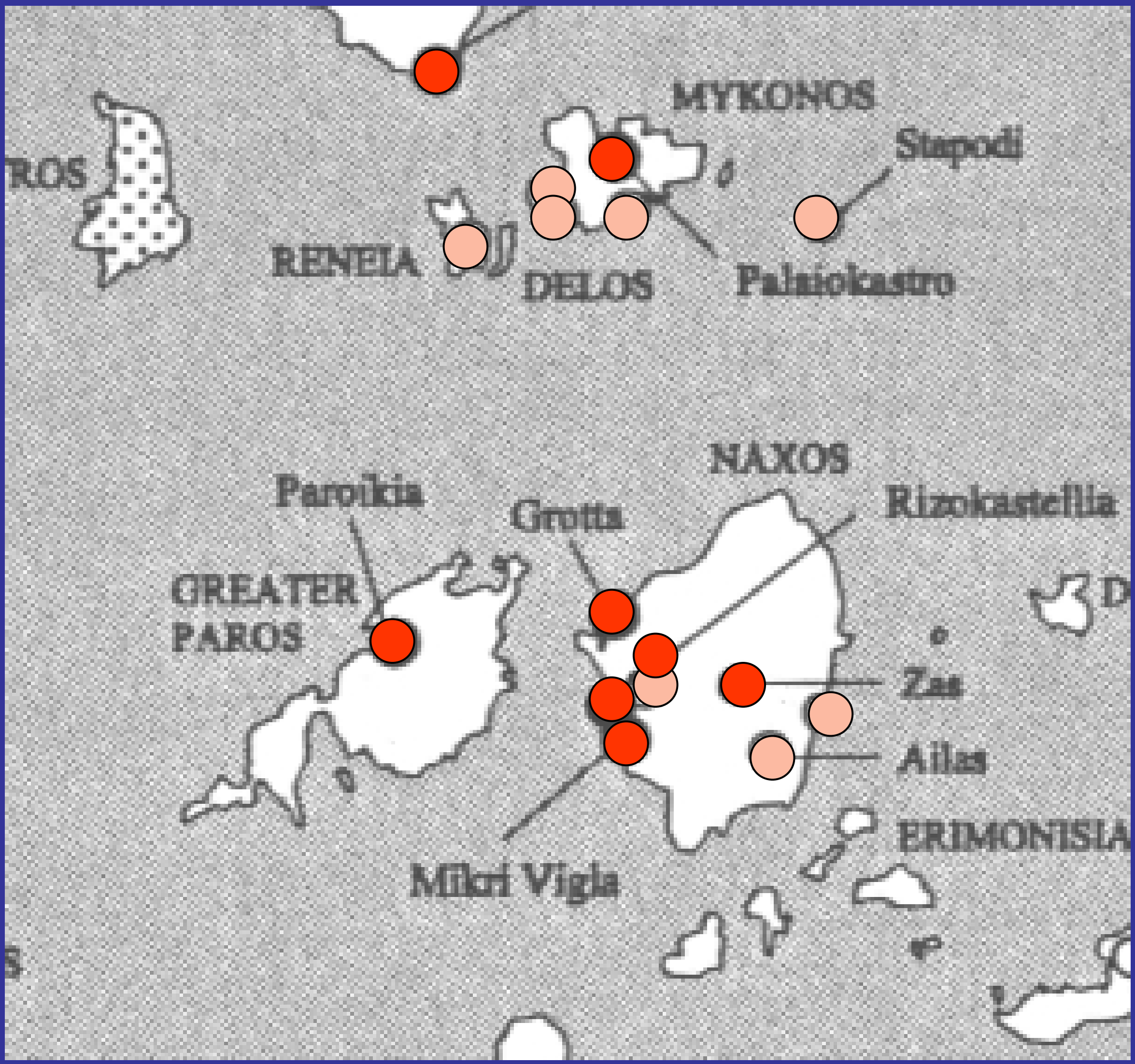
Meso – level not ignored

It's there but has no consequences

How do we understand the meso-level?

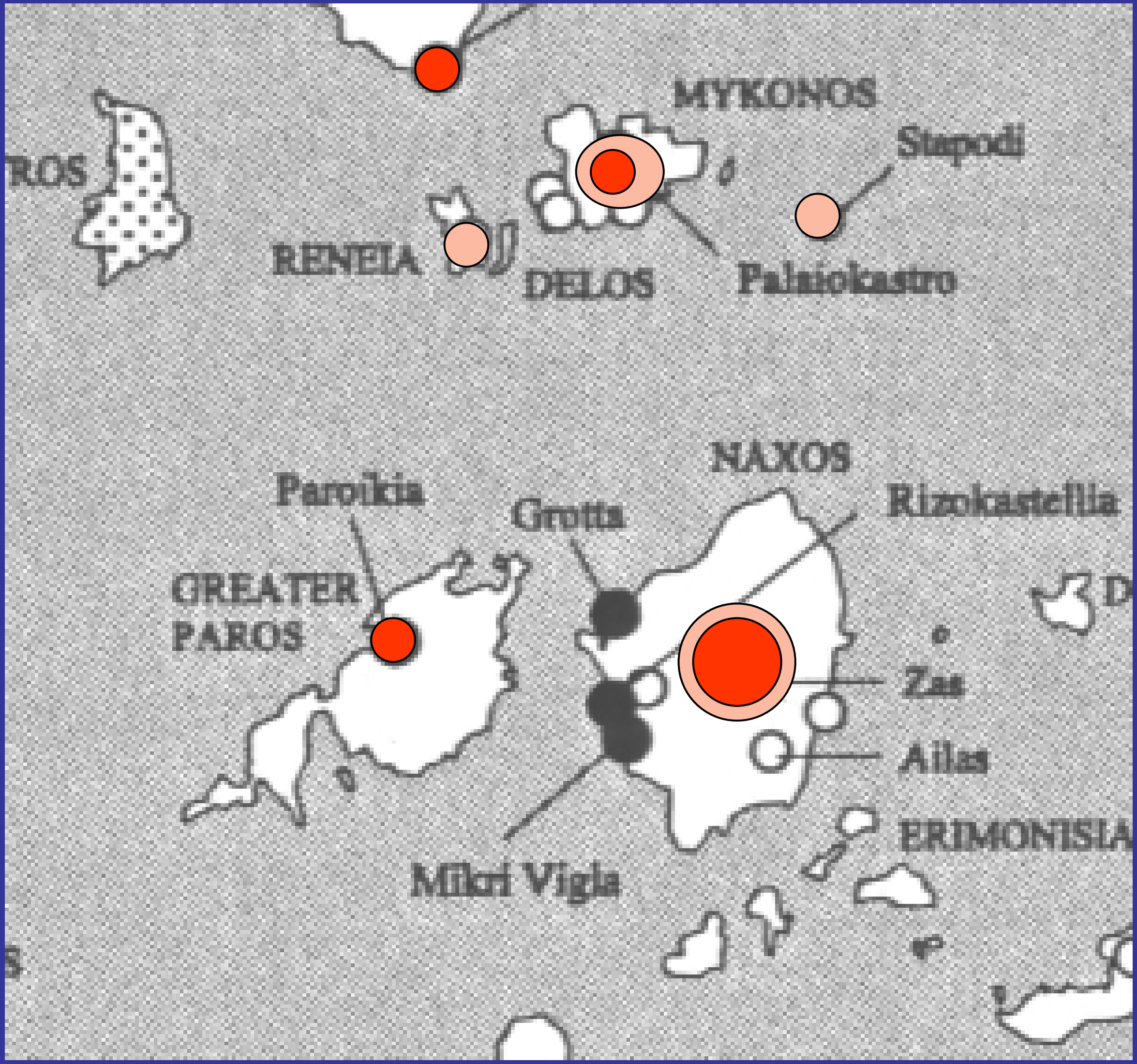


- major site
- limited or uncertain data
- unknown sites

Need to make individual archaeological sites invisible at both

- vertex level (I)
- link level (E)

Vertex level I : 'Centre of mass' approximation



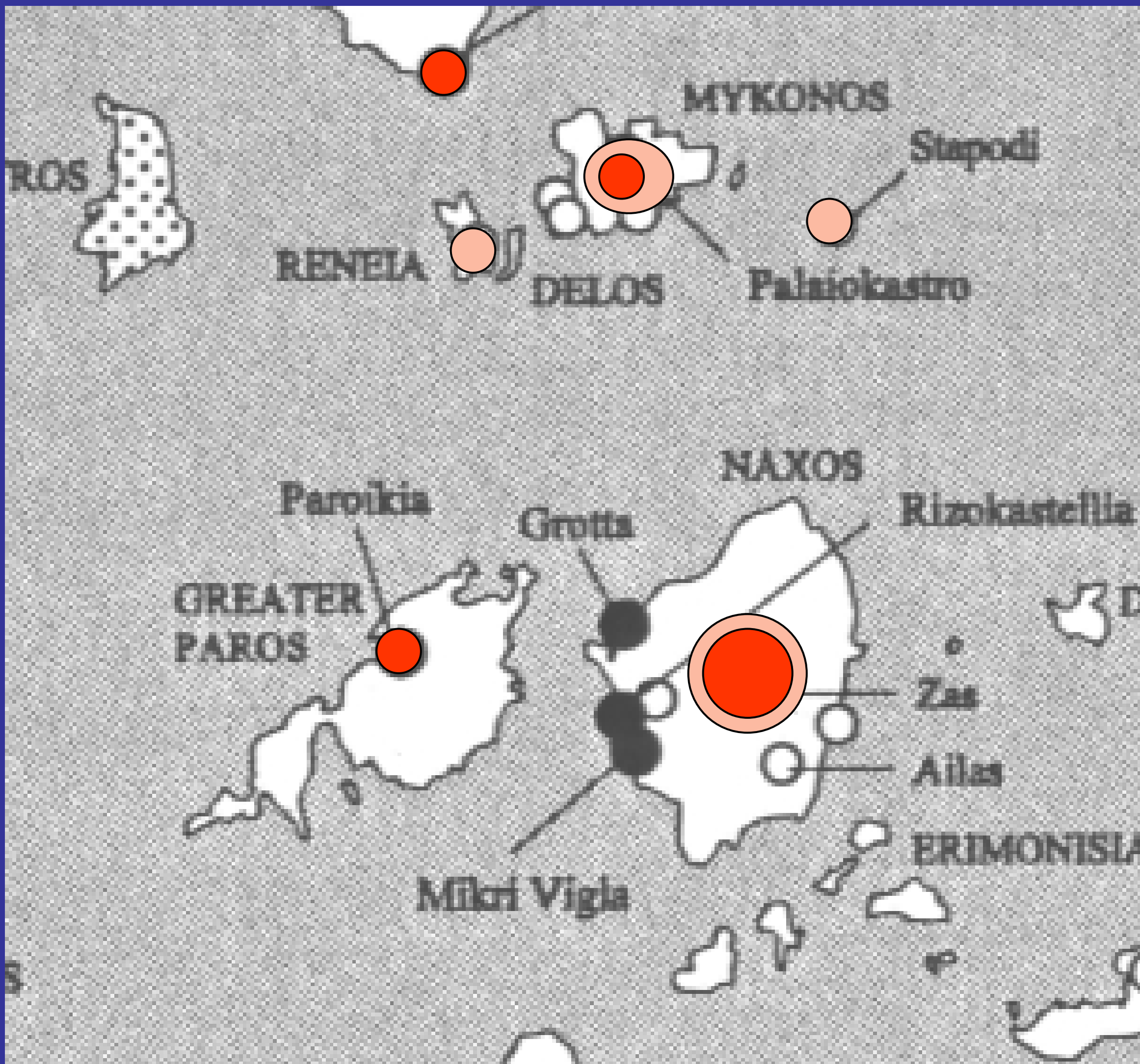
Assume that resource exploitation/population is extensive (linear). β = 1

That is, there is no benefit and no penalty in resource exploitation in communities splitting or amalgamating

- In which case we can replace individual sites by an aggregate site
- This means that population/ exploitation (output) can be distributed as we wish

Vertex level I : 'Centre of mass' approximation

Obvious form of coarse-graining



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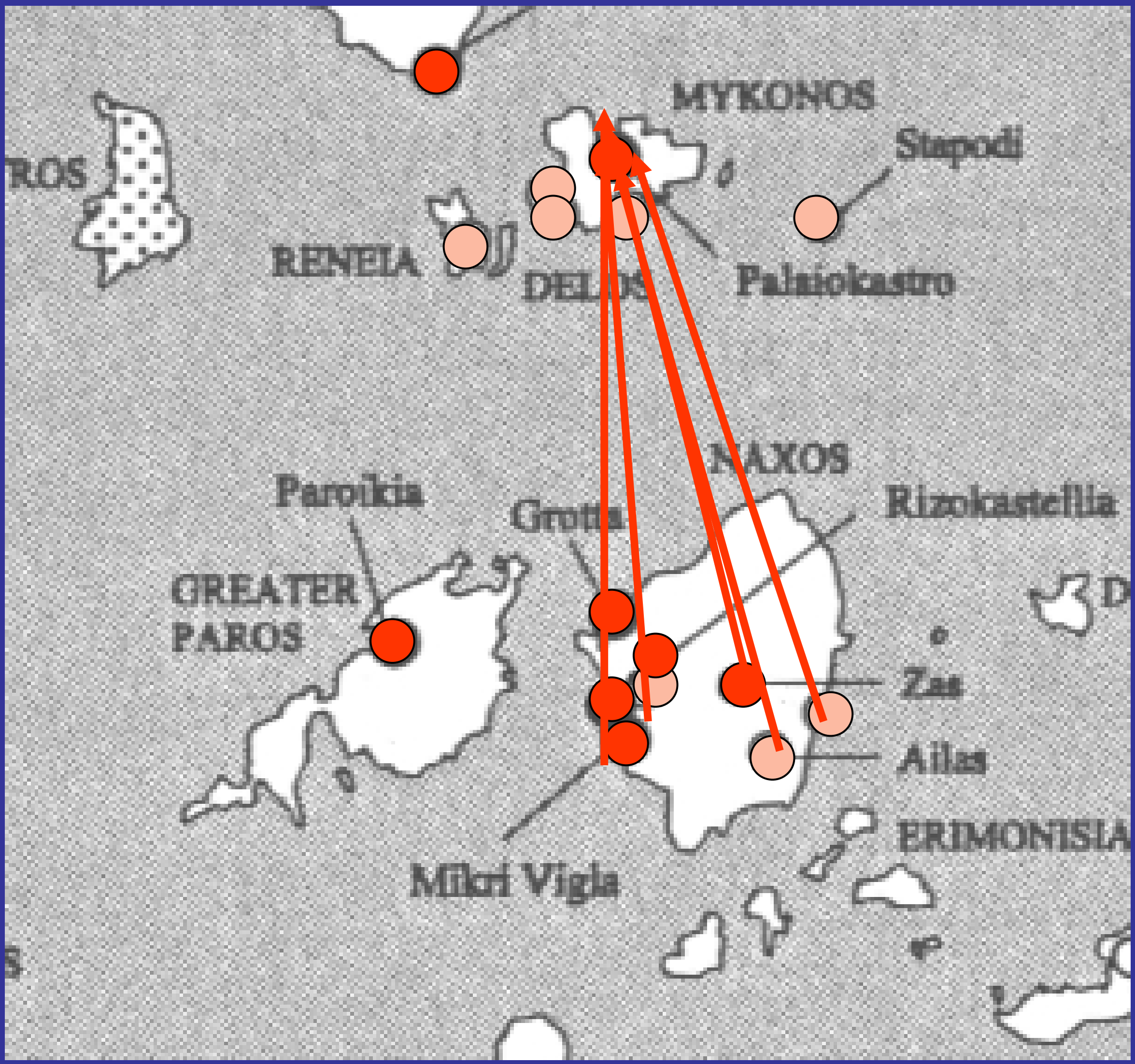
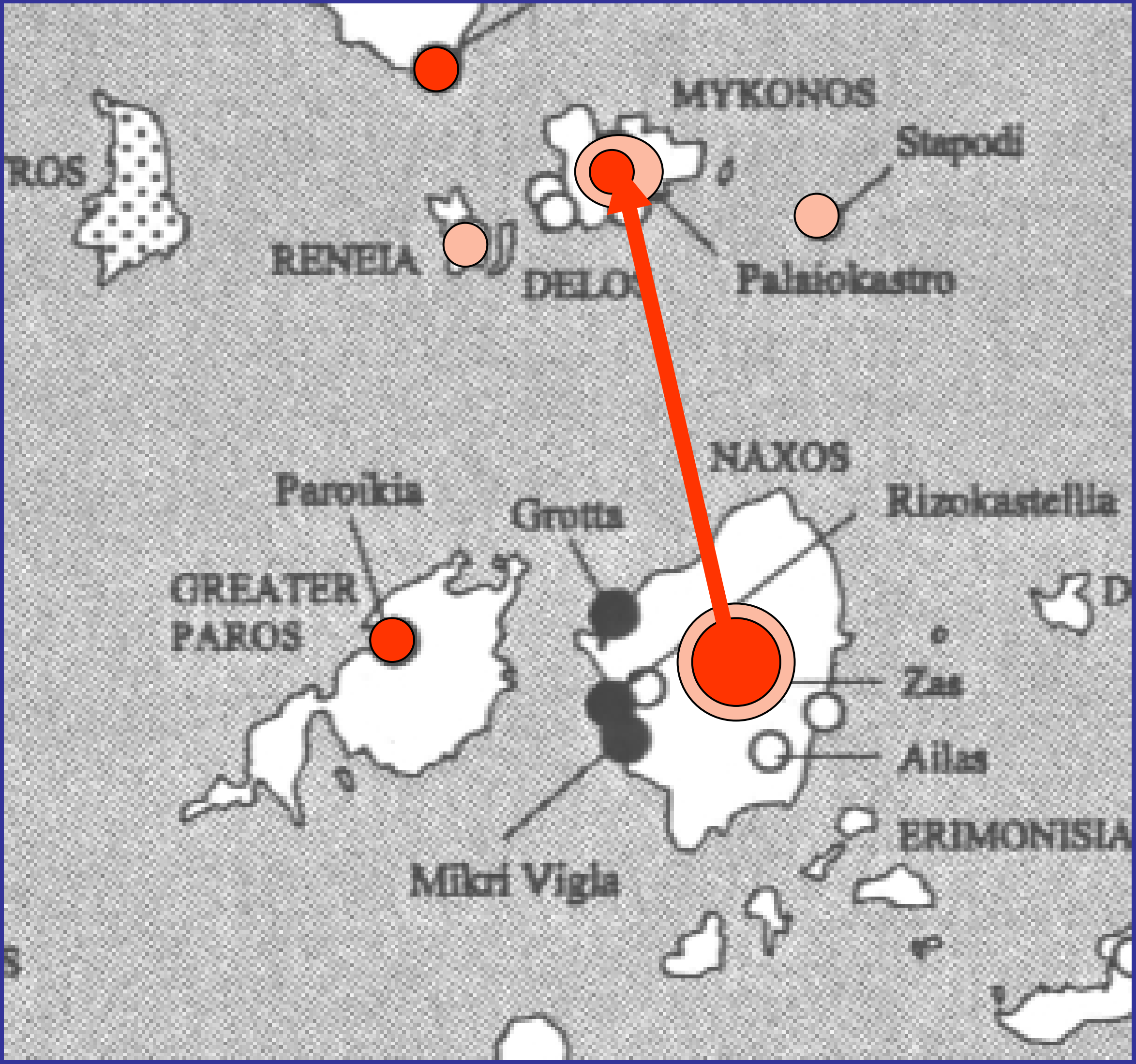
At link level E



Replace clusters of individual links between individual sites by single link(s) between collective sites

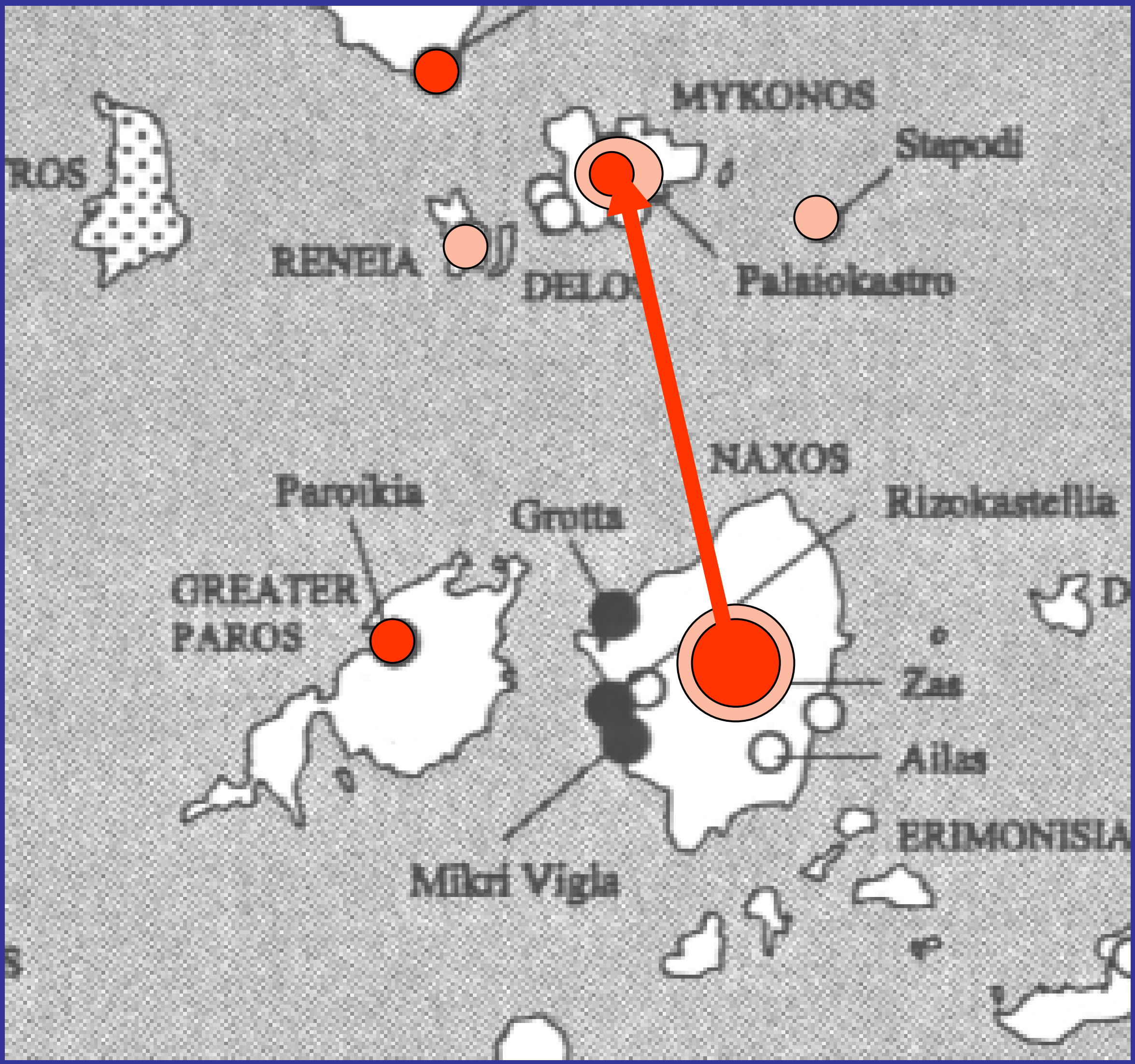
At link level E



Replace clusters of individual links between individual sites by single link(s) between collective sites

This means that the link strength (output) is replicated approximately between sites

At link level E

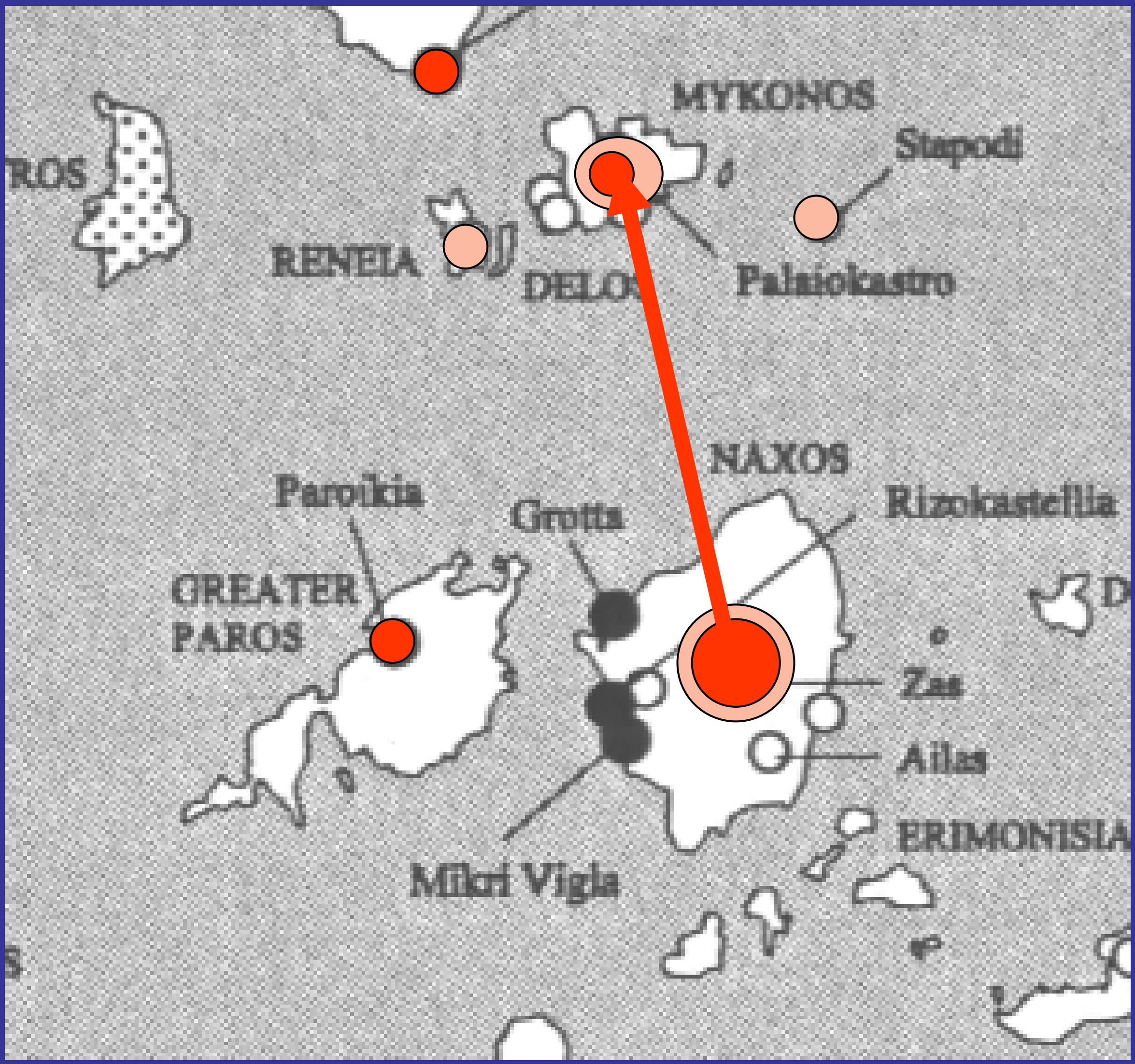


Replace clusters of individual links between individual sites by single link(s) between collective sites

'Gravity' Model !

At link level E

Additional coarse-graining – scaling/block renormalisation



Replace clusters of individual links between individual sites by single link(s) between collective sites

‘Gravity’ Model !

Gravity Models

Definition:

E: Benefits of a link are proportional to the product of exploited resources/ populations at sites at the end of the link. Large connects to large.

Simplification: Meso-level distances between adjacent islands approximately equal

I : Resource exploitation extensive. For a single ‘island’ the whole is the sum of the parts ($\beta = 1$)

Even then, a crude/first approximation – not unique

Gravity Models

Implications:

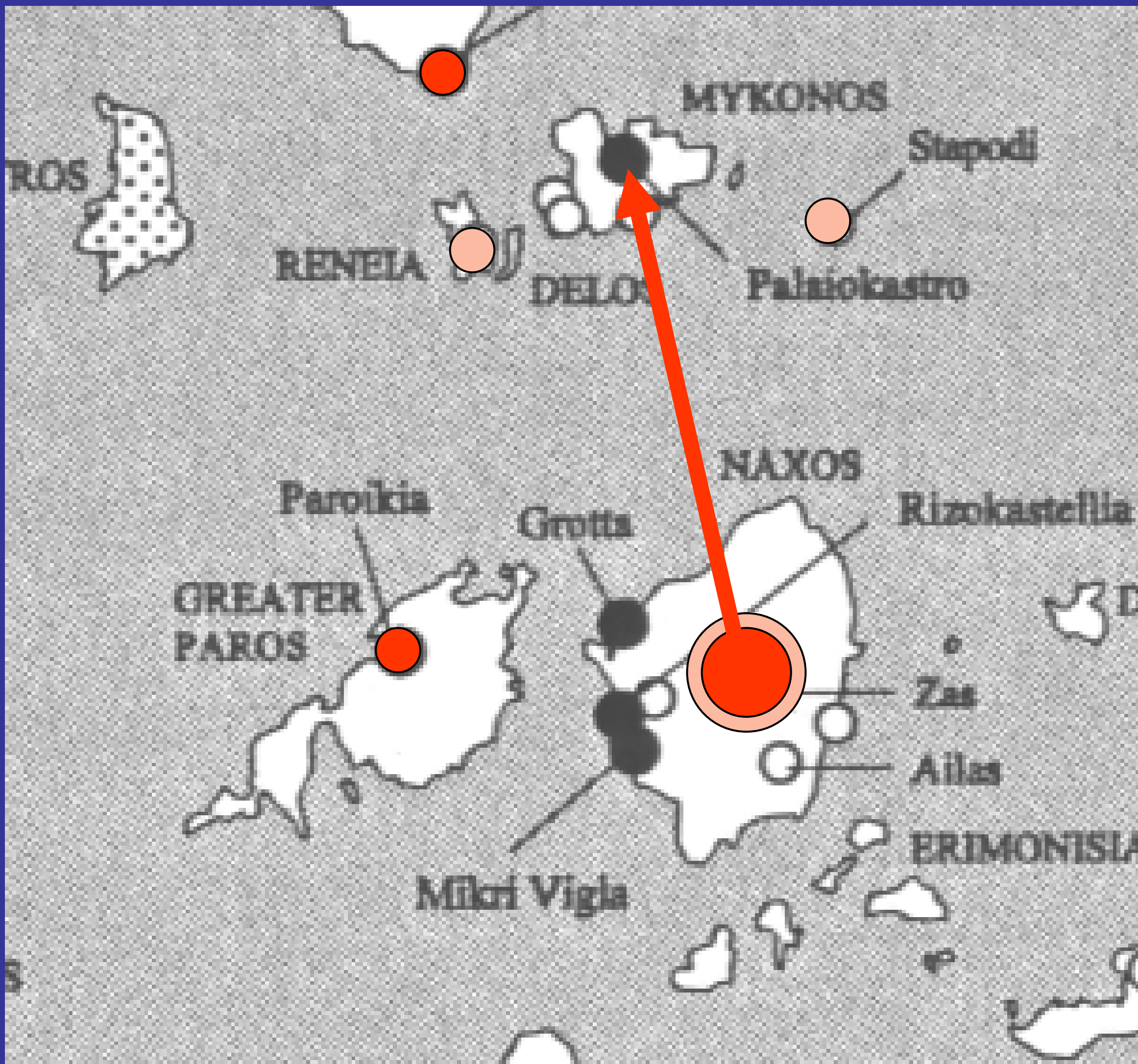
Approximate block renormalisation – scale invariance minimises our ignorance

e.g. if a major site is discovered we do not have to include it, since island-wide output can be distributed as we wish

Desirable since archaeological record is very patchy

Gravity models very Robust

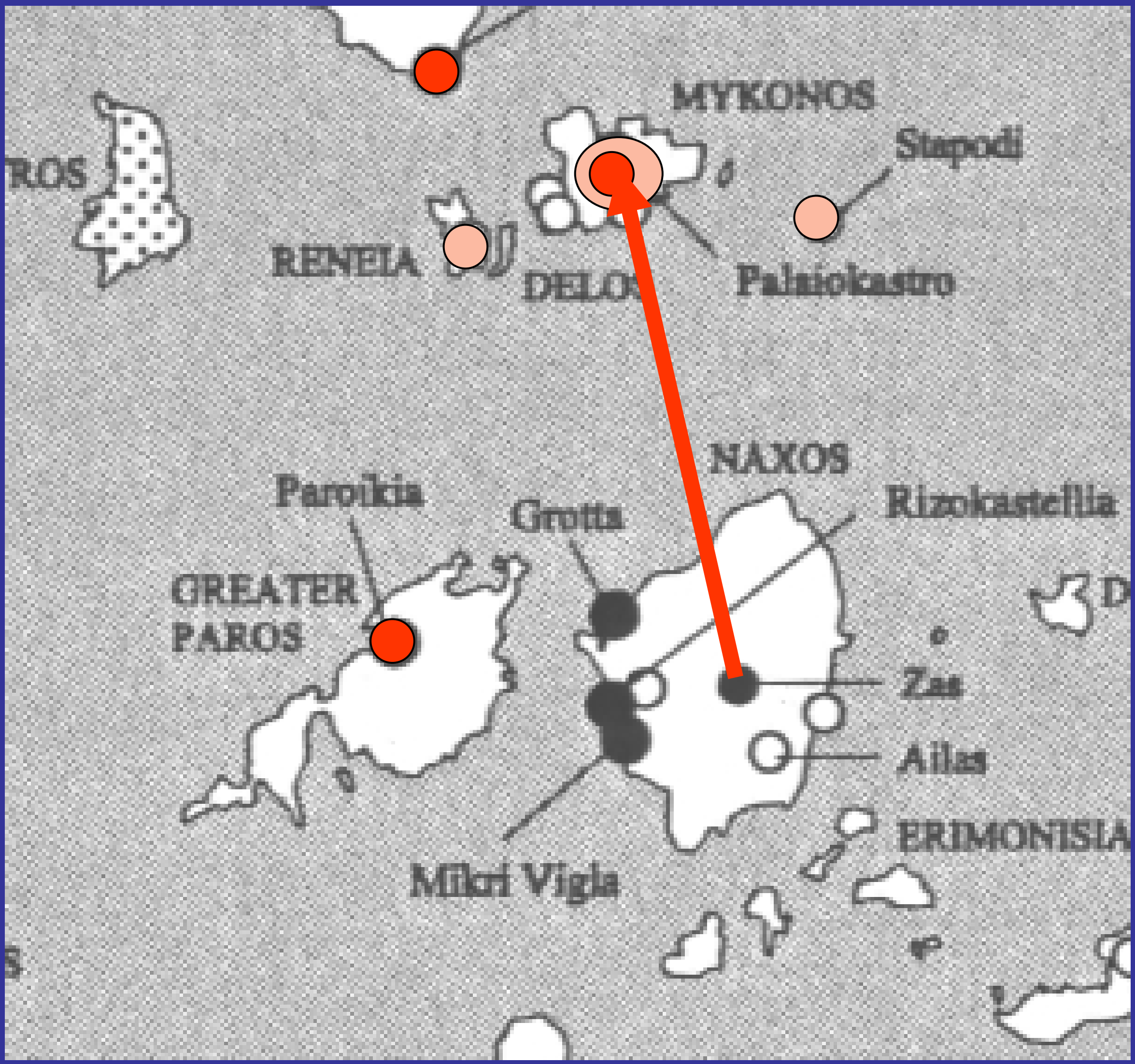
Non-gravity models exist (with centre-of-mass I)



‘Supply-side’ models

Doesn’t go to a single site but recipient carries unit weight

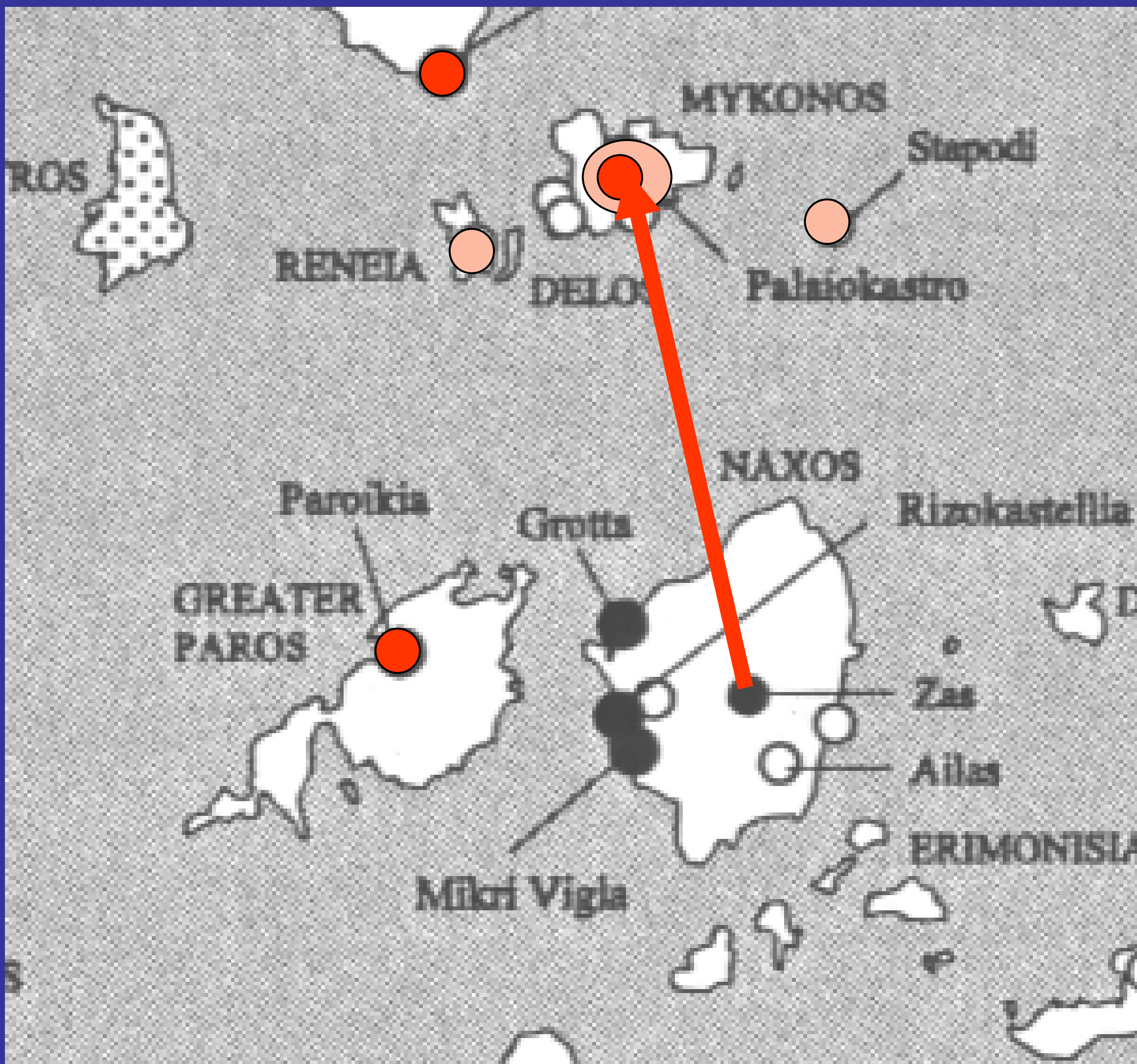
Non-gravity models exist (with centre-of-mass I)



'Demand-side' models

In this case donor site carries unit weight

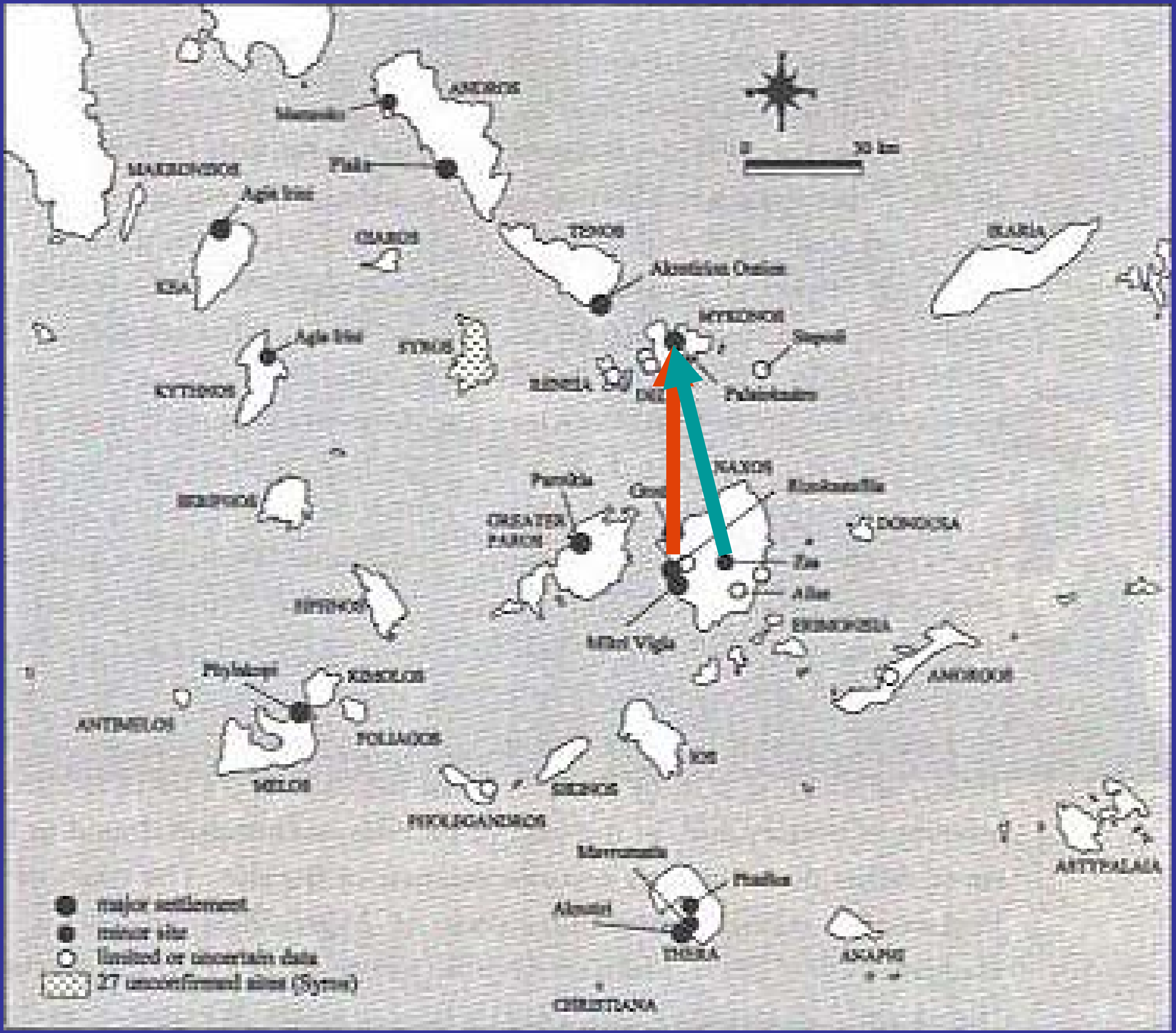
Non-gravity models exist (with centre-of-mass I)



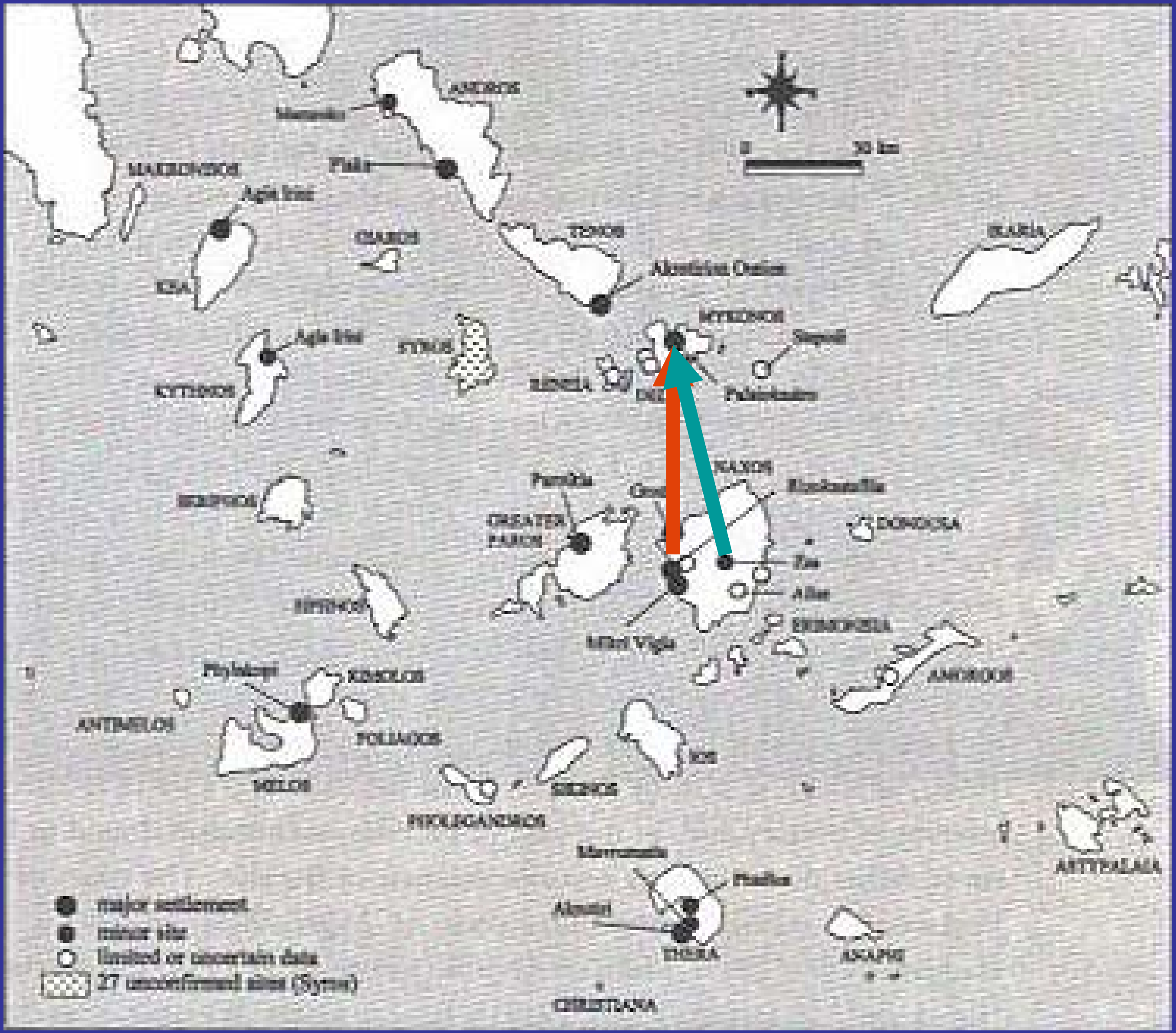
‘Demand-side’ models

In each case, adding an additional site would give a different answer

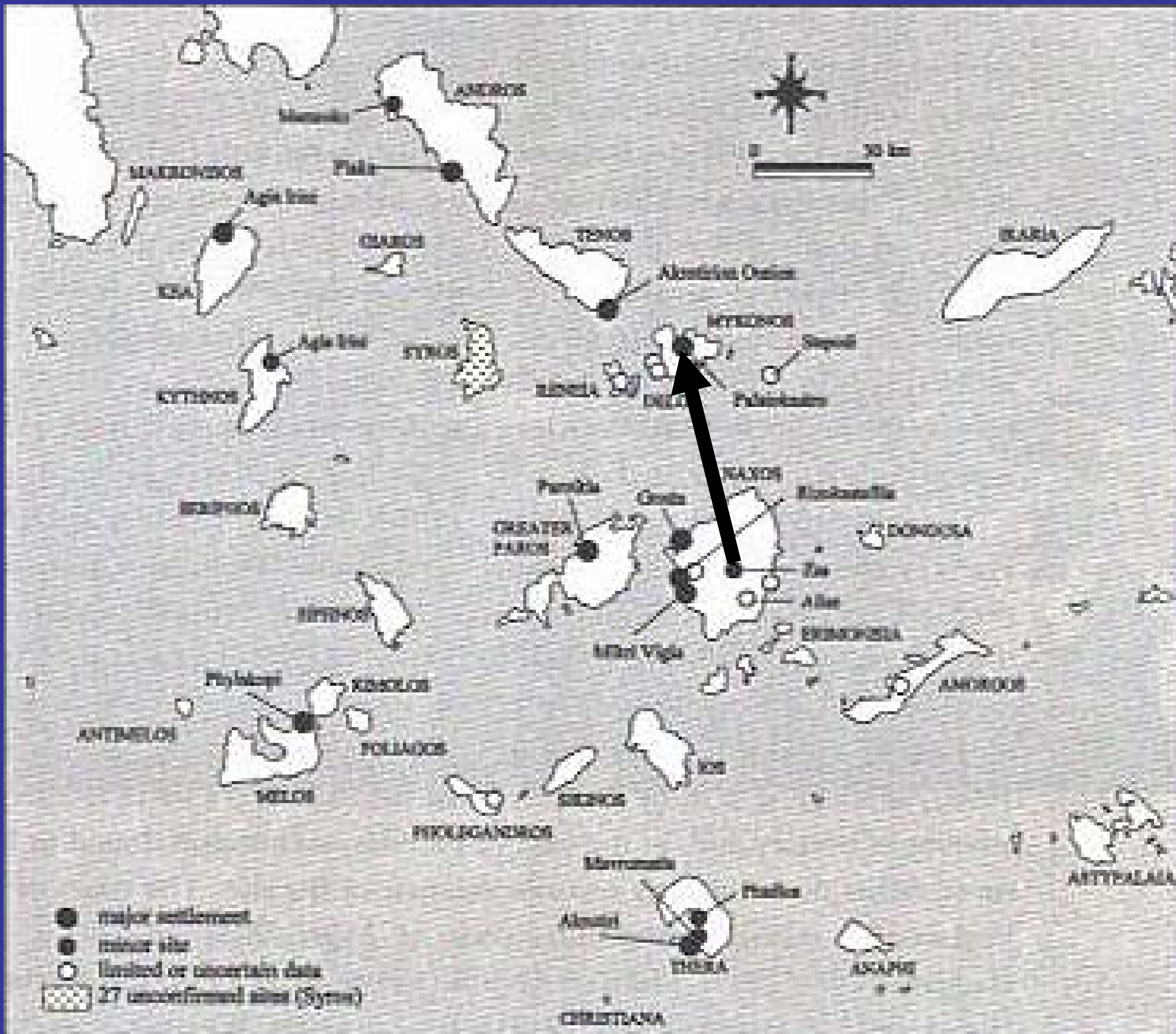
Consider site splitting



Then


ANDROS
MAKRONISOS
TENOS
IKARIA
MYKONOS
SYROS
RINEIA
KYTHNOS
SERIPHOS
NAXOS
DONOUSA
GREATER PAROS
SIPHNOS
KIMOLOS
ANTIMELOS
POLIAGOS
MELOS
IOS
SIKINOS
PHOLEGANDROS
AMORGOS
ASTYPALAIA
THERA
ANAPHI
CHRISTIANA
Phylakopi
Mikri Vigla
0 30 km
major settlement
minor site
limited or uncertain data
27 unconfirmed sites (Syros)

≠



ANDROS
Plaka
MAKRONISOS
KEA
TENOS
IKARIA
MYKONOS
SYROS
KYTHNOS
NAXOS
Paroikia
Grotta
GREATER PAROS
DONOUSA
SERIPHOS
SIPHNOS
Mikri Vigla
ERIMONISIA
AMORGOS
Phylakopi
KIMOLOS
ANTIMELOS
POLIAGOS
MELOS
IOS
SIKINOS
ASTYPALAIA
Akrotiri
THERA
ANAPHI
CHRISTIANA
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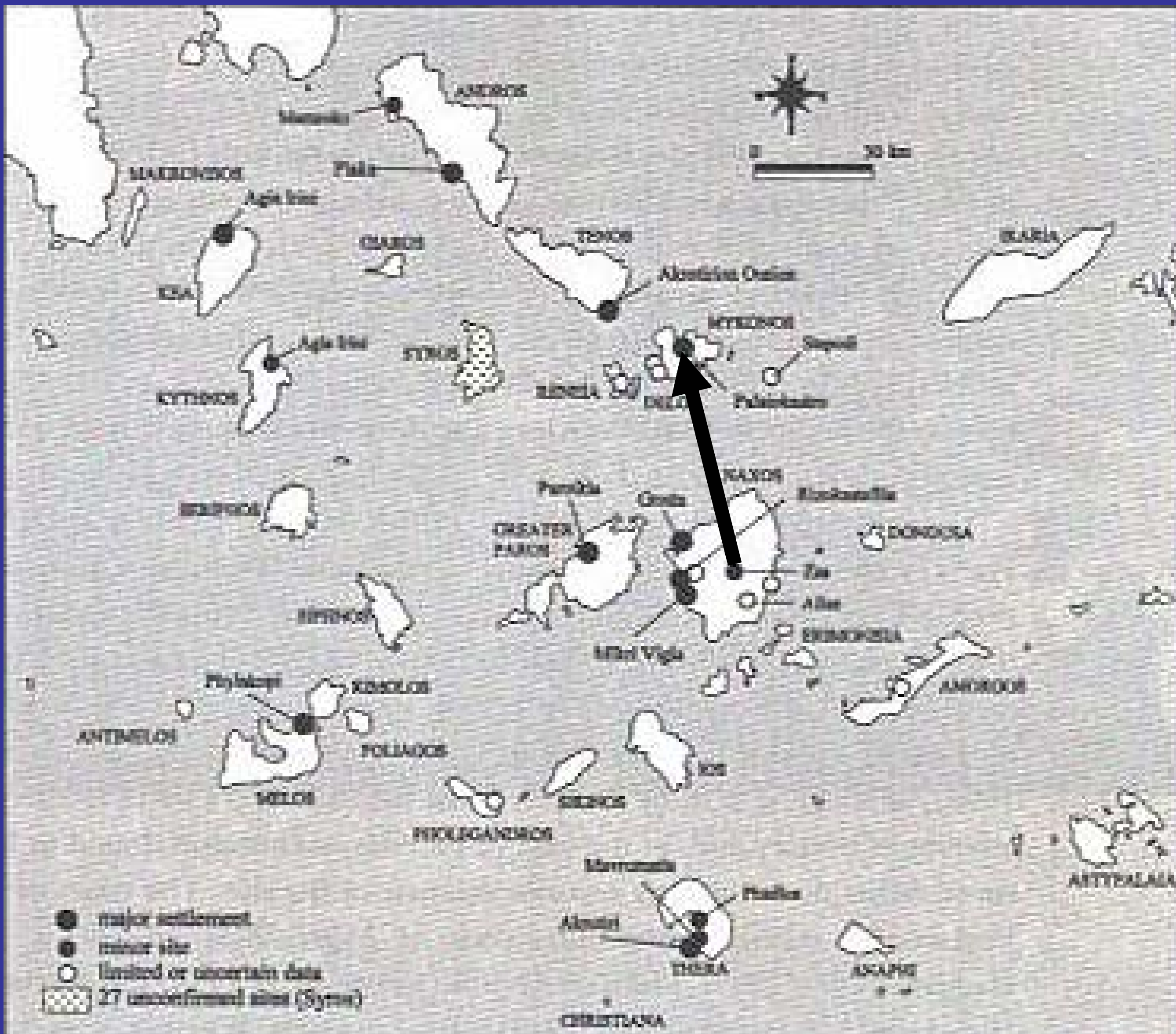


Not Robust

Last ISCOM meeting

Conclusions: Work backwards

- Archaeological record for MBA Aegean very patchy
- Can minimise ignorance at meso-level by choosing 'gravity' models, which are insensitive to this level.

  These are the only robust models we know
- Not inevitable – EBA Cyclades

  Robust does not mean correct
- Look plausible for MBA - explore consequences (Tim)
- If gravity models not correct alternative models not robust

  Not robust does not mean not correct
- Needs new input at the meso-level, which we don't possess

  cf. Broodbank

Coda

Q. Given the importance of discriminating between gravitational and non-gravitational models, are there any generic distinguishing characteristics

A. One possible answer is that, for optimal models, networks are naturally unstable for gravitational models, in a way that they are not for non-gravitational models

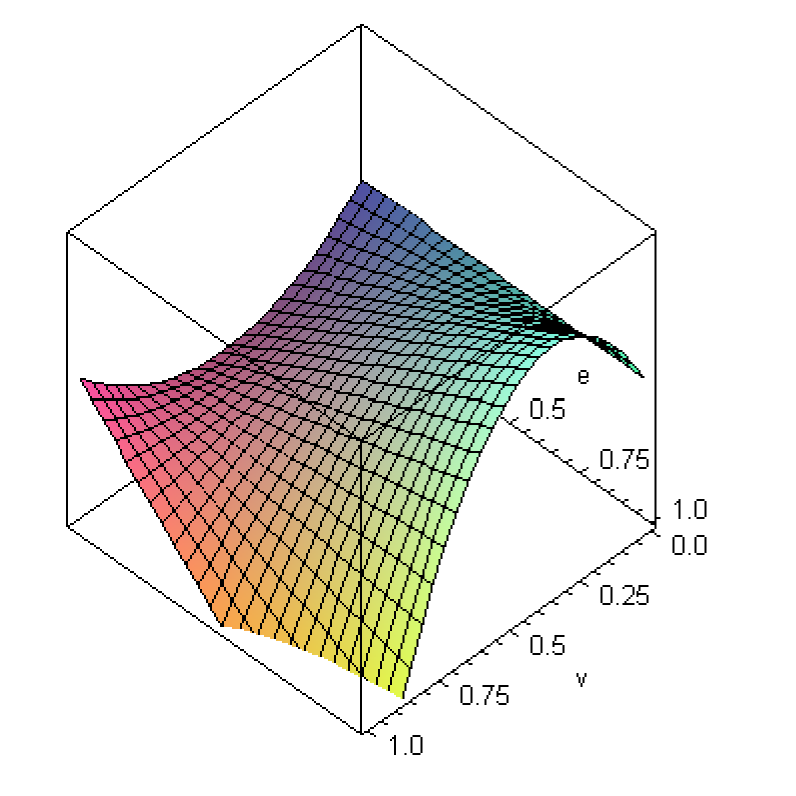
- more likely to 'collapse'

Note: Two ways for a network to collapse

- To lose links i.e. islands more self-sufficient (e.g. Broodbank)
- Population collapse

Both EBA and MBA show the latter

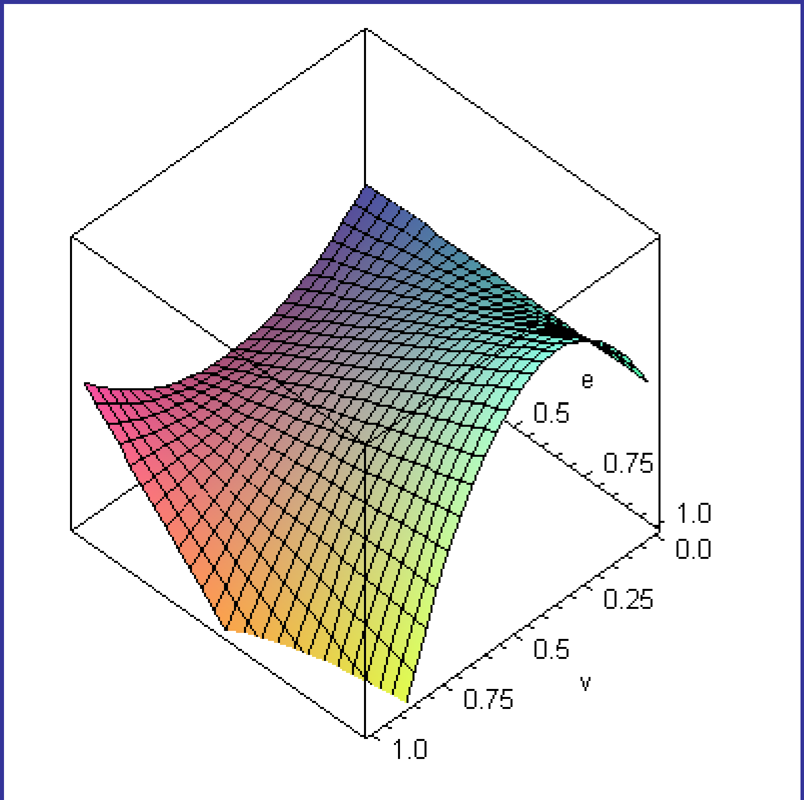
Reason:



- Gravitational models have negative eigenvalues - instability
- Typically ‘growth’ so that network falls off the ‘hill’ in the energy ‘landscape’ to increasing resource exploitation v
- Constraints on population and network costs can reset the origin so that the network falls off the ‘hill’ in the energy ‘landscape’ the wrong way

Energy ‘landscape’ H as a function of average resource exploitation v and link strength e

Reason:



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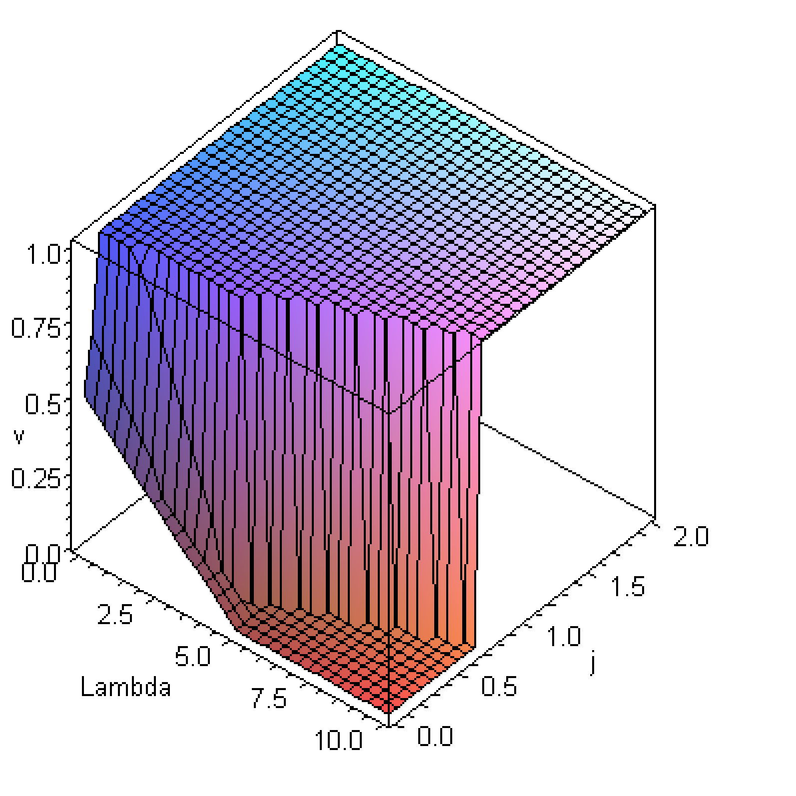
Not the case for non-gravitational models of the type proposed here

Collapse (of population)



Resource exploitation as a function of

- 'insularity' - the relative importance of establishing links to exploiting own resources

- population

'Cliff edge' shows rapid collapse for small parameter change – slice through the simplest 'catastrophe' fold