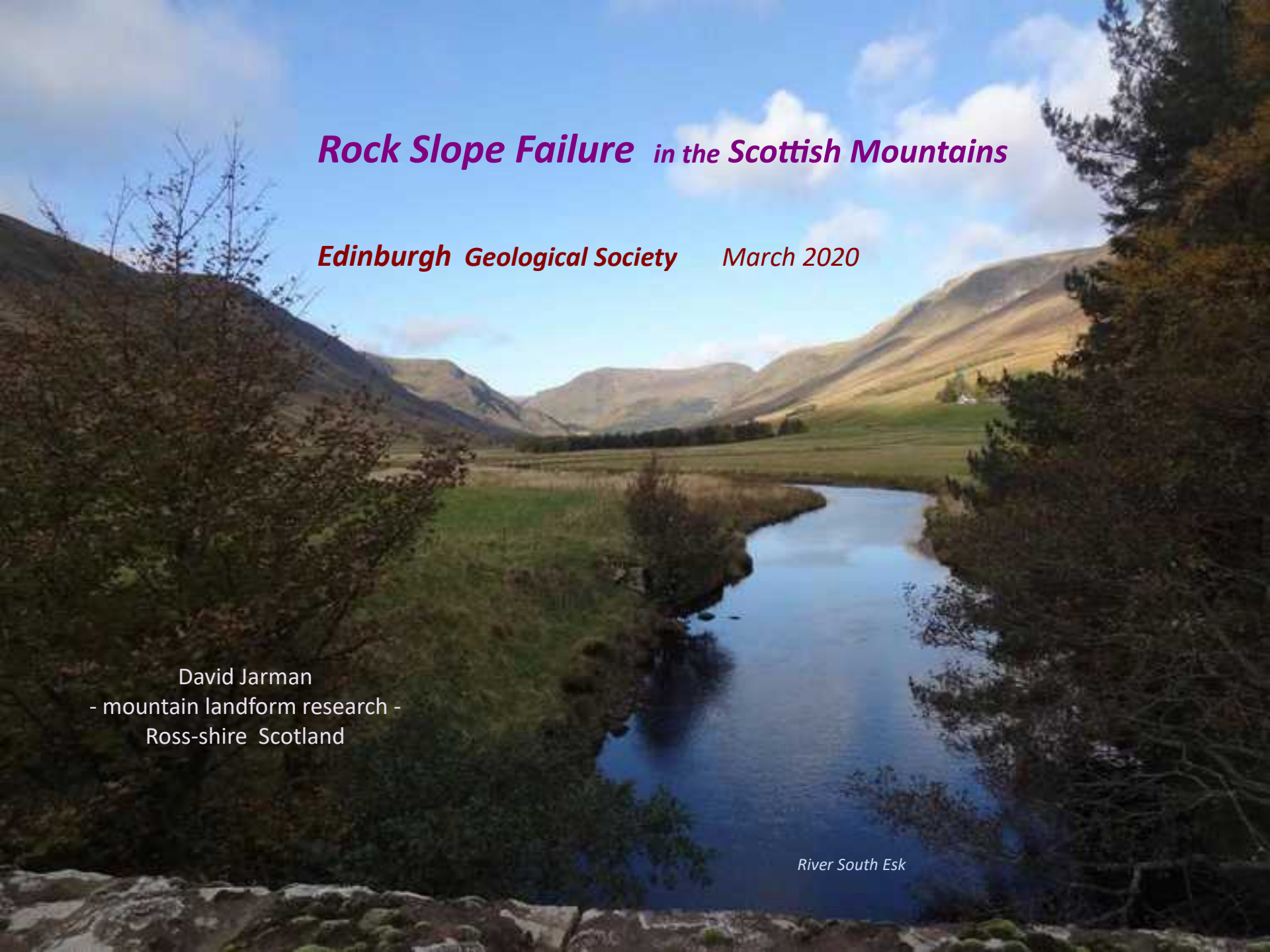


Rock Slope Failure in the Scottish Mountains

Edinburgh Geological Society *March 2020*

David Jarman
- mountain landform research -
Ross-shire Scotland

River South Esk

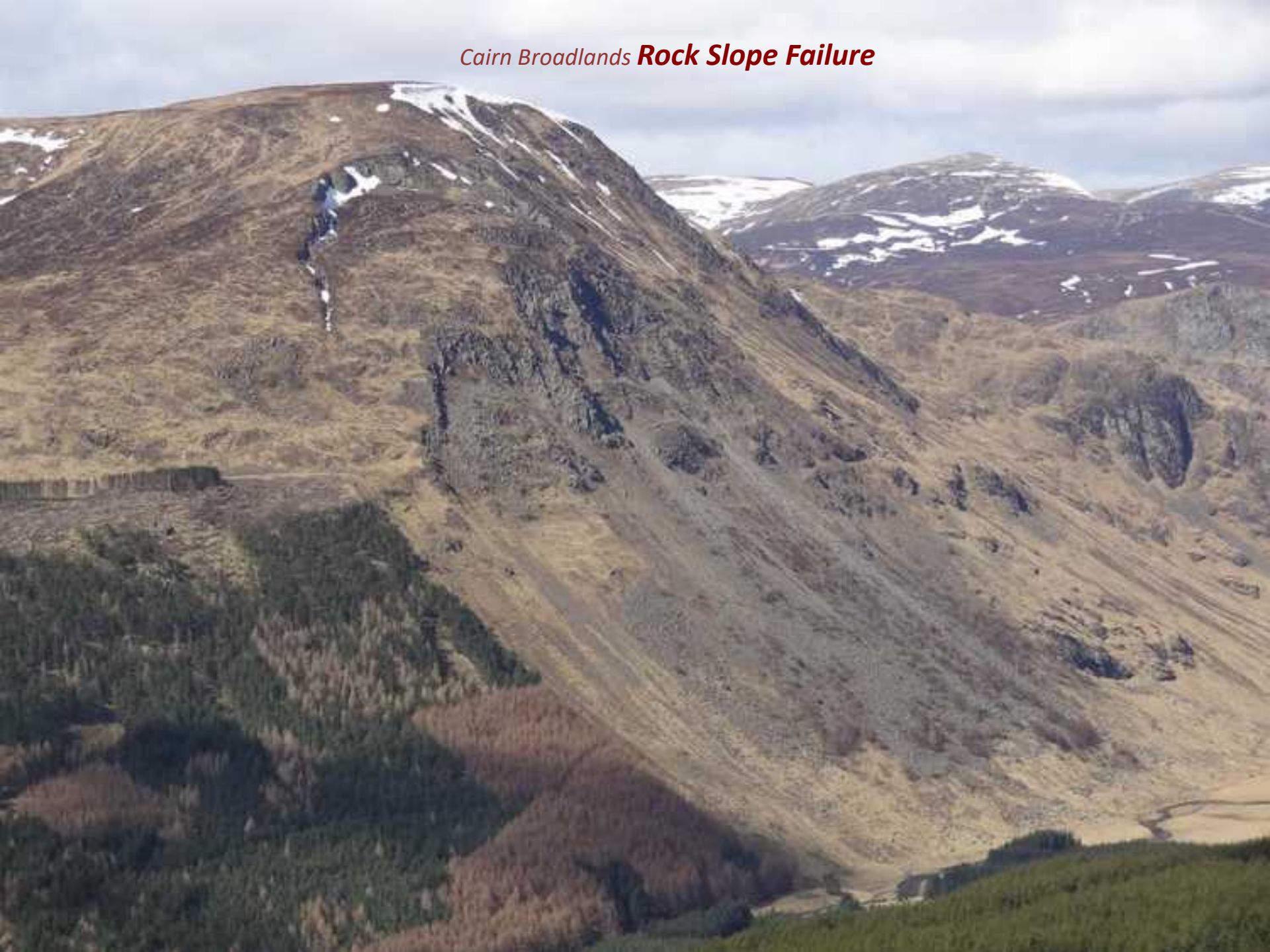

Glen Doll
upper
Glen Clova
Glen Clova


Cairn Broadlands
Glen Doll
upper
Glen Clova
Glen Clova

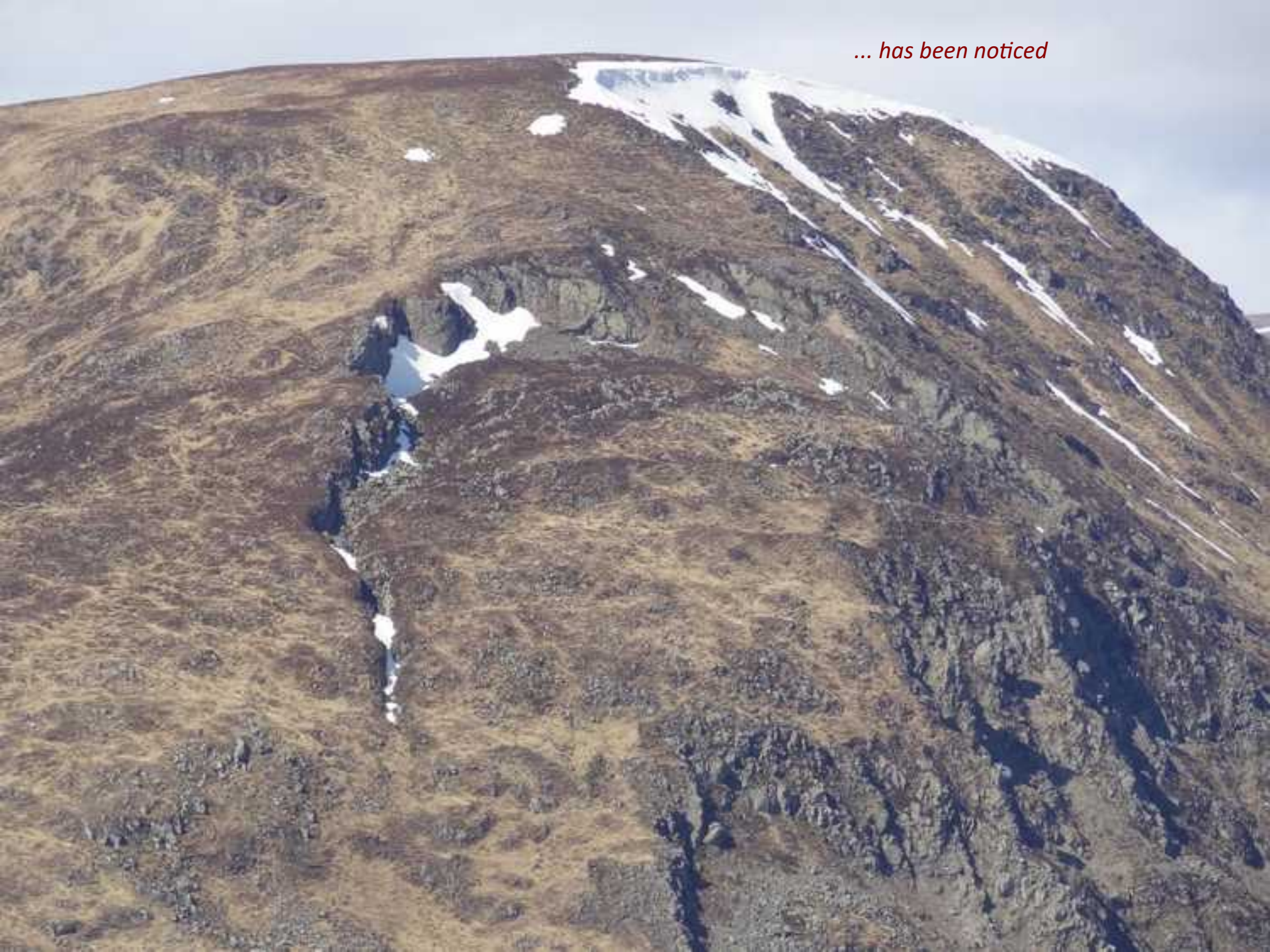

Cairn Broadlands


Cairn Broadlands
852
Lochnagar
1155
upper Glen Clova

Cairn Broadlands ***Rock Slope Failure***



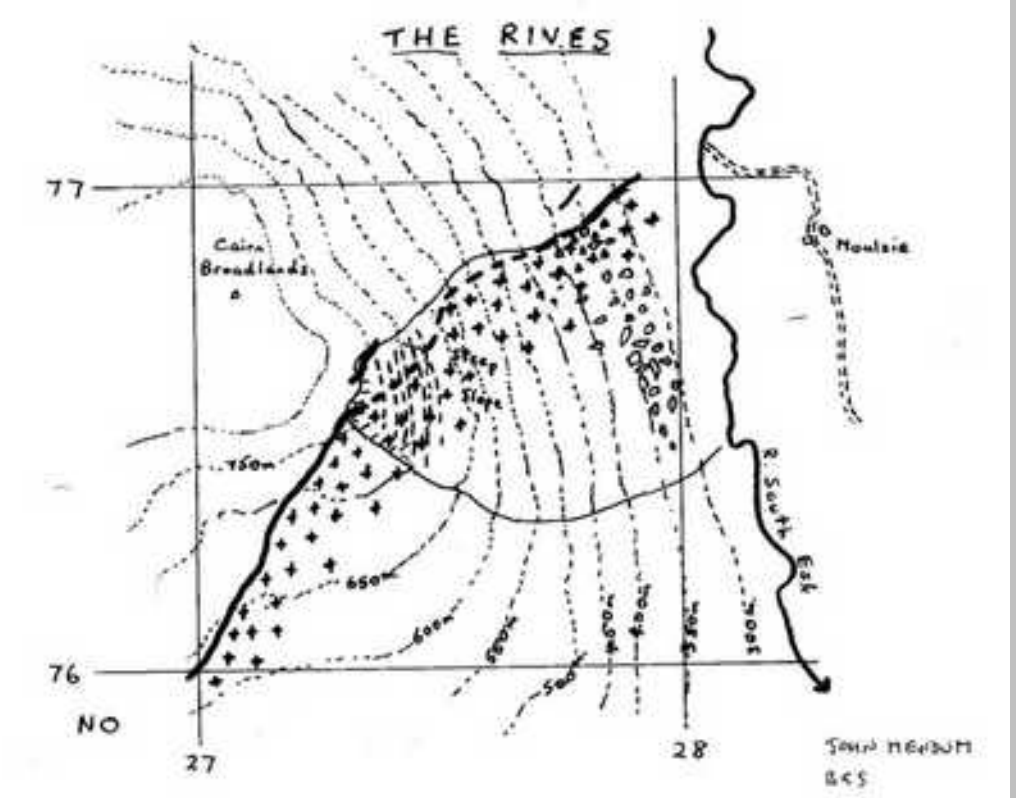

Cairn Broadlands Rock Slope Failure
(RSF)

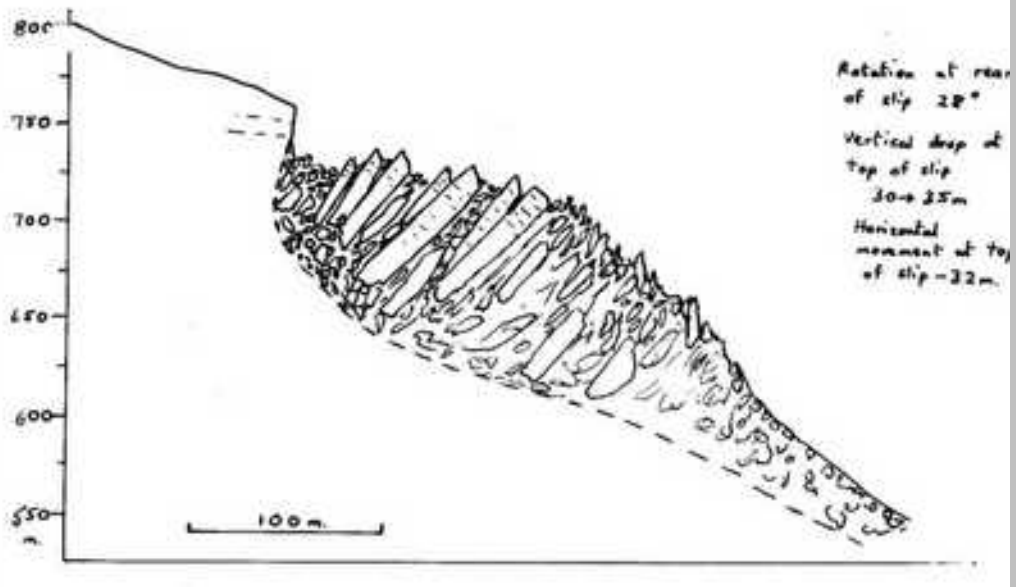

... has been noticed

JK St Joseph

Air Photograph Collection Cambridge

a rare RSF in this early archive, based largely on what they saw from the air, not previously known



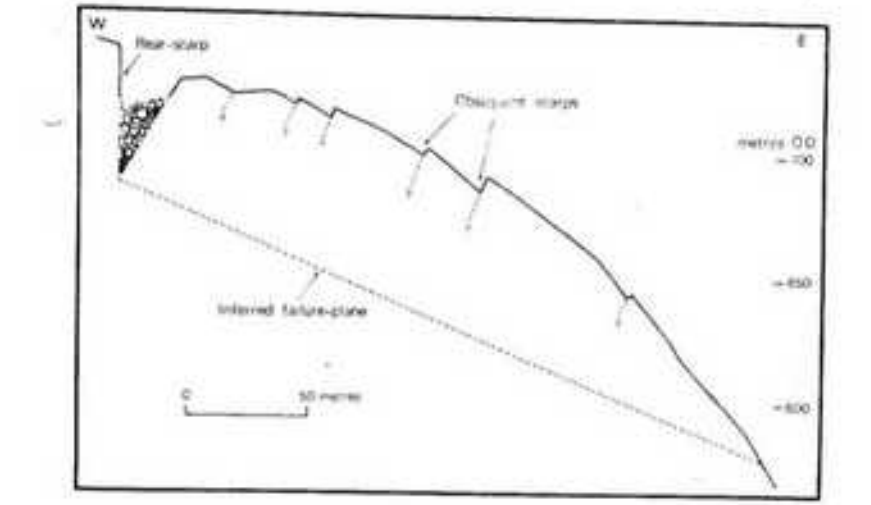


the late ***John Mendum***
formerly BGS Edinburgh

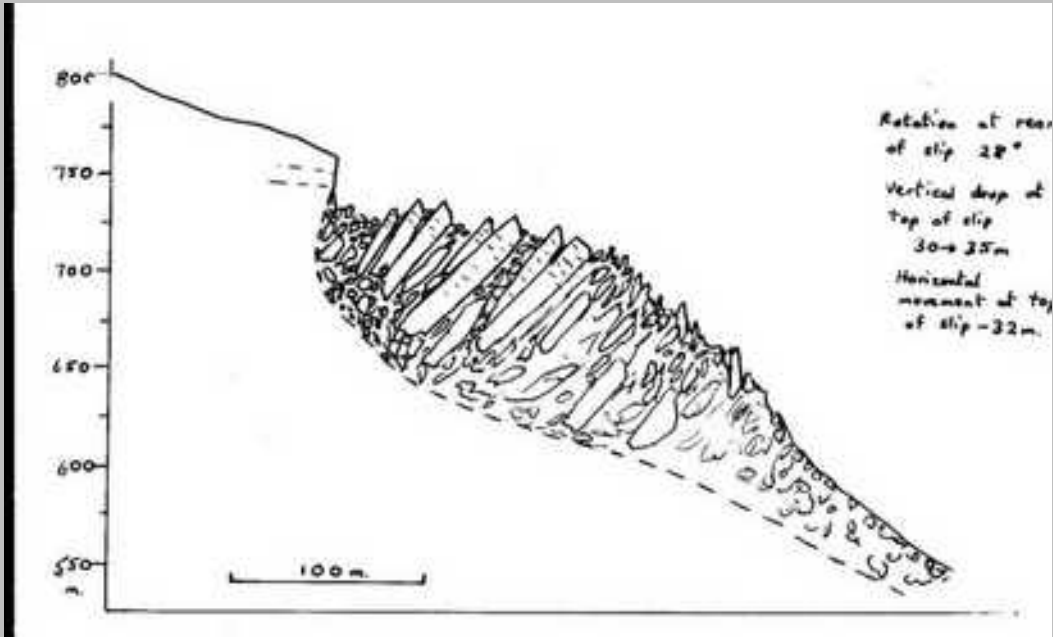
- *an early attempt at field mapping a large RSF*

Graham Holmes PhD 1984

Edinburgh University RSF - Scottish Highlands .

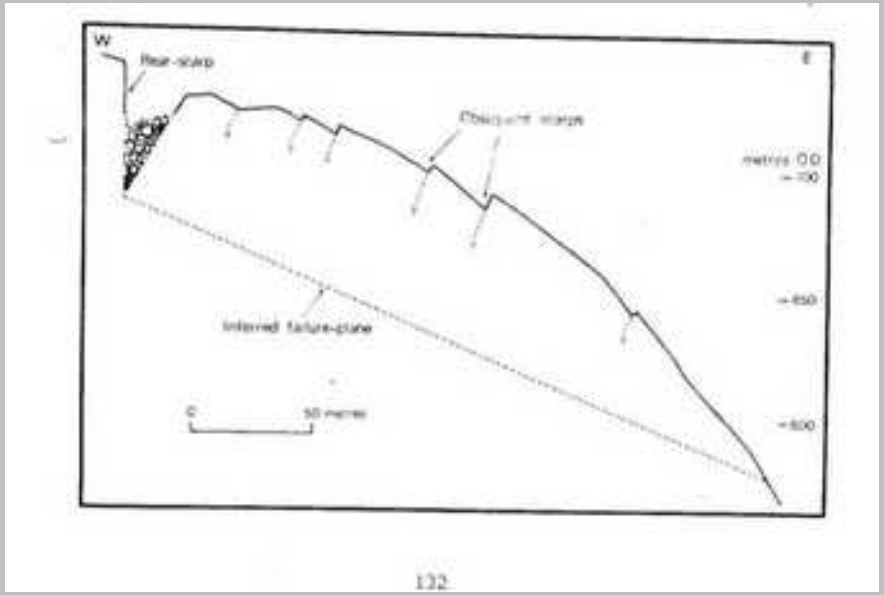


122



Graham Holmes PhD 1984

Edinburgh University *- last student of* ***Brian Sissons***



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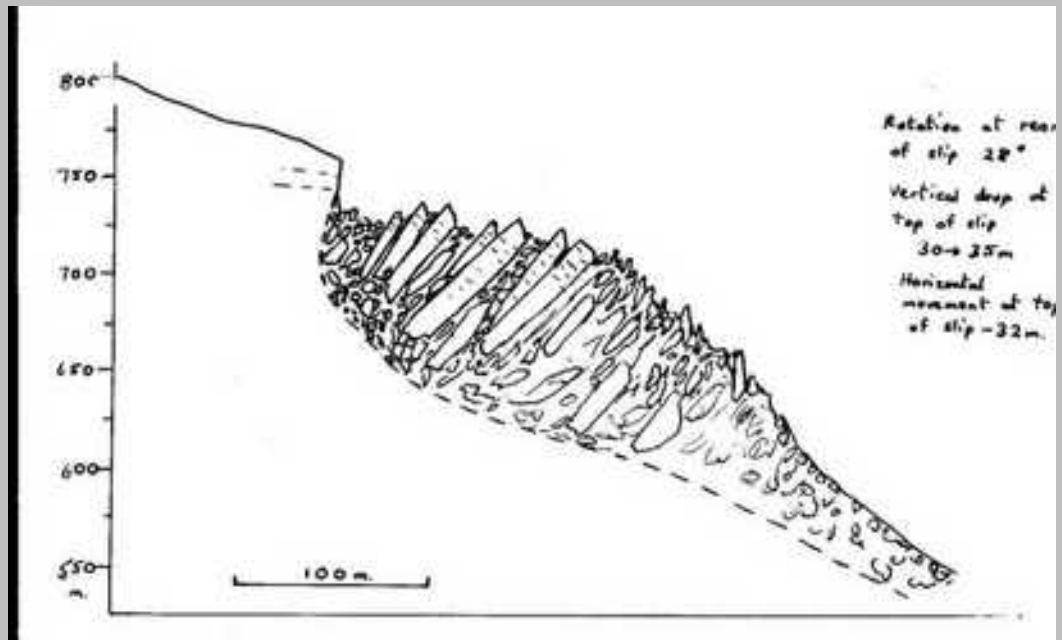


Cairn Broadlands

The Rives


exceptionally high headscarp
30-35 m

site photos (c) Wishart Mitchell

The Rives

antiscarps *6-9 m high*

imagery of exceptional quality

Bing maps


Image © 2019 Getmapping plc
32 m


Image © 2019 Getmapping plc


stalkers path from
Glen Doll Lodge
car park
Image © 2019 Getmapping plc

Juanjorge ***rock avalanche***
- exceptional tree cover


ice off Mounth plateau into trough-head
Juanjorge rock avalanche
isolated ‘moraine’
- glacially reworked earlier event ?

Glen Doll - Craig Maud
rock avalanche

and morainised debris ?

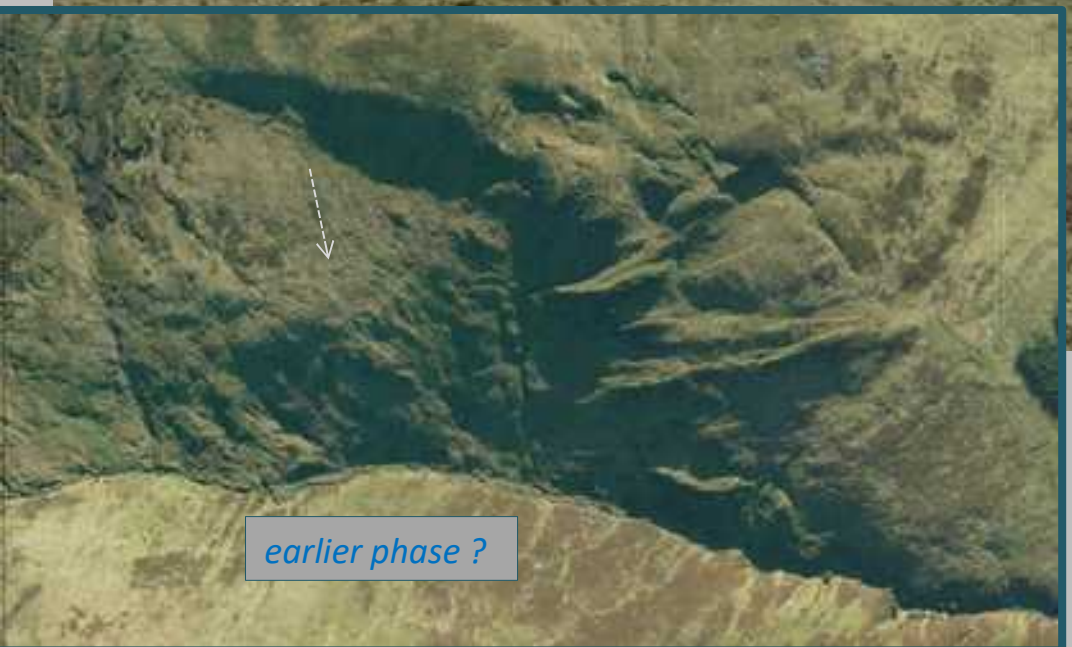

Corrie
Fee
#16.06C
Craig Maud
Glen Doll
the Clova glaciated trough-heads
#16.07A
Juanjorge
#16.07
Cairn Broadlands
upper Glen Clova


Corrie
Fee
#16.06C
Craig Maud
Glen Doll
the Clova glaciated trough-heads
- paraglacial RSF
#16.07A
Juanjorge
#16.07
Cairn Broadlands
upper Glen Clova


Corrie
Fee
#16.06C
Craig Maud
Glen Doll
the Clova glaciated trough-heads
- paraglacial RSF
#16.07A
Juanjorge
#16.07
Cairn Broadlands
upper Glen Clova
the Clova fluvial incisions
- parafluvial RSF
#16.08
#16.07B

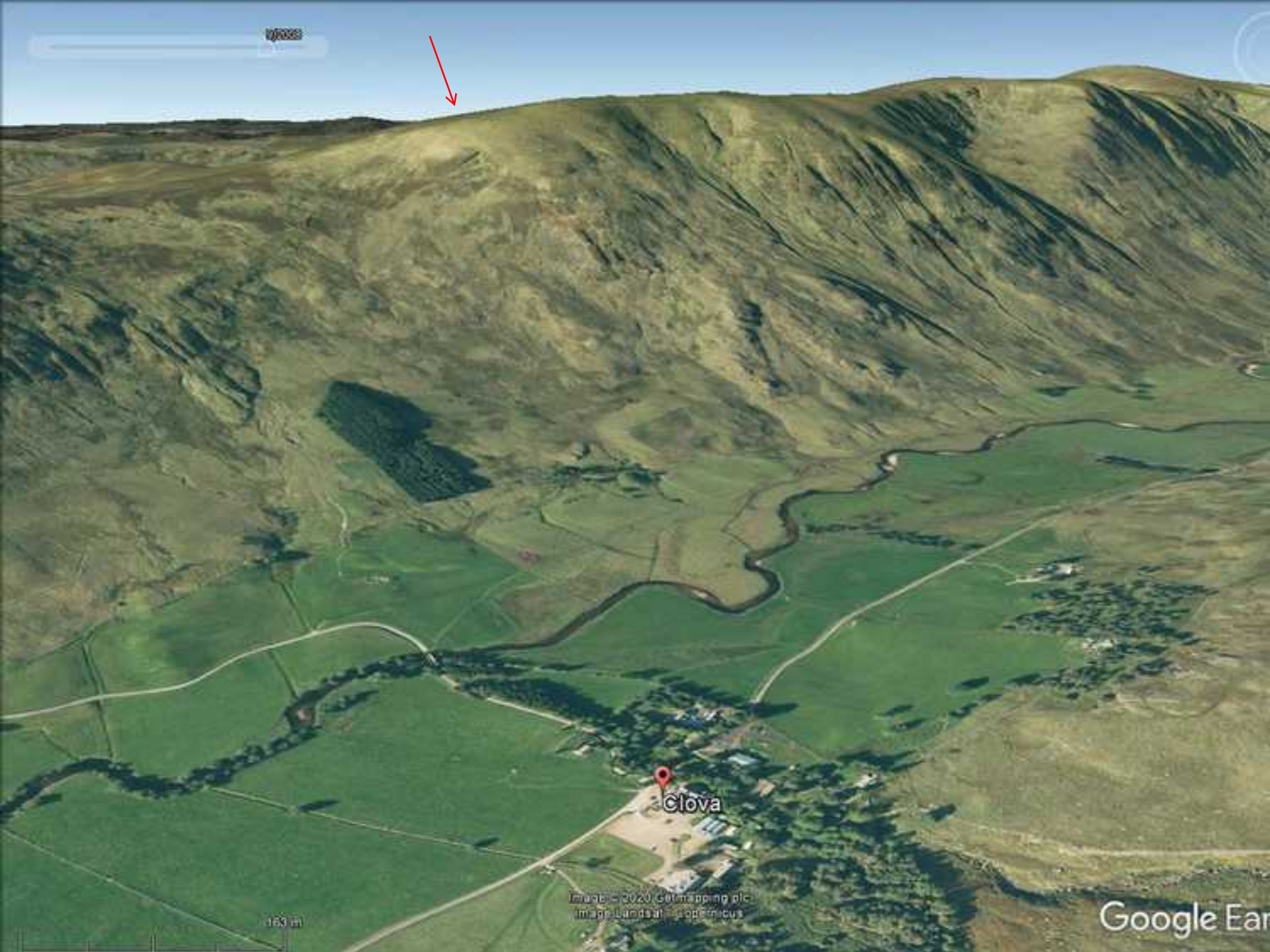
#16.08 Capel Burn

*classic **parafluvial** RSF in competent rock sustaining long antiscarps*



earlier phase ?


Image © 2019 Getmapping plc
Google

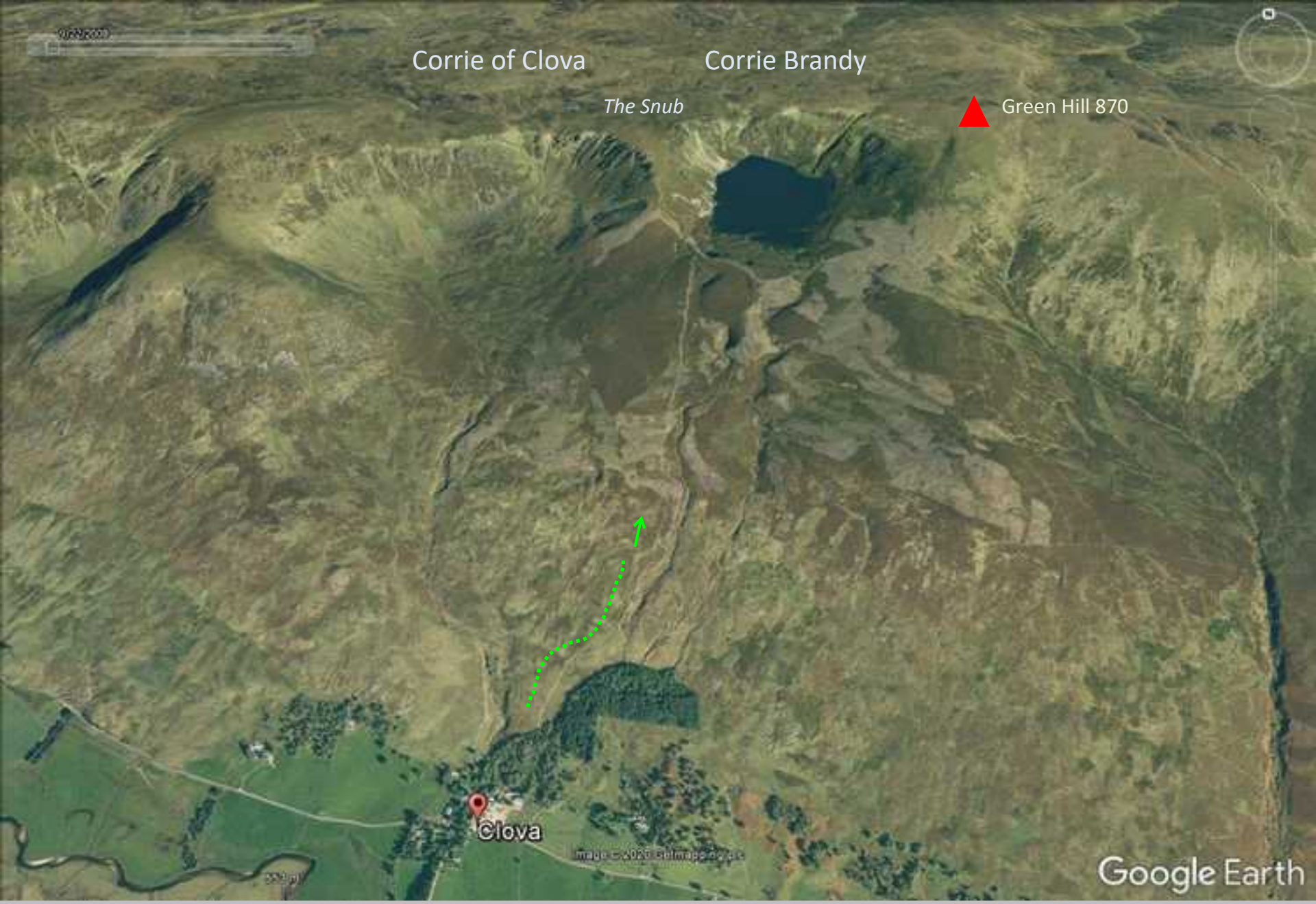

Clova
Google Ear

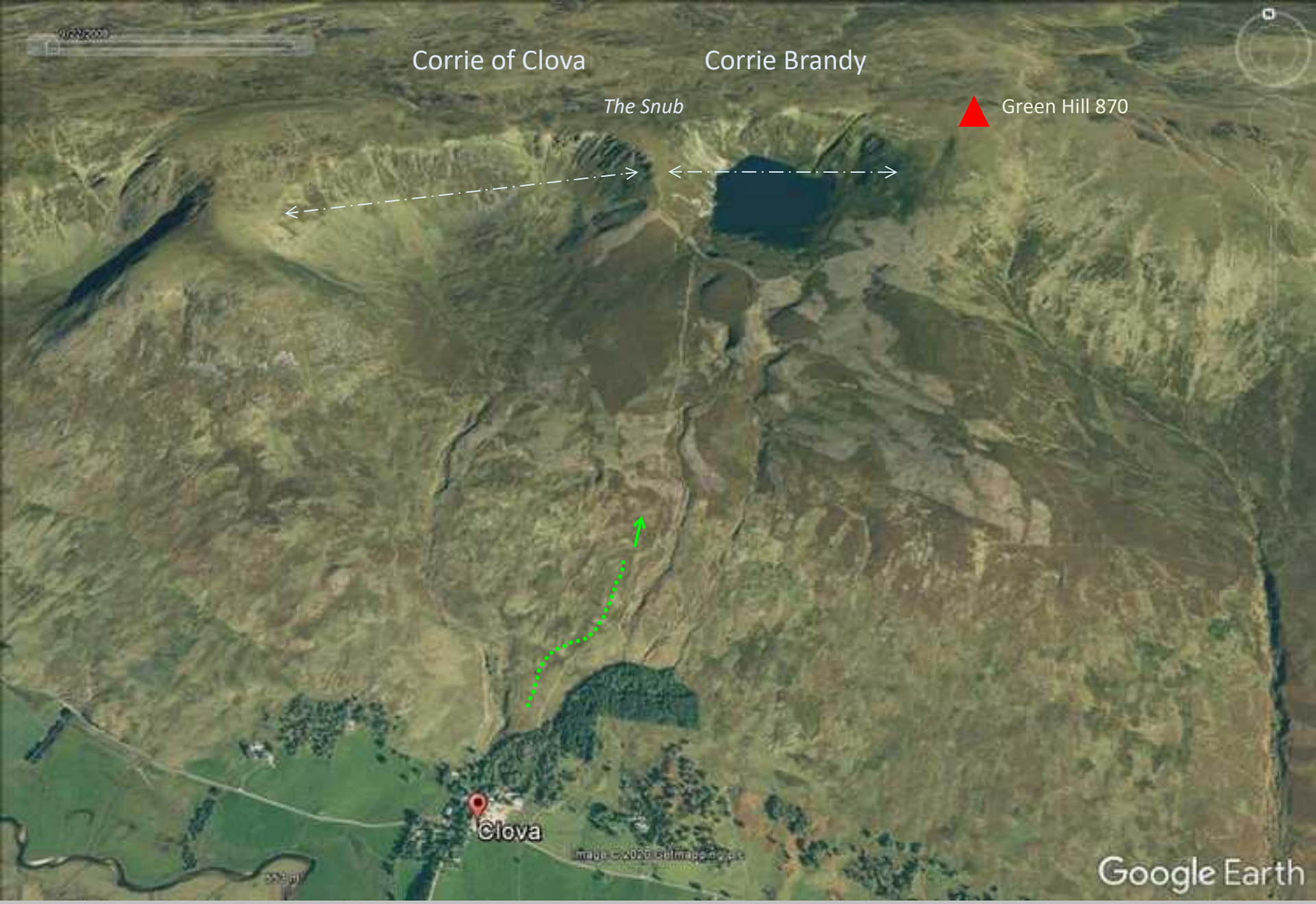
#16.06 Cairn Inks

- *very small RSF 0.02 km²*


Corrie : Bonhard Clova Brandy Wharral Lochanluie
876
896
HOTEL
upper Glen Clova
Corrie Bonhard
Corrie of Clova
Corrie Brandy
Loch Wharral
Cairn Broadlands
Clova Shelf
HOTEL


Corrie : Bonhard Clova Brandy Wharral Lochanluie
876
896
N
HOTEL
upper Glen Clova
Corrie Bonhard
Corrie of Clova
Corrie Brandy
Loch Wharral
Cairn Broadlands
Clova Shelf
HOTEL


Corrie of Clova
Corrie Brandy
The Snub
Green Hill 870
Clova
Google Earth



Corrie of Clova is twice as wide

#16.10-13 Corrie of Clova -- Corrie Brandy RSFs

relict RSFs

DDAs


Corrie of Clova
#16.10

Corrie of Clova

DDA below - possible earlier RSF phase ?

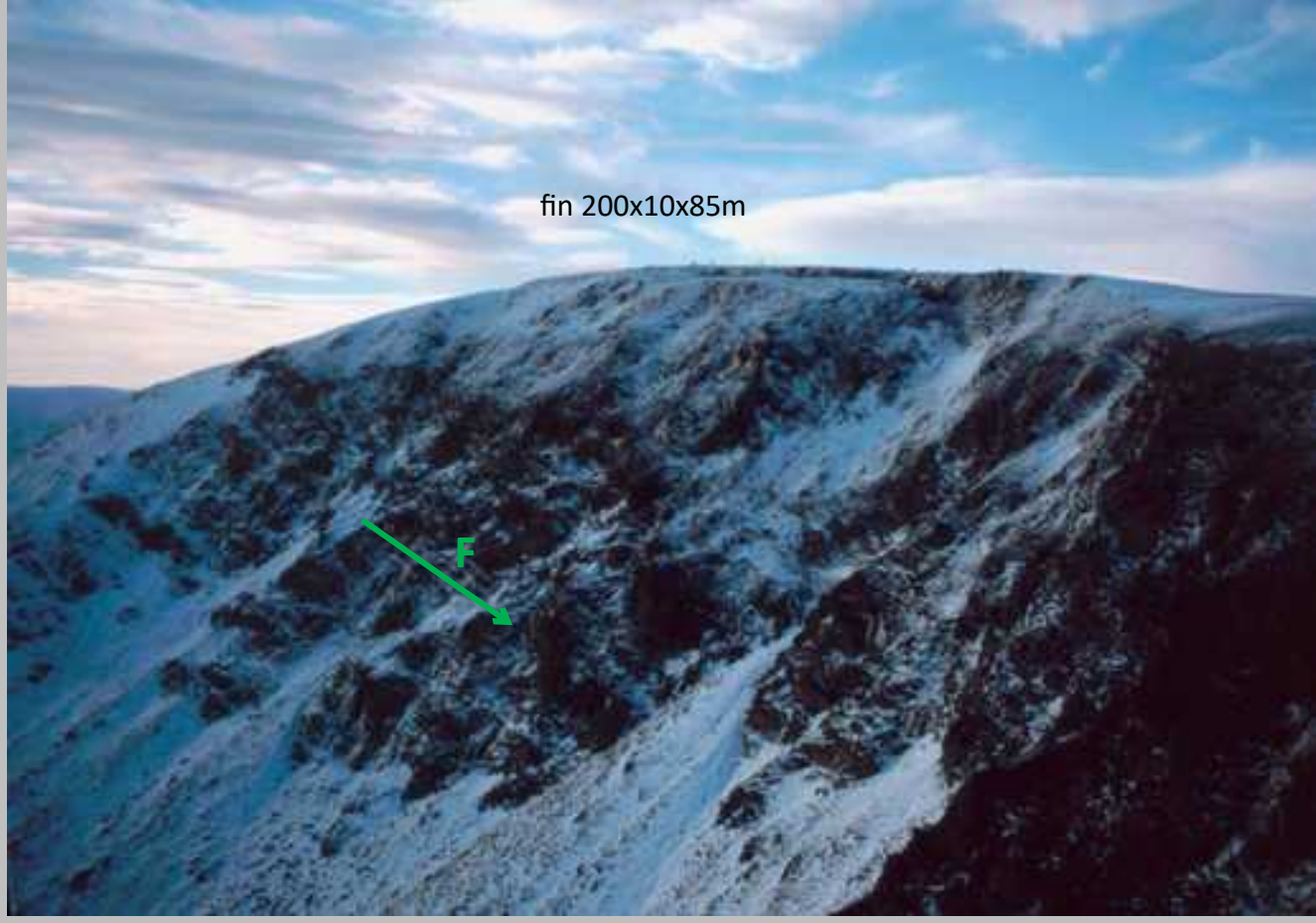
former 'Snub' - destroyed by RSF, yielding compound cirque ?

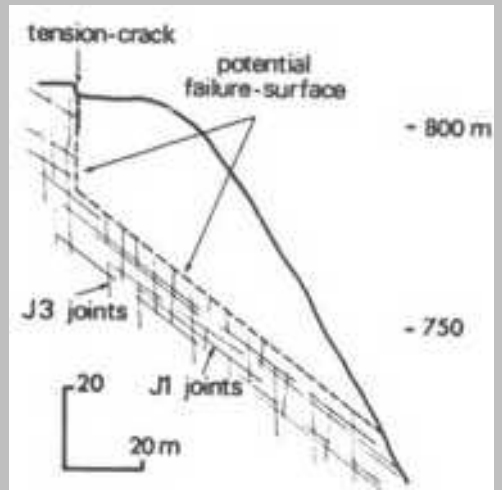
Corrie Brandy W

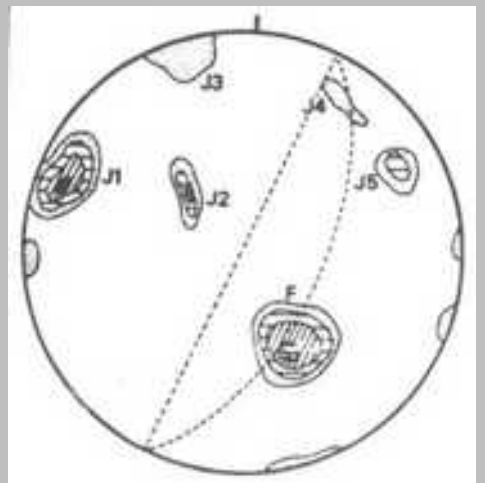
***#16.12 The Snub** east flank*

Graham Holmes PhD 1984
geotechnical analysis

*'bedding' **F** dips into slope, resisting sliding*







Corrie Brandy W

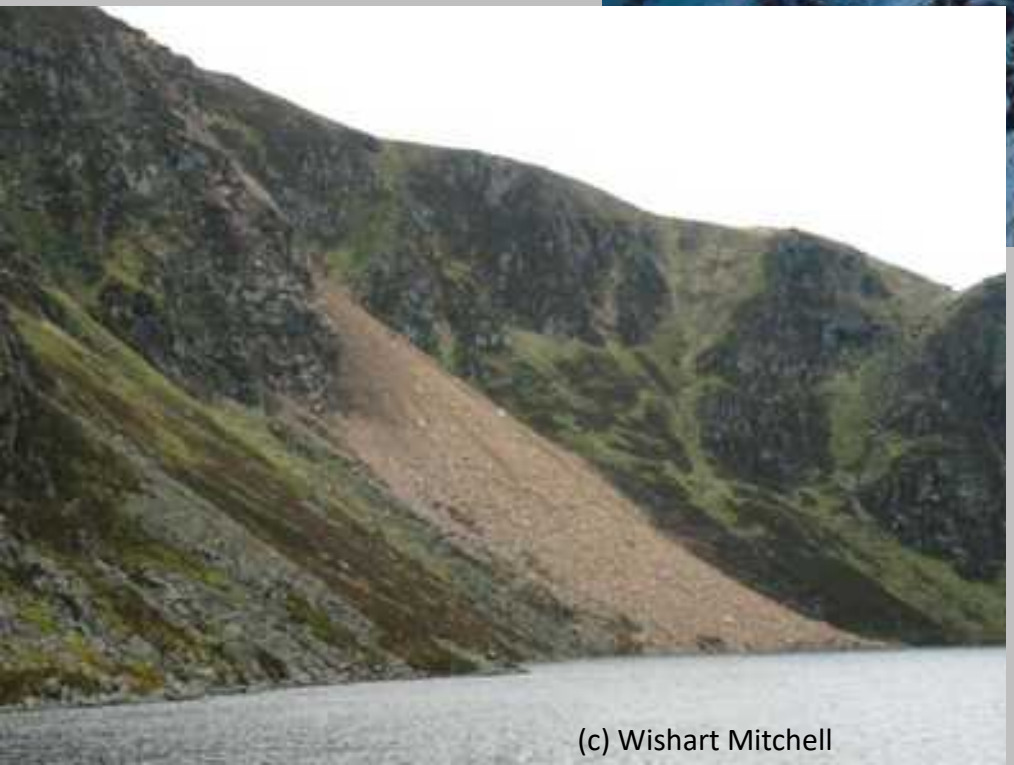
***#16.12 The Snub** east flank*

- detaching fin

Corrie Brandy W

***#16.12 The Snub** east flank*

collapse, winter 2016-17

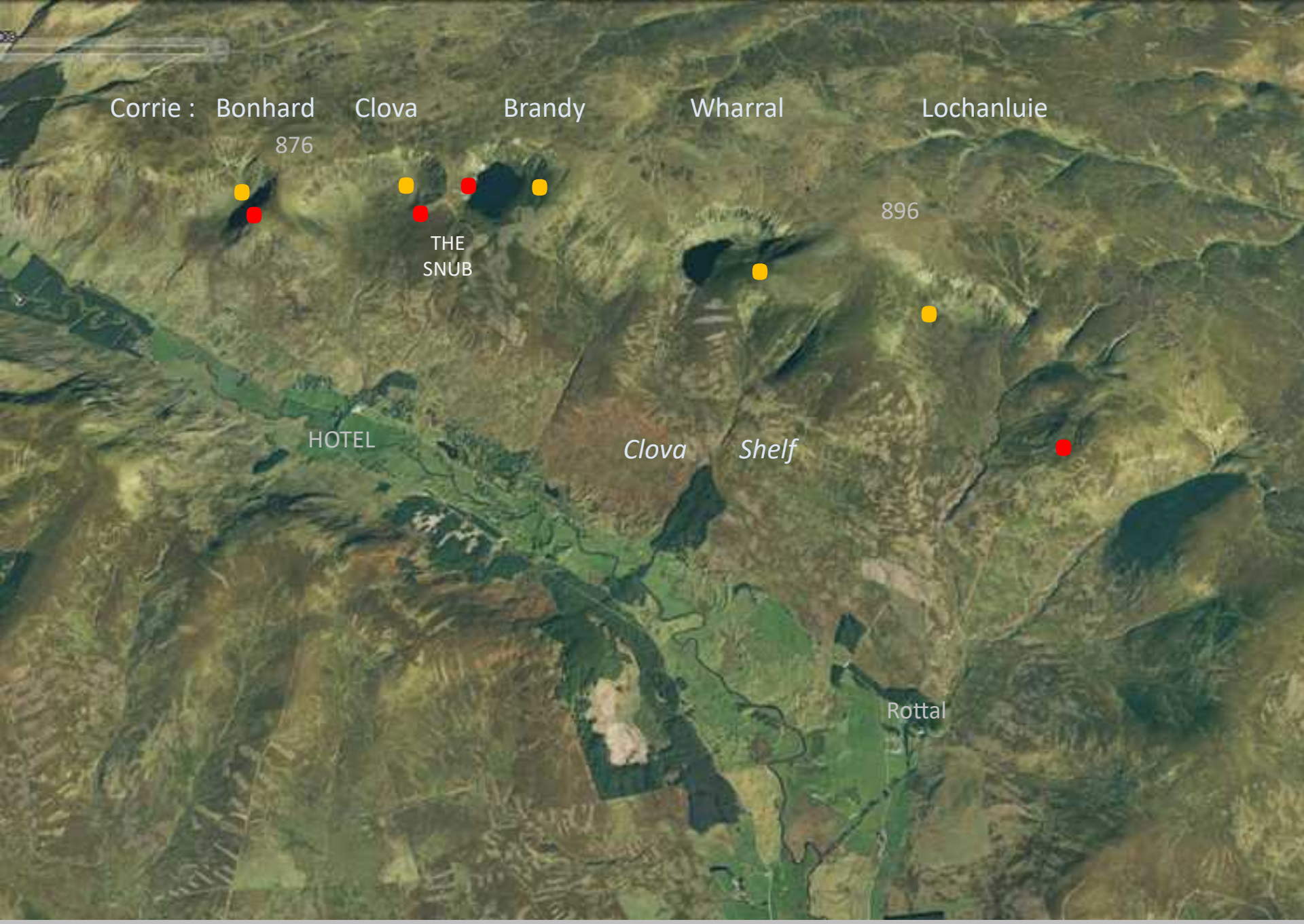


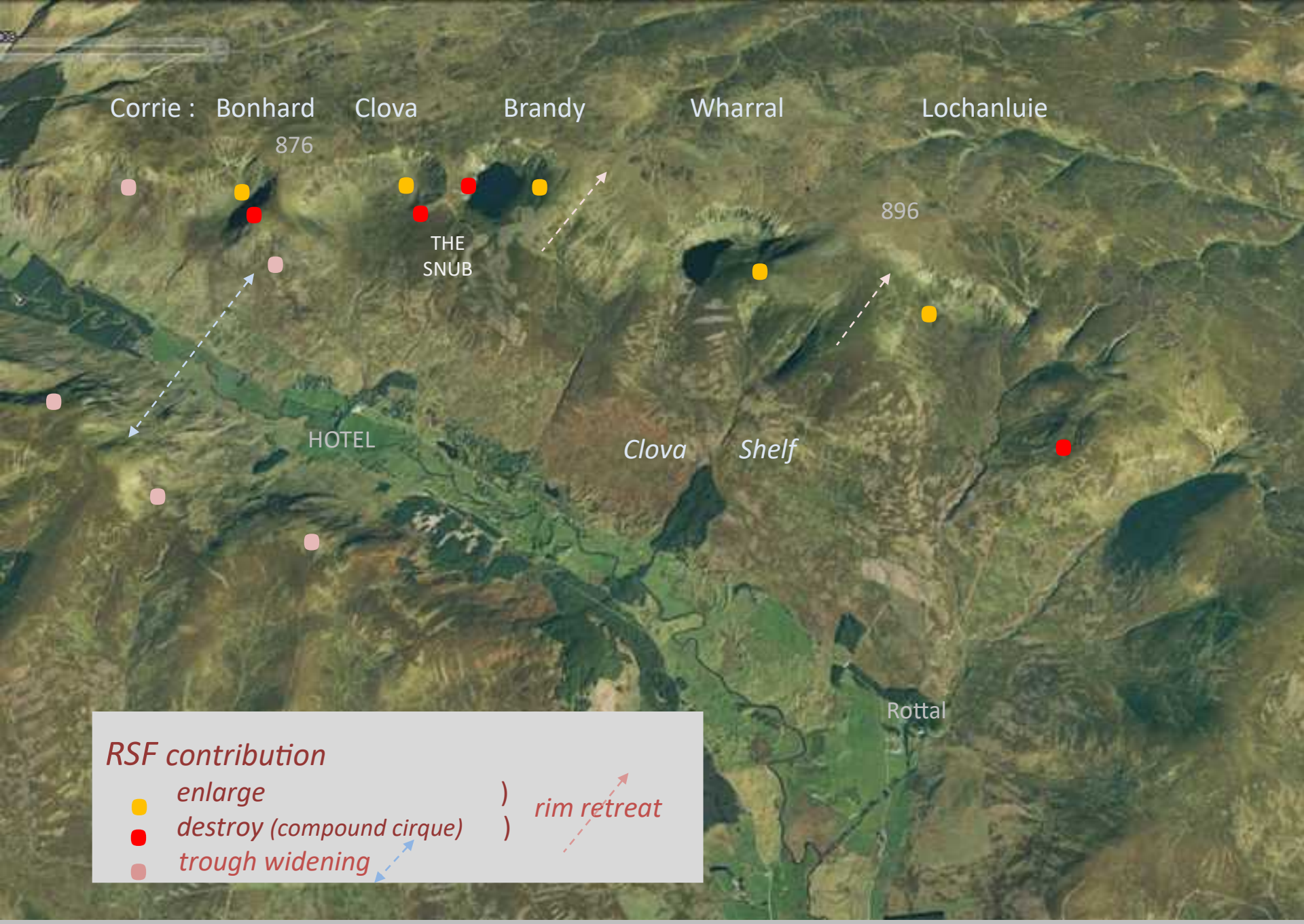
Corrie Brandy E #16.13 Green Hill

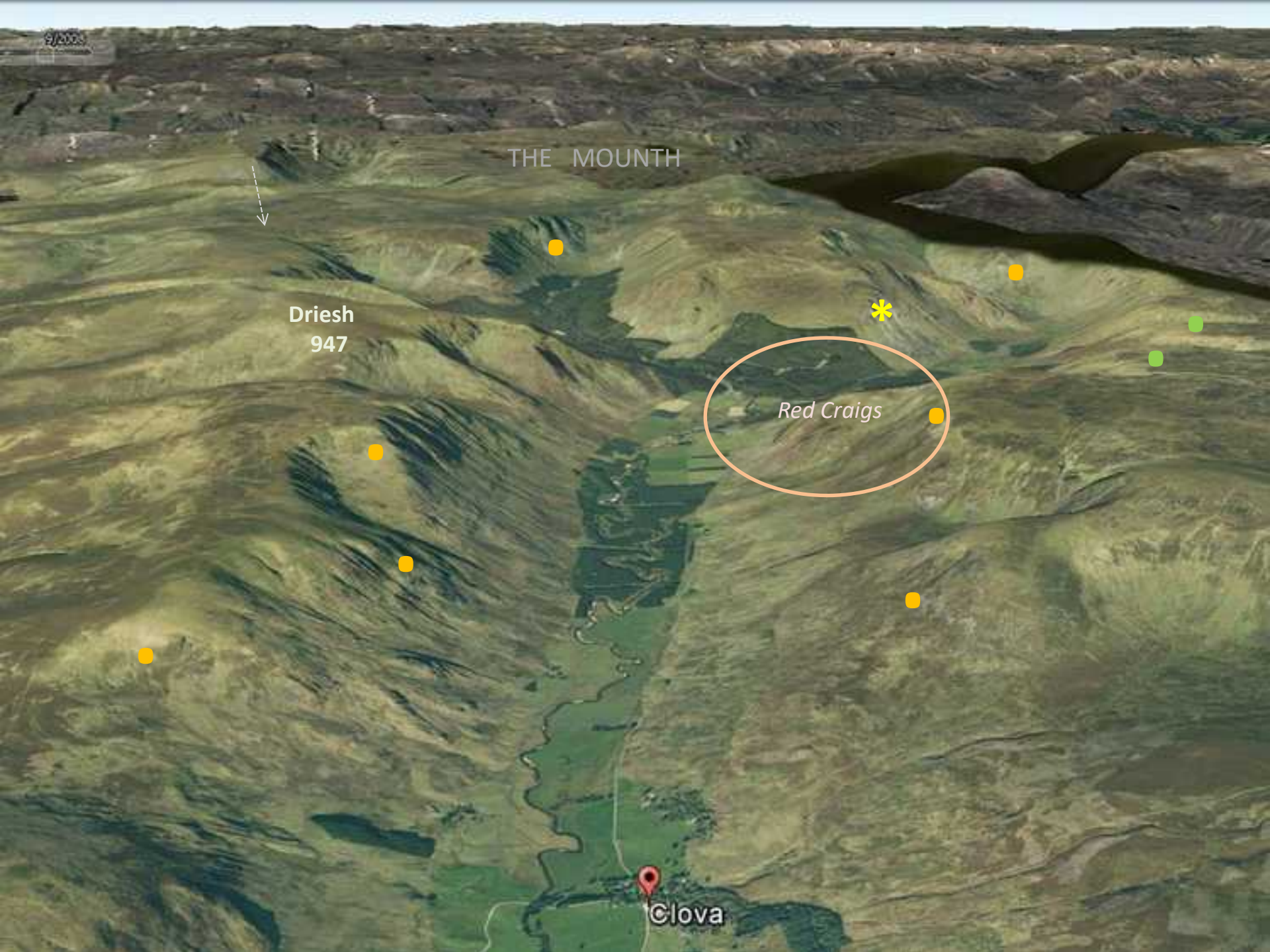
- rockslide (with incipient extension)

- one of largest Clova RSFs at 0.20 km²

- one of deepest rim invasions in GB at 130 m (Jarman 2009)


Corrie :
Bonhard
876
Clova
Brandy
Wharral
Lochanluie
896
THE
SNUB
HOTEL
Clova
Shelf
Rottal


Corrie :
Bonhard
876
Clova
Brandy
Wharral
Lochanluie
896
THE
SNUB
HOTEL
Clova
Shelf
Rottal
RSF contribution
enlarge
destroy (compound cirque)
trough widening
rim retreat


THE MOUNTH
Driesh
947
Red Craigs
Clova

#16.08A Red Craigs ***rock slope deformation***

#16.08A Red Craigs ***rock slope deformation***

NORWAY
Oppdal-Kristiansund route

Vollan

NORWAY
Oppdal-Kristiansund route
Vollan

overall umbrella term	RSF (Rock Slope Failure)		
three main landform types	Rock Slope Deformation (RSD) extensional / compressional	Rockslide	Rock avalanche cataclasmic / sub-cataclasmic
typical landform character	➢ boundaries diffuse (some/all) ➢ short travel ➢ failed mass retains much integrity	➢ boundaries clear (cavity--slipmass) ➢ short--medium travel ➢ failed mass retains some integrity	➢ cavity above debris mass ➢ long--very long travel ➢ failed mass disintegrated

a

overall umbrella term	RSF (Rock Slope Failure)		
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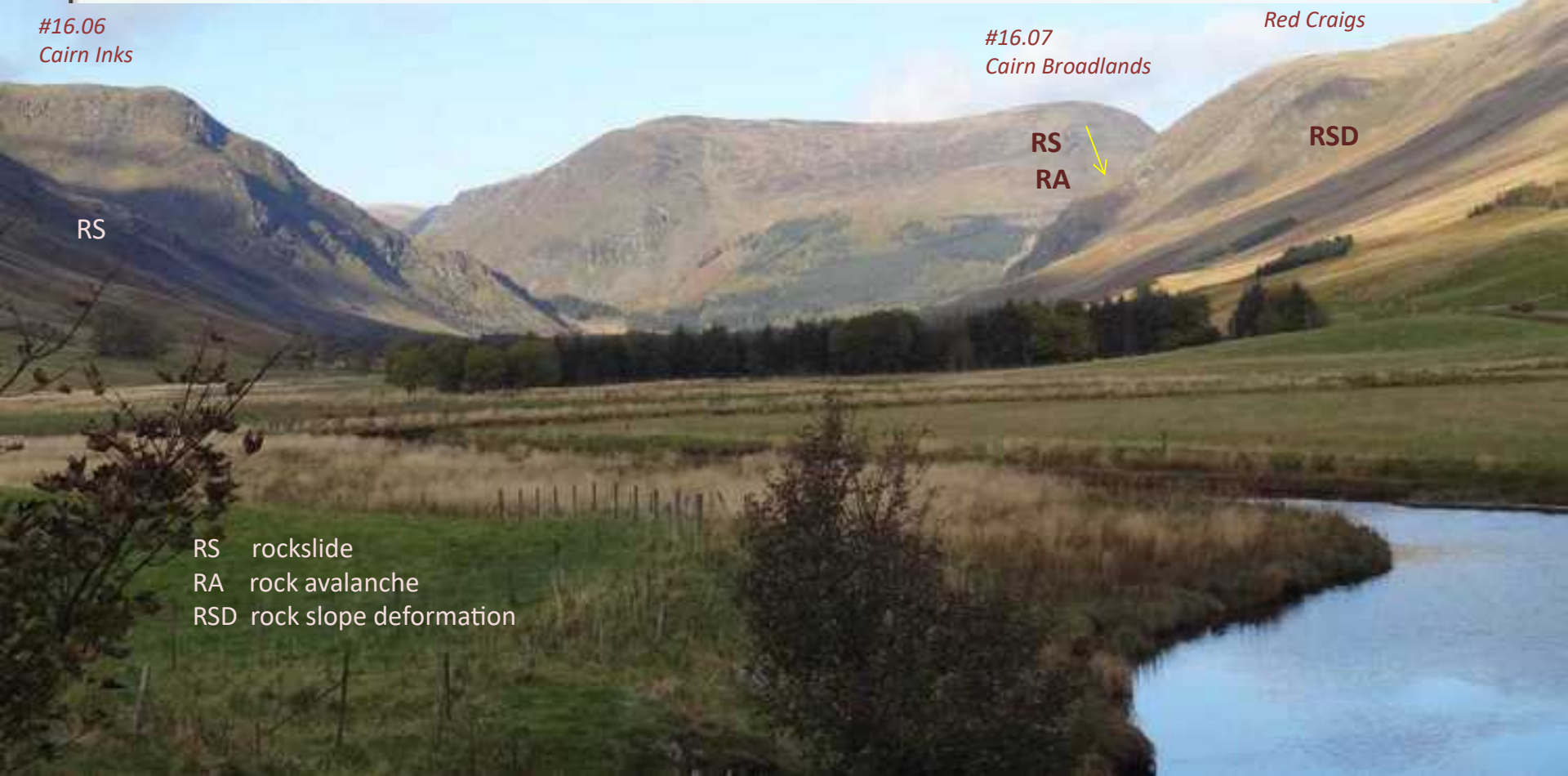
increasing degrees of travel and disintegration

overall umbrella term	RSF (Rock Slope Failure)		
three main landform types	Rock Slope Deformation (RSD) extensional / compressional	Rockslide	Rock avalanche cataclasmic / sub-cataclasmic
in Glen Clova :	**6**	**12**	**4**



Loch Treig
loco now buried

these are not RSFs !!

Rest & be Thankful

Glen Ogle

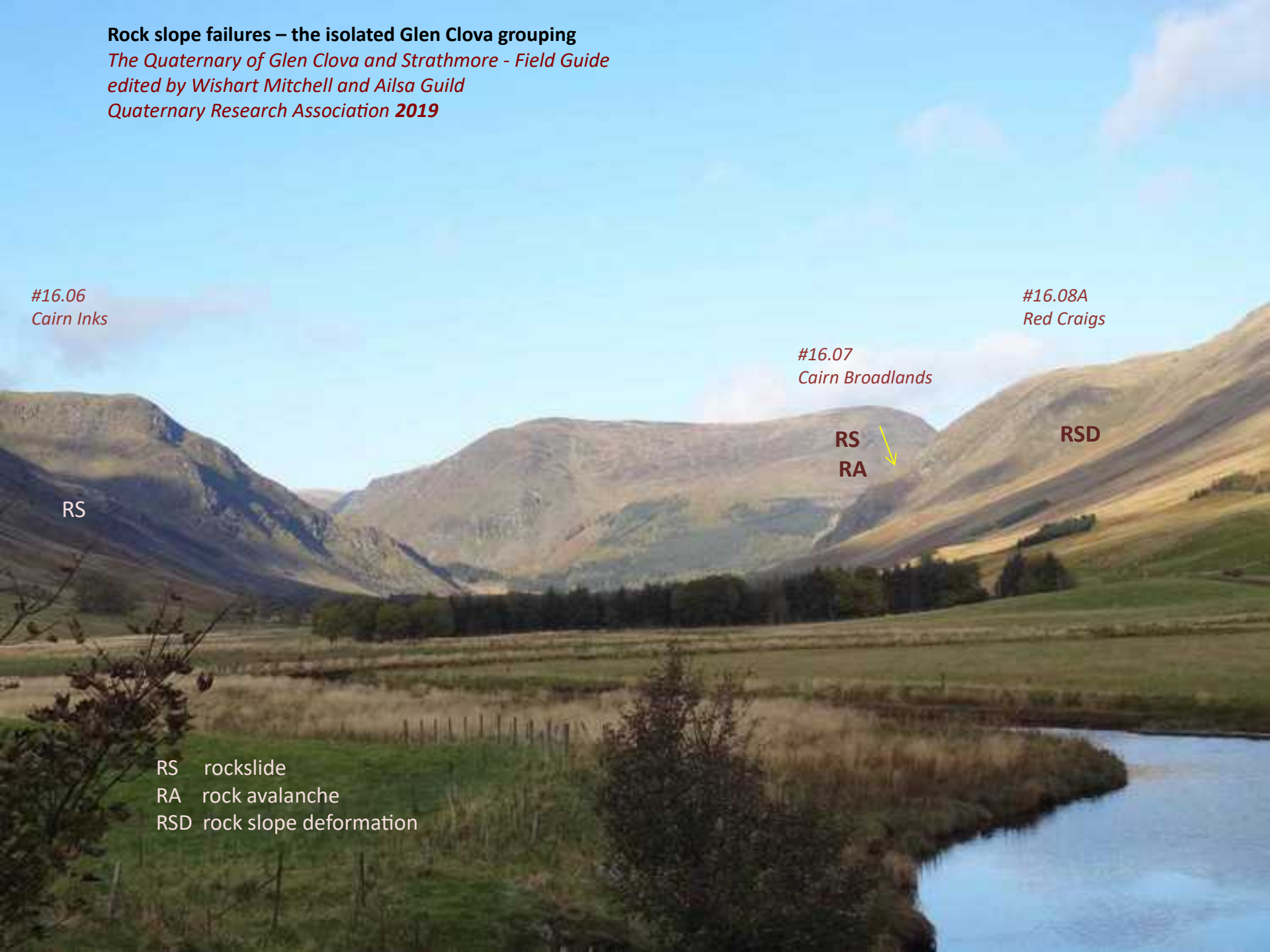
Glen Coe

The road has been closed to allow workmen to clear the landslip

The A83 in Argyll could be closed for up to 24 hours after a landslide.

Rock slope failures – the isolated Glen Clova grouping

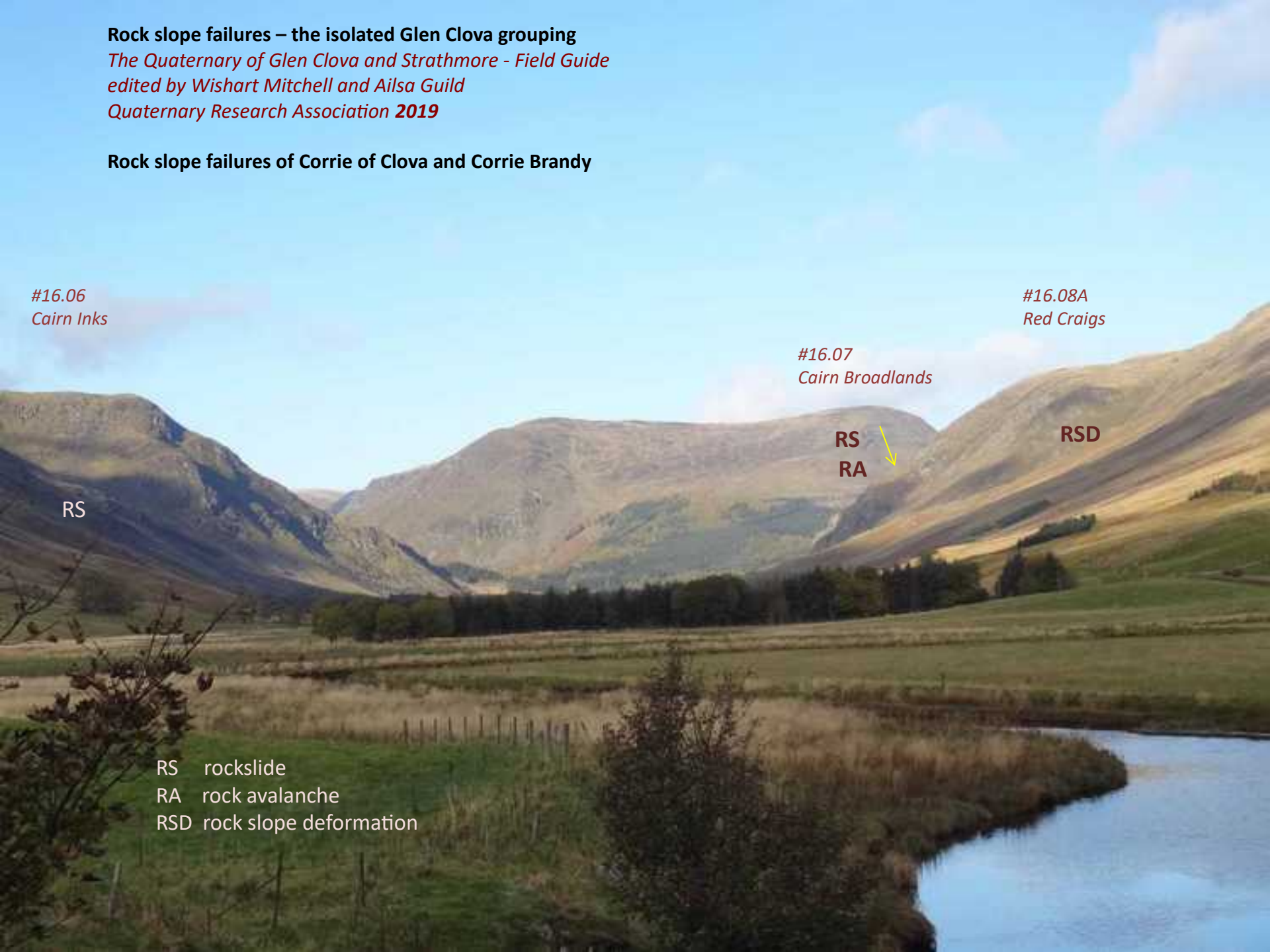
The Quaternary of Glen Clova and Strathmore - Field Guide
edited by Wishart Mitchell and Ailsa Guild
Quaternary Research Association ***2019***



Rock slope failures – the isolated Glen Clova grouping

The Quaternary of Glen Clova and Strathmore - Field Guide
edited by Wishart Mitchell and Ailsa Guild
Quaternary Research Association ***2019***

Rock slope failures of Corrie of Clova and Corrie Brandy



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Landscape evolution of the Mounth

Rock slope failures – the isolated Glen Clova grouping

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edited by Wishart Mitchell and Ailsa Guild
Quaternary Research Association ***2019***

Landscape evolution of the Mounth

Adrian Hall

Glen Clova RSF mini-cluster

22 RSFs *- total 2 km²*

half RSF average size 0.20 km²

6 identified by Graham Holmes PhD 1984

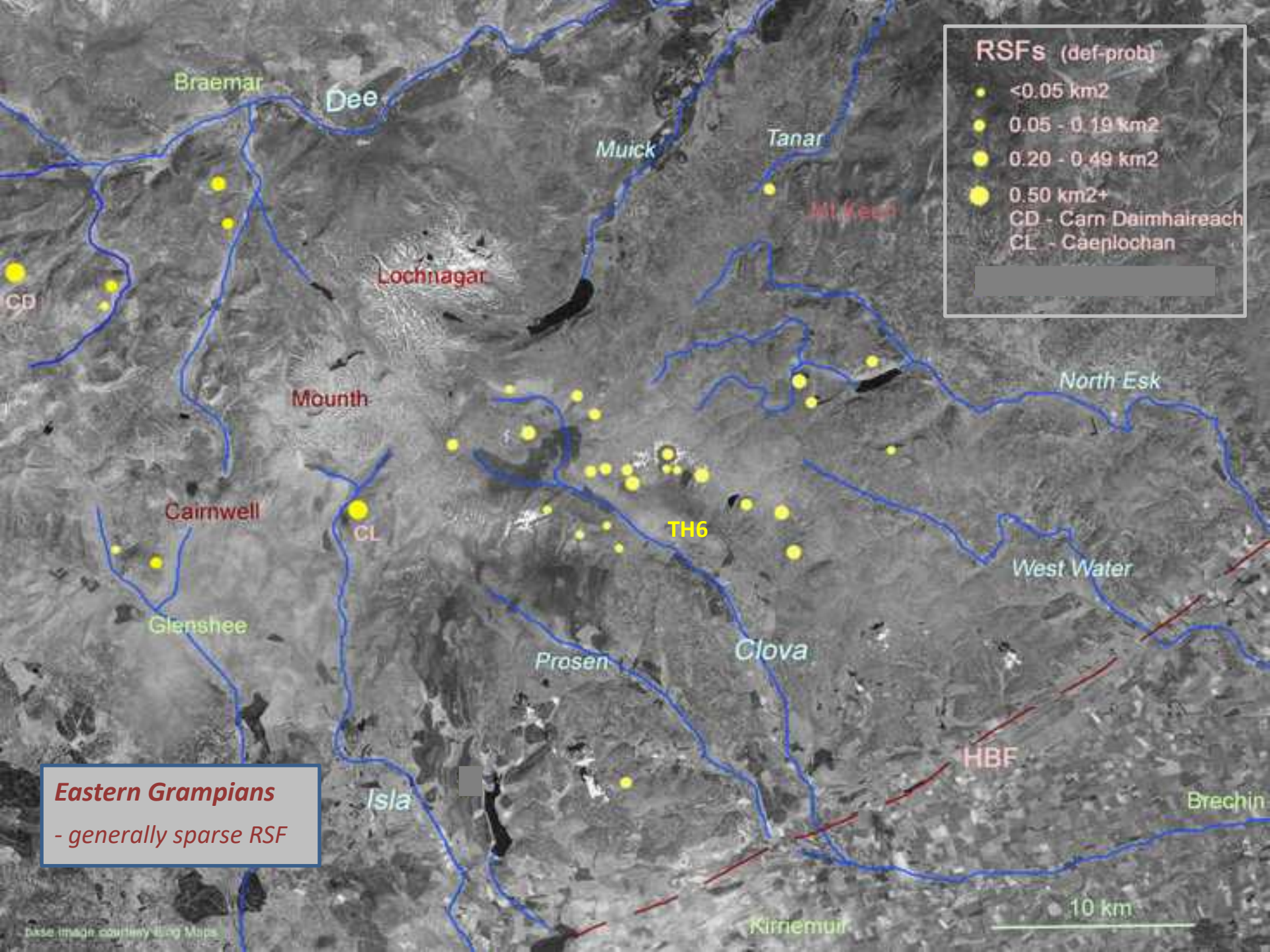
Cairn Broadlands ***0.25 km²*** *175 larger...*

Glen Clova RSF mini-cluster

22 RSFs *- total 2 km²*

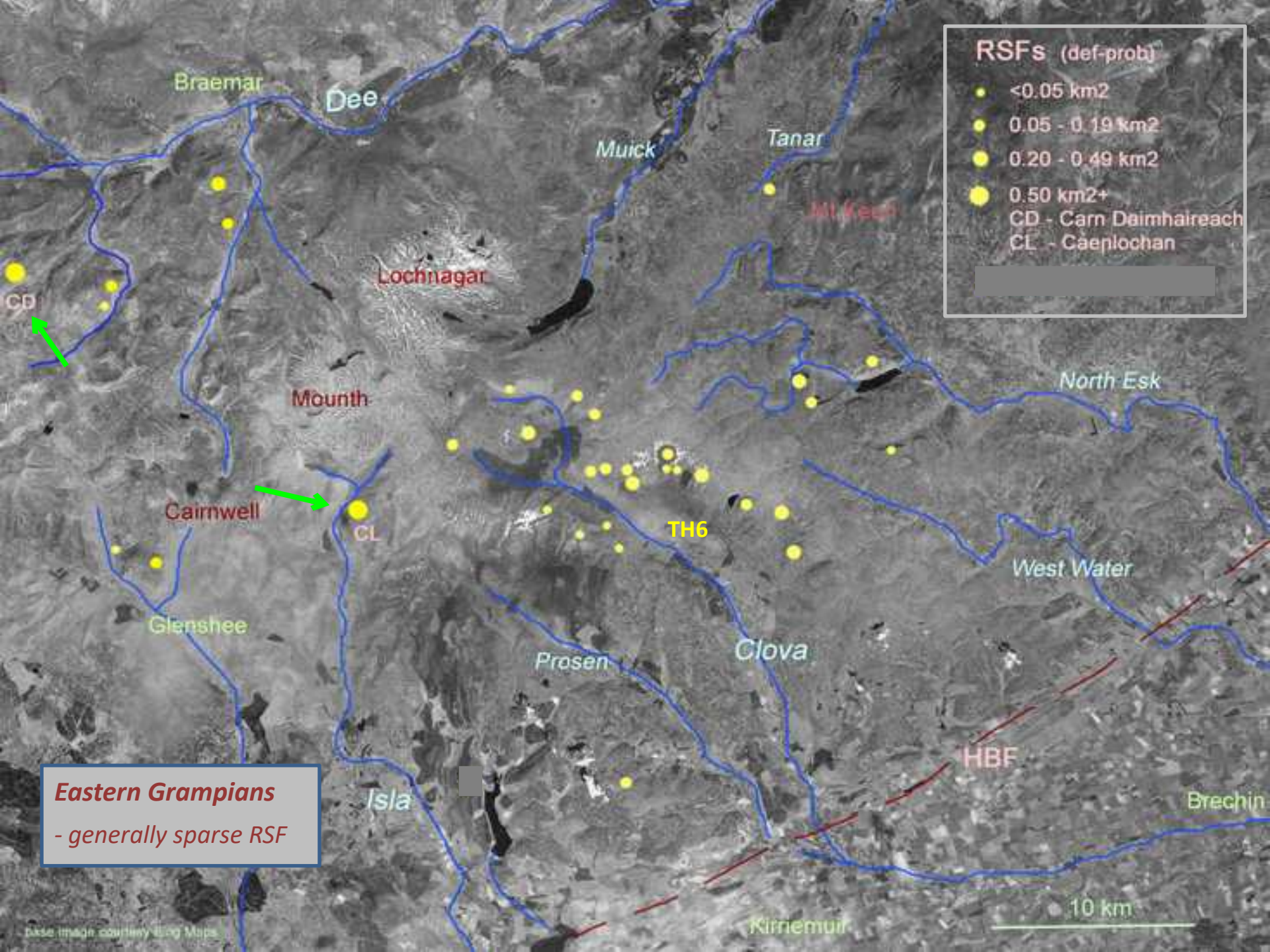
half RSF average size 0.20 km²

6 identified by Graham Holmes PhD 1984



Eastern Grampians

- generally sparse RSF



Eastern Grampians

- generally sparse RSF

photo (c) Wishart Mitchell

#16.02 Caenlochan SE

0.72 km²

Glen Isla

#15.21 Carn Damhaireach

'Top of the Battery'

1.07 km²

Glen Ey, Deeside

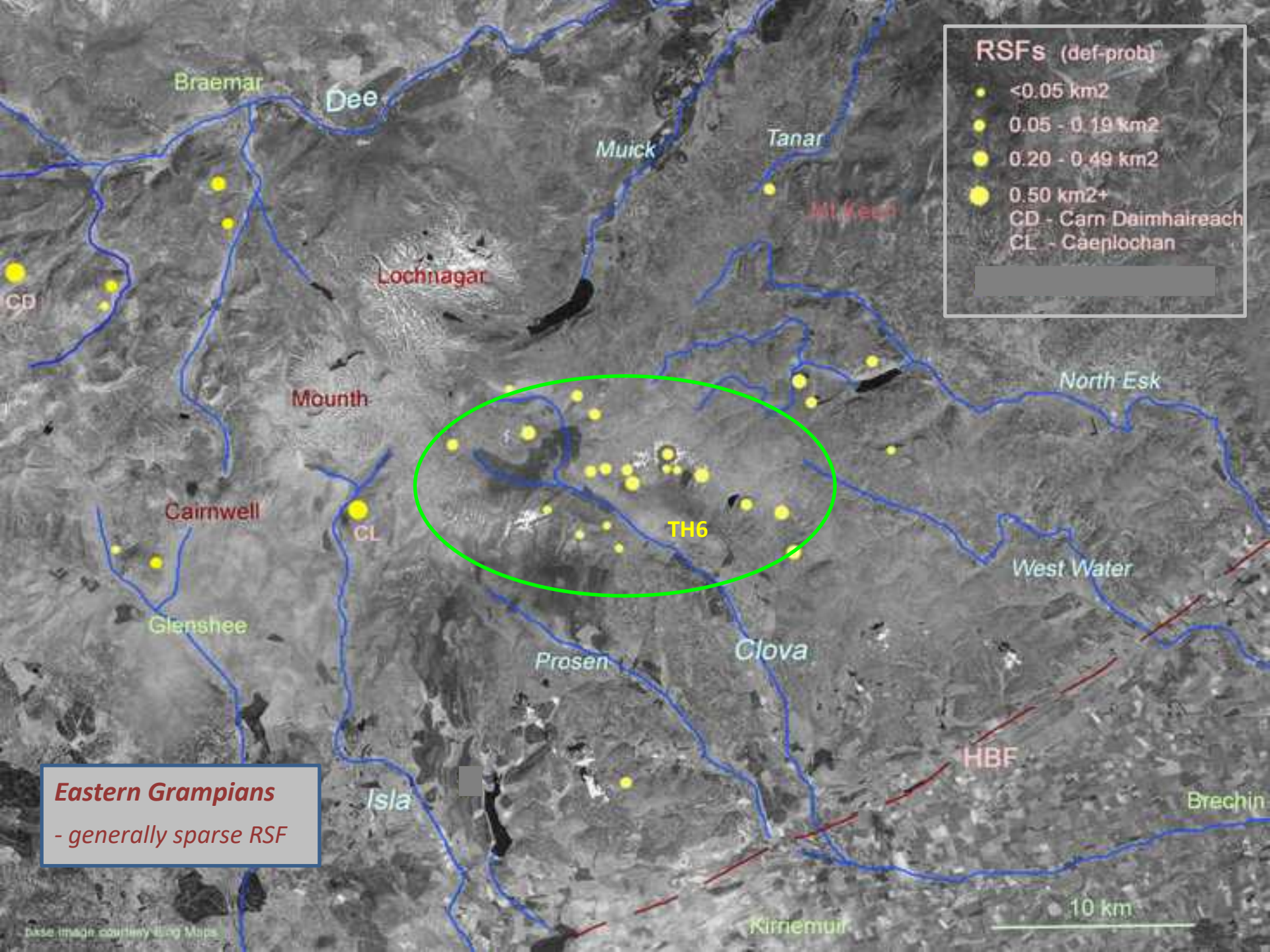
photo (c) Bert Barnett

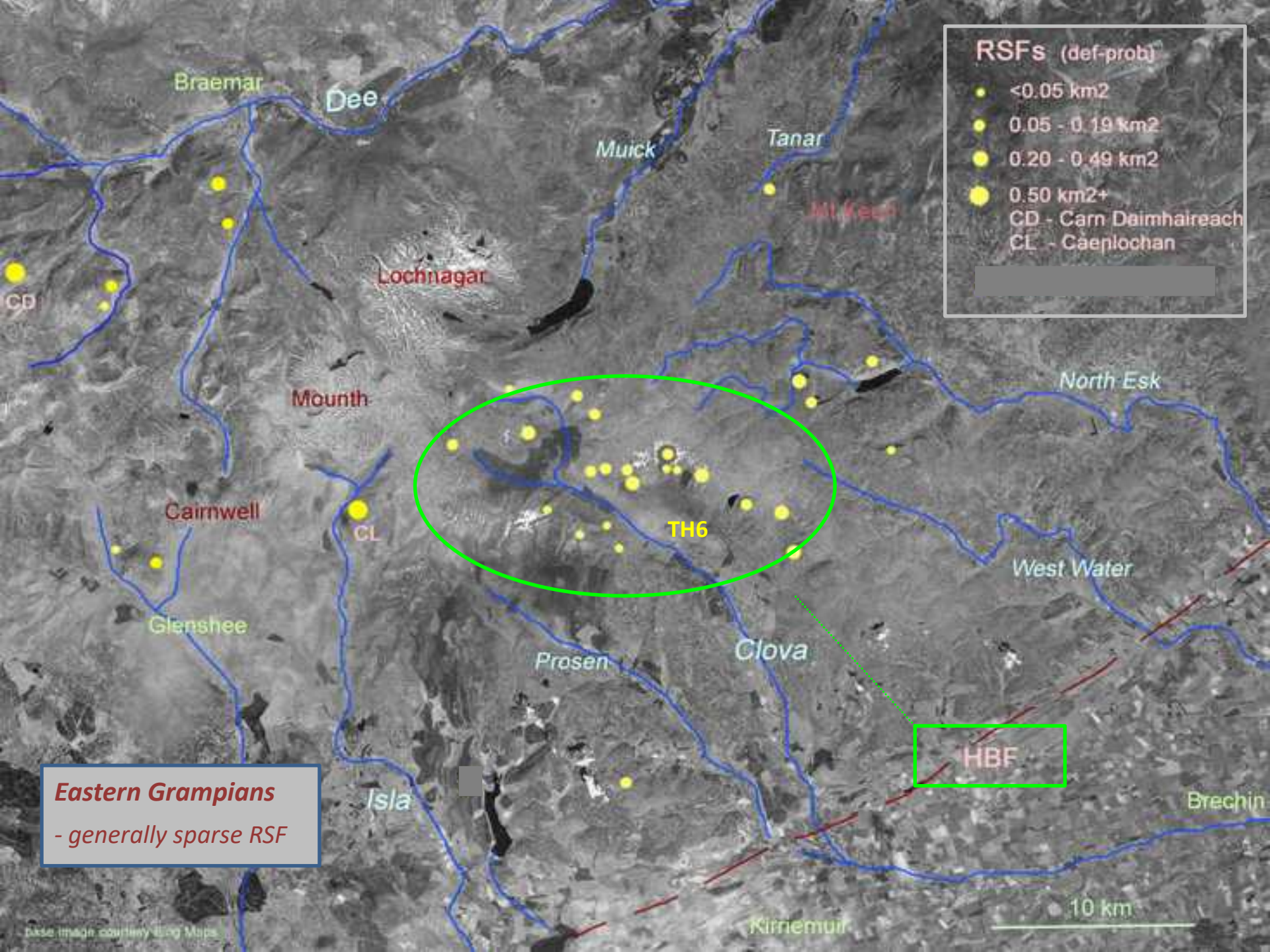
#15.21 Carn Damhaireach

'Top of the Battery'

1.07 km²

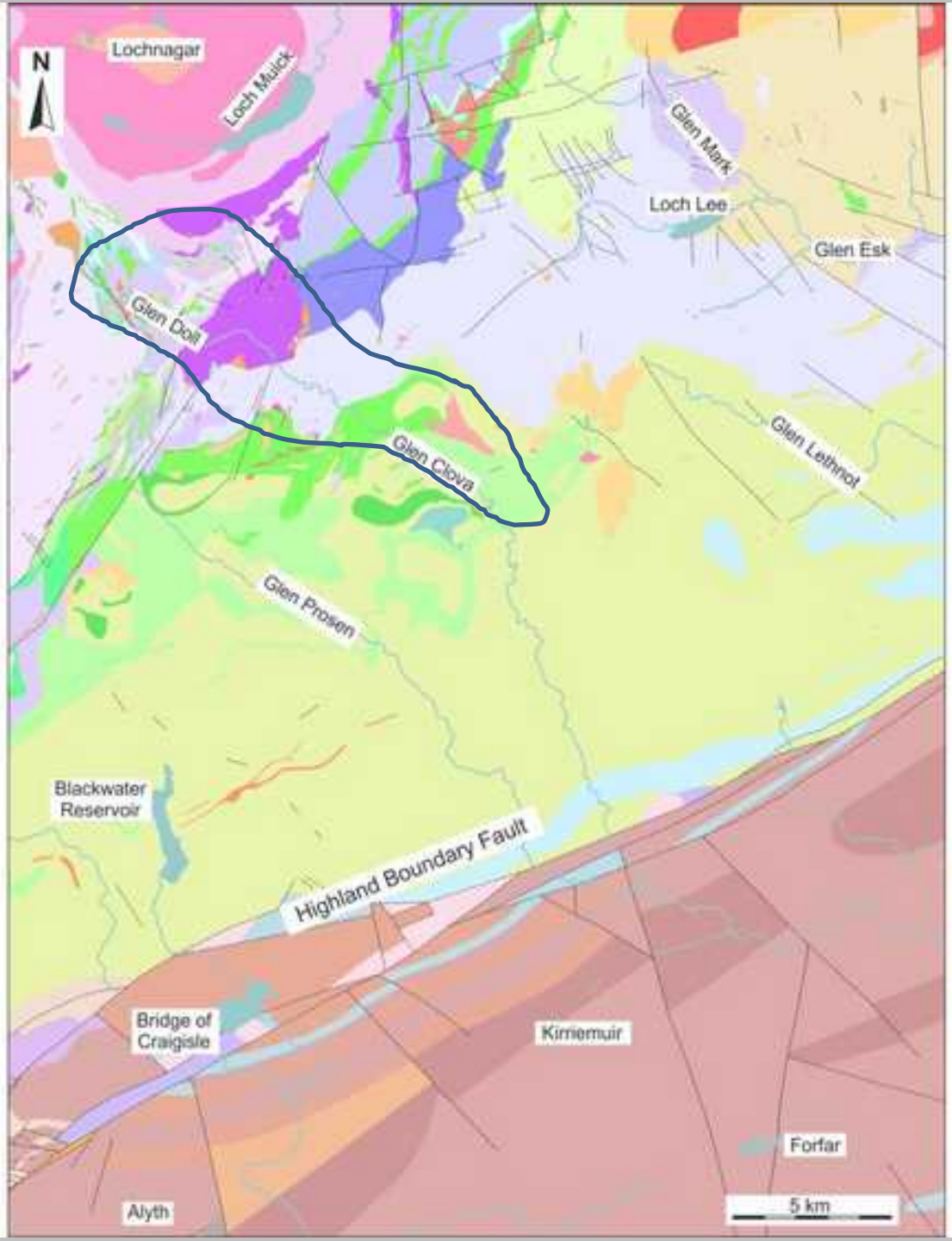
Glen Ey, Deeside


RSFs (def-prob)
<0.05 km2
0.05 - 0.19 km2
0.20 - 0.49 km2
0.50 km2+
CD - Carn Daimhaireach
CL - Caenlochan
Braemar
Dee
Muick
Tanar
Lochnagar
CD
Mounth
North Esk
Cairnwell
CL
TH6
West Water
Glenshee
Prosen
Clova
HBF
Isla
Brechin
Kirriemuir
10 km
Eastern Grampians
- generally sparse RSF



Eastern Grampians

- generally sparse RSF



Intrusive igneous rocks

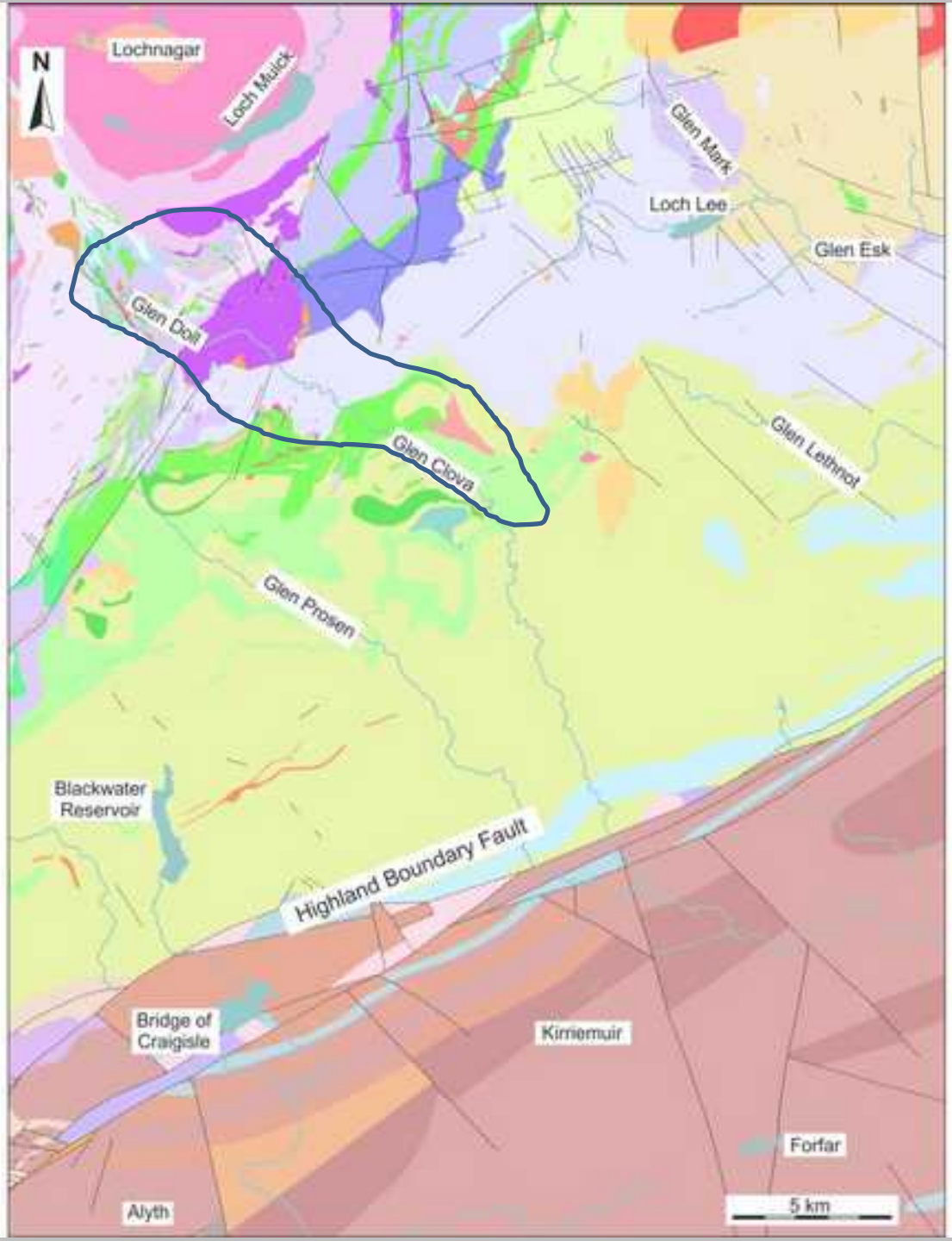
- Lochnagar Pluton (phase 2: leucogranite)
- Lochnagar Pluton (microgranite)
- Lochnagar Pluton (phase 1: biotite-granite)
- Dioritic intrusions (Glen Doll, Juan Jorge, Cul Nan Gad plutons)
- Rough Craig Intrusion (gneissose granite)
- Granitic pegmatite intrusions
- Felsite intrusions
- Cairn Trench Intrusion (granite)

Glen Clova RSF mini-cluster** and **geology

Neoproterozoic metasedimentary and meta-igneous rocks

- Glen Effock Schist Formation
- Tarfside Psammite Formation
- Glen Tanar Quartzite Member
- Neoproterozoic basic minor intrusions (amphibolites)
- Glen Lethnot Grit Formation (psammite and pelite)
- Glen Lethnot Grit Formation (pelite)
- Southern Highland Group (metalava and metatuff)
- Neoproterozoic basic minor intrusions (amphibolites)

- thrusts/slides
- major faults
- lakes
- rivers



Intrusive igneous rocks

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- Rough Craig Intrusion (gneissose granite)
- Granitic pegmatite intrusions
- Felsite intrusions
- Cairn Trench Intrusion (granite)

Glen Clova RSF mini-cluster** and **geology

- ***not** obviously related to lithology*
- *except absent on granite*
- *no marked structural response*
  (no big mapped faults, possible transverse shears)
- *no RSFs near Highland Boundary Fault*

Neoproterozoic metasedimentary and meta-igneous rocks

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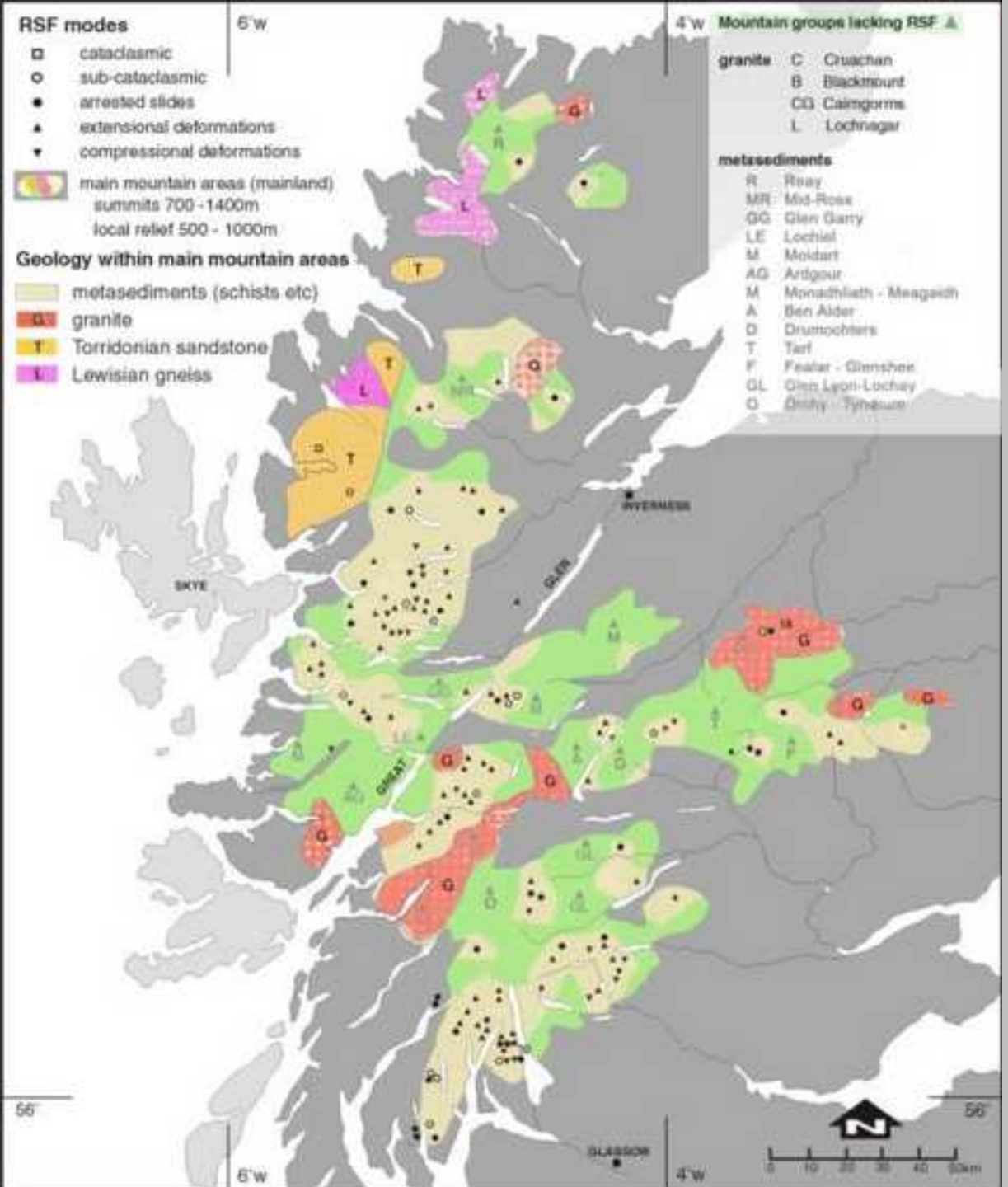
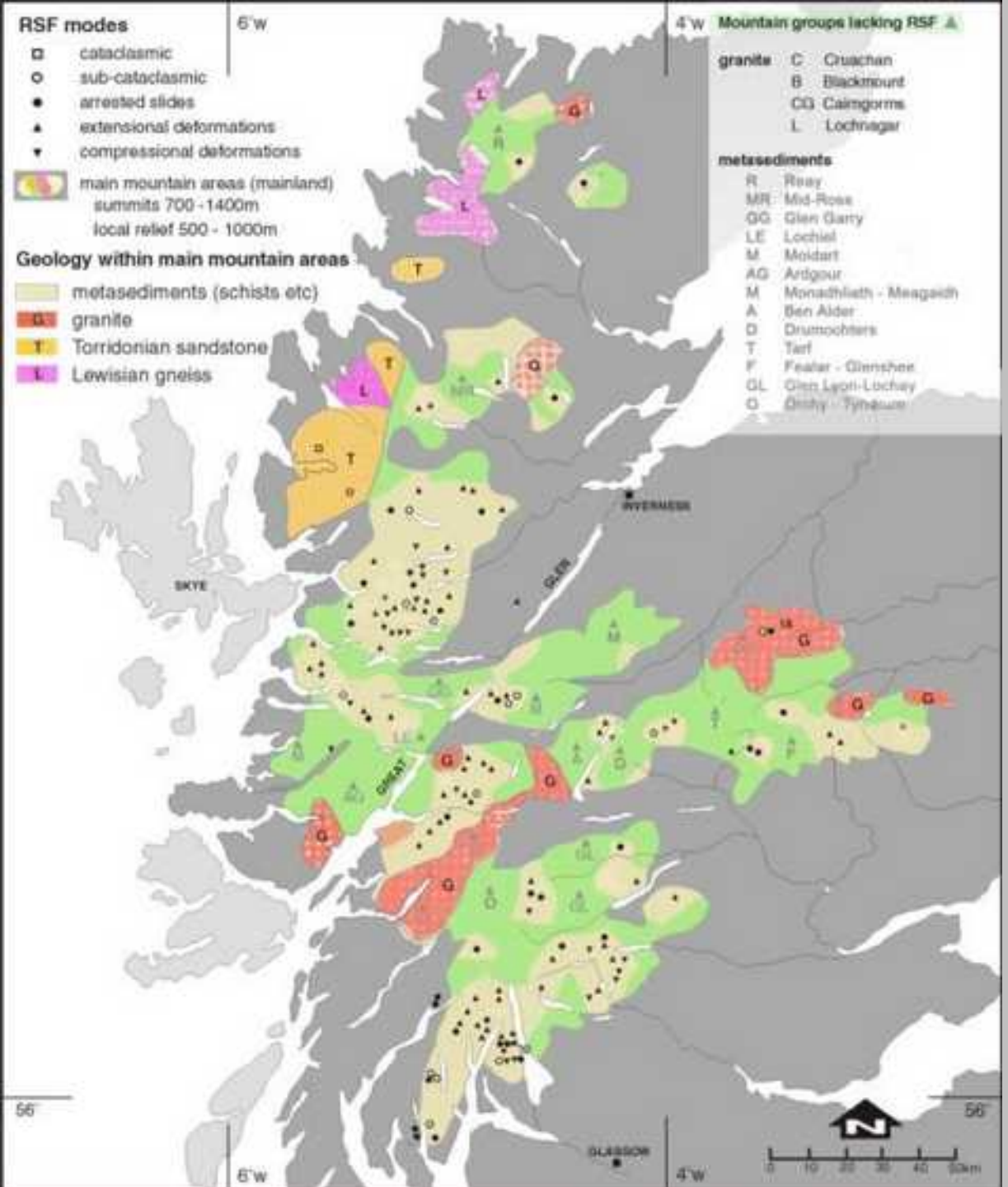
- thrusts/slides
- major faults
- lakes
- rivers



RSF and geology

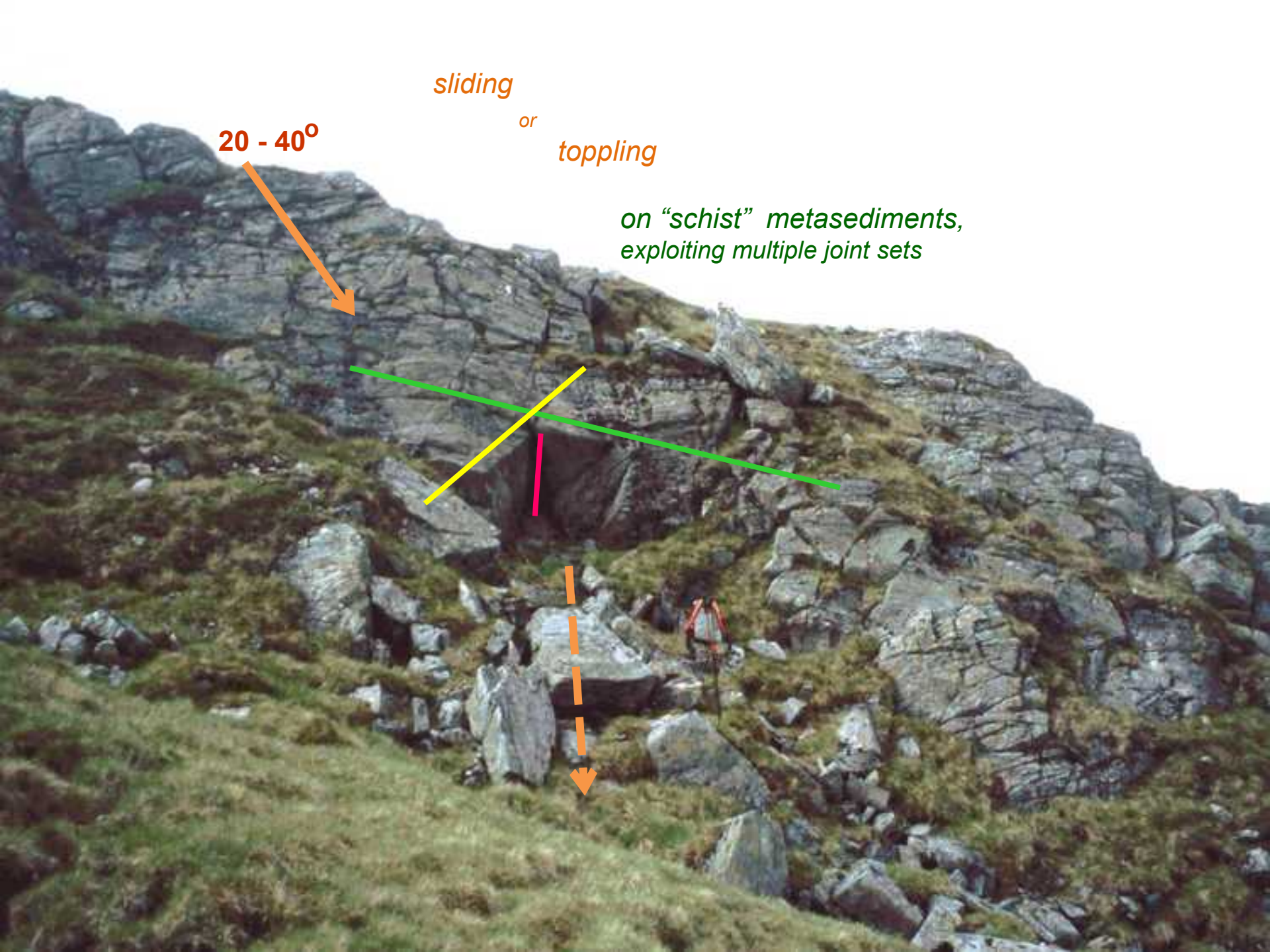
- ***dense*** *and* ***sparse*** *on schists*
- *occurs on all other lithologies*



RSF and geology

- ***dense*** *and* ***sparse*** *on schists*
- *occurs on all other lithologies*

- *a* ***secondary control*** *on RSF mode*

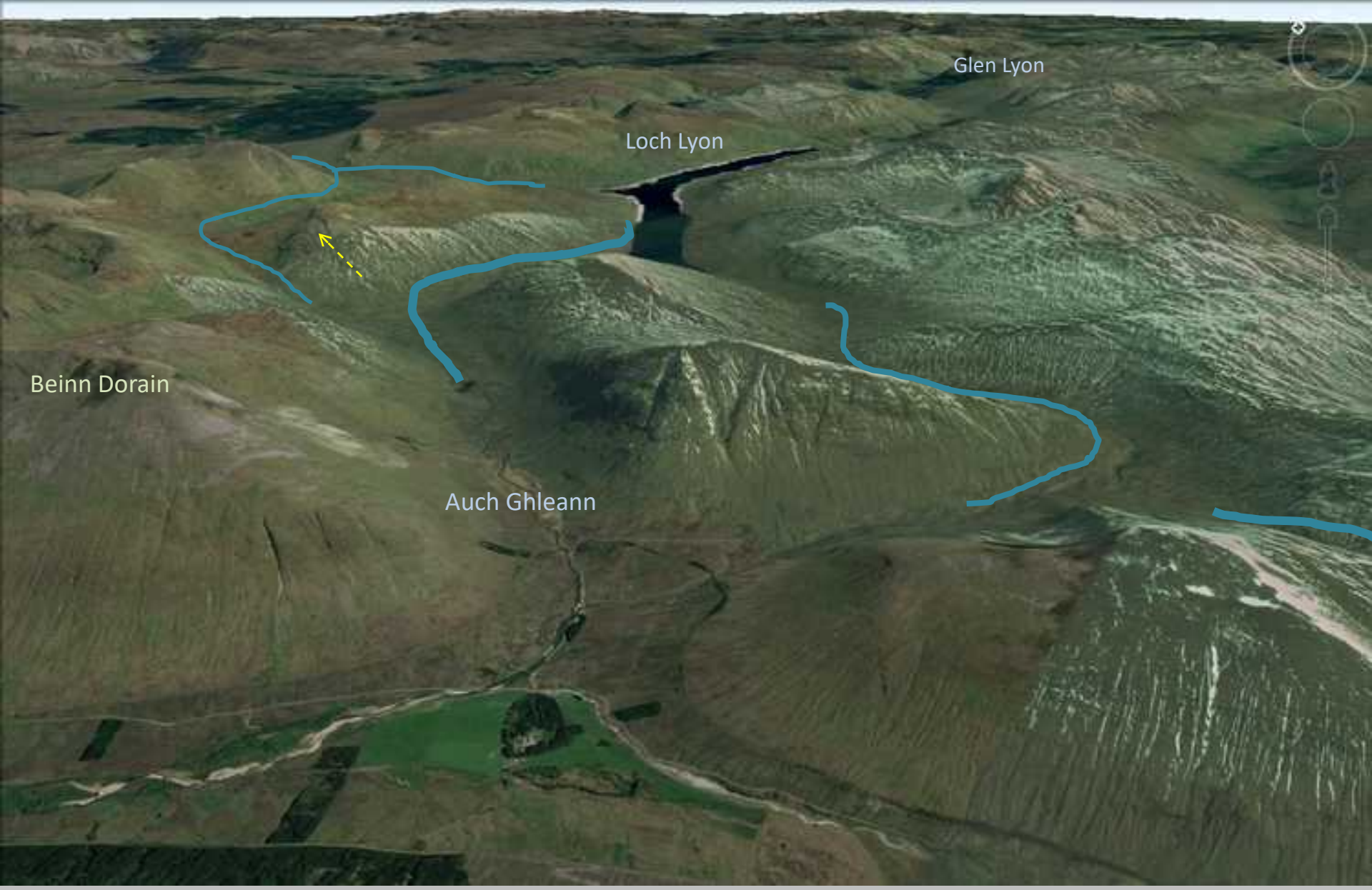

sliding
or
toppling
20 - 40°
on “schist” metasediments,
exploiting multiple joint sets

West Highland Railway
Horseshoe Curve

West Highland Way

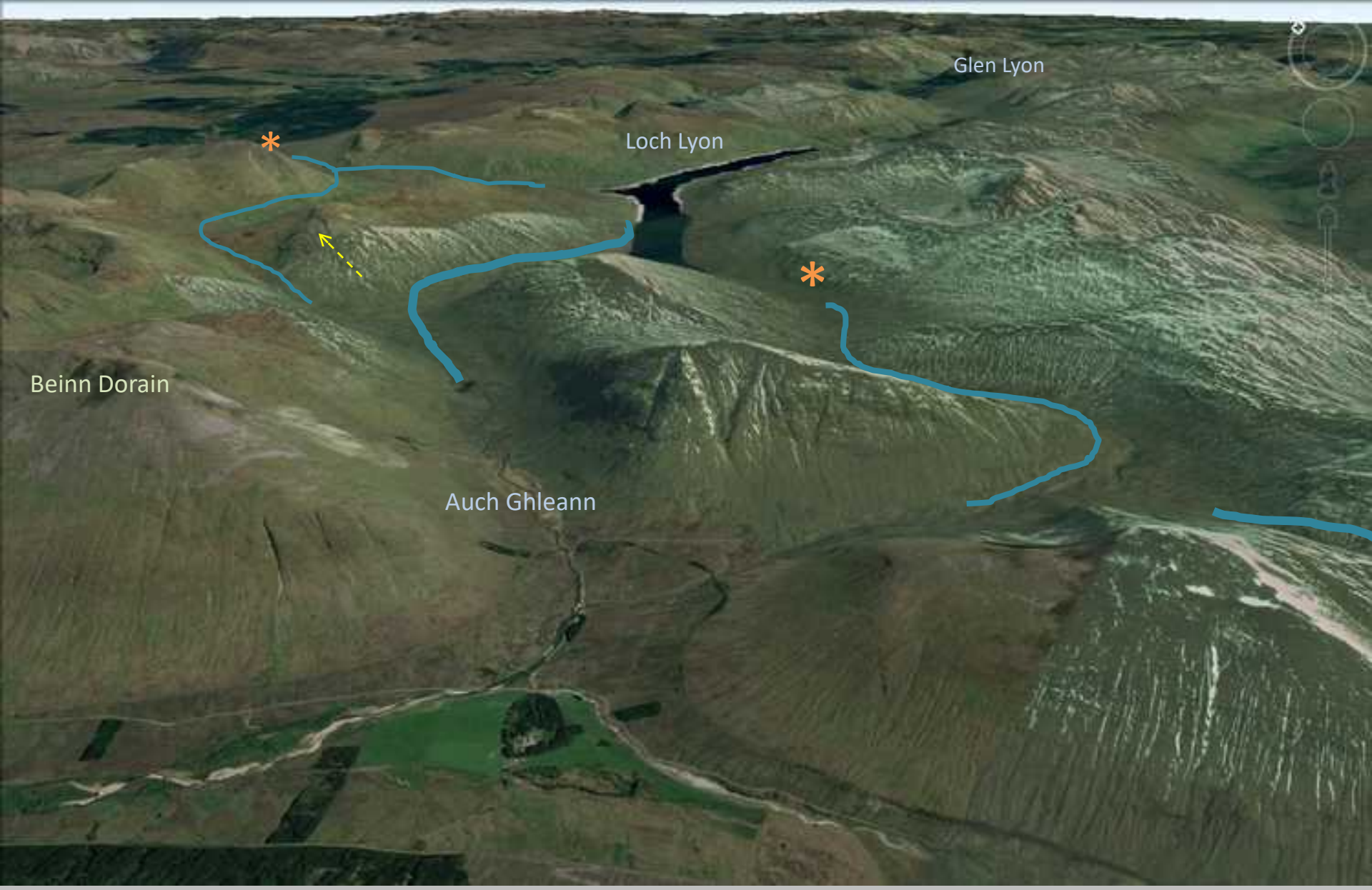
#3.08 Beinn a' Chuirn

Beinn Mhanach Orchy Munros



***glacial breaches** of Main Highland Watershed*

west - River Orchy, Loch Awe *east - Glen Lyon, River Tay*



***glacial breaches** of Main Highland Watershed*

***west** - River Orchy, Loch Awe* ***east** - Glen Lyon, River Tay*

#3.08A-C Beinn a' Chreachain
Orchy - Lyon

#3.08A-C Beinn a' Chreachain
Orchy - Lyon

Millennium Tent

#3.08A-C Beinn a' Chreachain
Orchy - Lyon

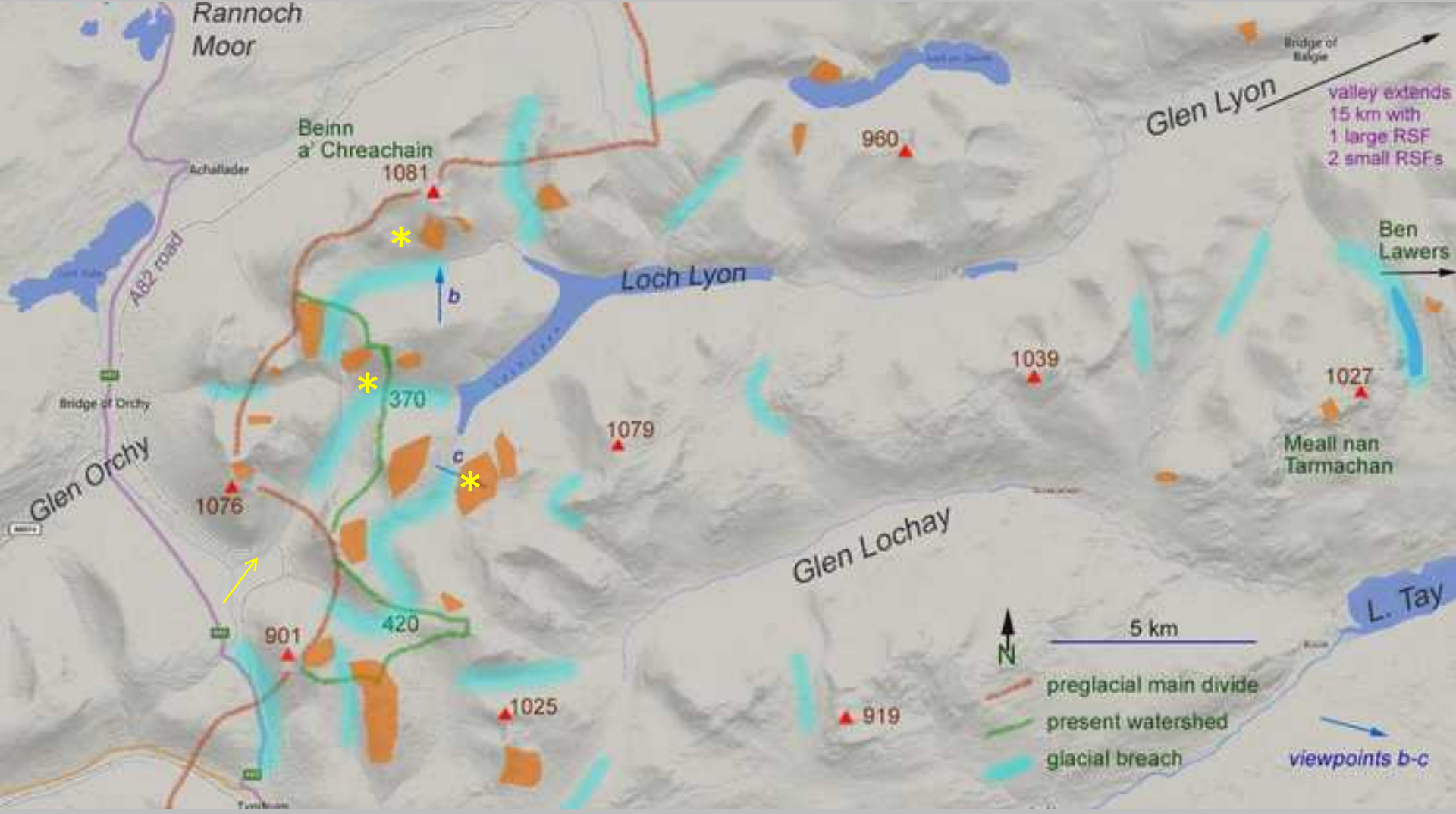
domed peak >>> 'horn'

#3.08A-C Beinn a' Chreachain

Orchy - Lyon

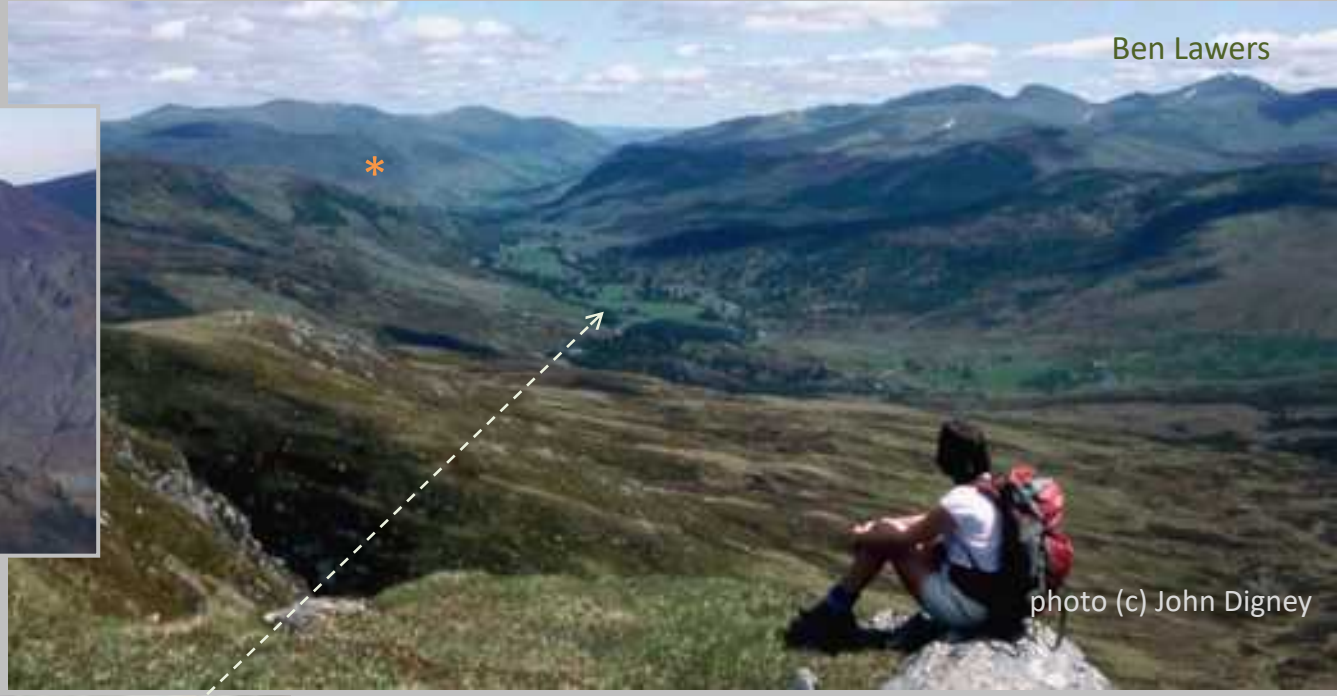
#3.07 Meall Tionail - Coire Chirdle
Orchy - Lyon

#3.07 Meall Tionail - Coire Chirdle
Orchy - Lyon



Orchy - Lyon RSF cluster ***Glen Lyon / Lochay zone of sparsity***

14 RSFs 4 large



Glen Lyon / Lochay zone of sparsity


photo (c) John Digney


ruin is formal, devil's work
consecutive and slow -
fail in an instant no man did
slipping is crash's law
Emily Dickinson

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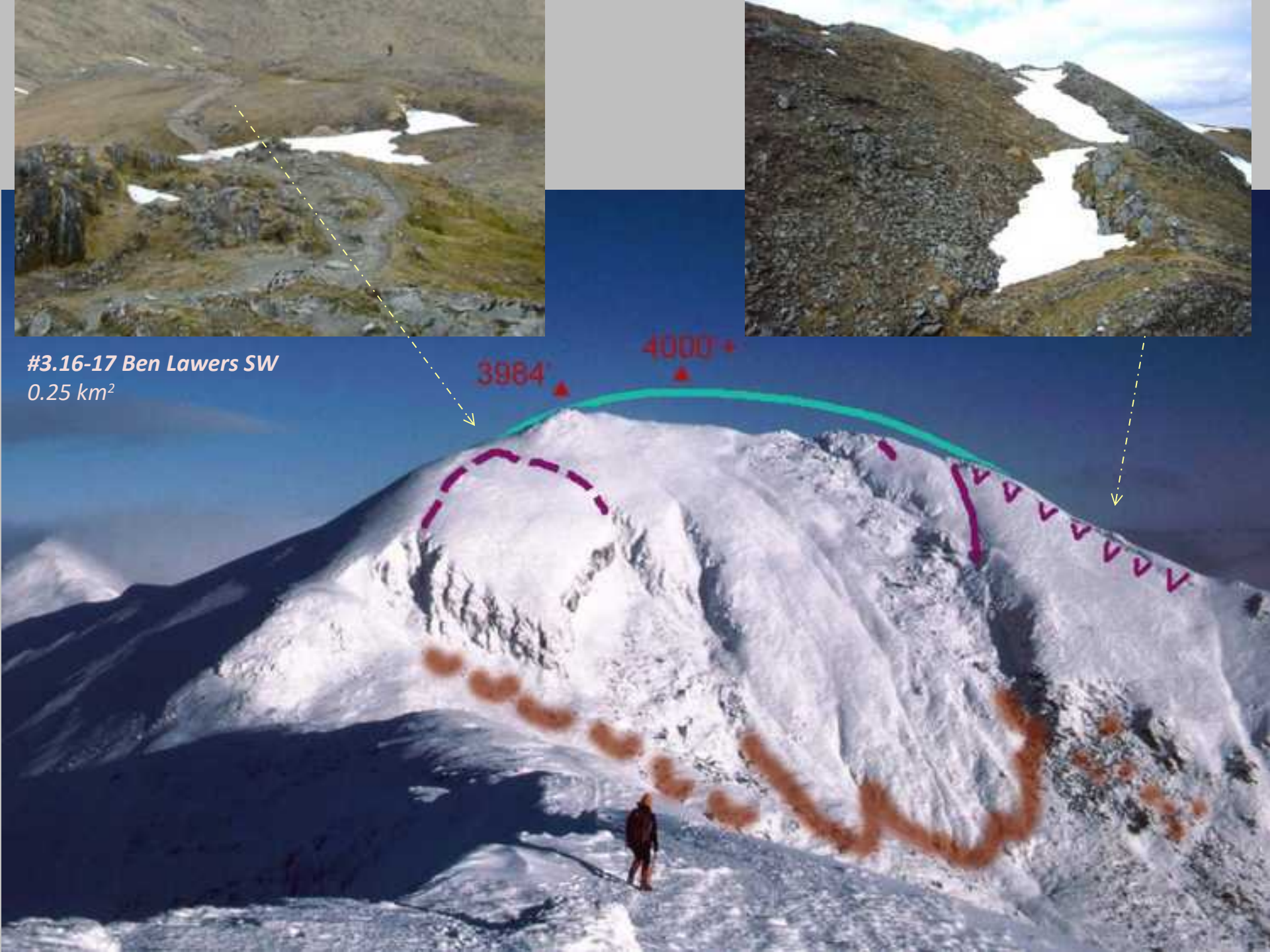
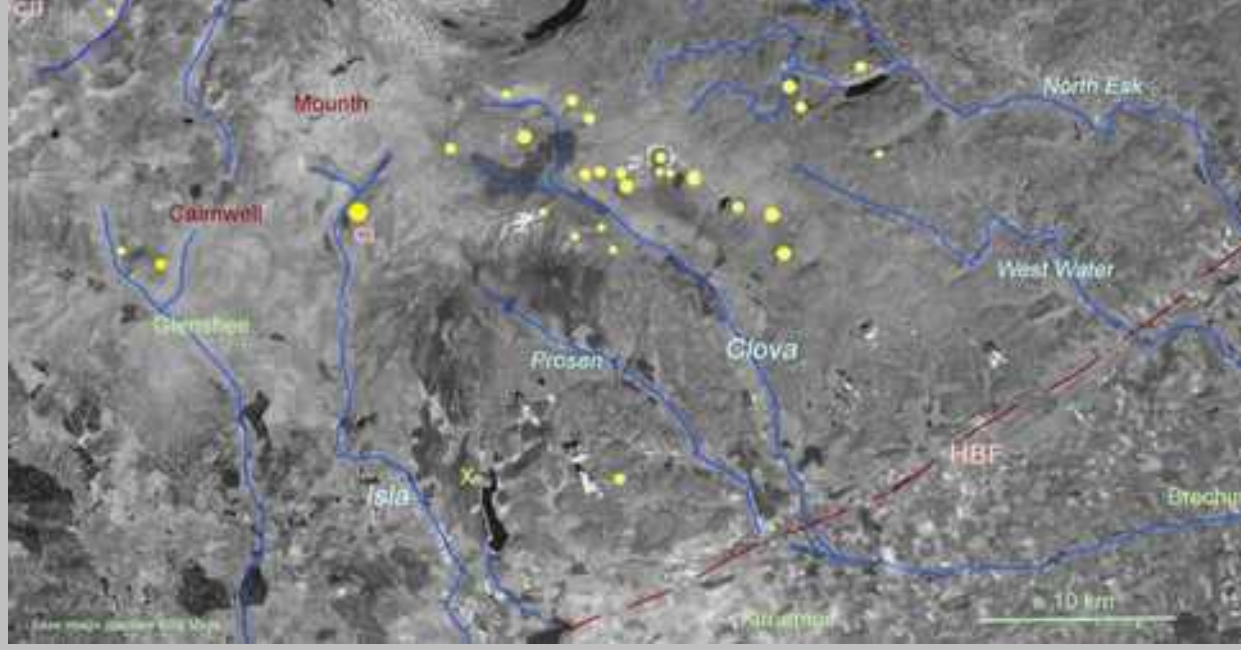


#3.16-17 Ben Lawers SW

0.25 km²

Glen Clova

- *trough-head incision*
- *cirque enlargement*

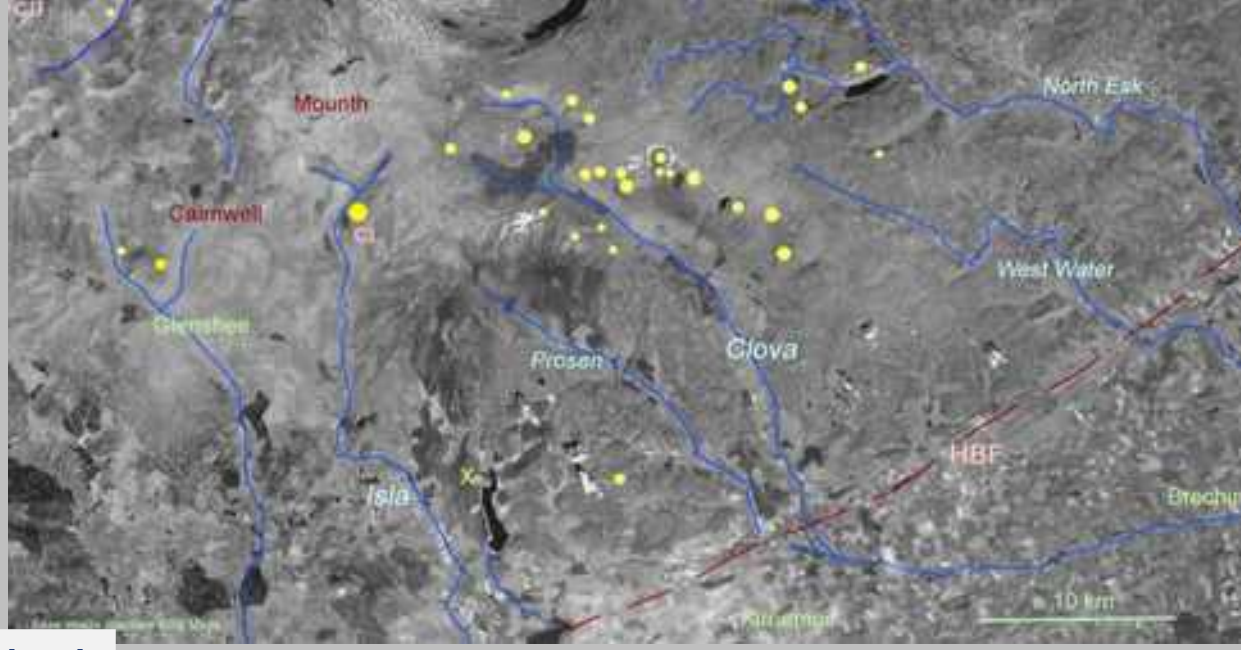


Orchy-Lyon breachplex

- *late-stage glacial transfluence*

Glen Clova

- *trough-head incision*
- *cirque enlargement*

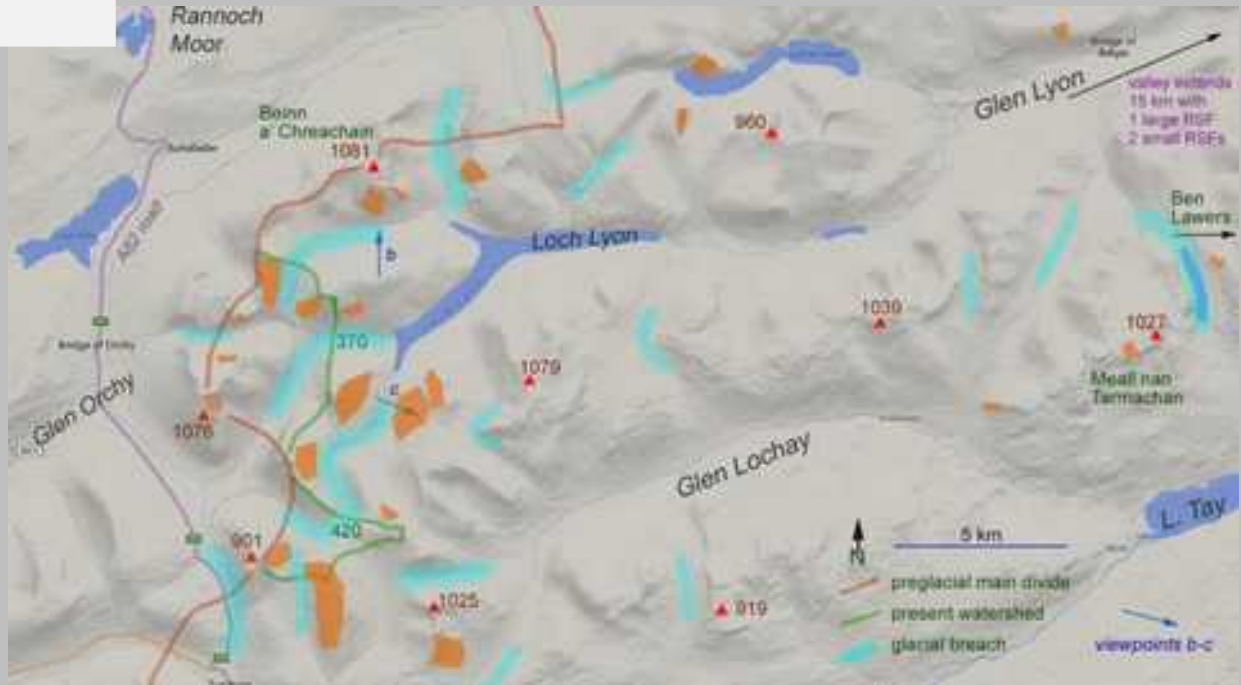


CEB – Concentrated Erosion of Bedrock

[CEB] : [RSF]

Orchy-Lyon breachplex

- *late-stage glacial transfluence*



Geomorphology 340 (2019) 202–233

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Rock slope failure in the British mountains

David Jarman [a,*], Stephan Harrison [b]

[a] Mountain Landform Research, Scotland IV7 8JJ, UK
[b] College of Life and Environmental Sciences, Exeter University, Penryn, Cornwall TR10 9EZ, UK

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Rock slope failure
Concentrated erosion of bedrock
Paraglacial
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ABSTRACT

In this first full review of extant Quaternary Rock Slope Failure (RSF) in the British mountains, we provide a near-complete inventory of 1082 sites, 40% being rock slope deformations, 40% arrested rockslides, and 20% rock avalanches. Current RSF activity is negligible, and this relict population is predominantly paraglacial, with a parafluvial minority. Its spatial distribution is perplexing, with RSF density varying greatly, both regionally and locally. In the Scottish Highlands, eight main clusters account for 76% of RSF area in 15% of the montane area. Local concentrations occur in all the British ranges, across high and low relief, in core and peripheral locations, and on varied geological and glaciological domains; as conversely do extensive areas of sparsity, even in similar lithologies. Generic interpretations are thus precluded. Geology is only a secondary control. An association with Concentrated Erosion of Bedrock (CEB) is proposed, as a driver of intensified slope stresses. CEB is most evident at those glacial breaches of main divides where the most vigorous recent incision is inferred, and also in some trough-heads. A clear association between RSFs and these 'late-developing' breaches is demonstrated in the Highlands, in 42 localities, with sparsity away from them. It is also seen in seven Lake District localities. Glaciological models identify ice sheet volatility capable of driving breach ramification. High-magnitude paleoseismic events are generally unlikely to have provoked RSF clusters; a few candidates are considered. RSF has been underrated as an agent of mountain landscape evolution in Britain; its spatio-temporal incidence may assist in calibrating regional ice sheet models, and in assessing climate change impacts. We argue that the CEB:RSF association has global relevance in identifying primary drivers of mass movement in bedrock.

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online ***Supporting Files***
- *more key figures,*
- *slide sets for typical RSFs and main clusters*

(also available on ***ResearchGate*** *site)*

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Montane Rock Slope Failure - British Mountains ***research***

unpublished PhDs :

Watters RJ	(1972)	London	- engineering geology	20 sites analysed
Holmes G	(1984)	Edinburgh	- geomorphology	340 sites (20 analysed)
Fenton CF	(1992)	Glasgow	- geology / neotectonics	44 sites in NW Highlands

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published work :

BGS Memoirs

Clough	Cowal
Bailey	Ben Nevis & Glencoe - Mamores
Johnstone	West Highlands
Peacock	Glen Roy - Glen Gloy, Affric - Kintail
Merritt	Great Glen - Gaick - Beinn a' Ghlo
Krabbendam	Glen Almond

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published work :

BGS Memoirs

'the legendary CT Clough' Cowal 1897 'great landslips'

#1W37 ***Garbh*** *Loch Long*
1.75 km²

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Ballantyne CK	1986 / 91 / 97	overviews
	2013	cavities left by previous glacial cycle
	2014 etc	cosmodating (31 RSFs - rockavs only)
Jarman D	2006	Engineering Geology - Highlands overview
	2007	GCR Mass Movements - overview, 10 sites
	2009	paraglacial trough widening by RSF
	2003-2016	QRA Field Guides (6)
	2013	Geological Society of Glasgow website - Arrochar Alps

Lake District :

Wilson P	2004	Proc Cumberland Geol Soc	and site papers
& Jarman	2015 etc	QRA Field Guide	and two joint site papers

Southern Uplands / Wales : nil

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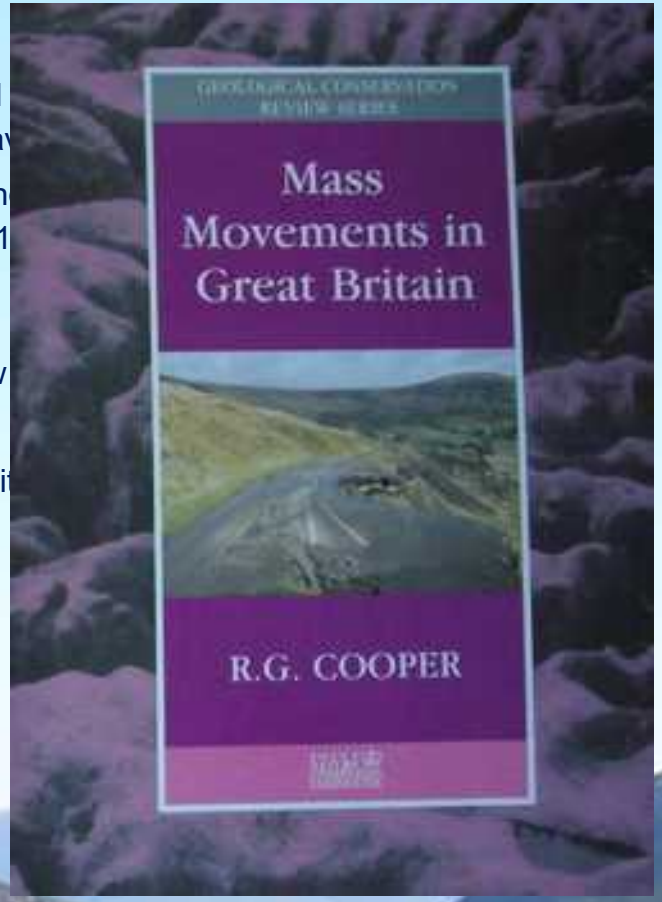
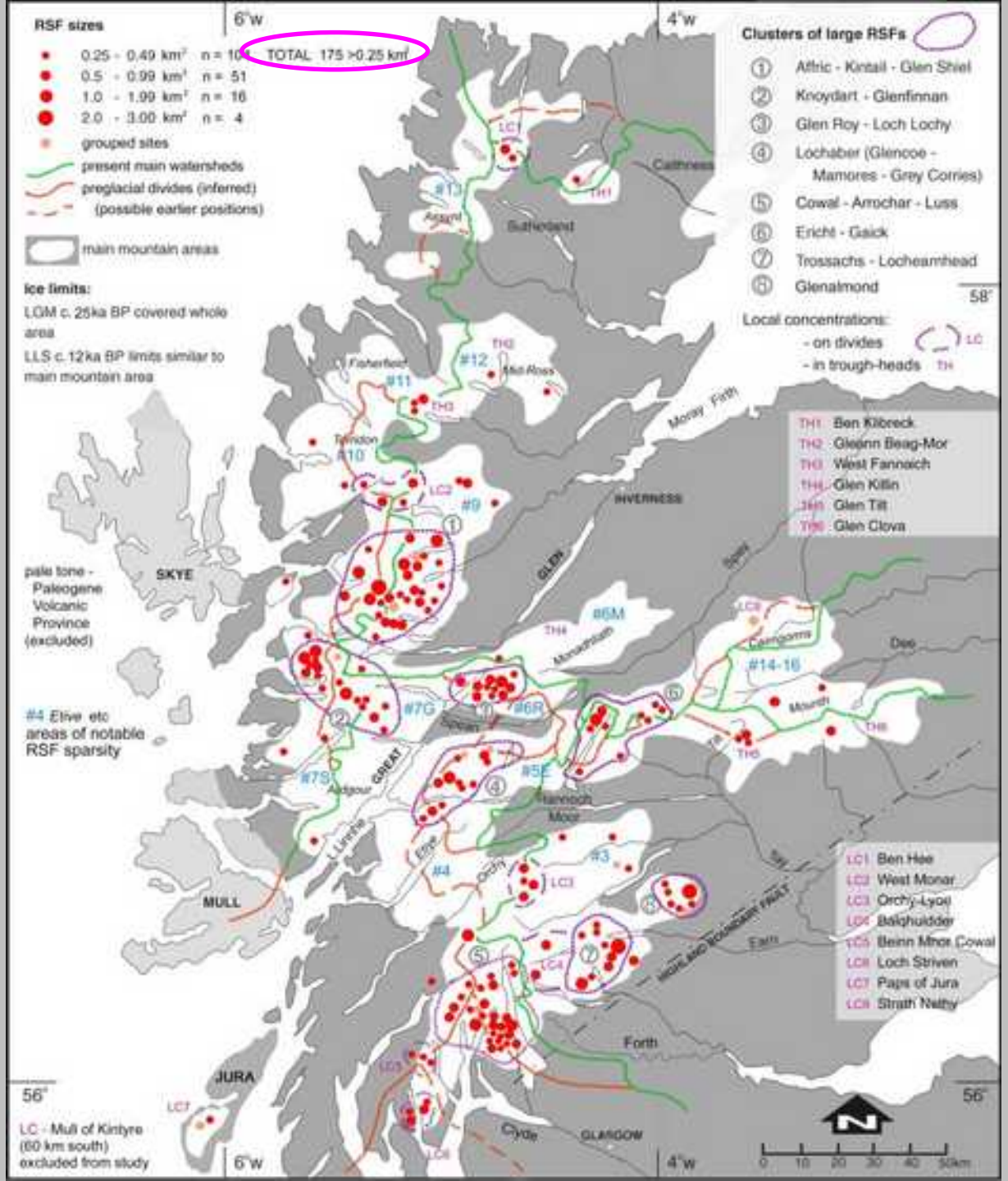


Montane Rock Slope Failure - Inventory 2018

(British mountains - pre-Devonian)

	sites >0.01km²		total area km²		average size km²		large sites >0.25 km²	
Scottish Highlands		**920**	164		0.18		177	
Southern Uplands		37	5		0.14		5	
Lake District	77	14		0.19		16		
Wales	48	8		0.17		10		
British mountains		**1082**	**191**		**0.18**		**208**	

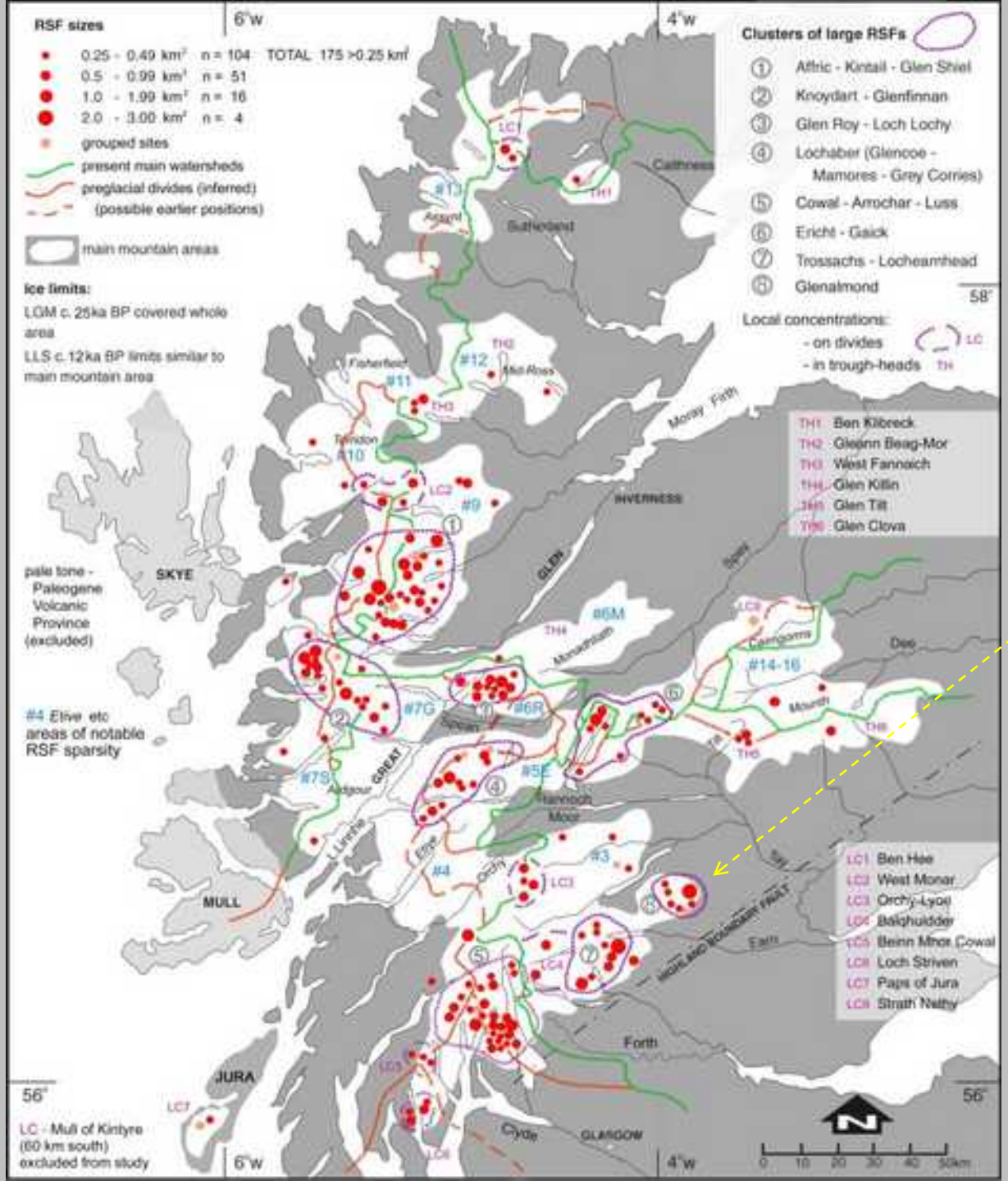
rock avalanche	20%
rockslide	40%
rock slope deformation	40%



Rock Slope Failure - clustering

Scottish Highlands :
920 sites
average size 0.18 km² max 3 km²

8 main clusters

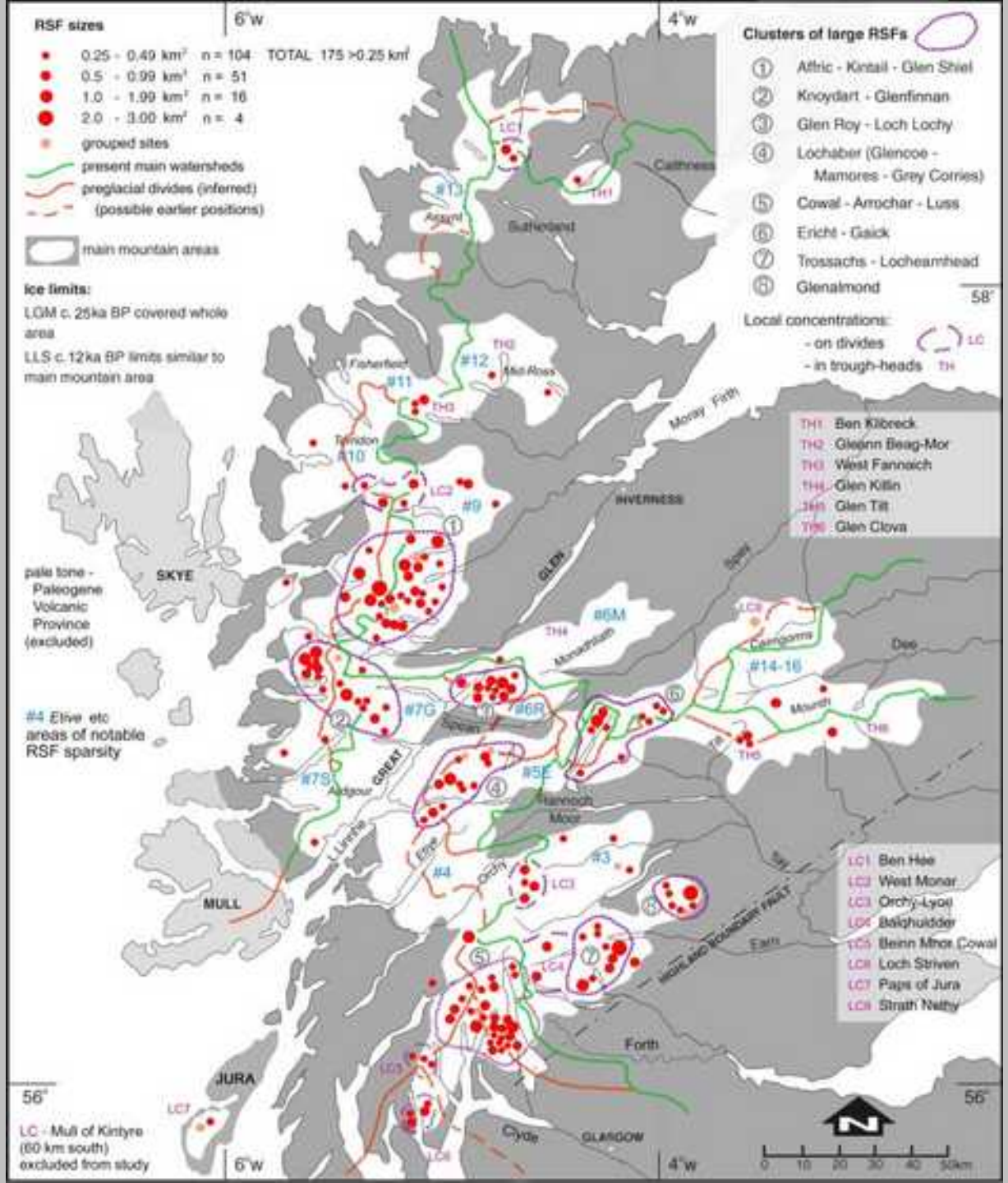


Rock Slope Failure - clustering

Scottish Highlands :
920 sites
average size 0.18 km² max 3 km²

8 main clusters

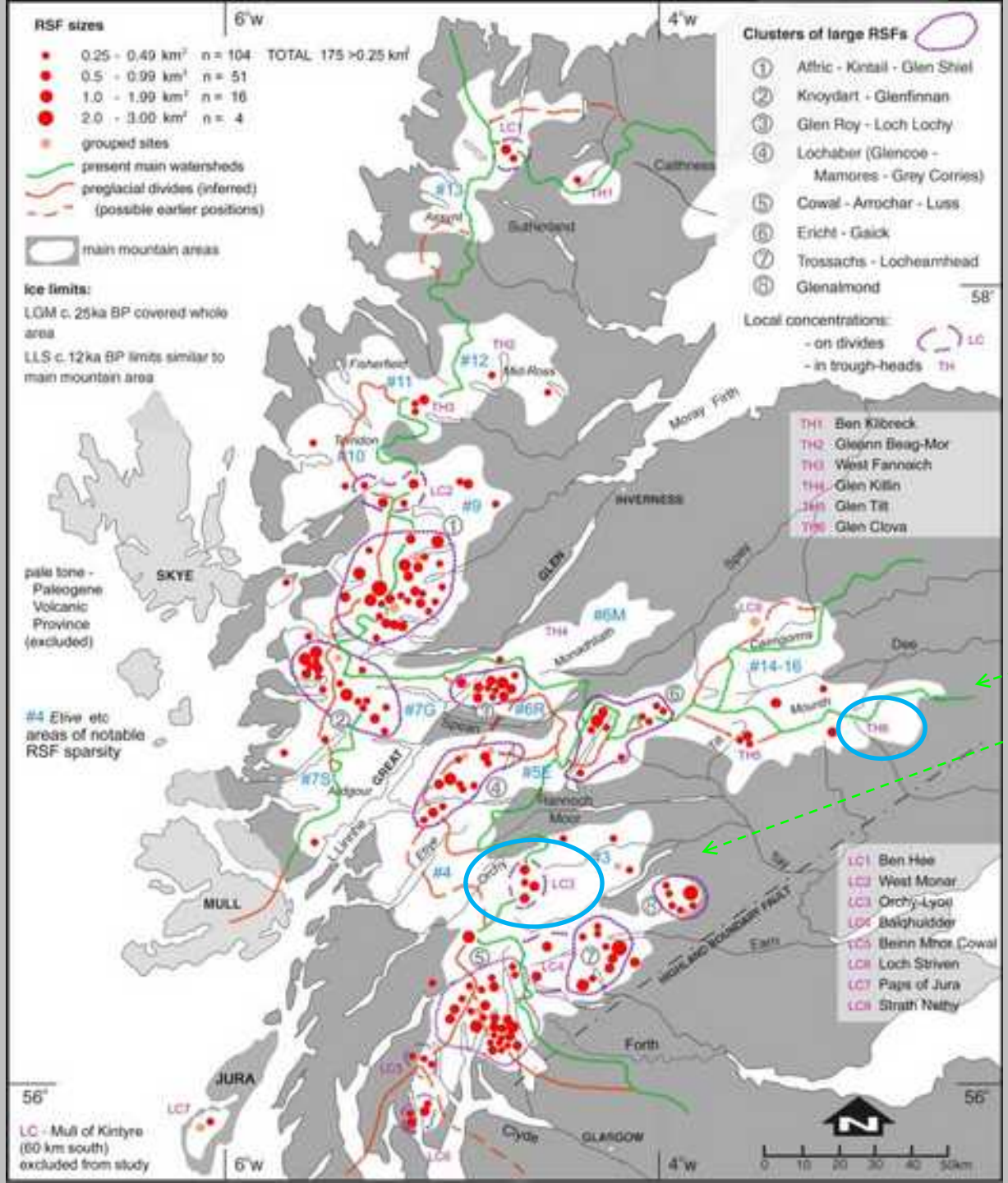
up from 7 in 2006 paper
Glen Almond



Rock Slope Failure - clustering

Scottish Highlands :
920 sites
average size 0.18 km² max 3 km²

***8 main clusters** - **76%** of RSF extent*
*- within **15%** of montane area*



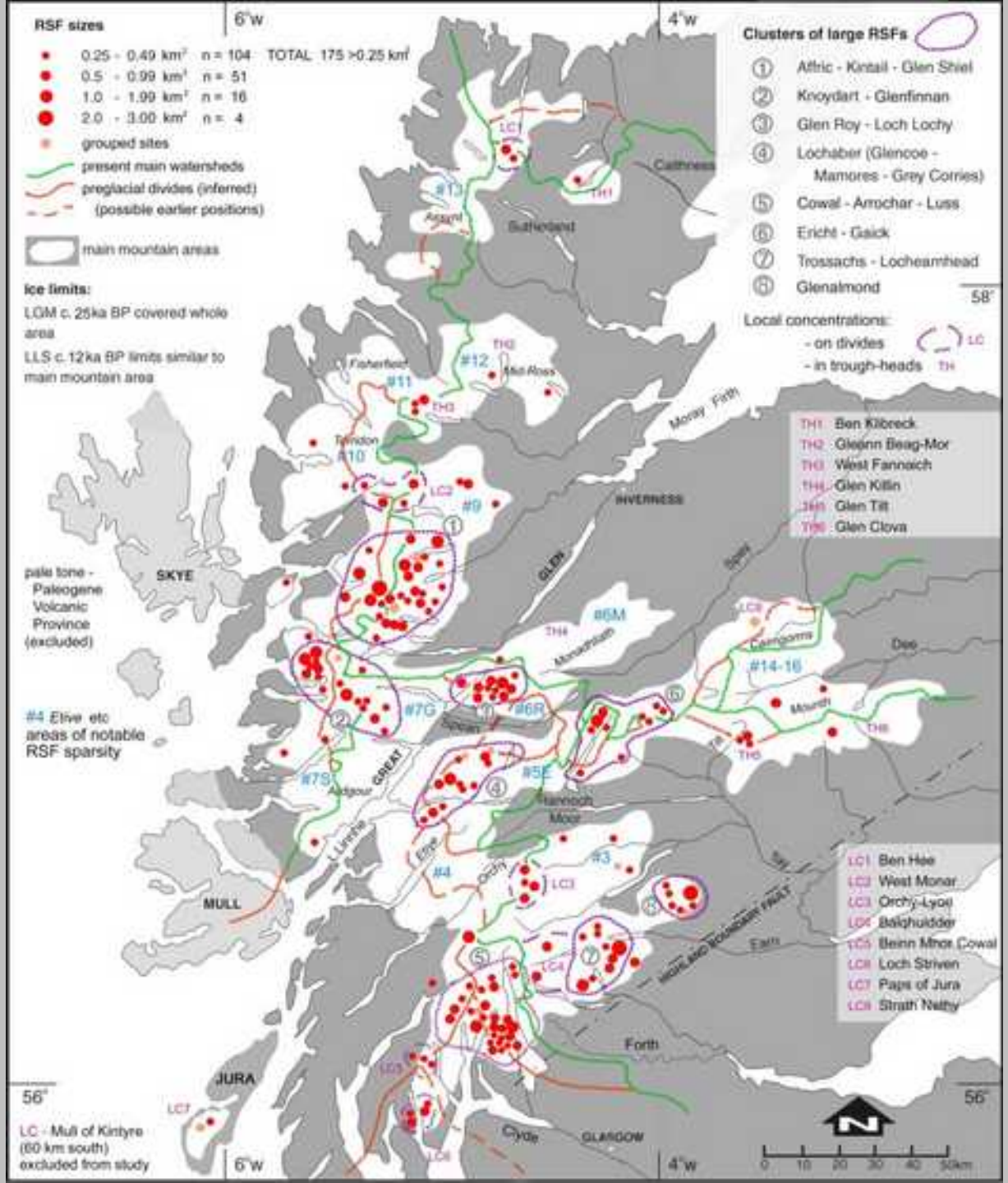
Rock Slope Failure - clustering

Scottish Highlands :
920 sites
average size 0.18 km² max 3 km²

14 Local Concentrations

TH6 Glen Clova *trough-head/cirques*

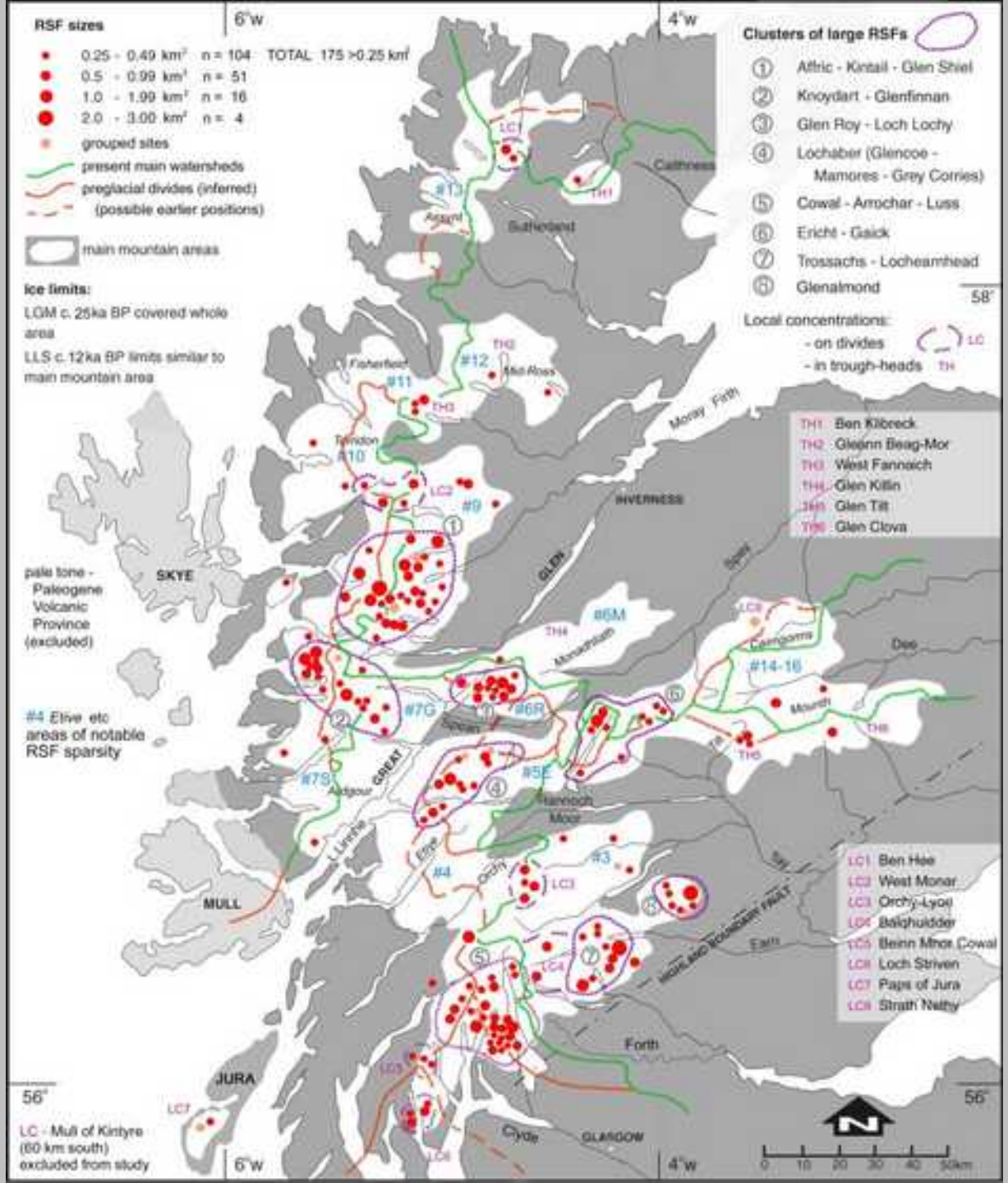
LC3 Orchy-Lyon *glacial breaches*



Rock Slope Failure - clustering

Scottish Highlands :
920 sites
average size 0.18 km² max 3 km²

*strong association with **glacial breaches***

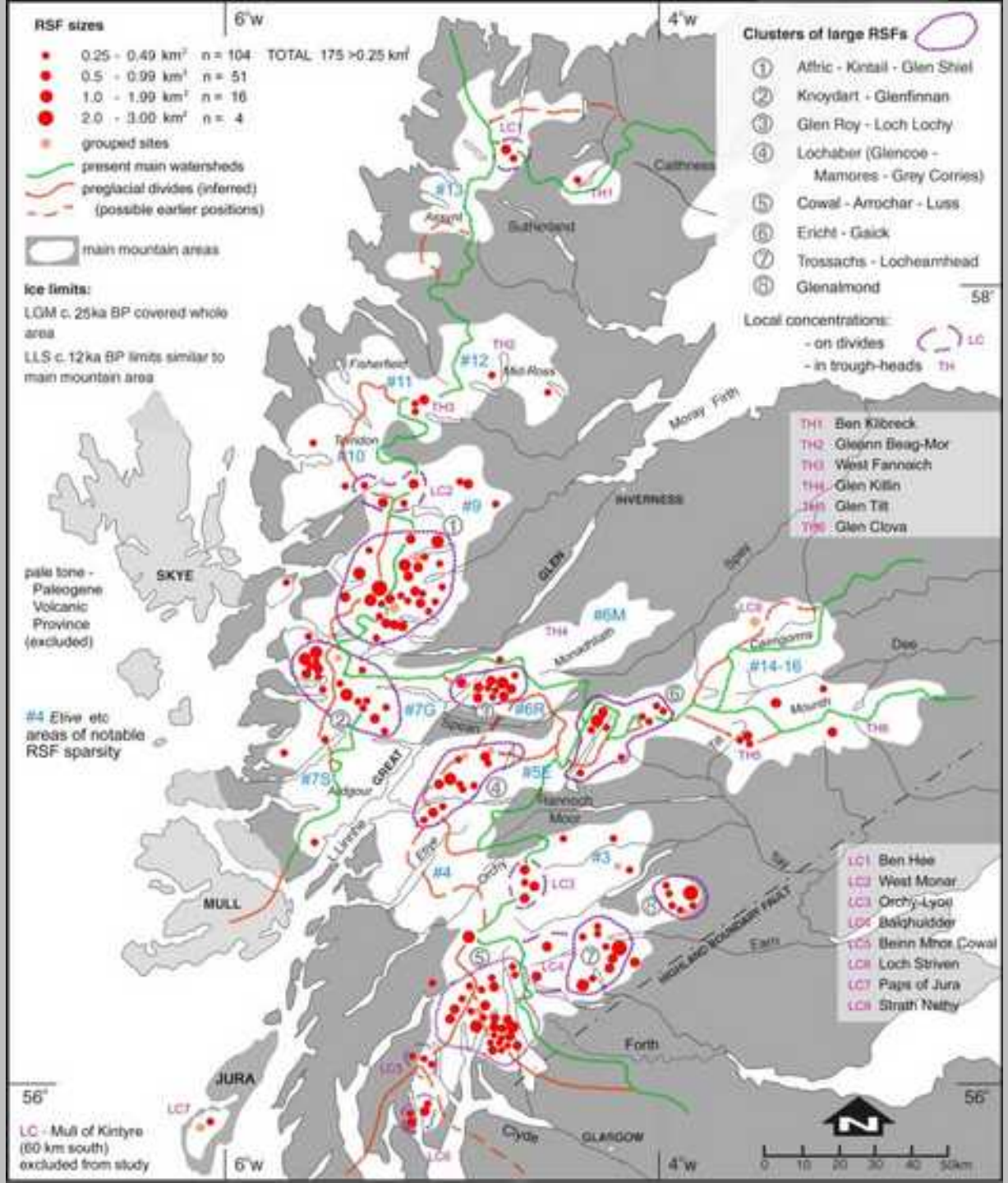


Rock Slope Failure - clustering

Scottish Highlands :
920 sites
average size 0.18 km² max 3 km²

*strong association with **glacial breaches***

*also with **trough-heads** (in E & N)*



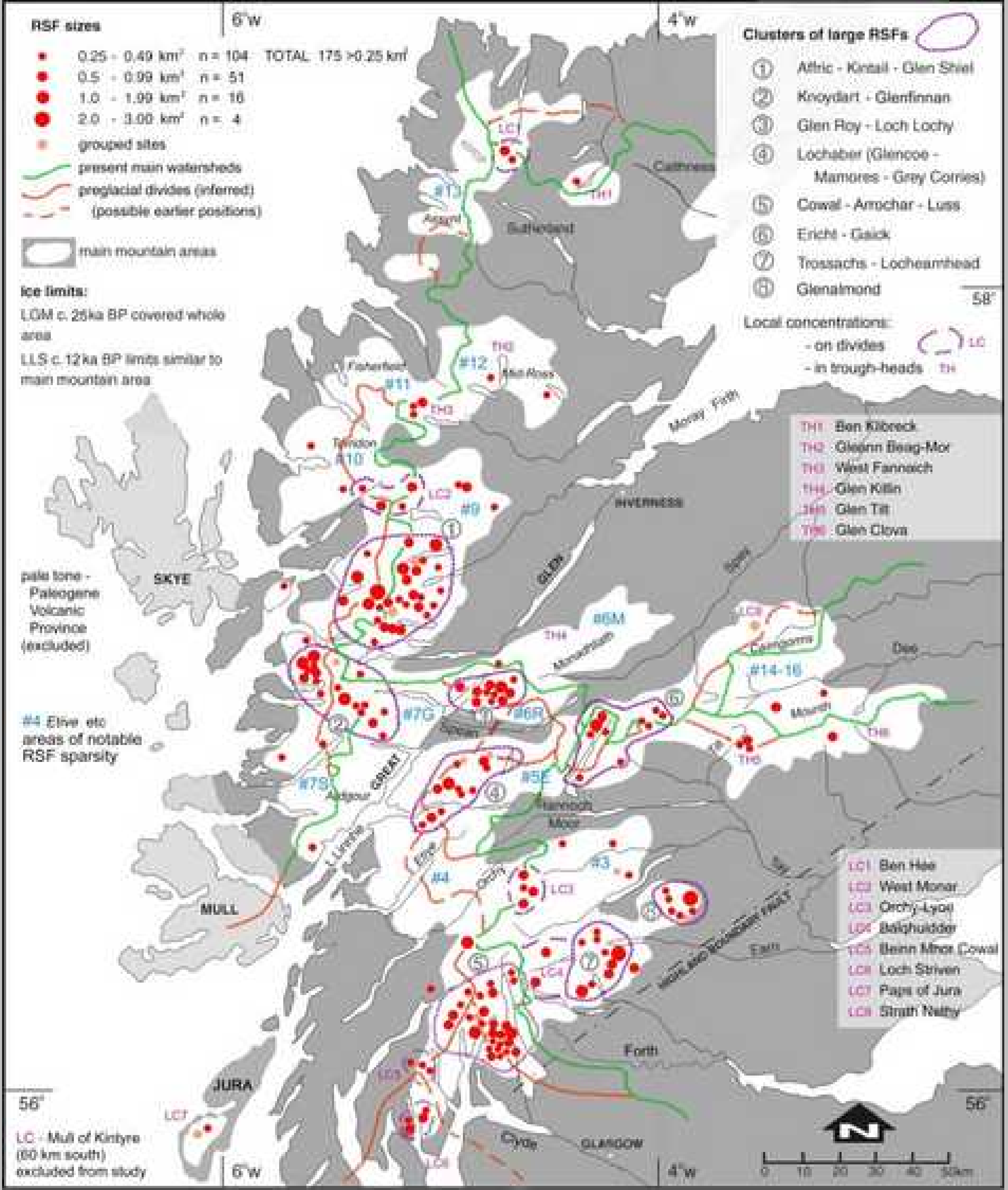
Rock Slope Failure - clustering

Scottish Highlands :
920 sites
average size 0.18 km² max 3 km²

*strong association with **glacial breaches** where*

[CEB] : [RSF]
Concentrated Erosion of Bedrock

focussed during last glaciation(s)



Rock Slope Failure - clustering

Scottish Highlands :
920 sites
average size 0.18 km²   max 3 km²

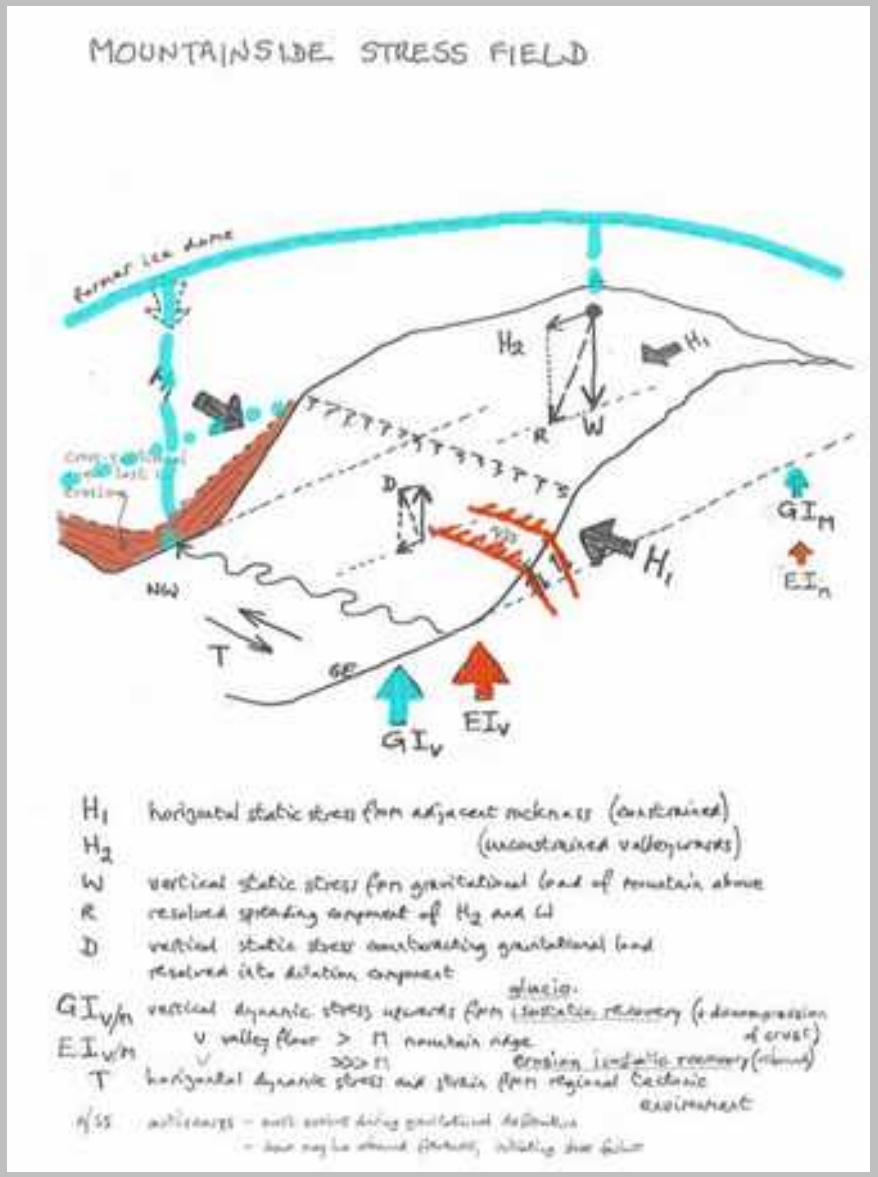
*strong association with **glacial breaches,** where*

[CEB] : [RSF]
Concentrated Erosion of Bedrock

focussed during last glaciation(s), ***augmenting slope stresses*** *to provoke failure*

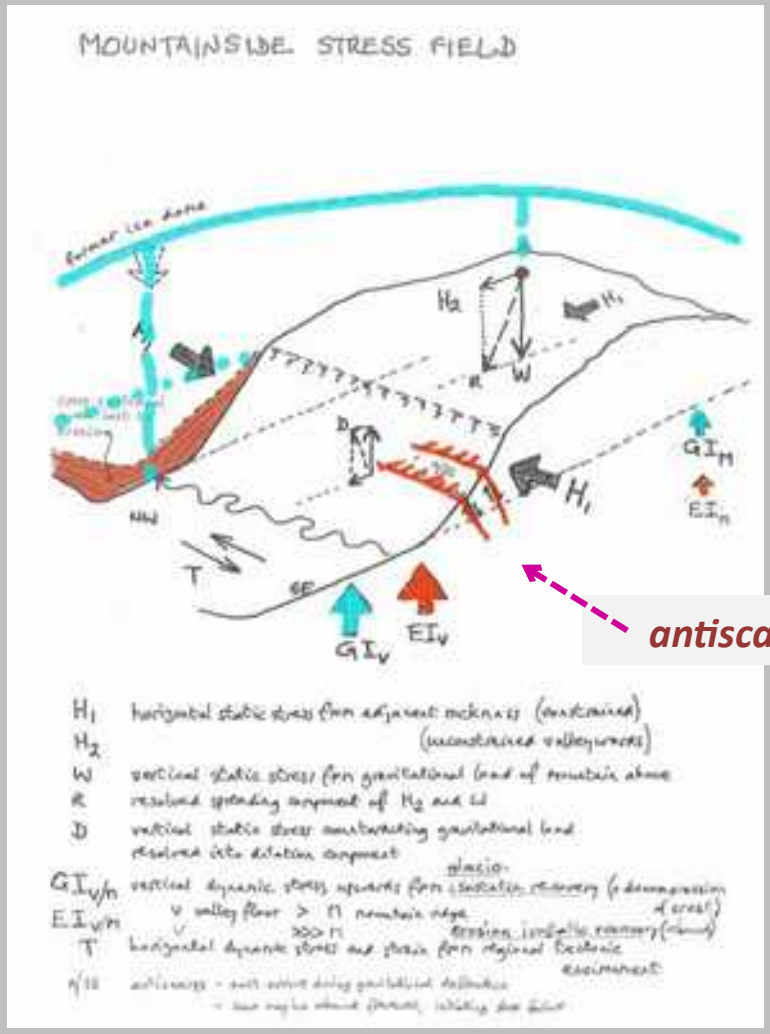
Rock Slope Failure - clustering

***augmenting slope stresses** to provoke failure*



Rock Slope Failure - clustering

augmenting slope stresses *to provoke failure*



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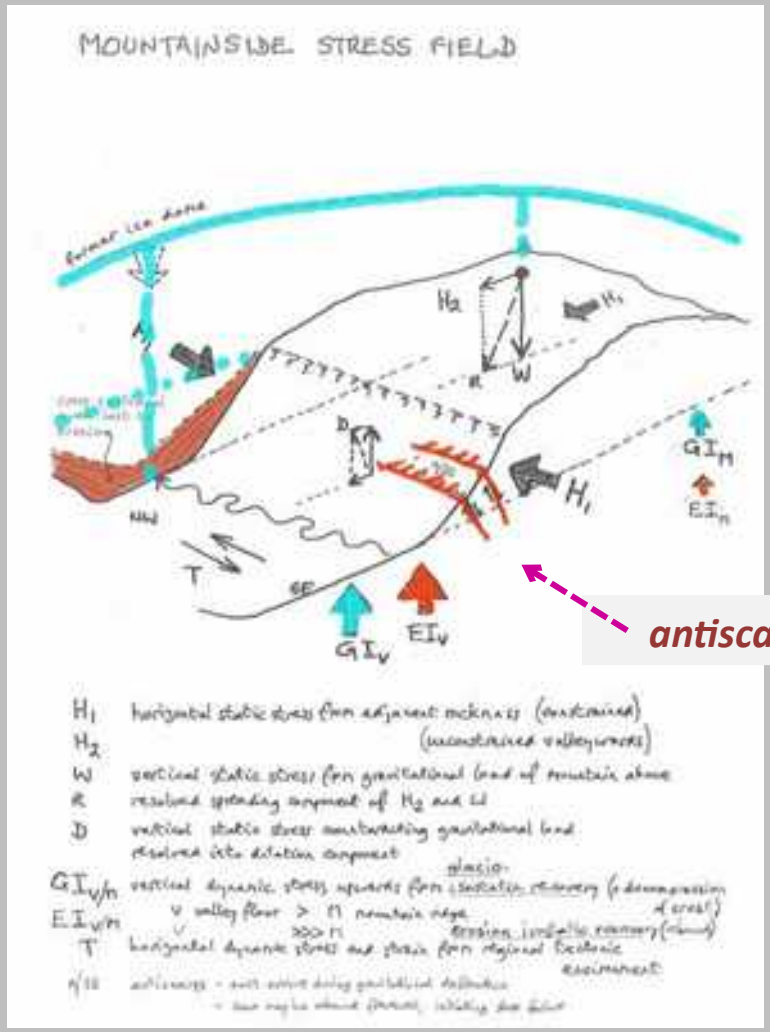
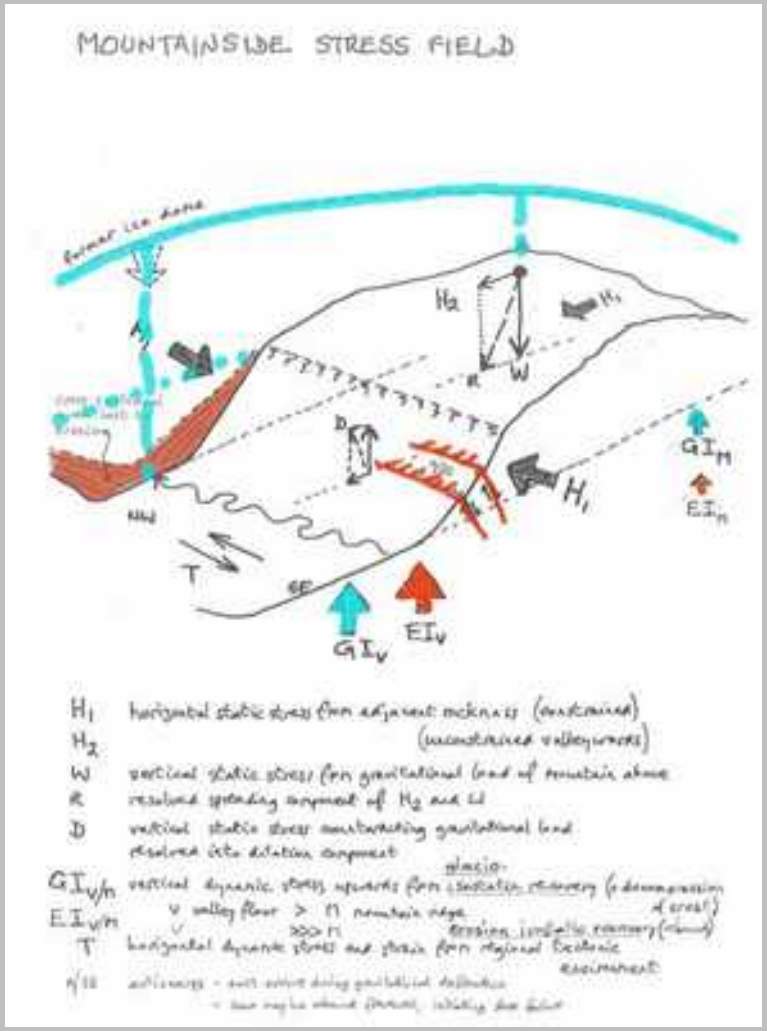
augmenting slope stresses *to provoke failure*



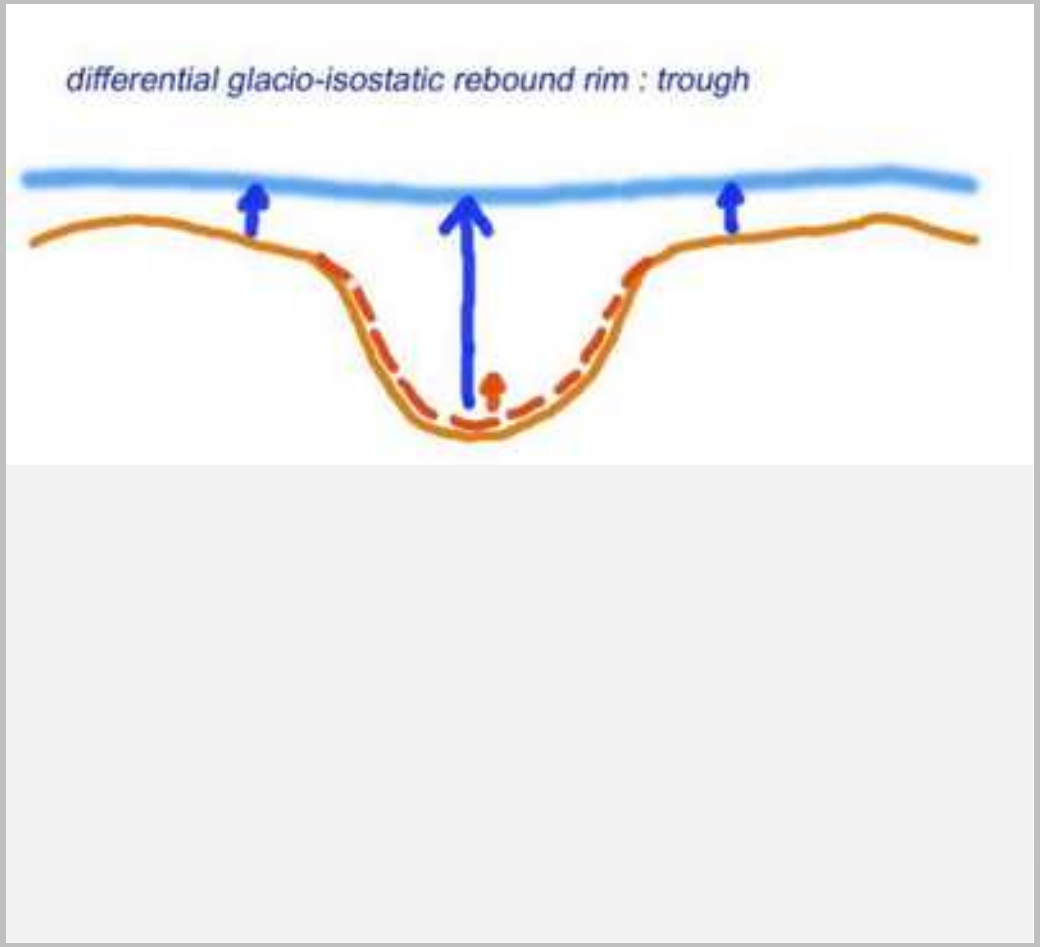
antiscarps

Rock Slope Failure - clustering

augmenting slope stresses *to provoke failure*



unloading after deglaciation



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augmenting slope stresses *to provoke failure*

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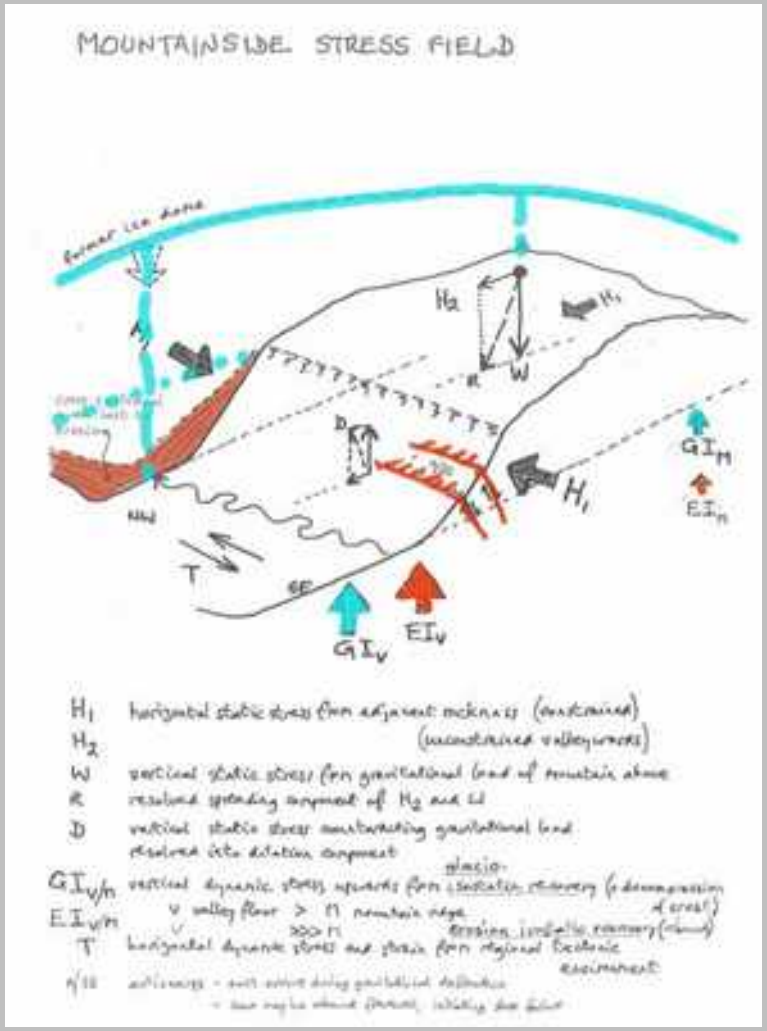
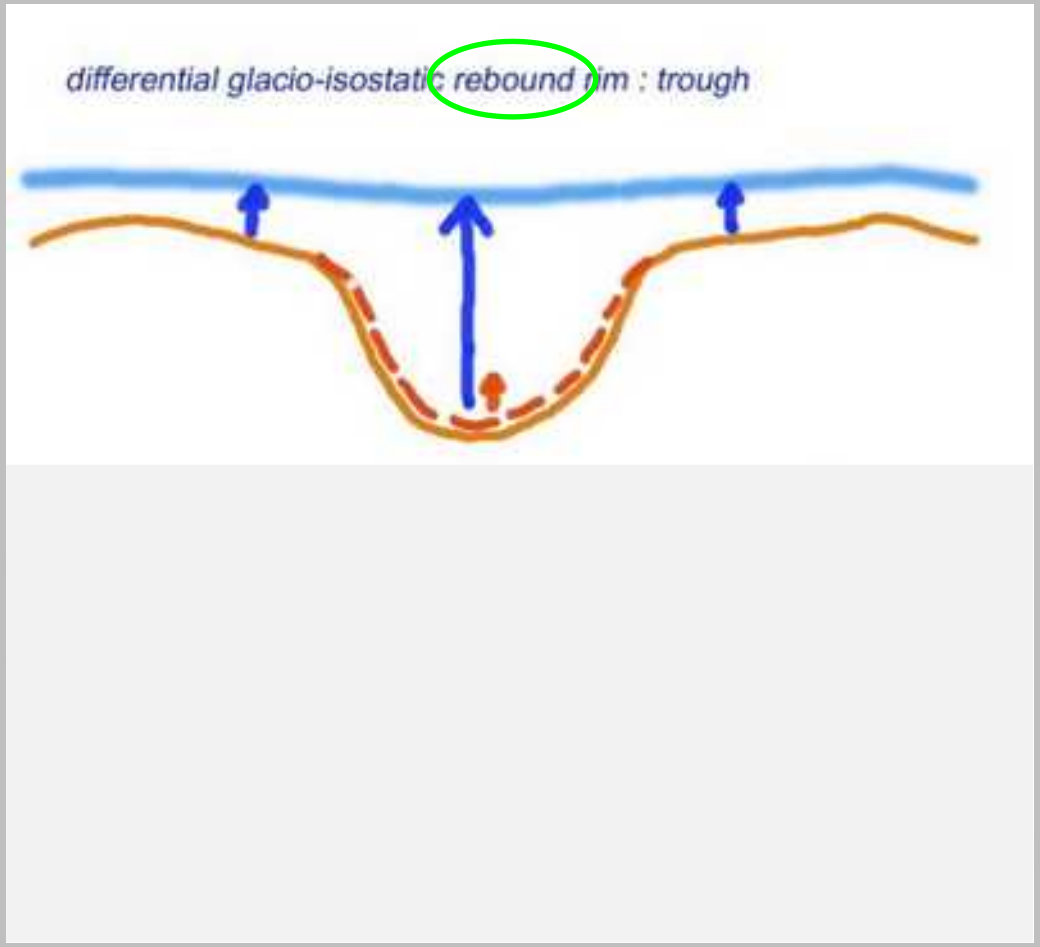




Rock Slope Failure - clustering

augmenting slope stresses *to provoke failure*

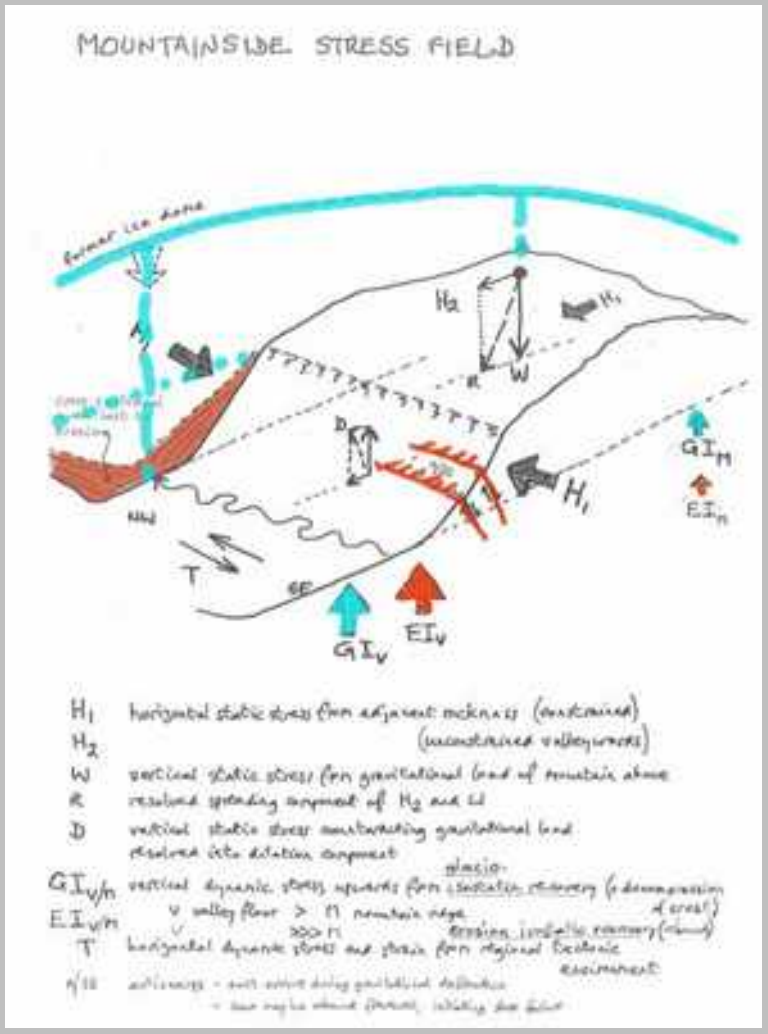
unloading after deglaciation

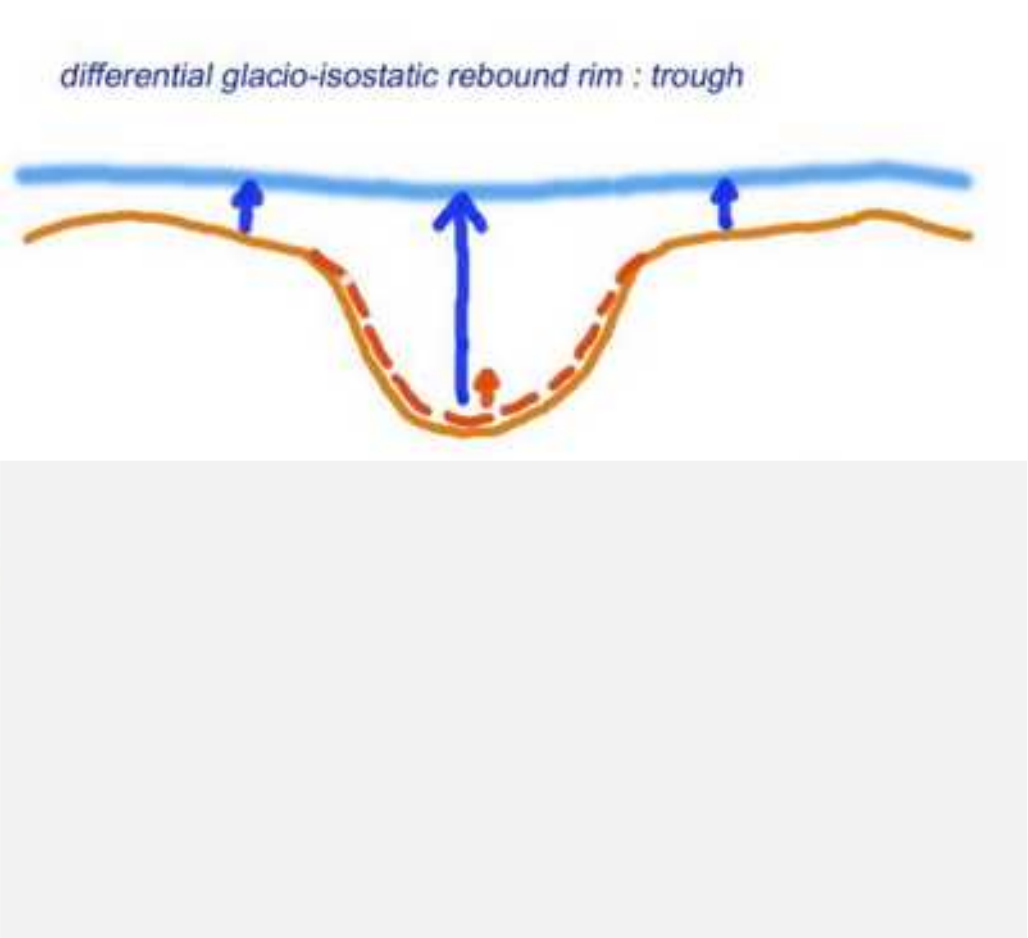
in main glen: *50N from ice weight*

(uniform all glens / whole length)

10N from erosion of bedrock

max 1-3 mm/yr 10--30 m cycle ?





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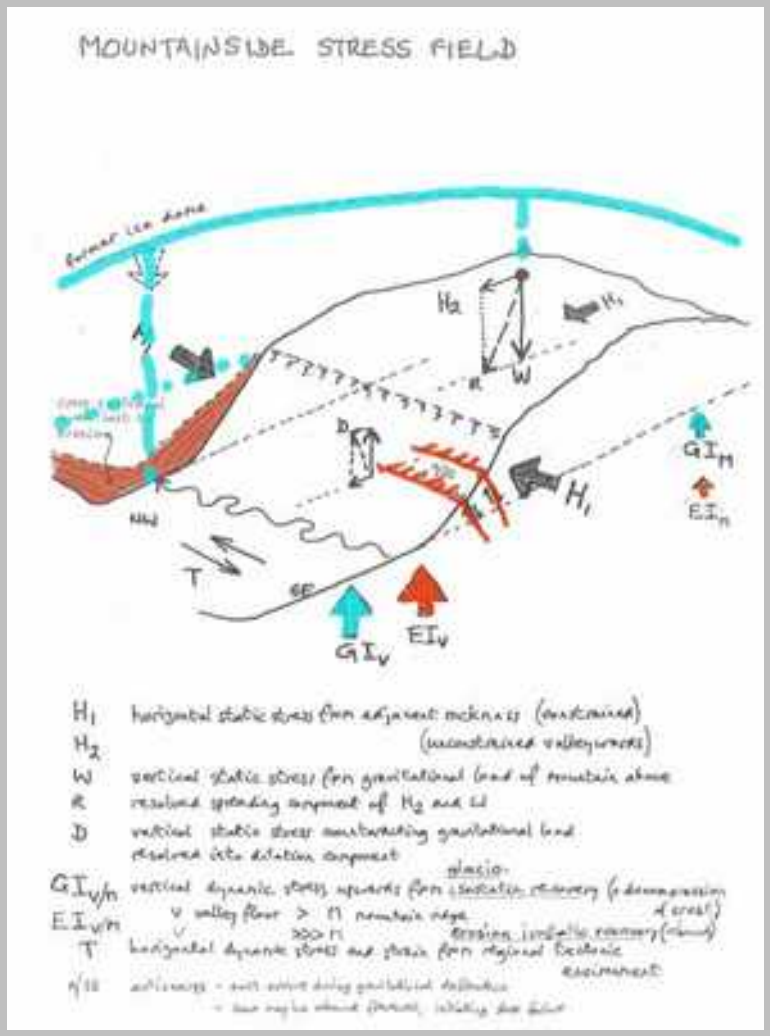
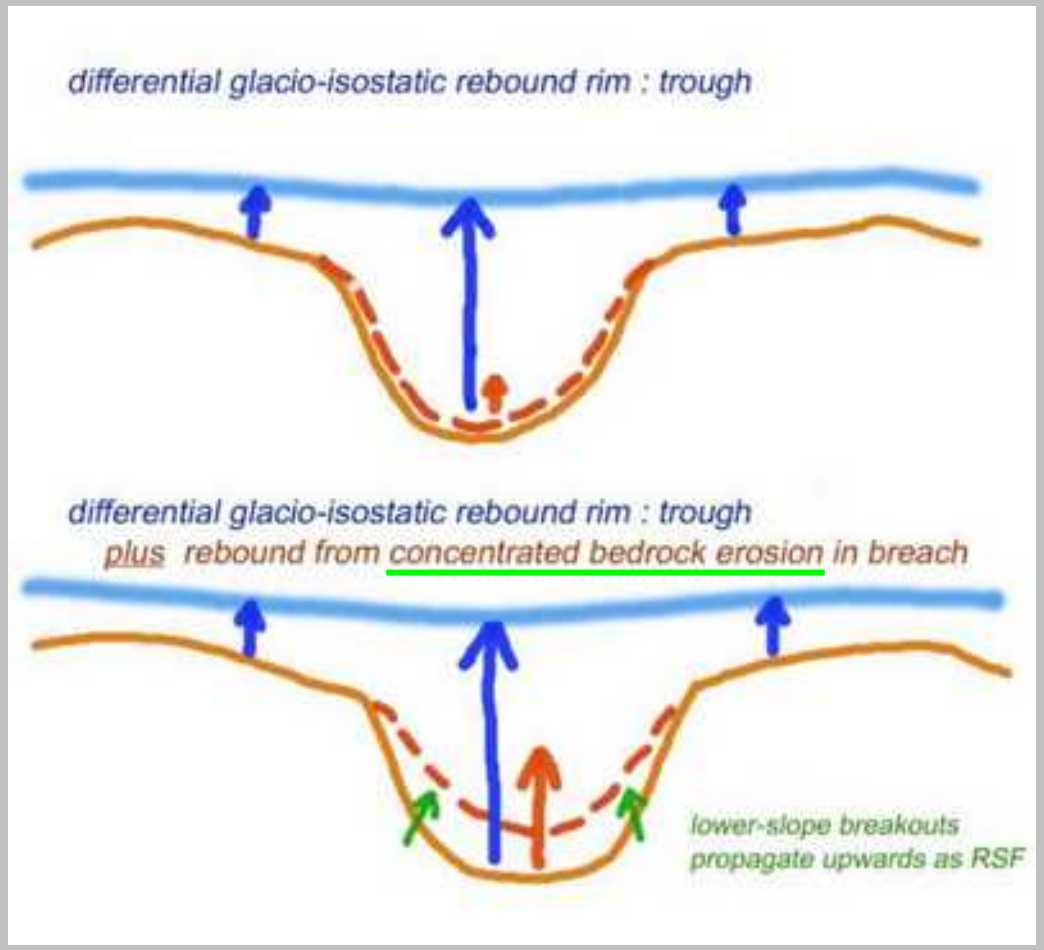
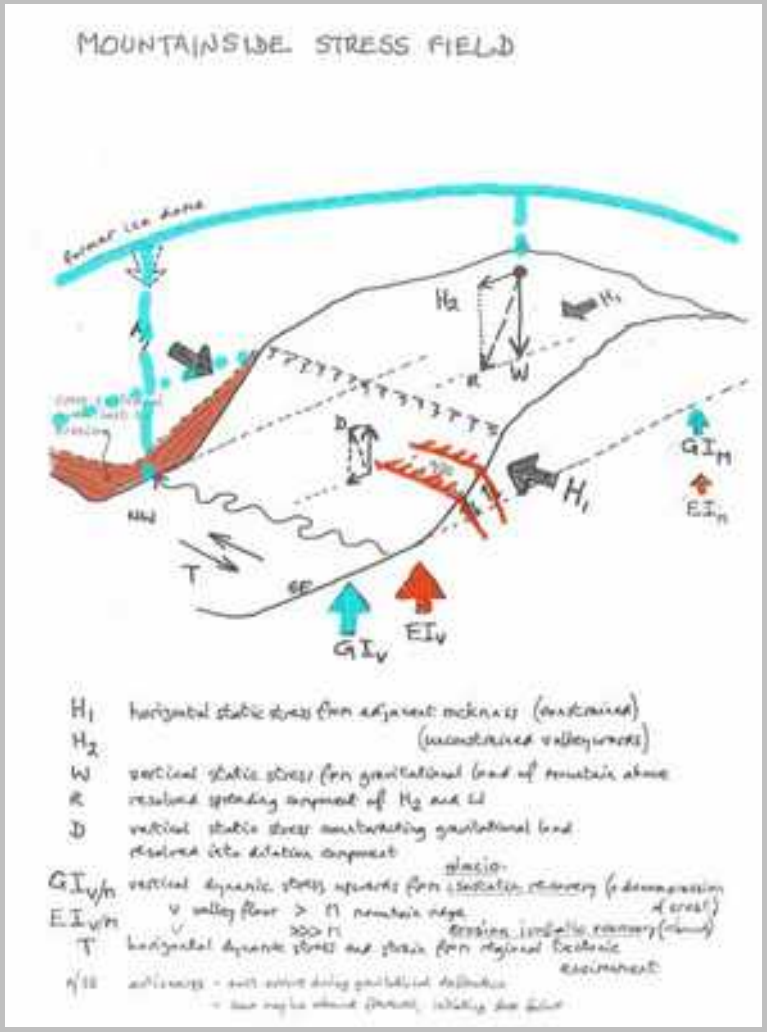




Rock Slope Failure - clustering

***augmenting slope stresses** to provoke failure*



unloading after deglaciation

in main glen: 50N from ice weight

(uniform all glens / whole length)

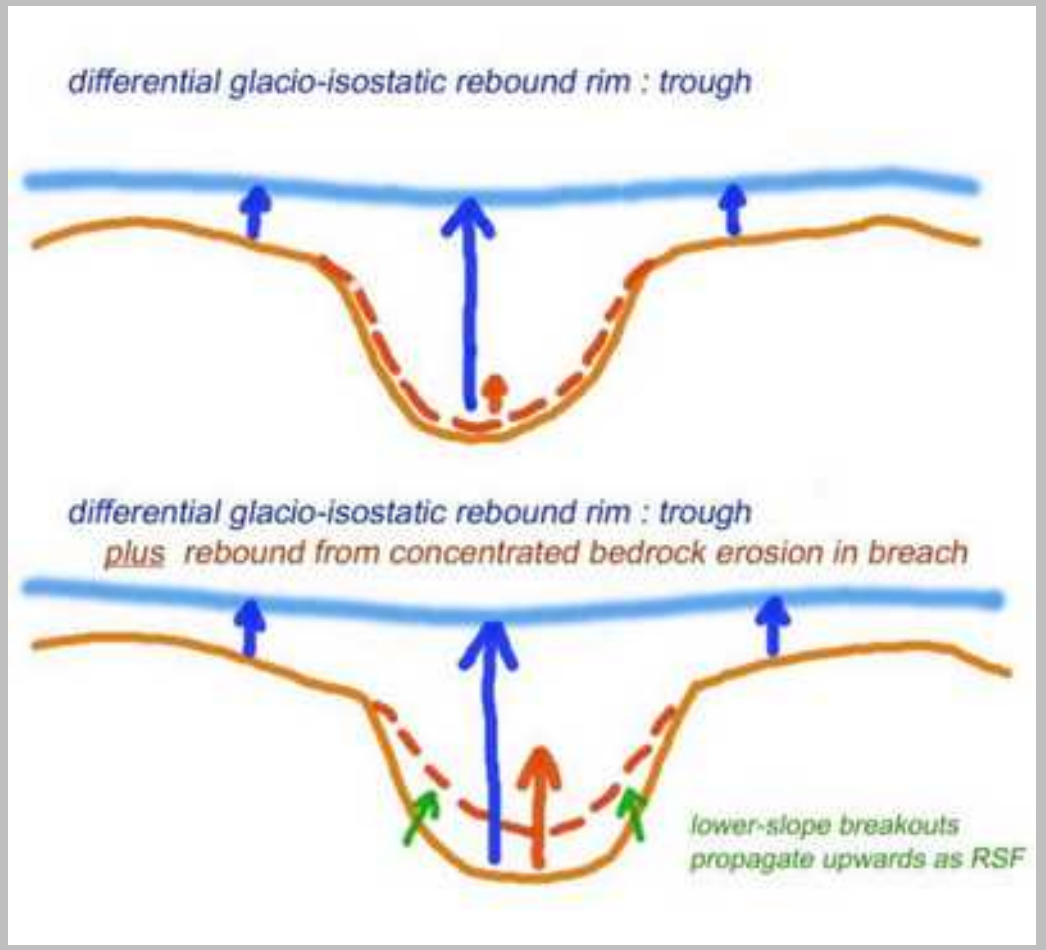
10N from erosion of bedrock

max 1-3 mm/yr 10--30 m cycle ?

in breach: 30N from ice weight

(breach not so deep)

50N from erosion of bedrock



Rock Slope Failure - clustering

***augmenting slope stresses** to provoke failure*

unloading after deglaciation

in main glen: 50N from ice weight

(uniform all glens / whole length)

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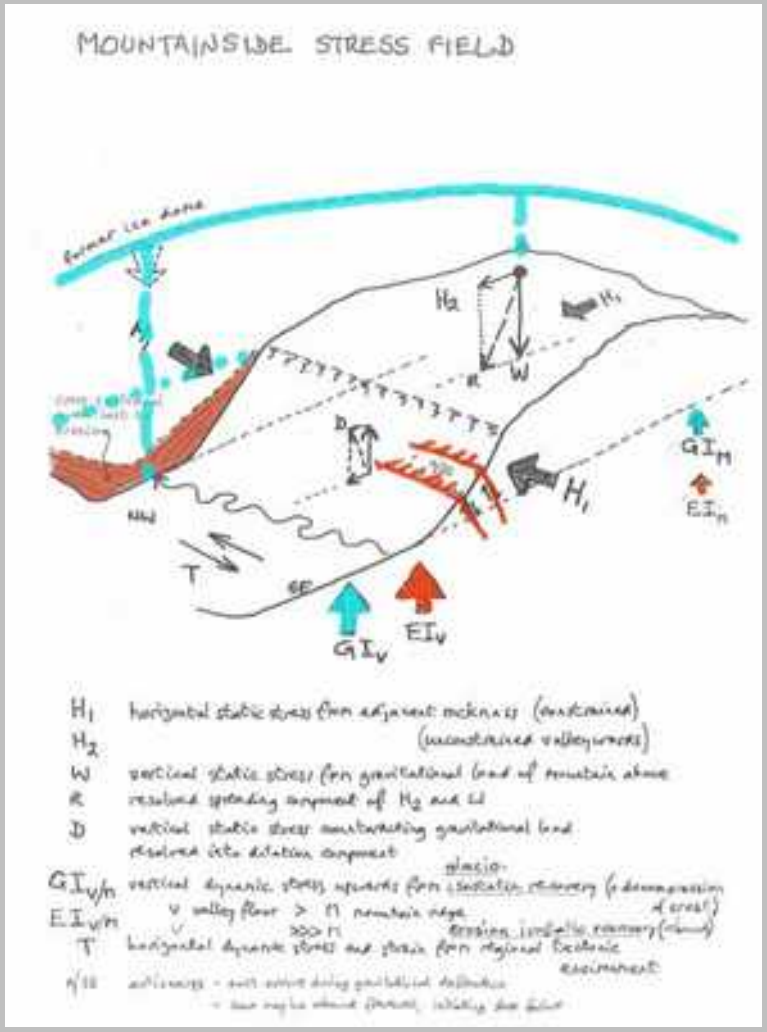
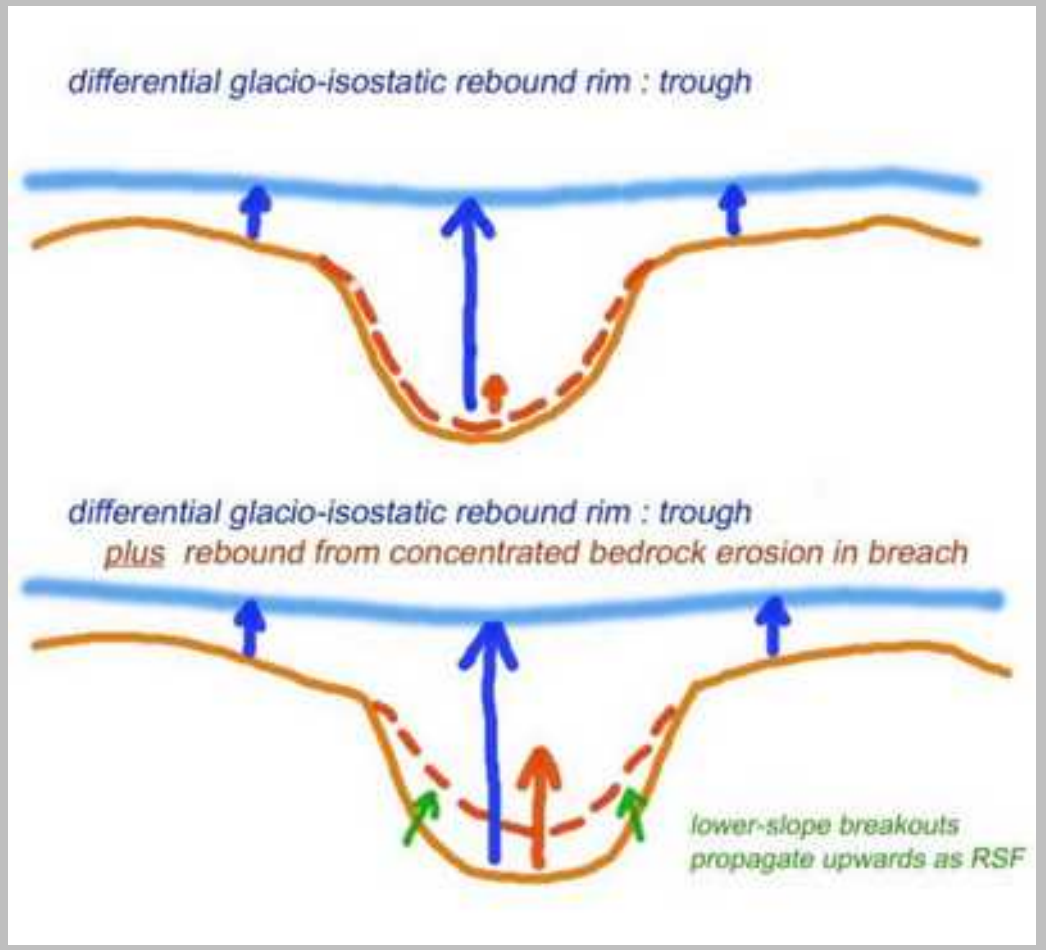
max 1-3 mm/yr 10--30 m cycle ?

in breach: 30N from ice weight

(breach not so deep)

50N from erosion of bedrock **[CEB]**





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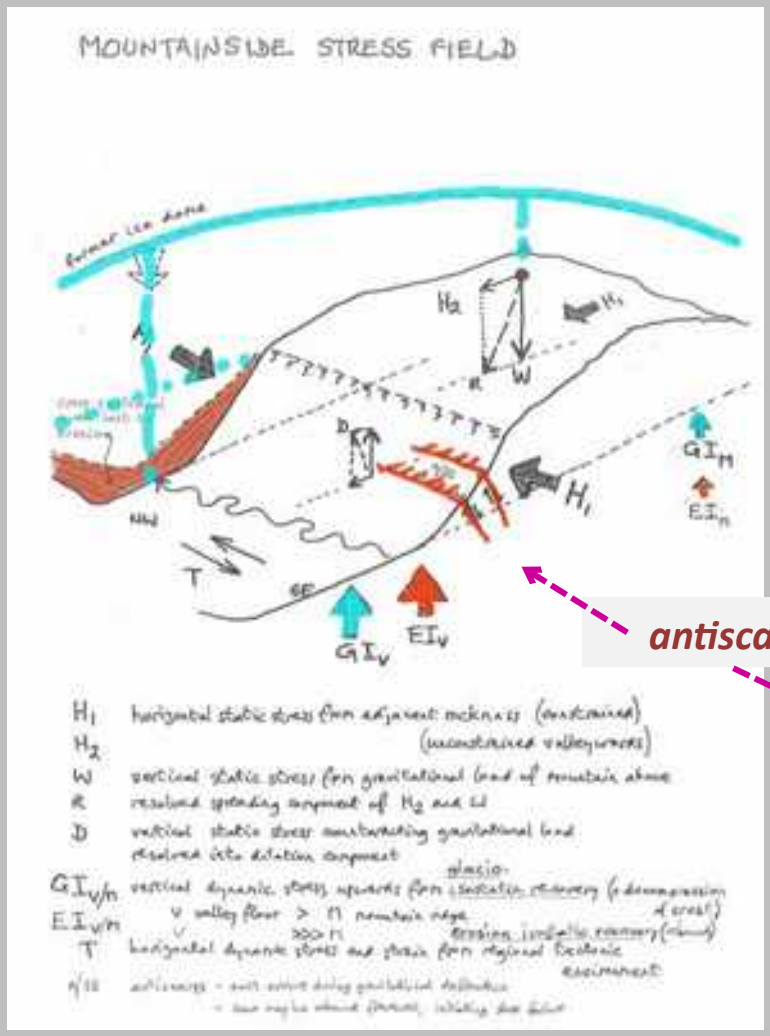
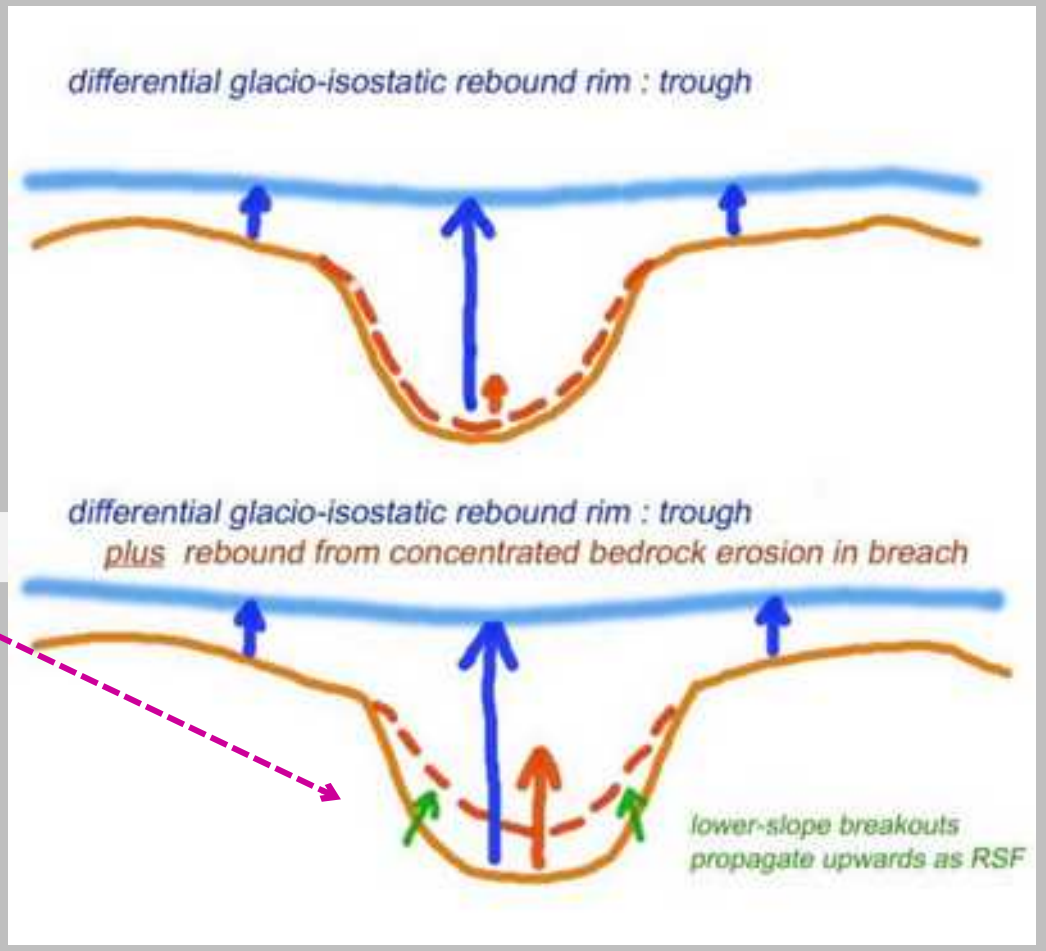
(uniform all glens / whole length)
10N from erosion of bedrock
max 1-3 mm/yr 10--30 m cycle ?
in breach: 30N from ice weight
(breach not so deep)
50N from erosion of bedrock

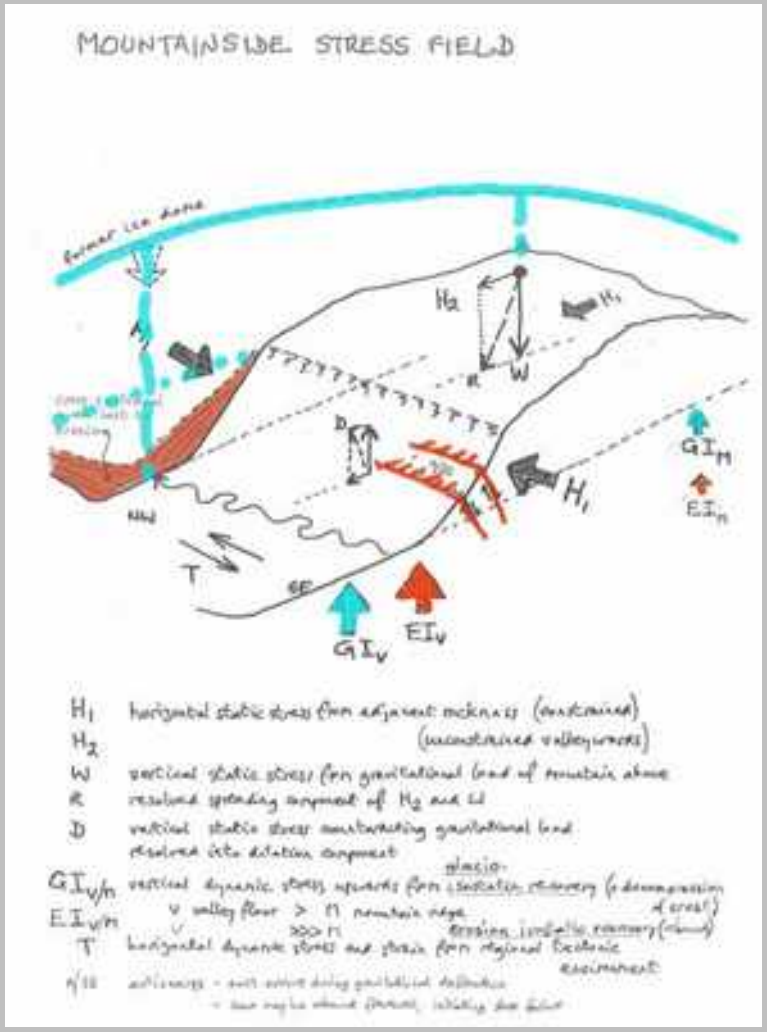


antiscarps



Rock Slope Failure - clustering

***augmenting slope stresses** to provoke failure*



unloading after deglaciation

in main glen: 50N from ice weight

(uniform all glens / whole length)

10N from erosion of bedrock

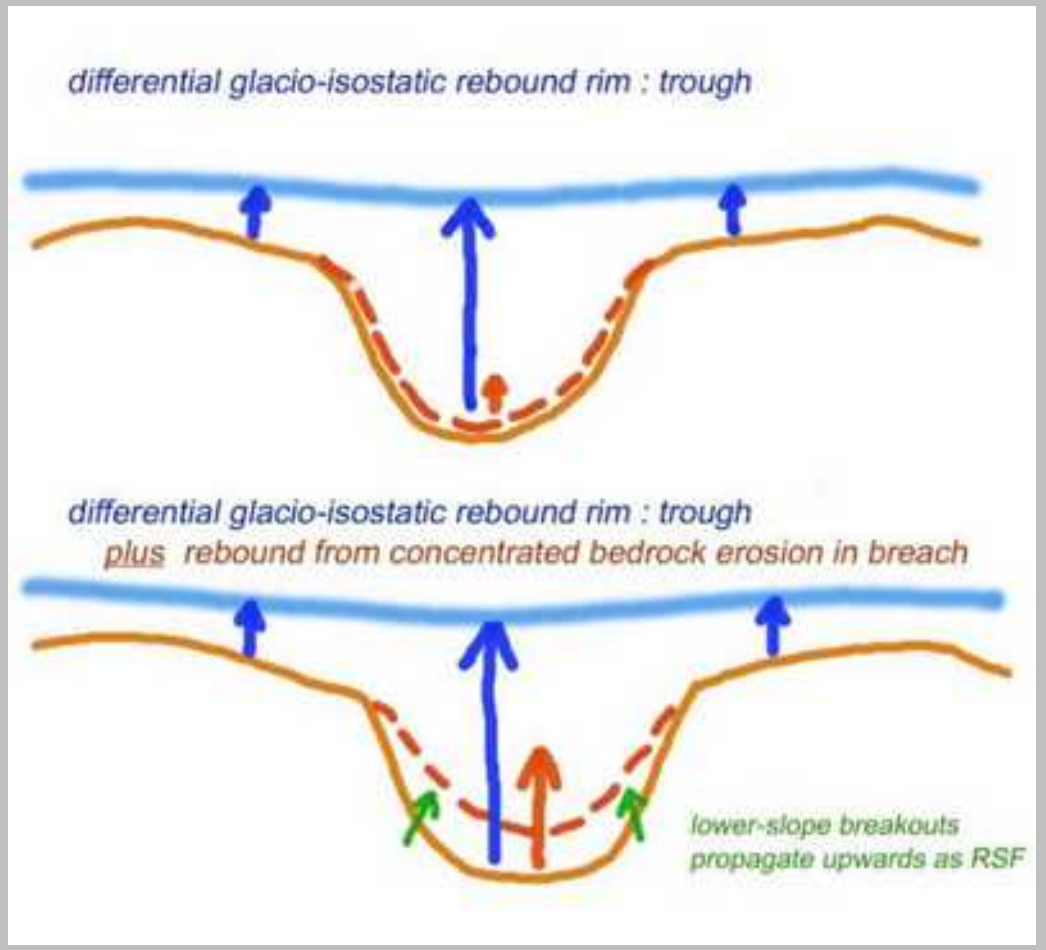
max 1-3 mm/yr 10--30 m cycle ?

in breach: 30N from ice weight

(breach not so deep)

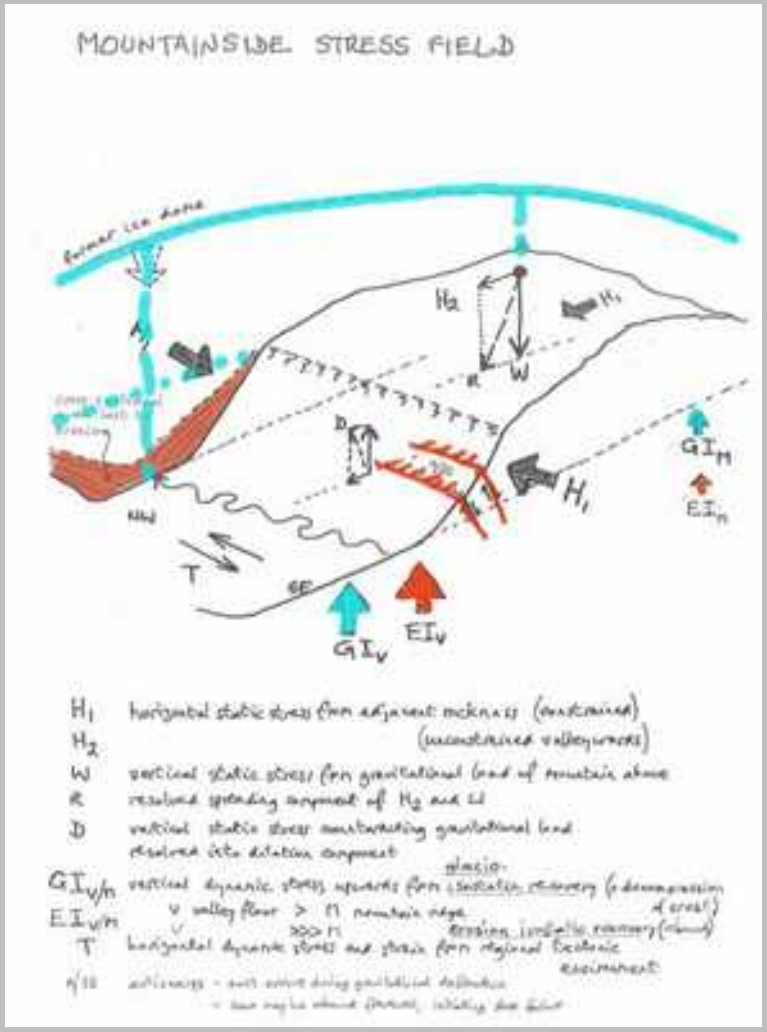
50N from erosion of bedrock

3-500 m in 1-2 cycles



Rock Slope Failure - clustering

***augmenting slope stresses** to provoke failure*



unloading after deglaciation

in main glen: 50N from ice weight

(uniform all glens / whole length)

10N from erosion of bedrock

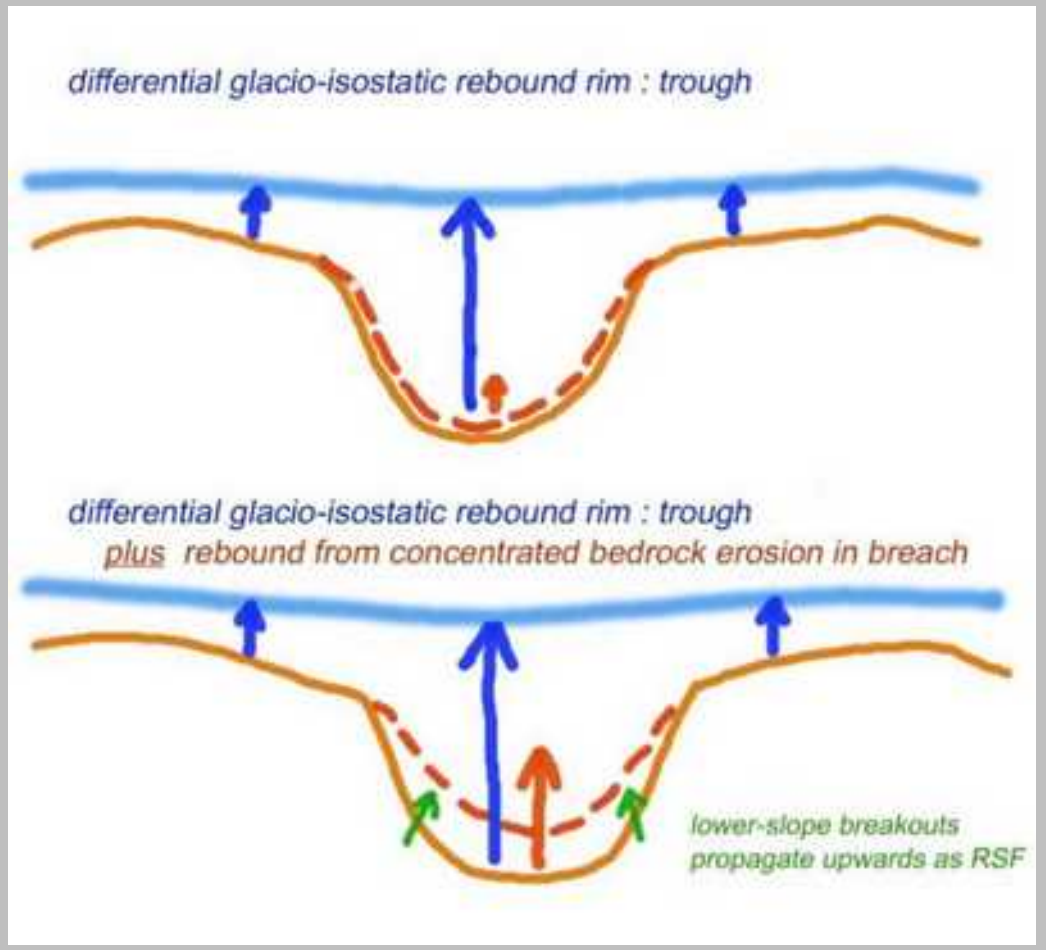
max 1-3 mm/yr 10--30 m cycle ?

in breach: 30N from ice weight

(breach not so deep)

50N from erosion of bedrock

5-10 x max** **3-500 m in 1-2 cycles



Rock Slope Failure - clustering

augmenting slope stresses *to provoke failure*

unloading after deglaciation

in main glen: *50N from ice weight*

(uniform all glens / whole length)

10N from erosion of bedrock

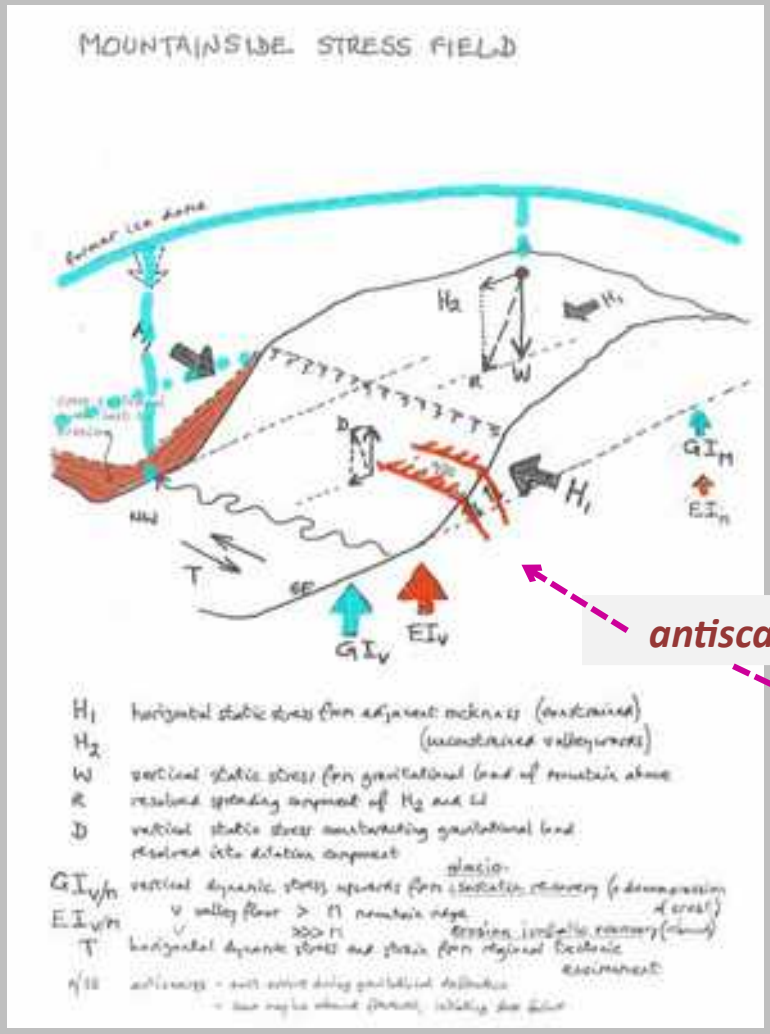
max 1-3 mm/yr 10--30 m cycle ?

in breach: *30N from ice weight*

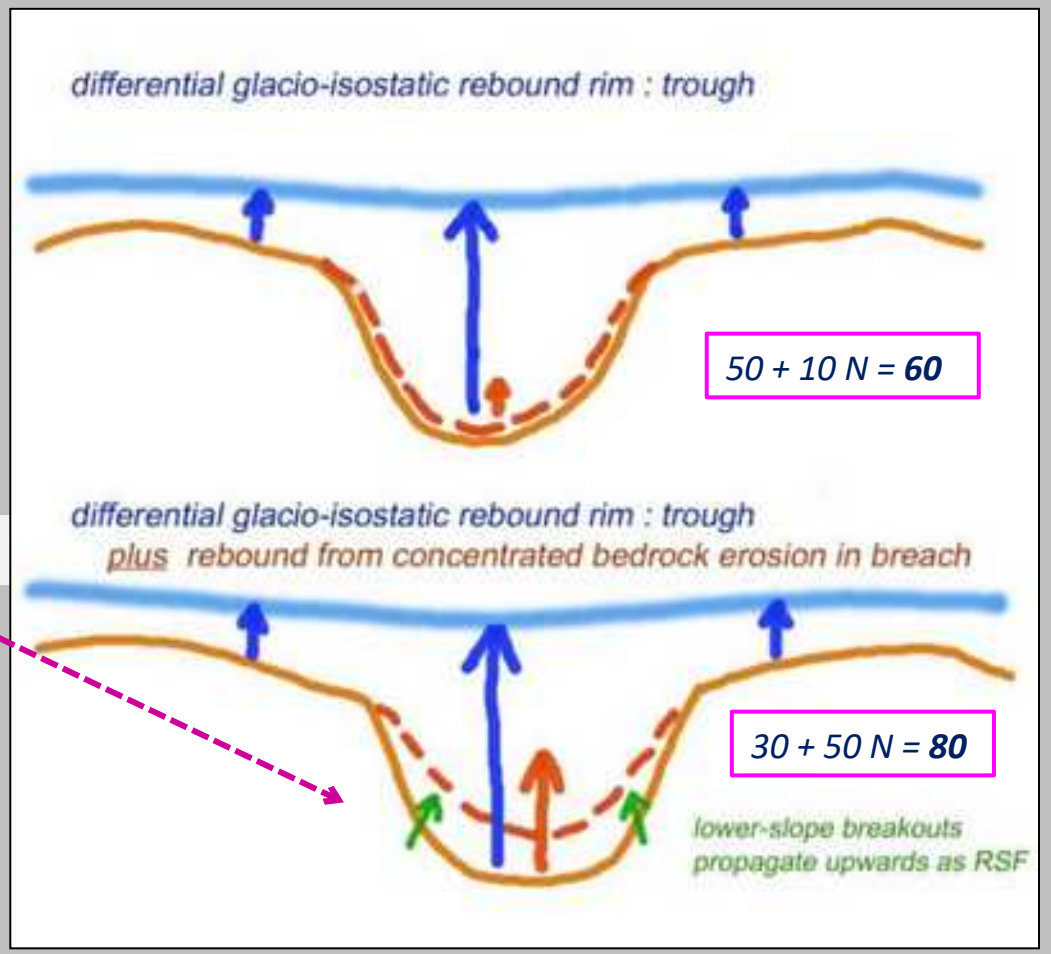
(breach not so deep)

50N from erosion of bedrock

5-10 x max 3-500 m in 1-2 cycles

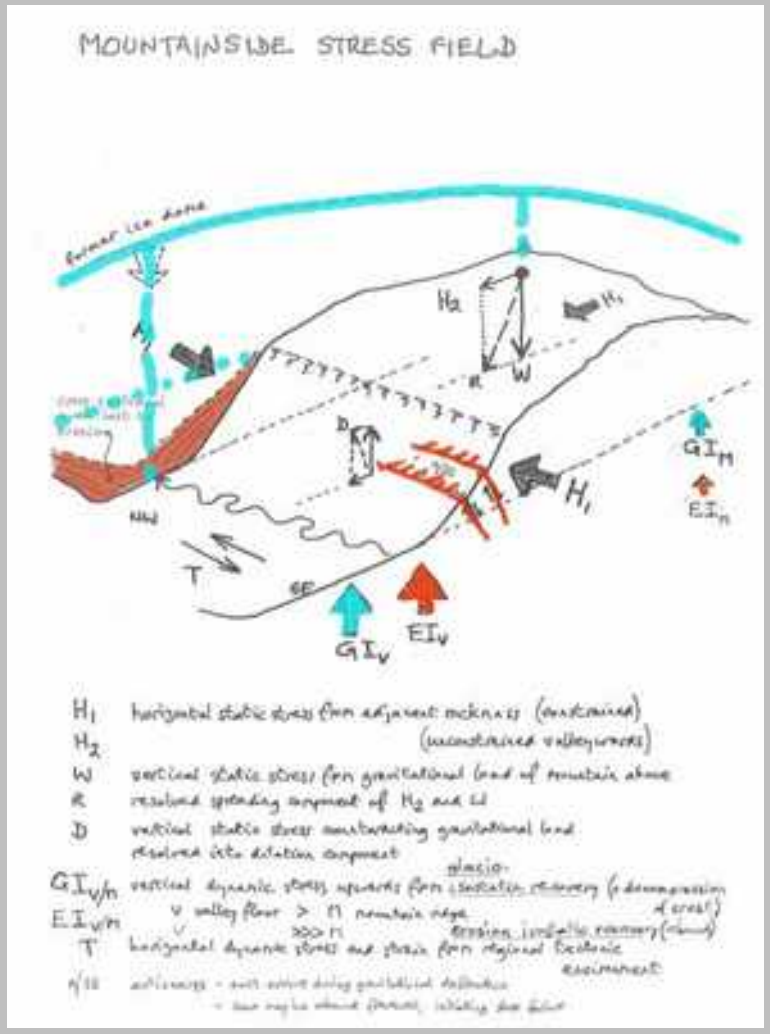


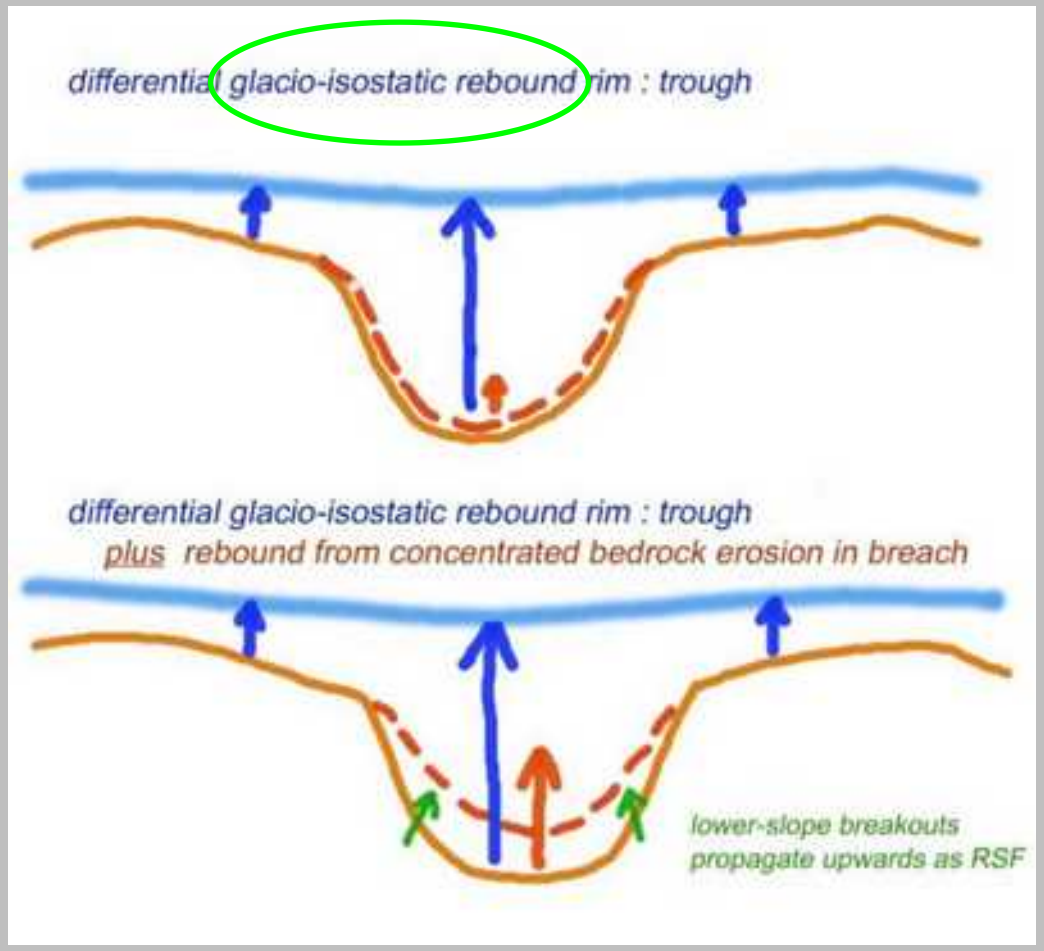
antiscarps



Rock Slope Failure - clustering

augmenting slope stresses *to provoke failure*

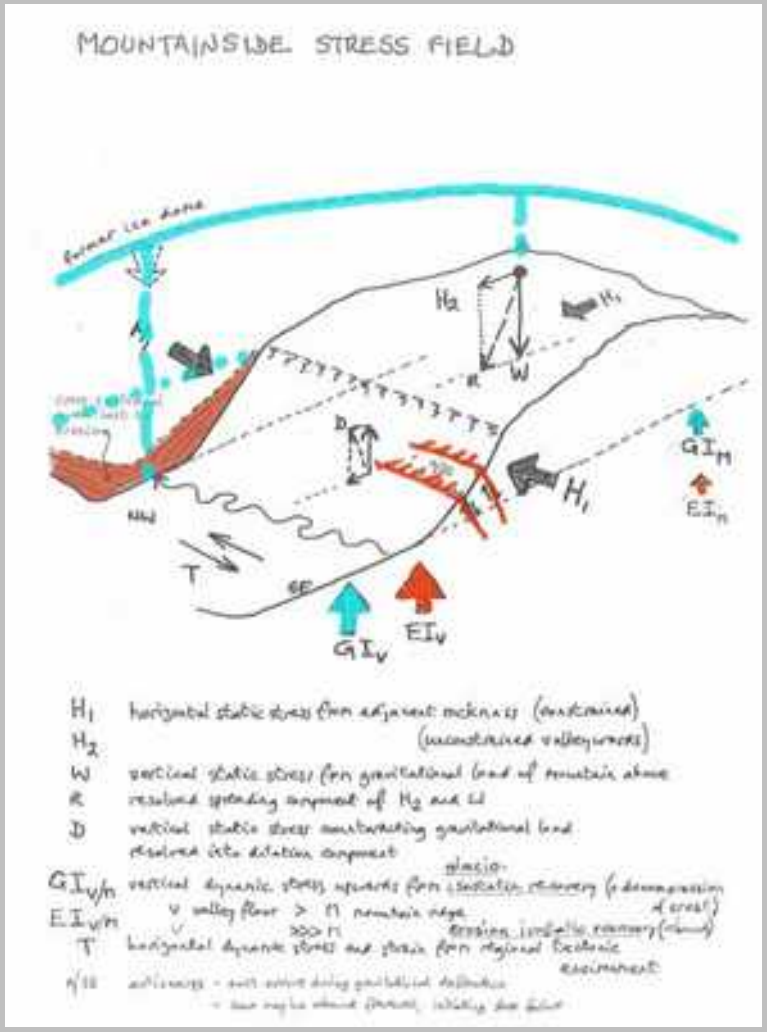


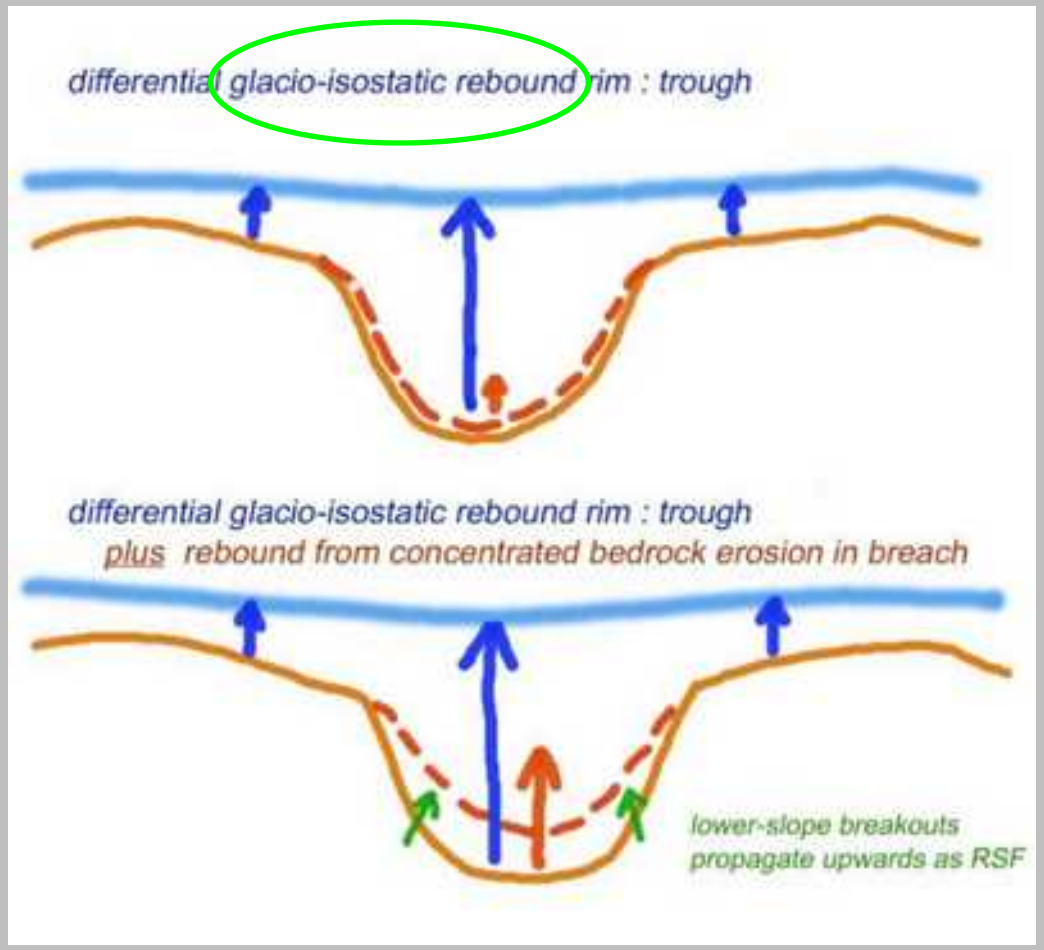


Rock Slope Failure - clustering

augmenting slope stresses *to provoke failure*

"petro-isostatic rebound"



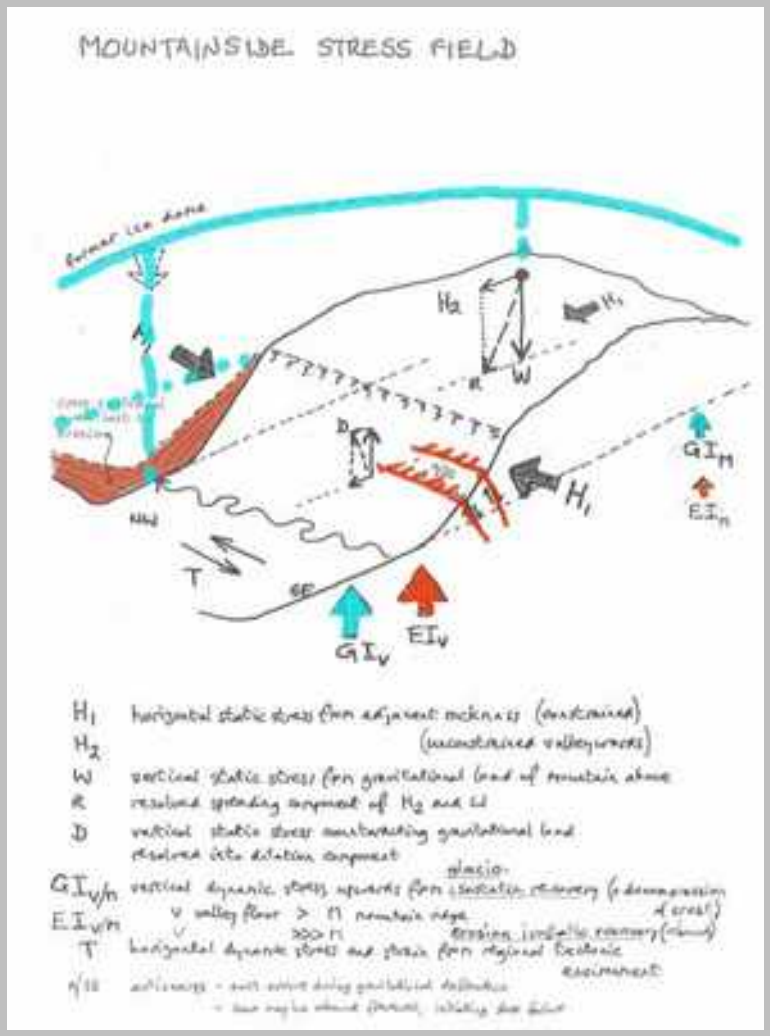


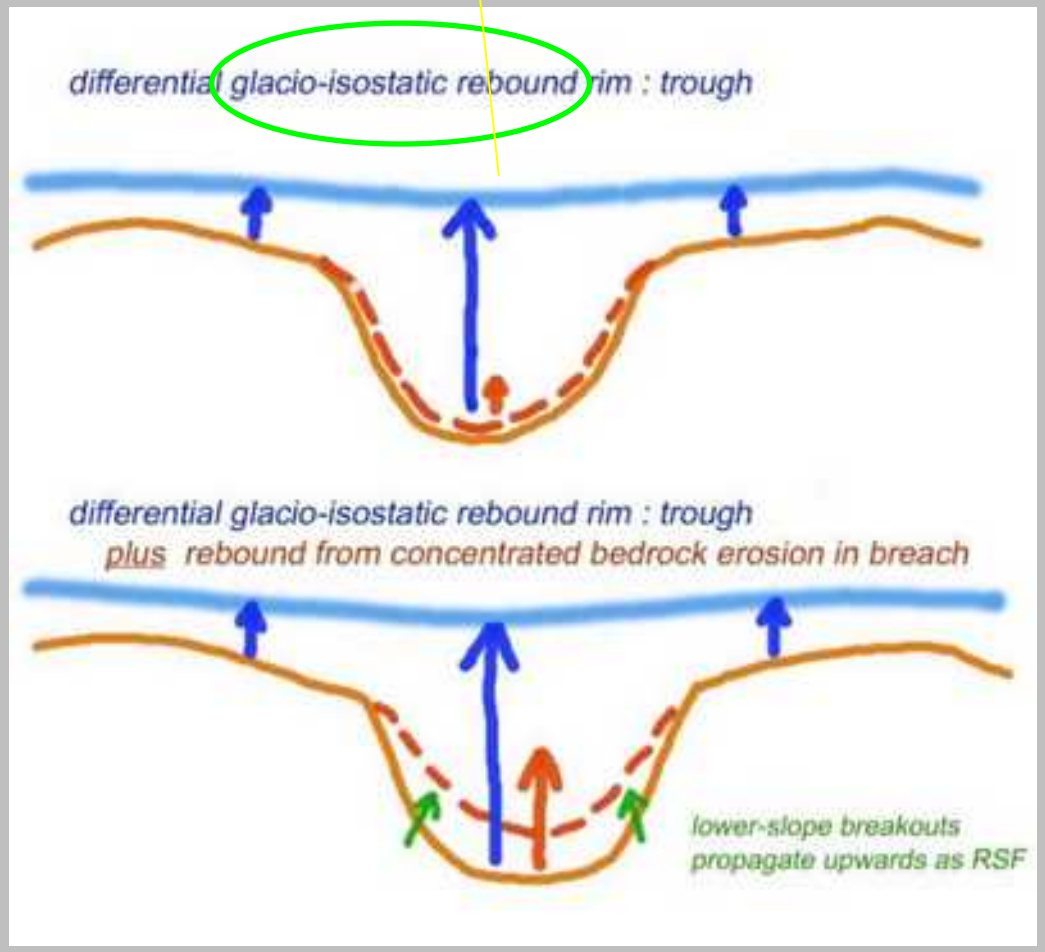
Rock Slope Failure - clustering

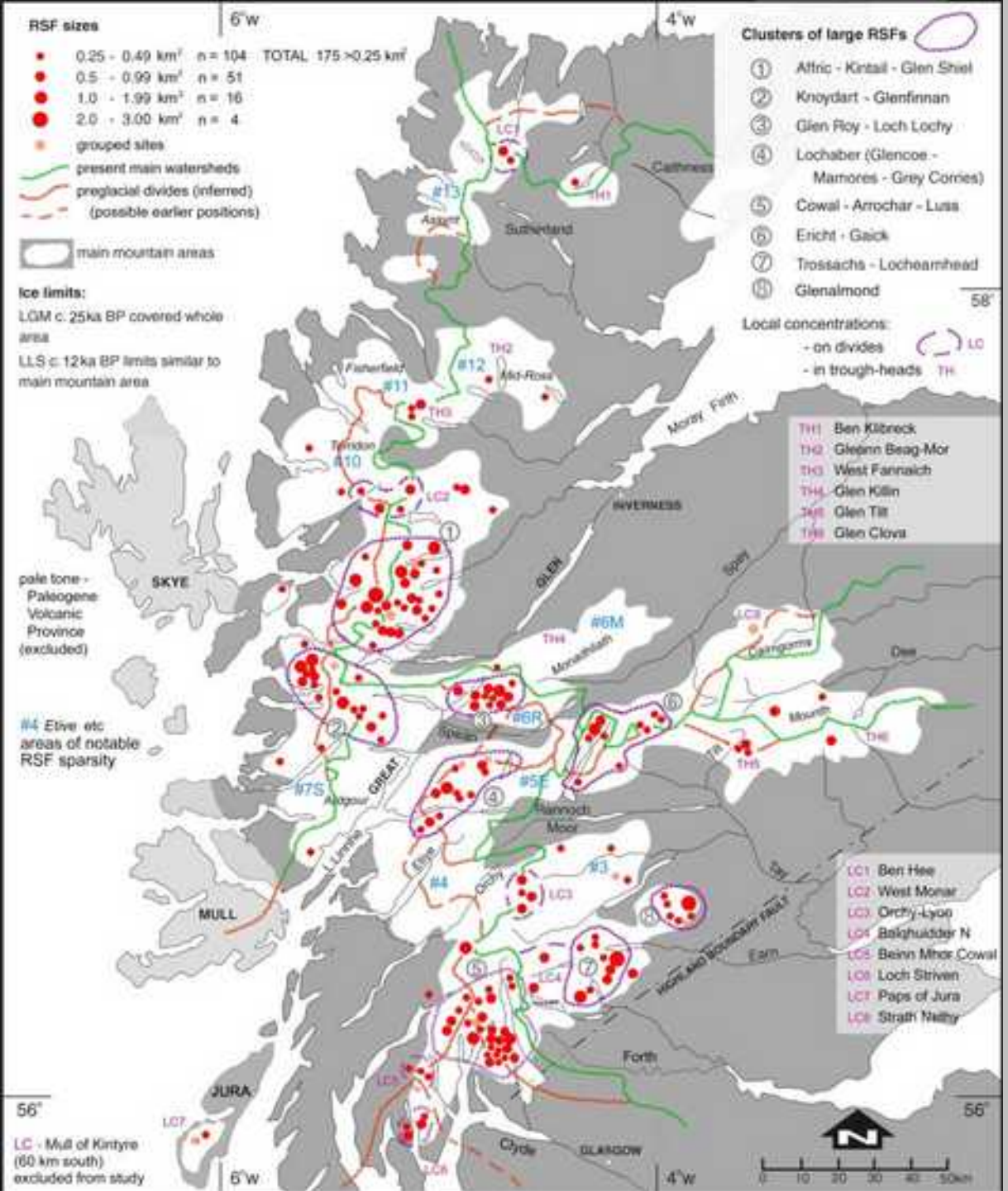
augmenting slope stresses *to provoke failure*

"petro-isostatic rebound"

*- **gravity** comes later*







RSF Scottish Highlands

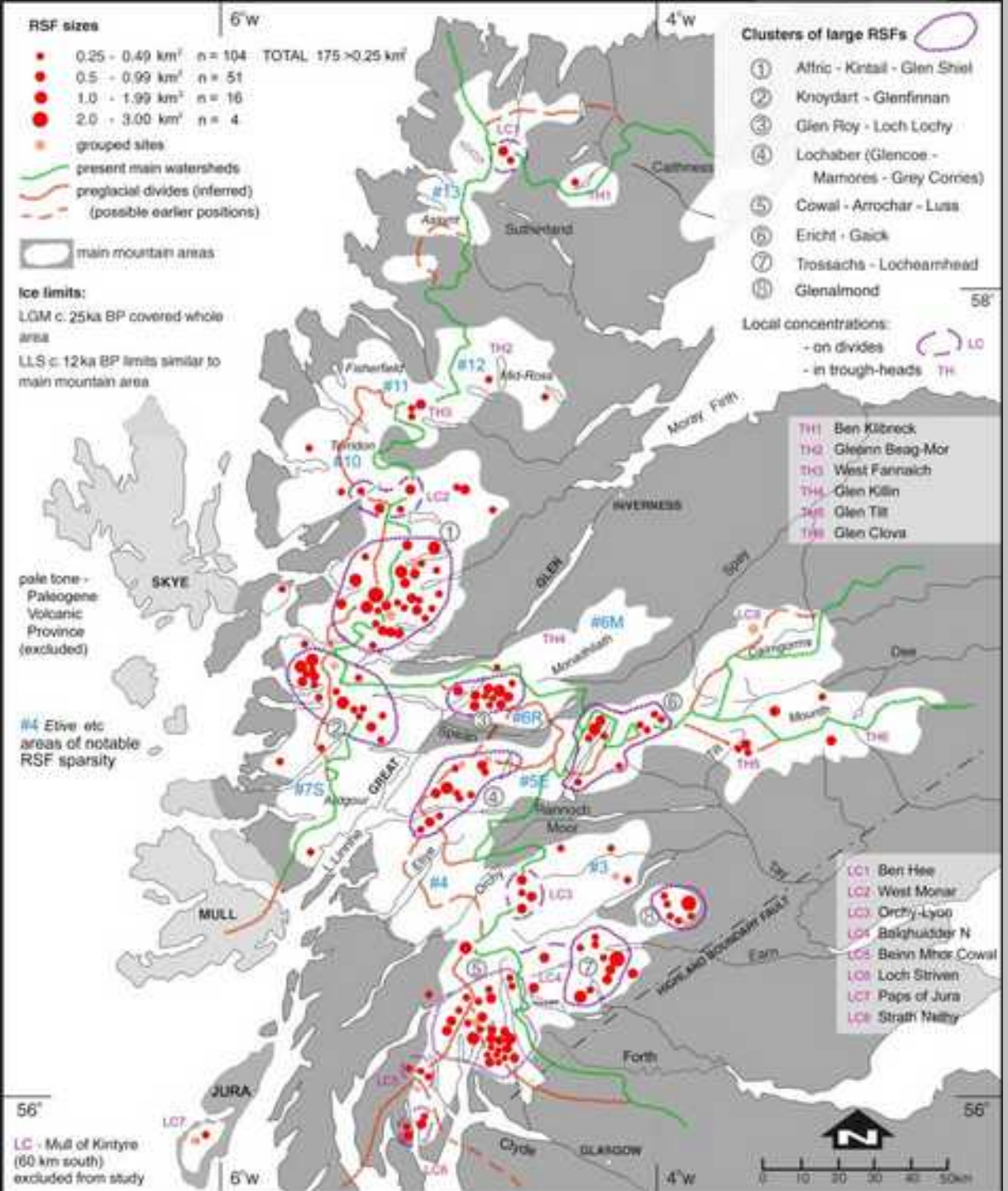
clustering -v- sparsity

clusters – glacial dissection

~50% RSFs in / below glacial breaches

window breach (col)

doorway breach (pass)



RSF Scottish Highlands

clustering -v- sparsity

clusters – glacial dissection

~50% RSFs in / below glacial breaches

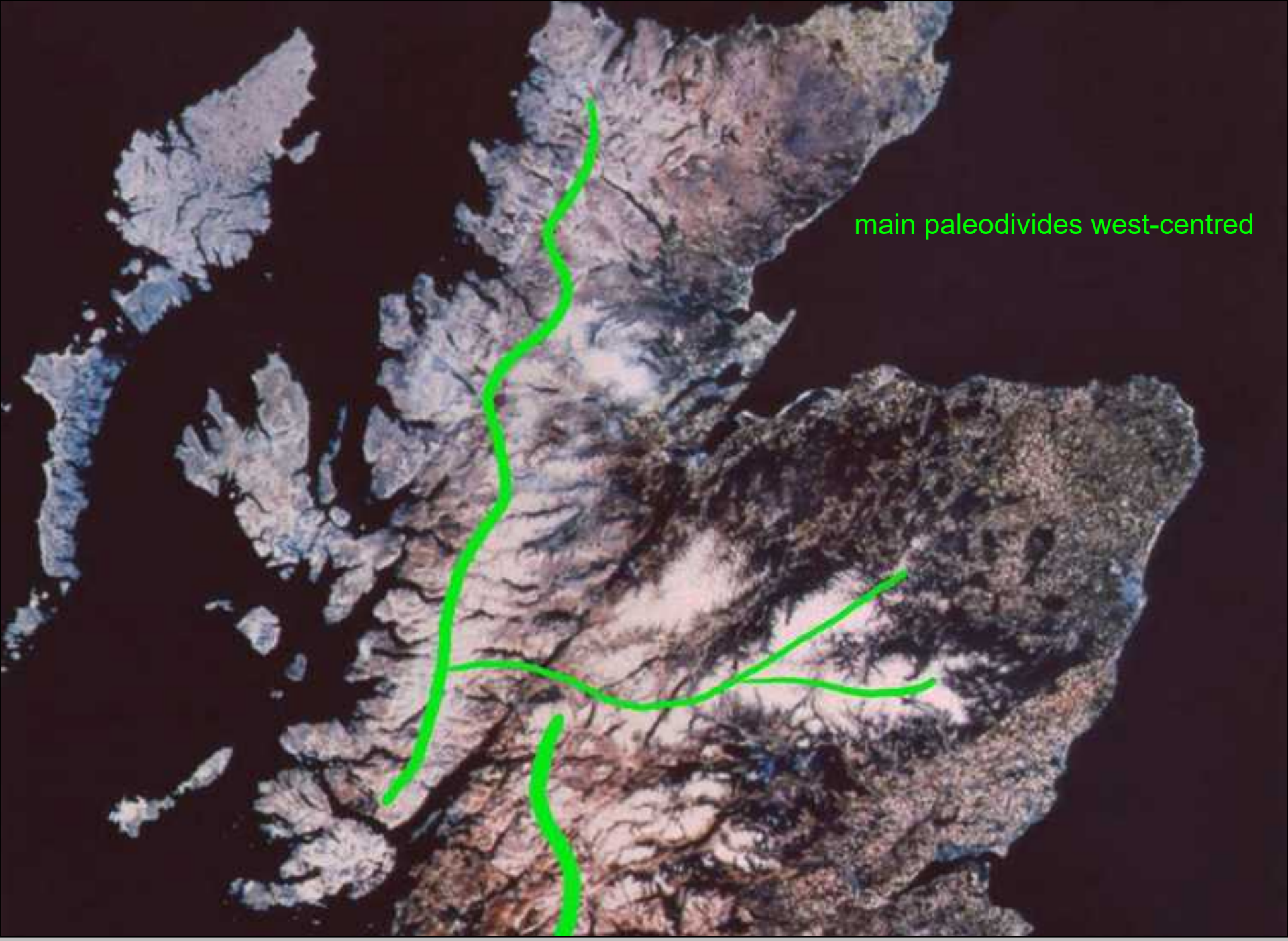
window breach (col)

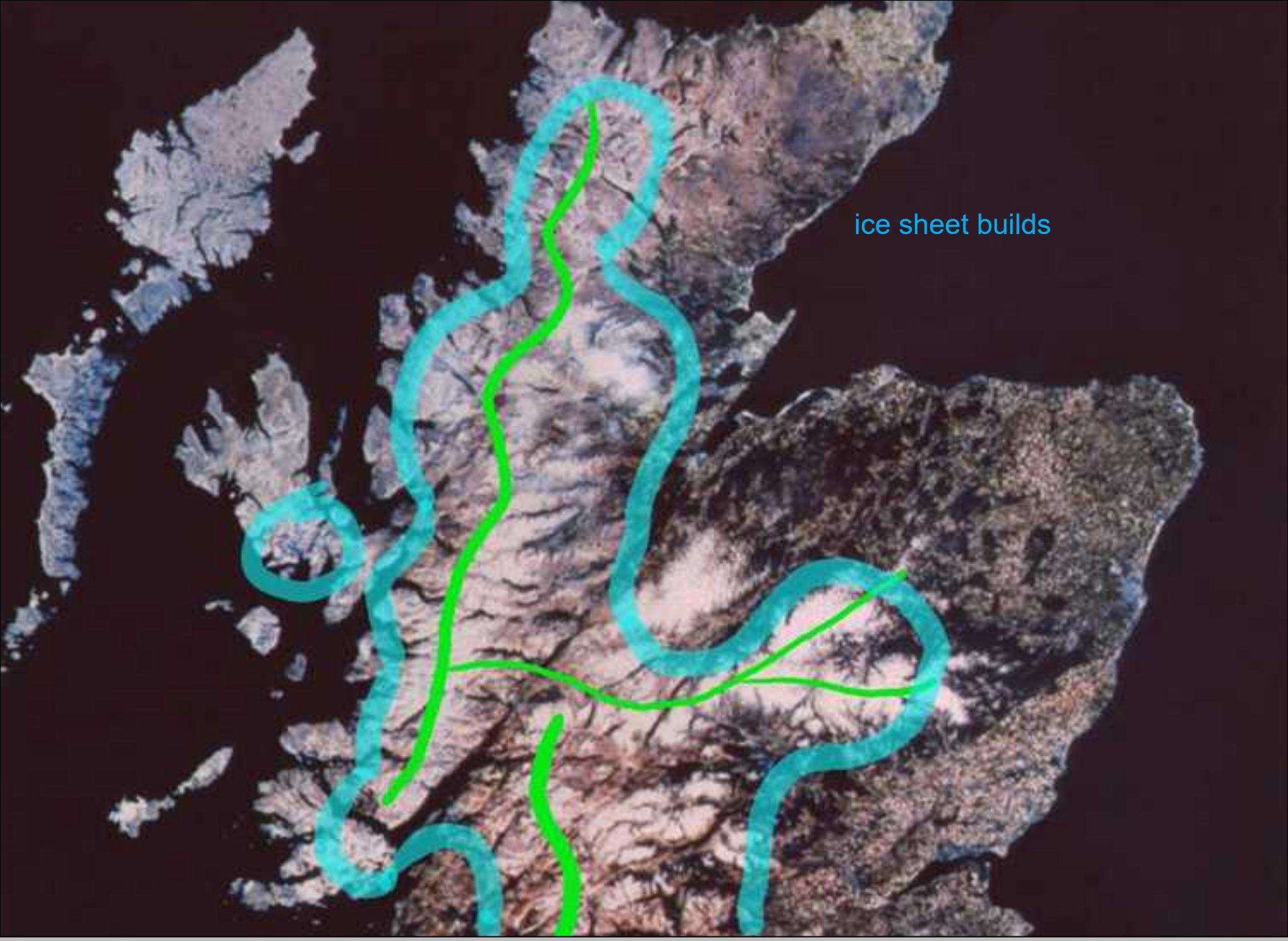
doorway breach (pass)

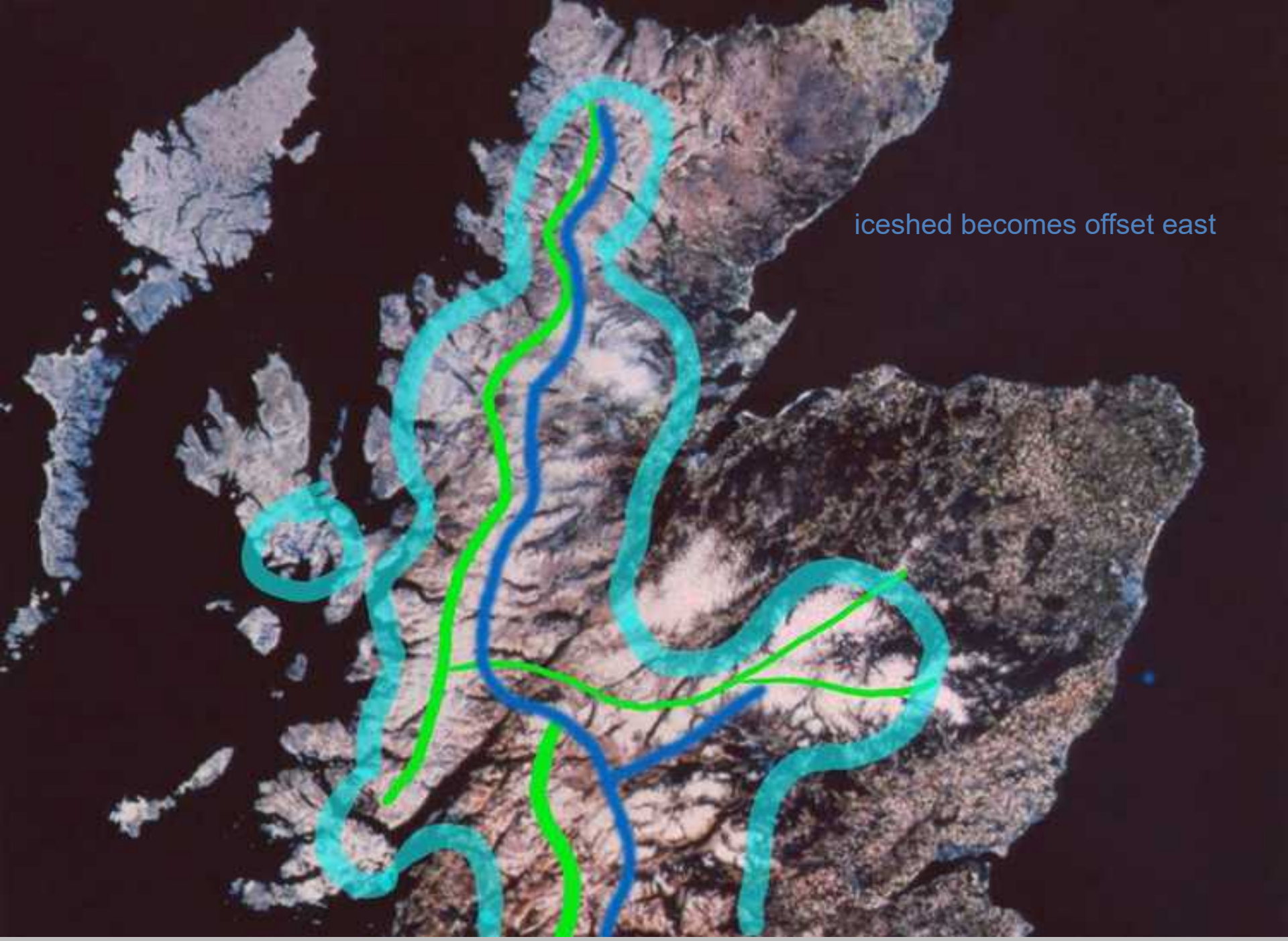
- breaches :

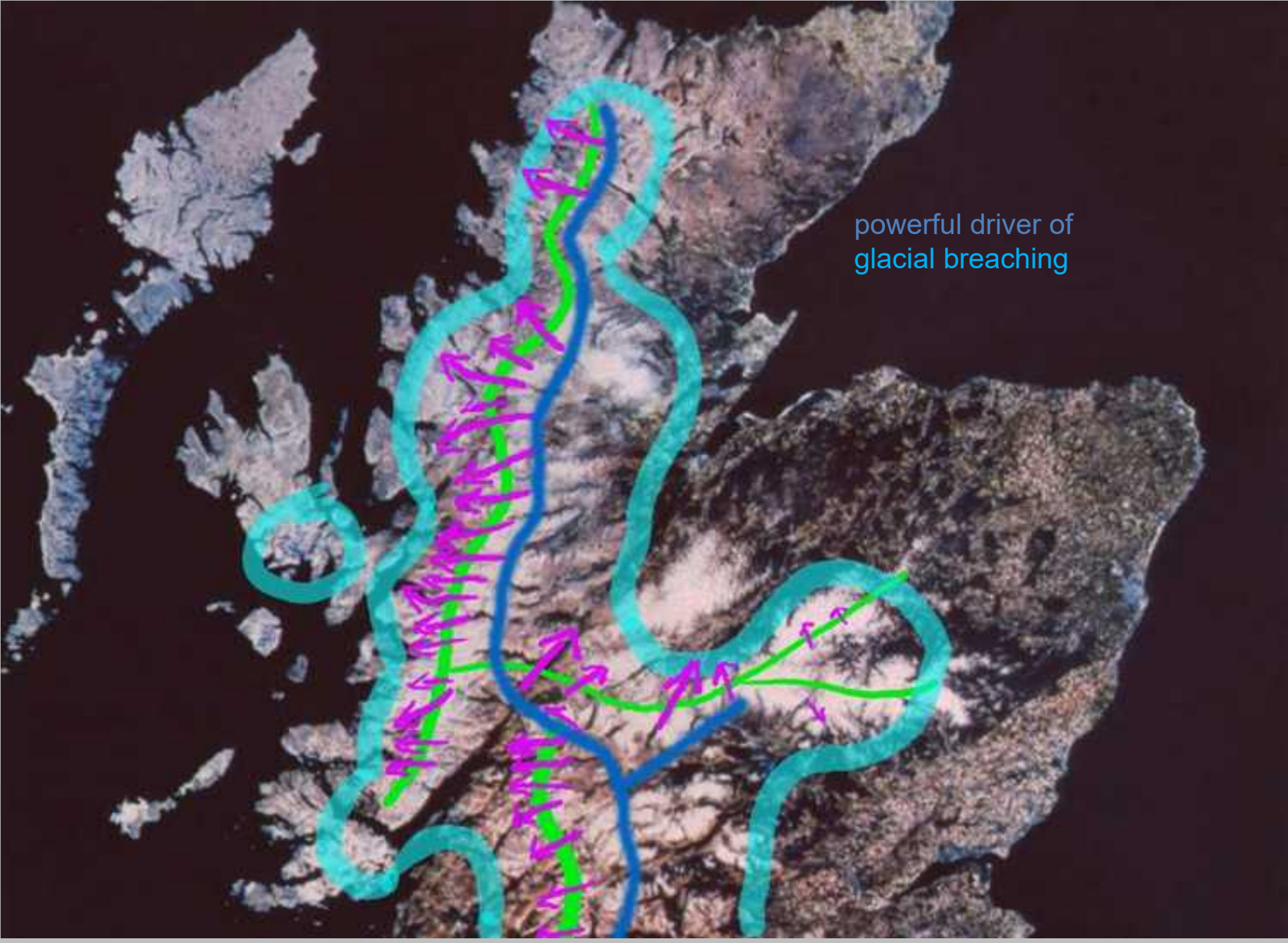
not of present main watersheds

but of preglacial paleodivides


main paleodivides west-centred

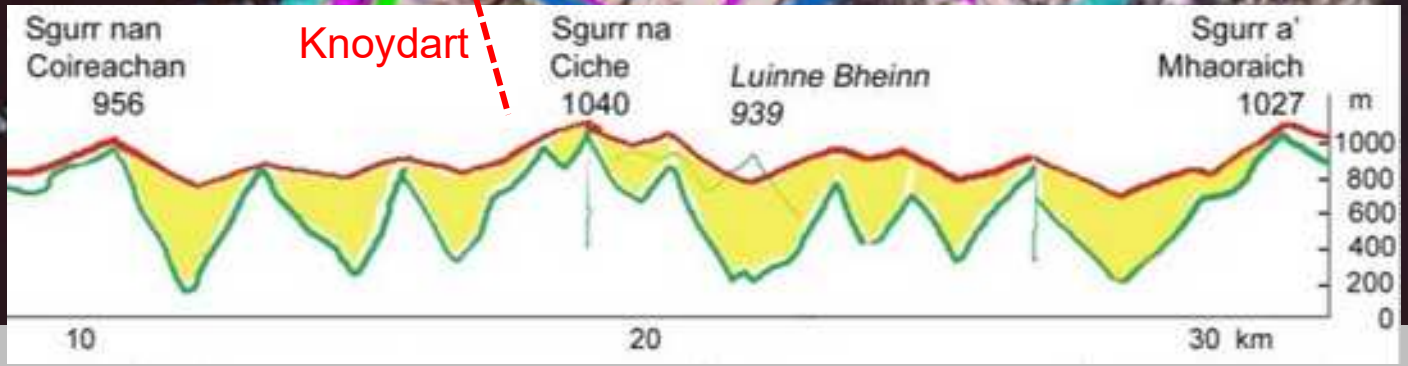

ice sheet builds

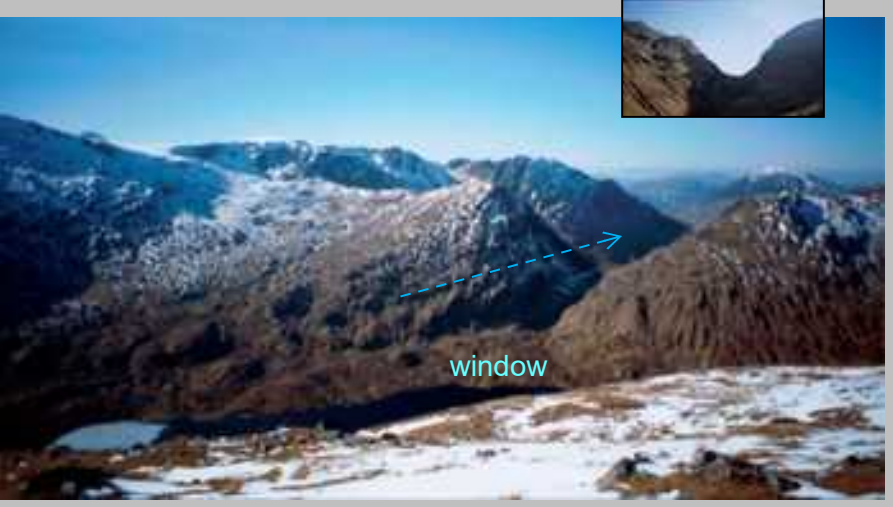

iceshed becomes offset east


powerful driver of
glacial breaching

powerful driver of
glacial breaching

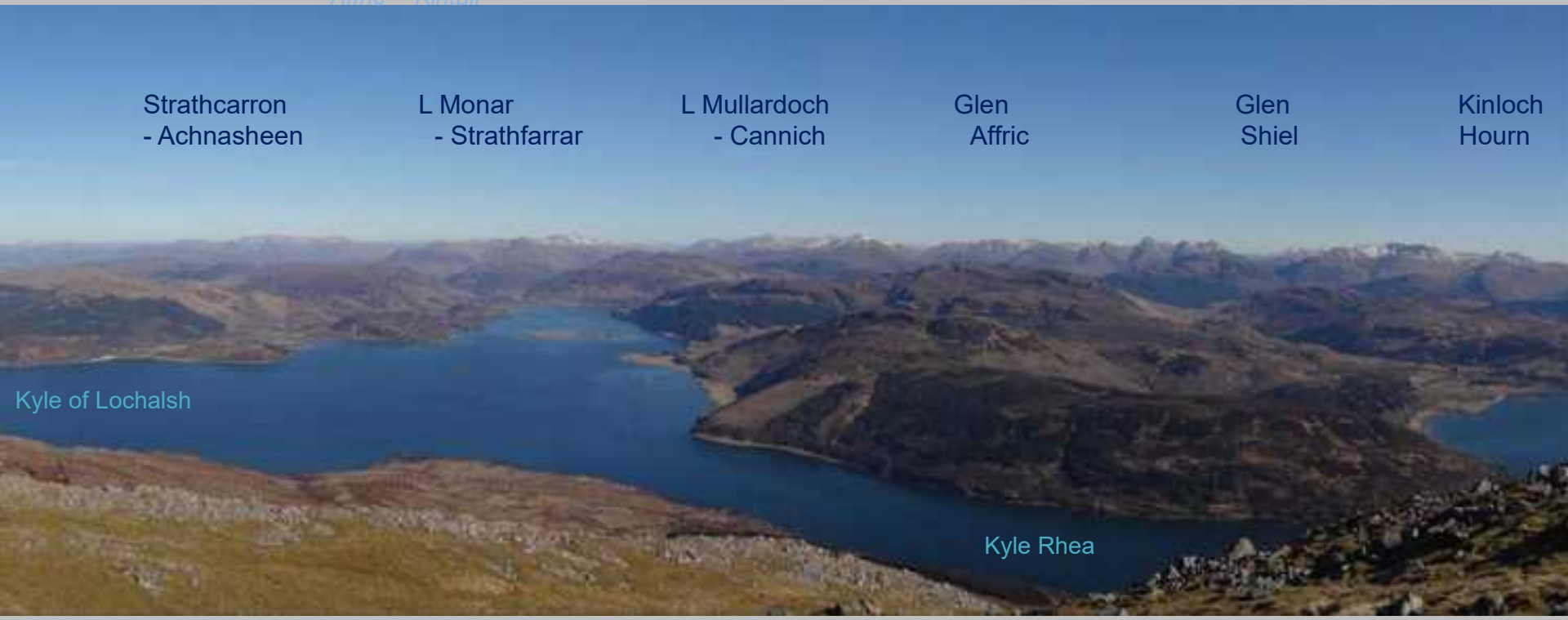
- intense perforation of divides

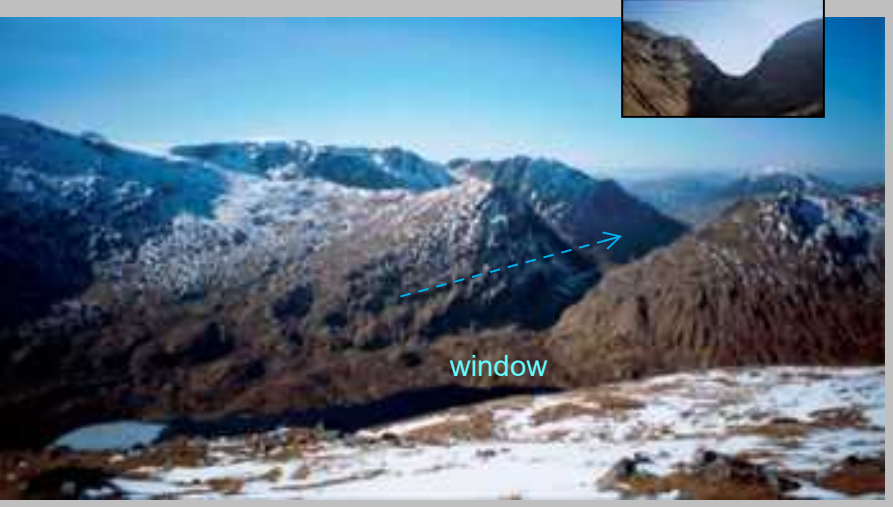




glacial through-breaches of the main NW Highland divide

Affric -- Kintail





glacial through-breaches of the main NW Highland divide

so no high passes (with hairpins or tunnels)

Affric -- Kintail

Strathcarron - Achnasheen

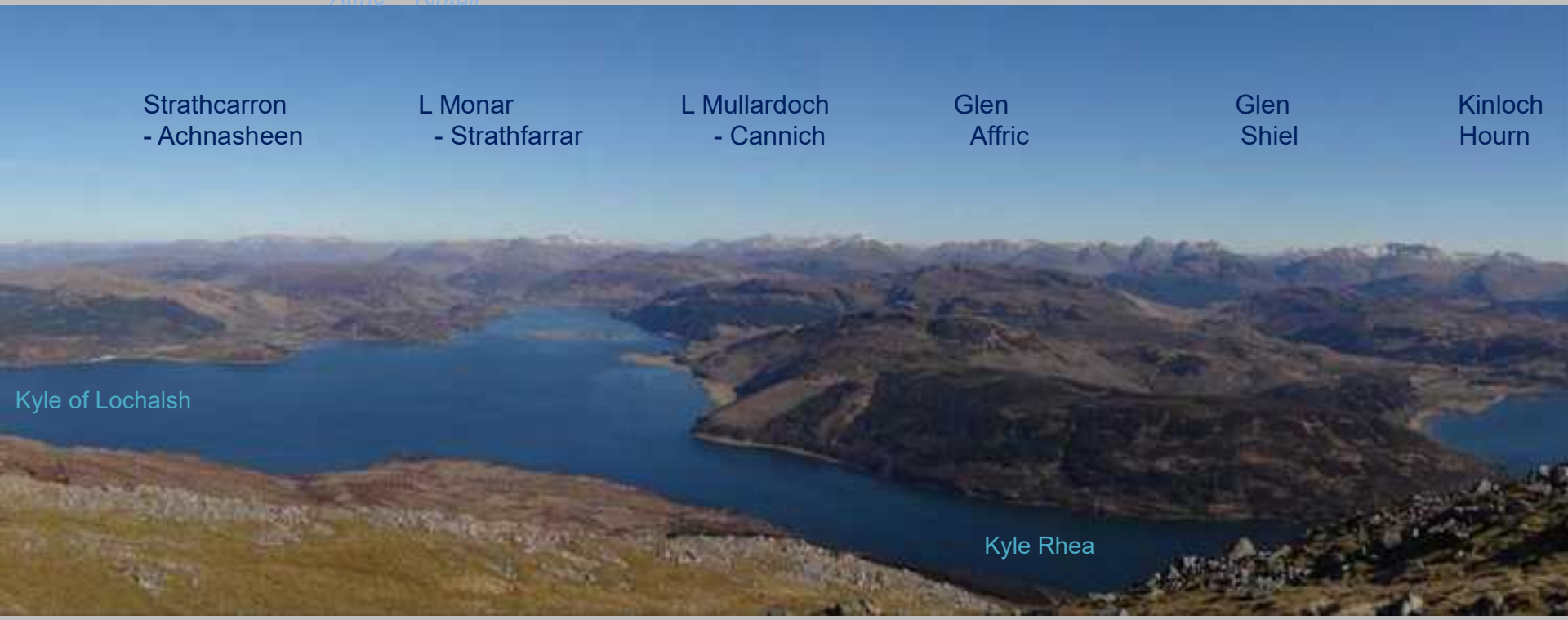
L Monar - Strathfarrar

L Mullardoch - Cannich

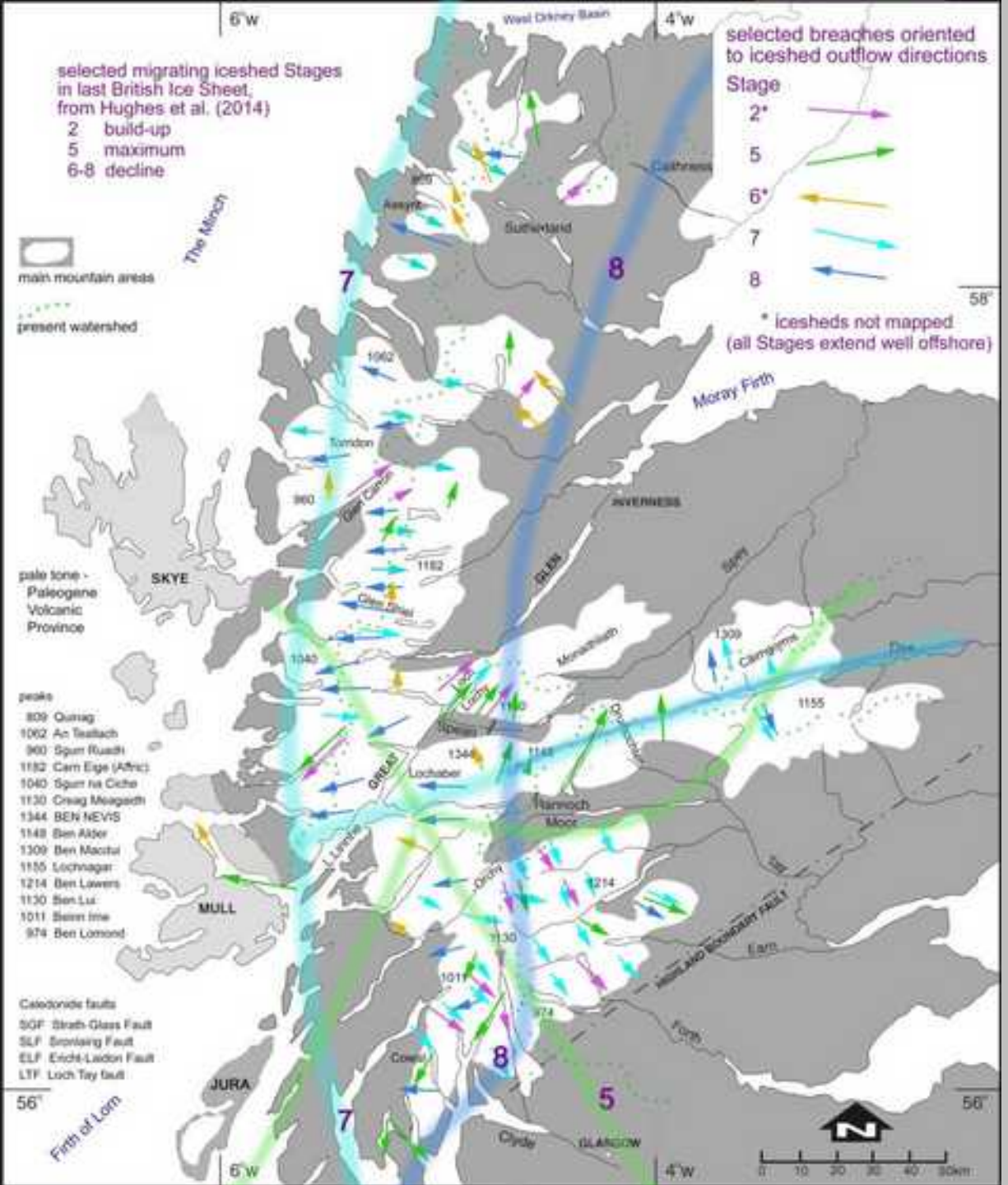
Glen Affric

Glen Shiel

Kinloch Hourn



intense in west - glacial dissection - localised or absent in east

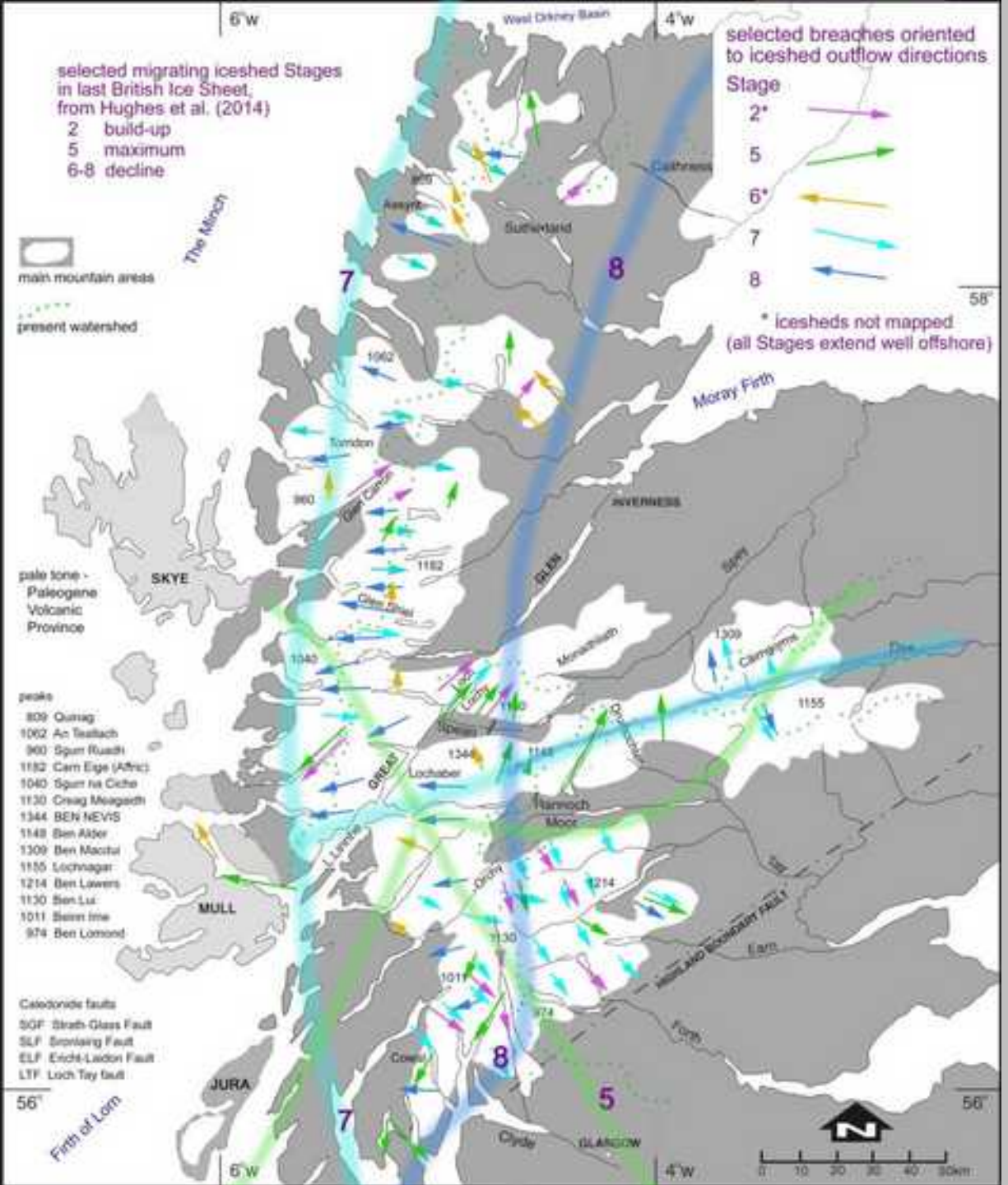


icesheet models

- Hughes et al 2014 (Chris Clark)

extraordinary insights into

- *ice divide migration*



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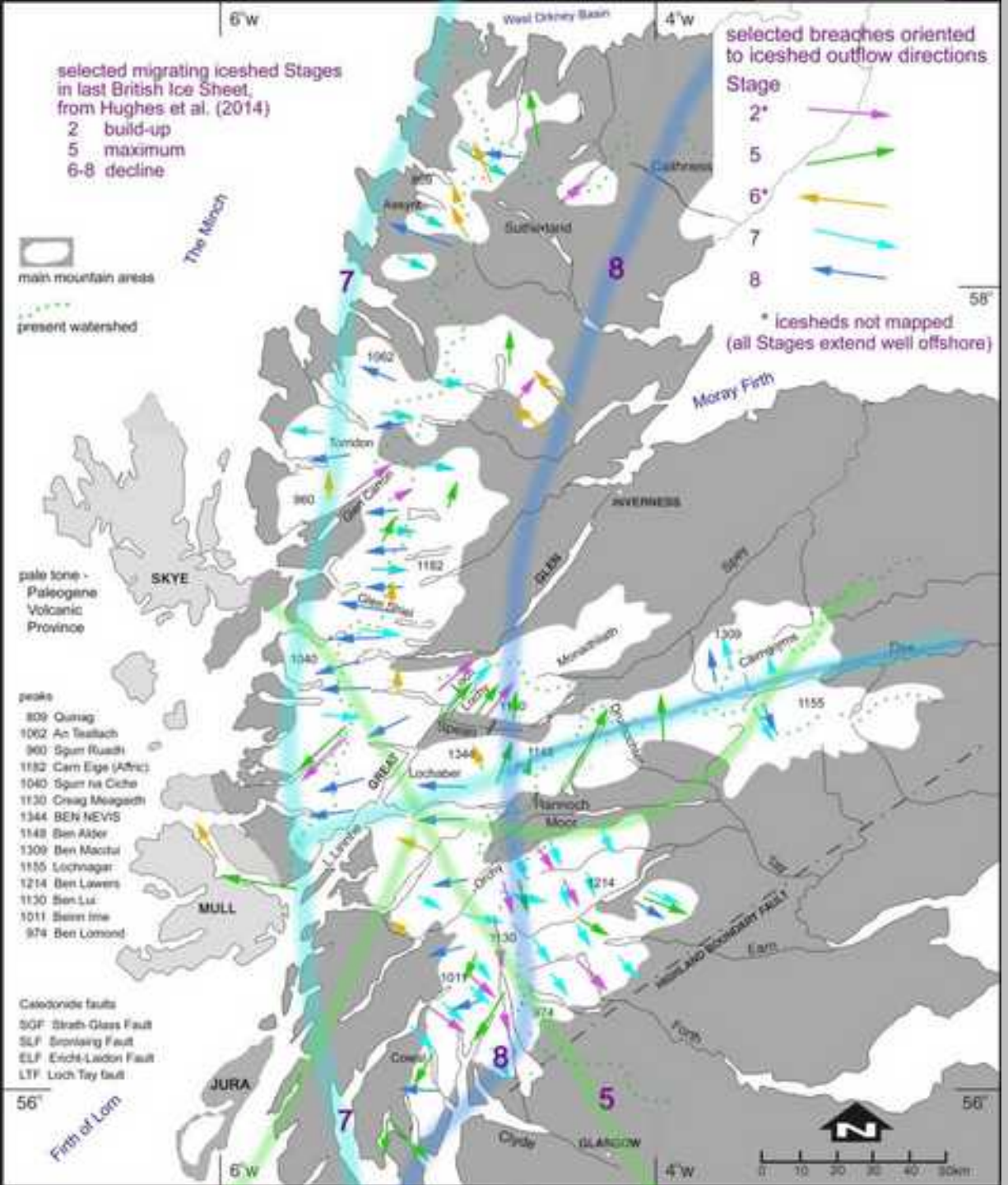
- *breaches cut by see-saw ice flow ?*



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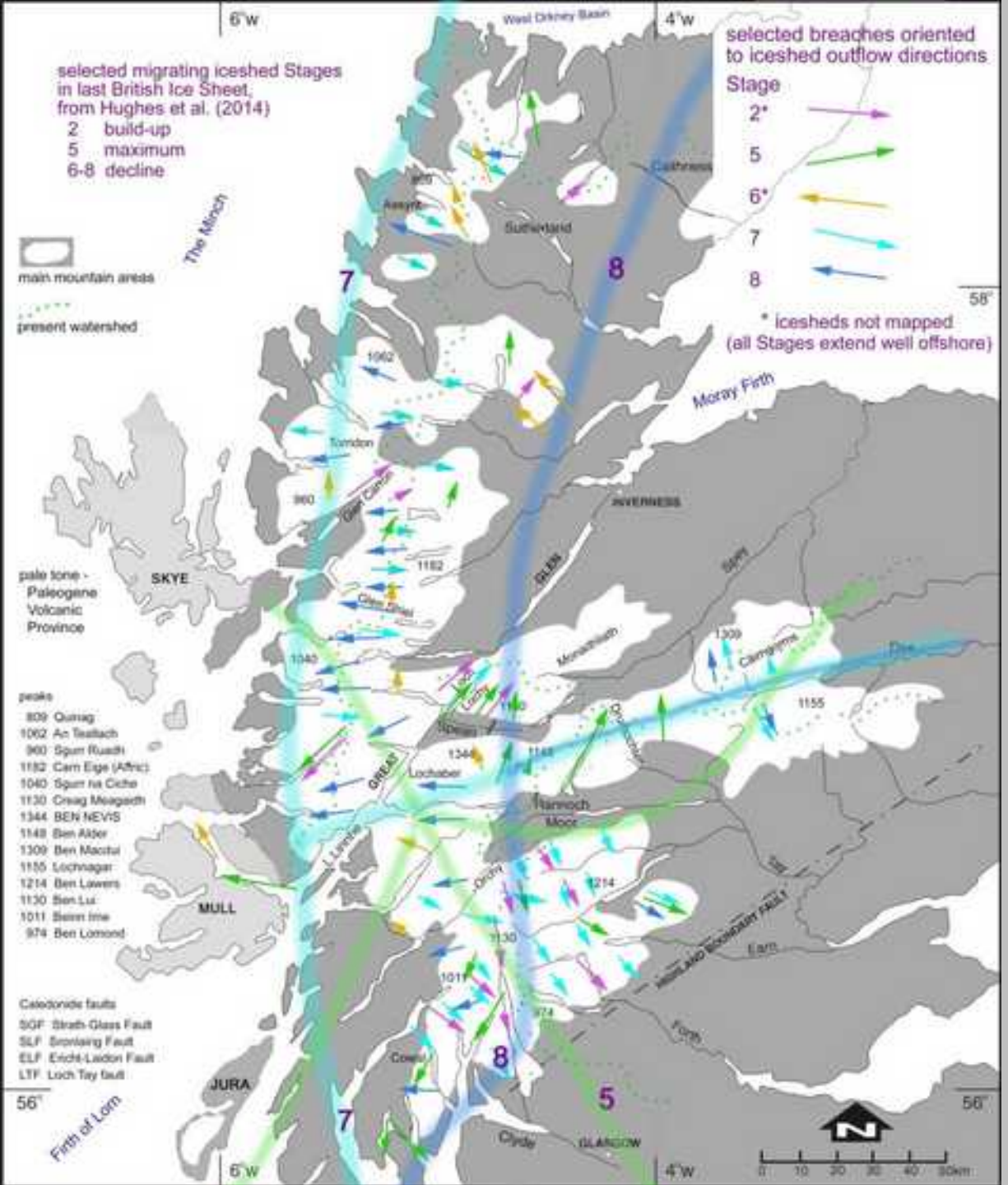
  *- possibly **'catastrophic'** incision rates*



icesheet models

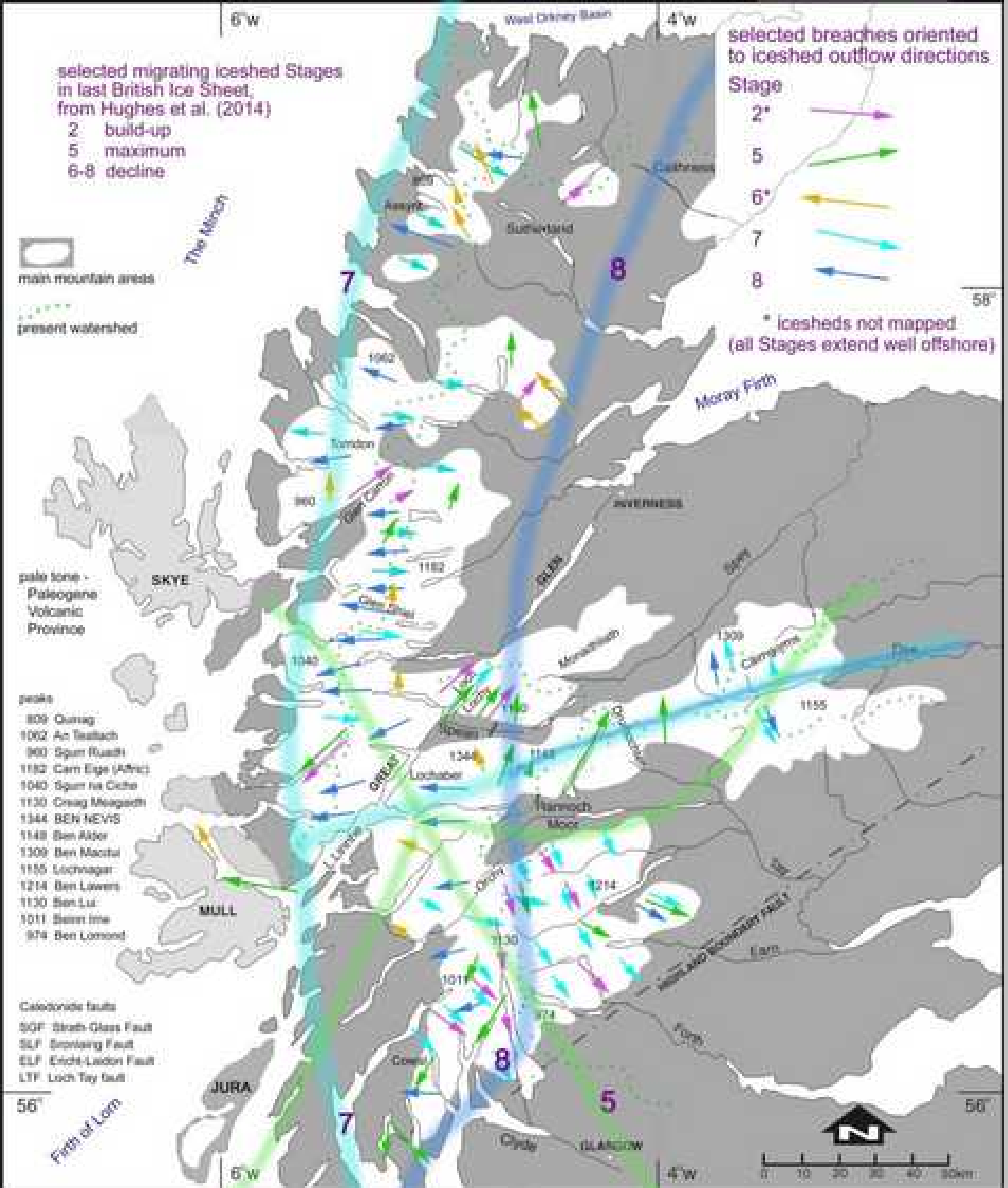
- Hughes et al 2014

extraordinary insights into

- *ice divide migration*
- *breaches cut by see-saw ice flow ?*

*- possibly **'catastrophic'** incision rates*

cf. glacifluvial ravines
- Corrieshalloch
- Spean Gorge
- Falls of Glomach



"ice tearing the mighty breach which carries Loch Lochy" (opening the Great Glen as a through-way)

David Linton, 1949

icesheet models

- Hughes et al 2014

extraordinary insights into

- *ice divide migration*
- *breaches cut by see-saw ice flow ?*

*- possibly **'catastrophic'** incision rates*

cf. glacifluvial ravines

- Corrieshalloch

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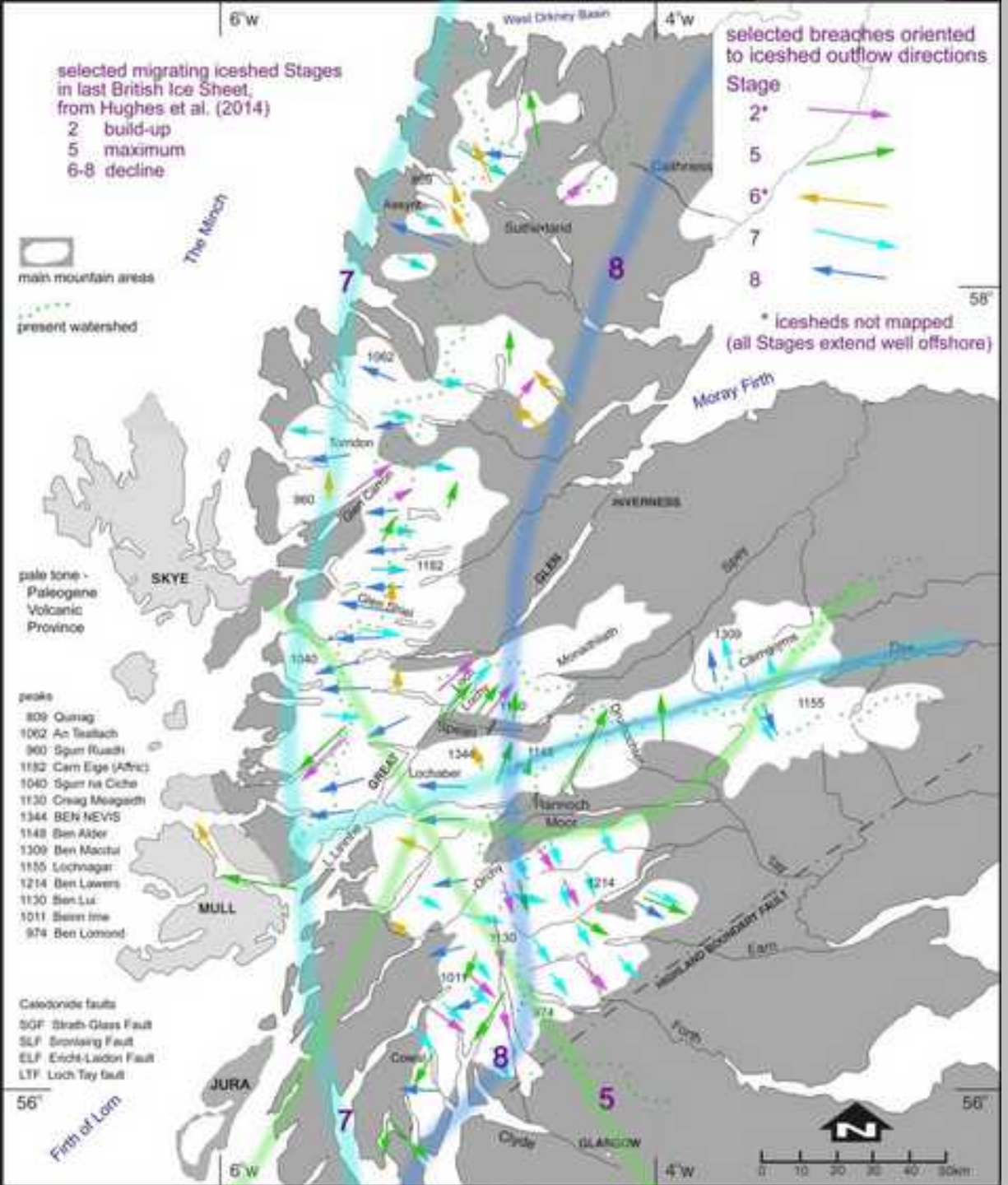
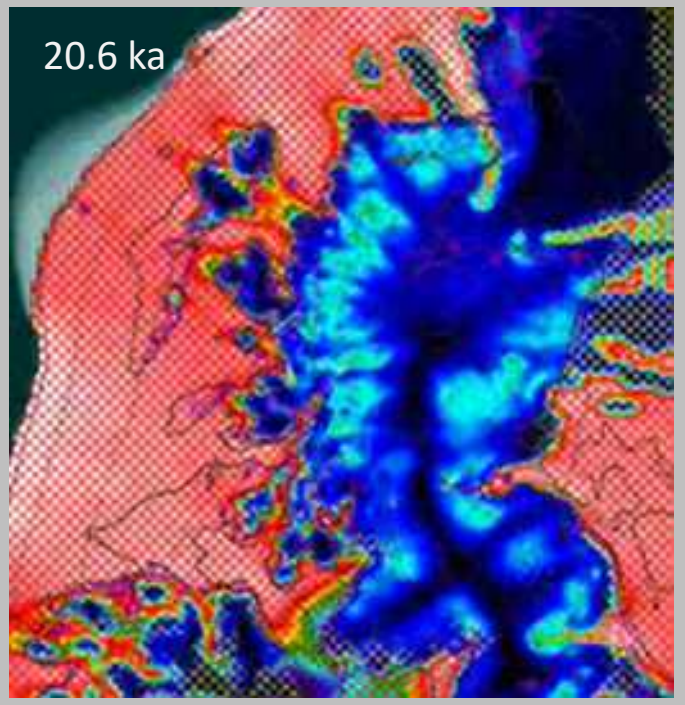


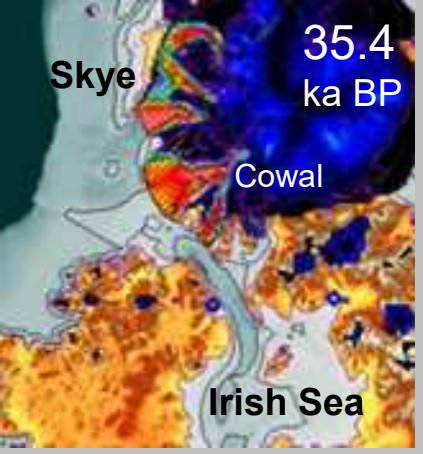


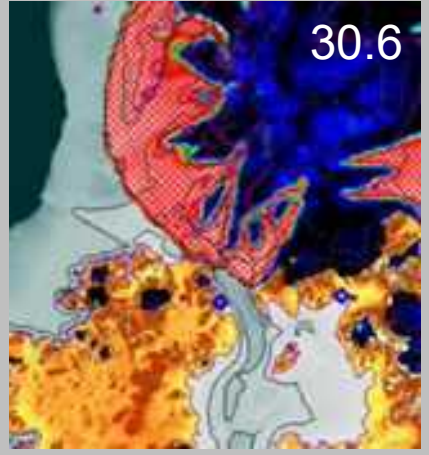
icesheet models

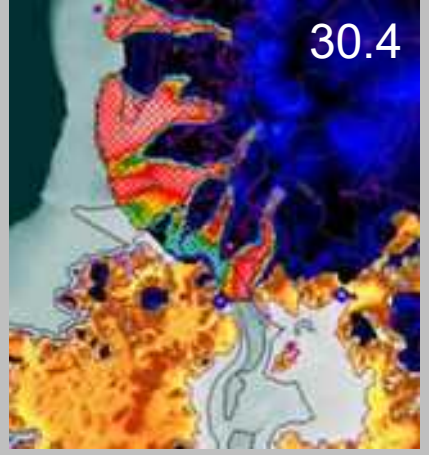
- Hubbard et al 2009
- Hughes et al 2014

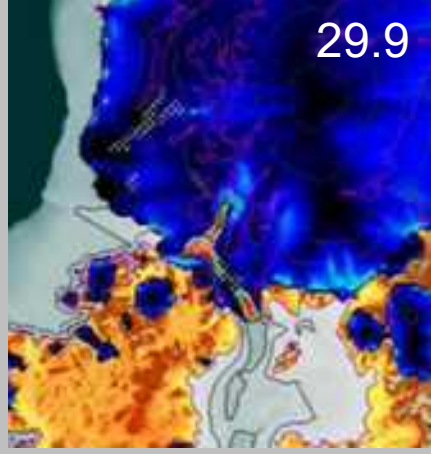
extraordinary insights into

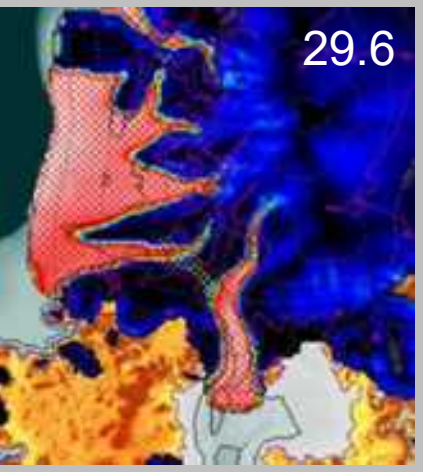
- *ice divide migration*
- *rapid oscillation*

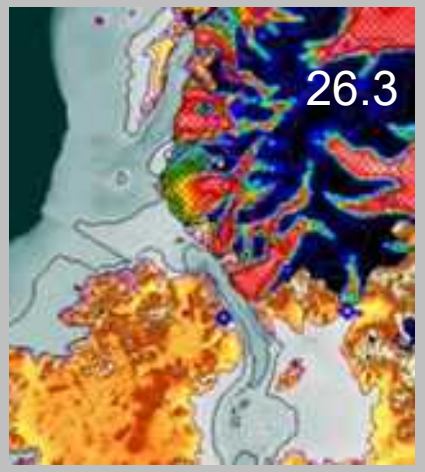


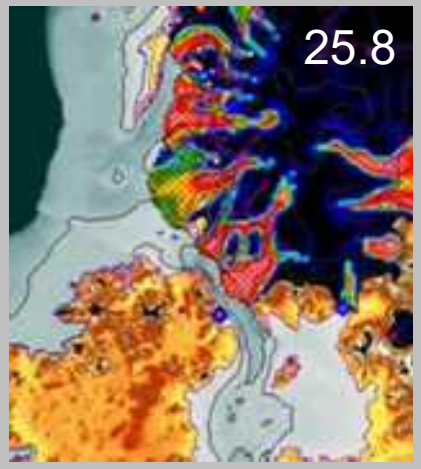






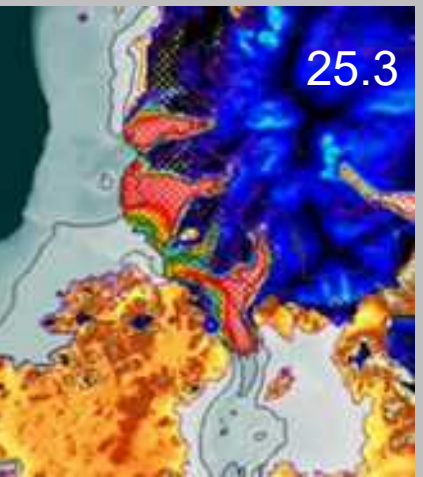


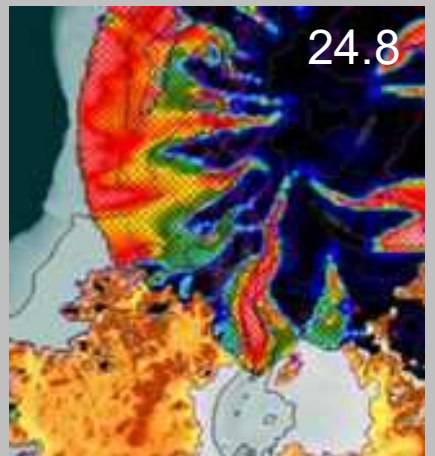


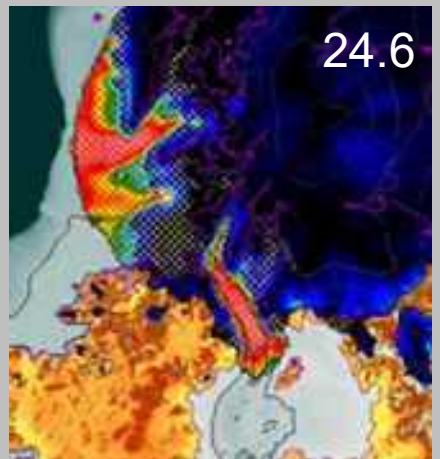


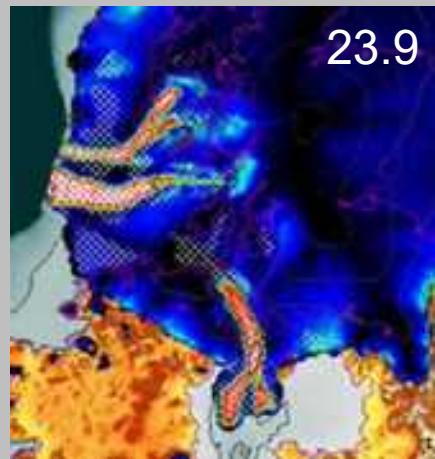
Hubbard ice sheet model 2009

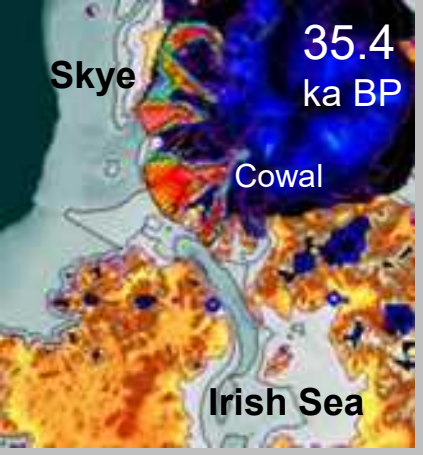
- *binge -- purge cycling*
- *flickering icestream tongues*
- *fast, wet-based glaciers*

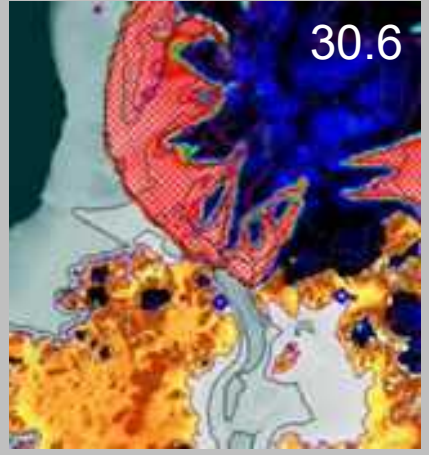


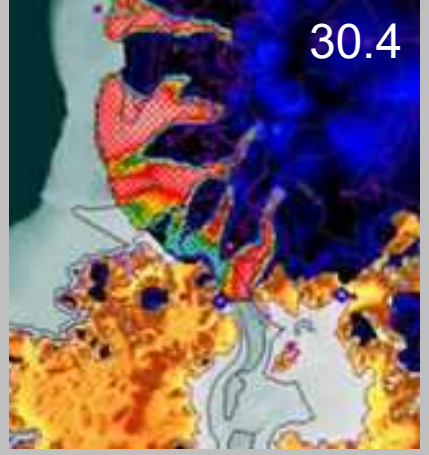


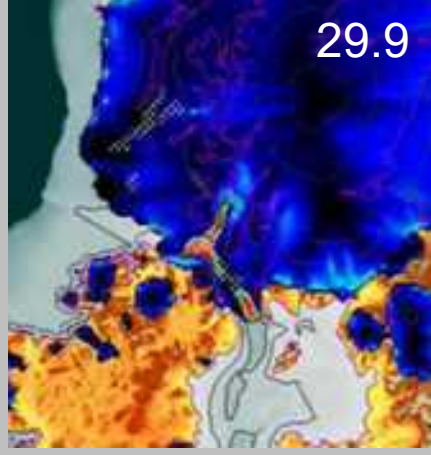


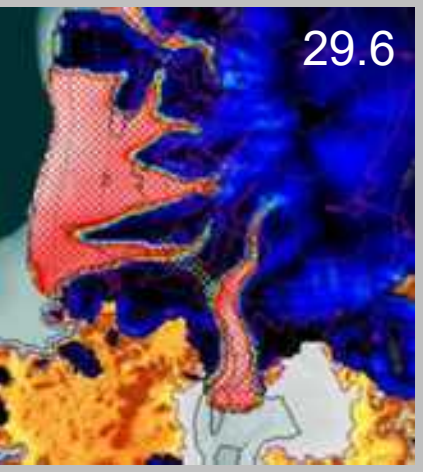


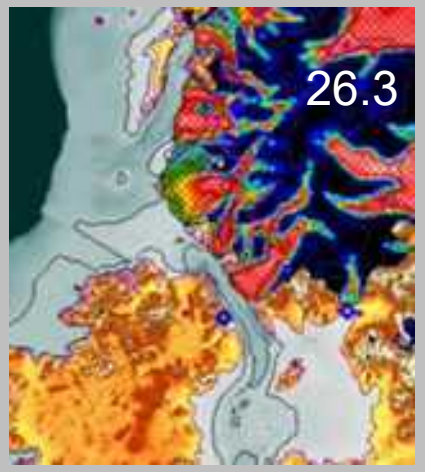


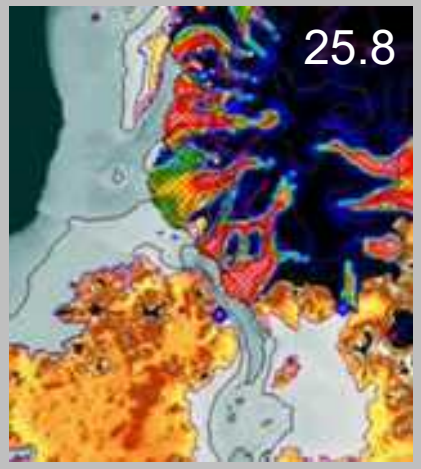








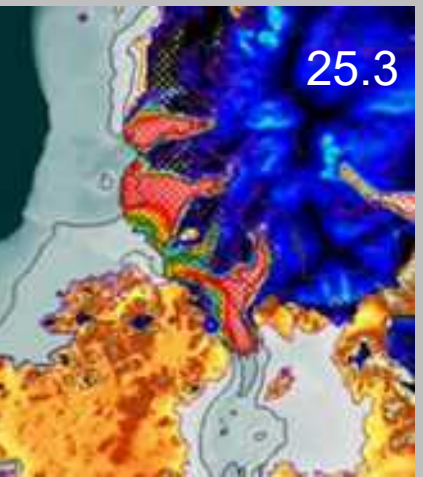


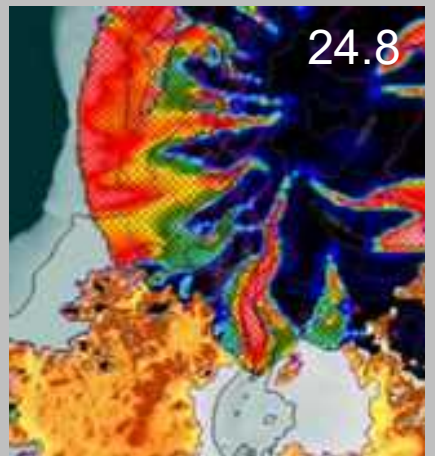


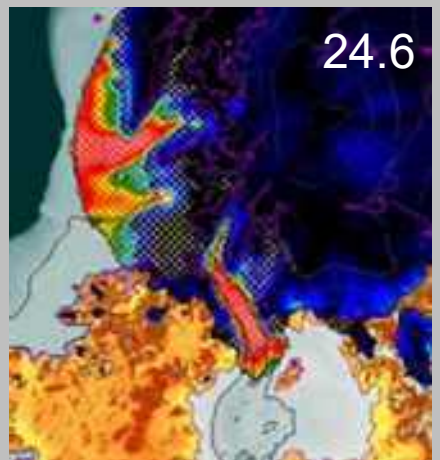
Hubbard ice sheet model 2009

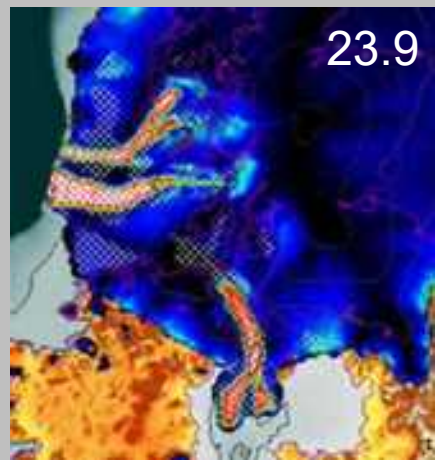
- *binge -- purge cycling*
- *flickering icestream tongues*
- *fast, wet-based glaciers*
- *glacial -- paraglacial cycling recharging bedload*

➢ *all highly erosive*

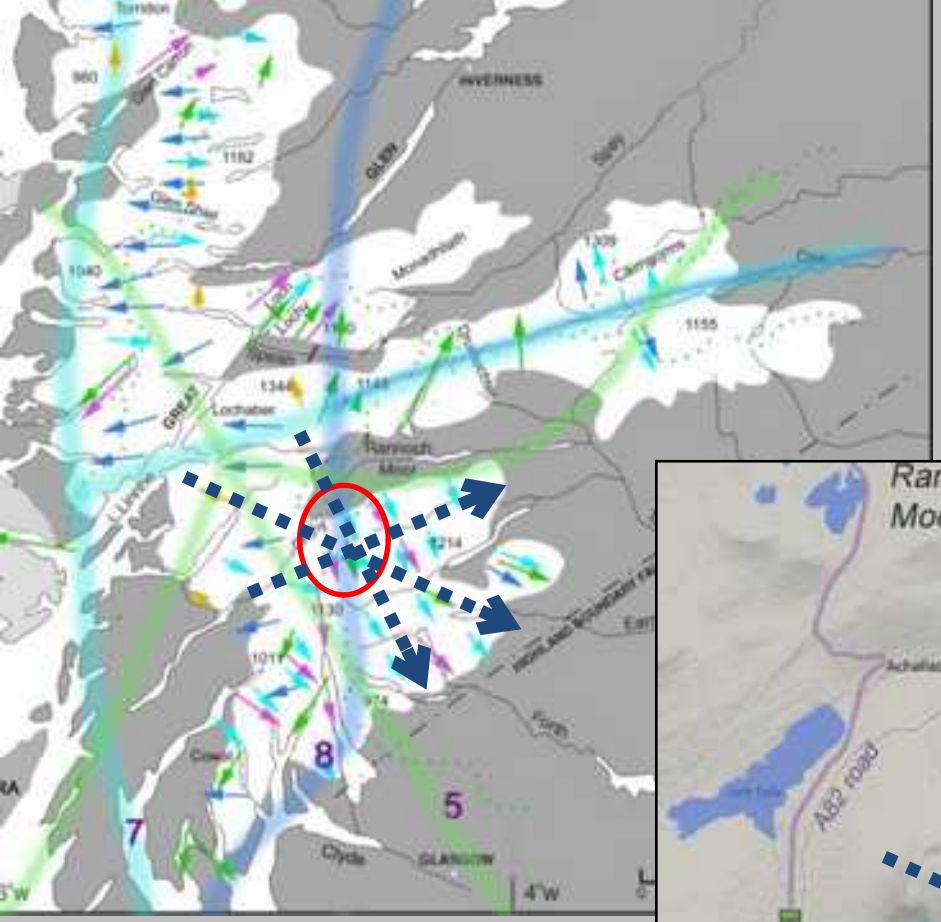








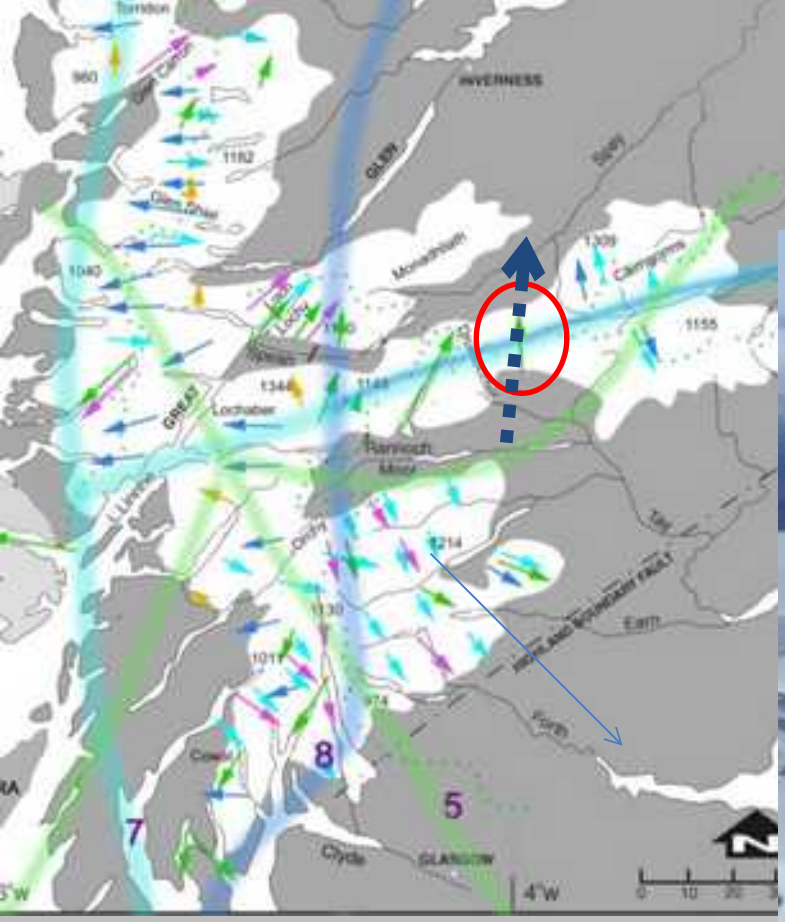
Orchy--Lyon breachplex



Gaick Pass

Loch an Duin 3-500 m deep breach of paleodivide

- *lined with RSFs*
- *recent response to southerly iceshed (Stage 5) ?*



other possible causes of RSF

- *high water pressures along ice margins at rapid deglaciation*
- *periglacial freeze-thaw*
- *debuttressing*

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these apply all along every deglaciated glen, RSF is localised and clustered

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  - *Glasgow school / CKB*
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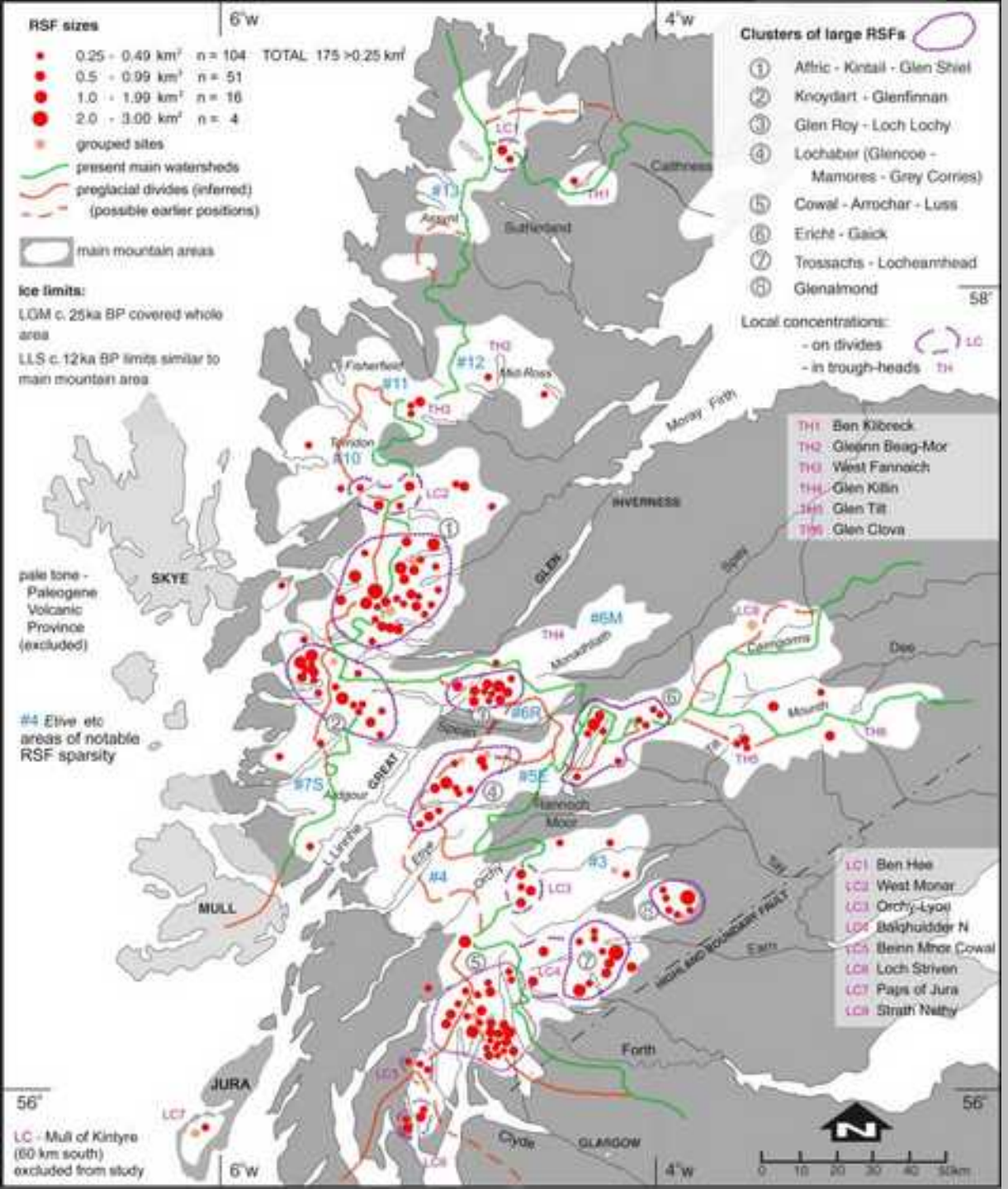
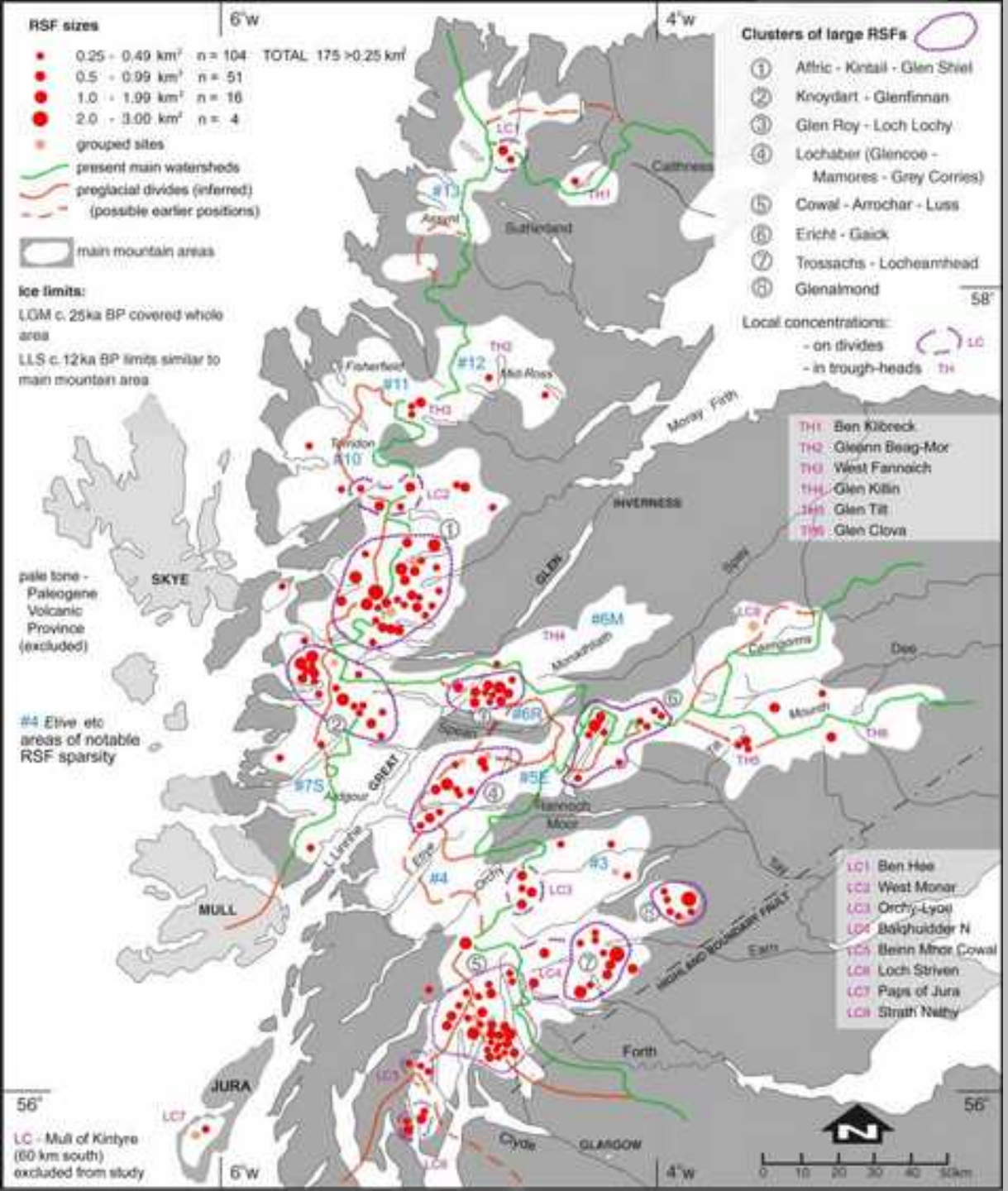
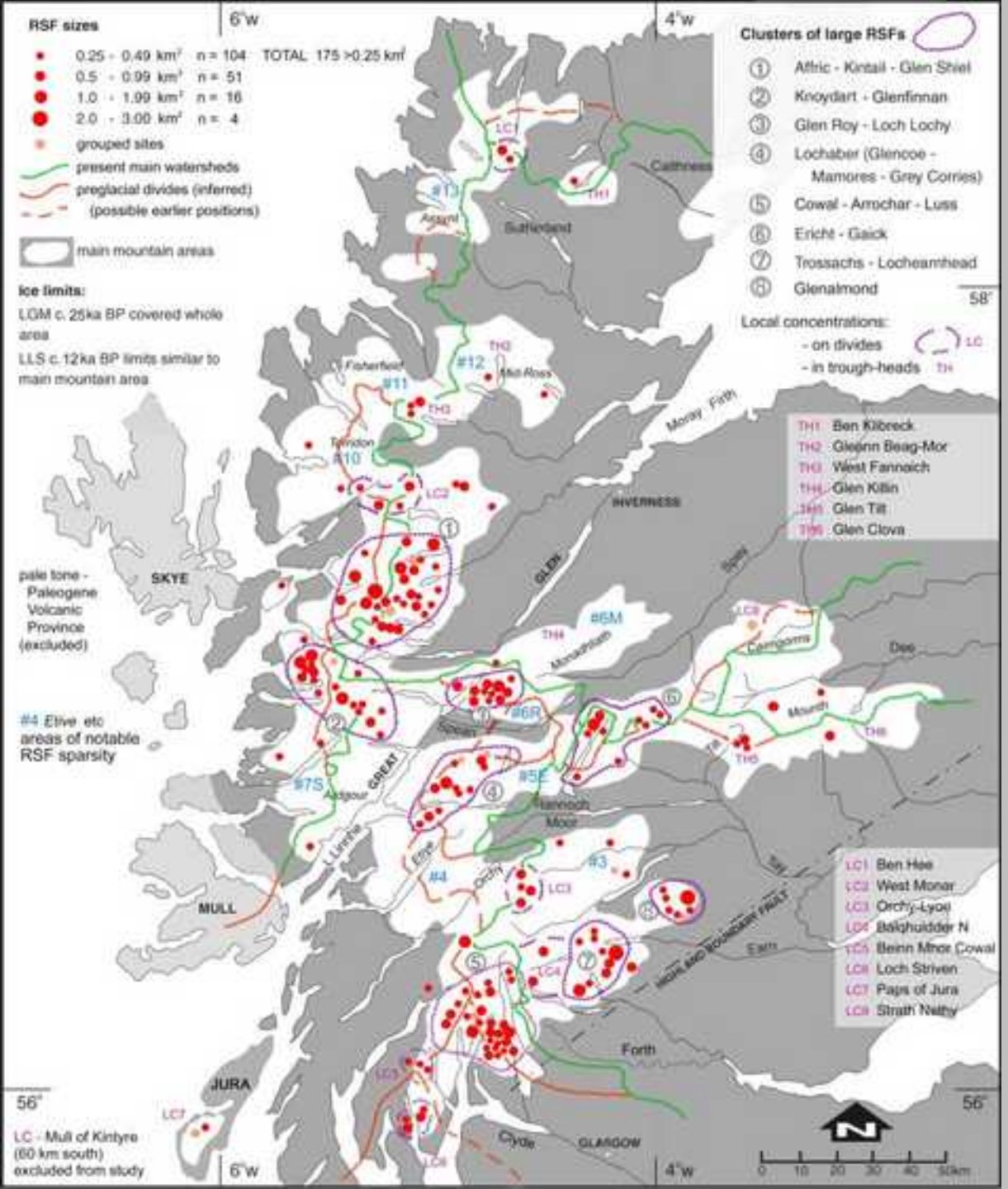


major RSF clusters



major RSF clusters density

MONTANE HIGHLANDS ***846*** ***0.8%***



major RSF clusters	density	
MONTANE HIGHLANDS	846	**0.8%**
#1 Glen Shiel / Kintail	111	4.0%
#3 Roy - Lochy	21	6.5%
#5 SW Highlands	130	5.2%
#8 Glen Almond	33	5.9%

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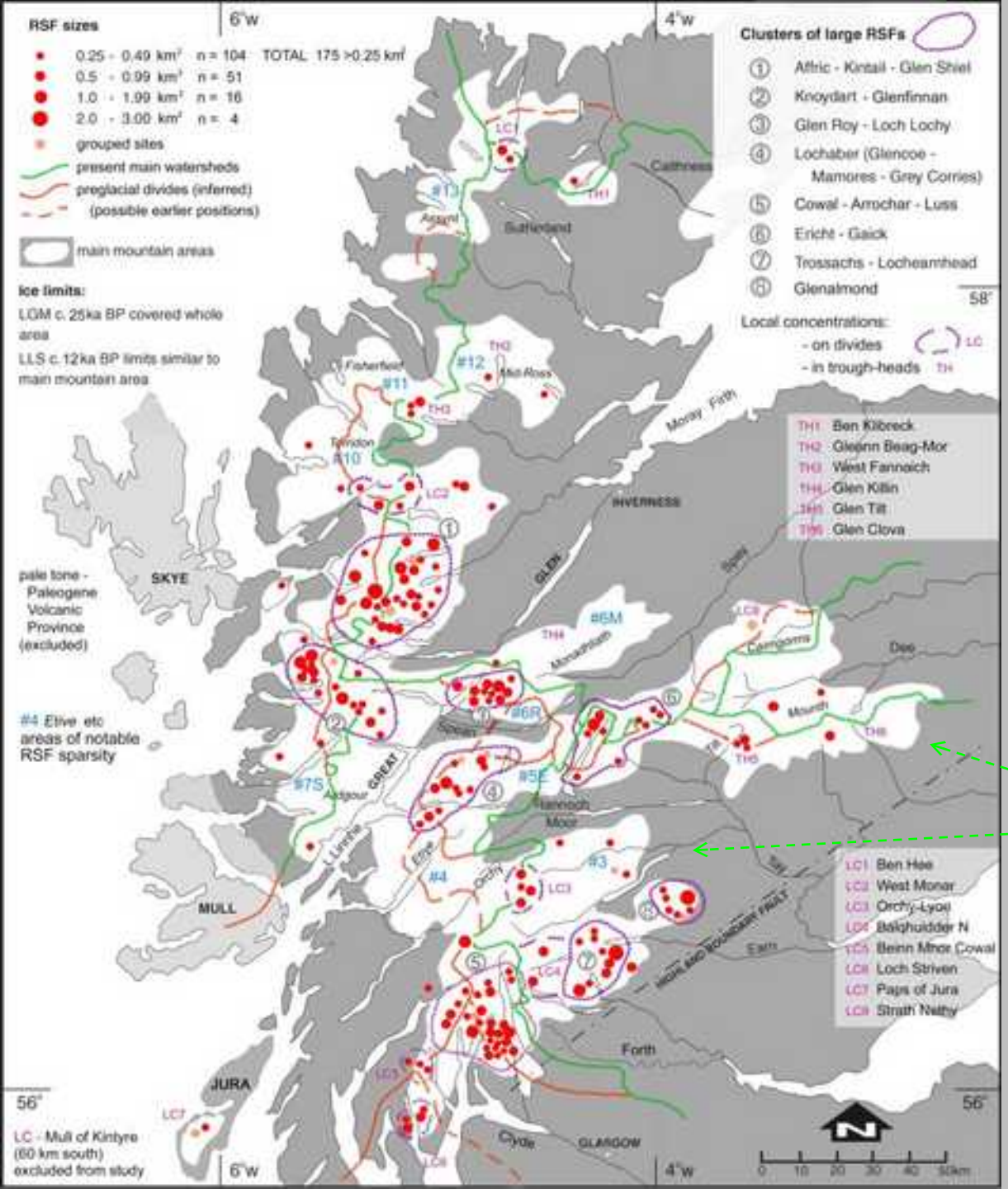

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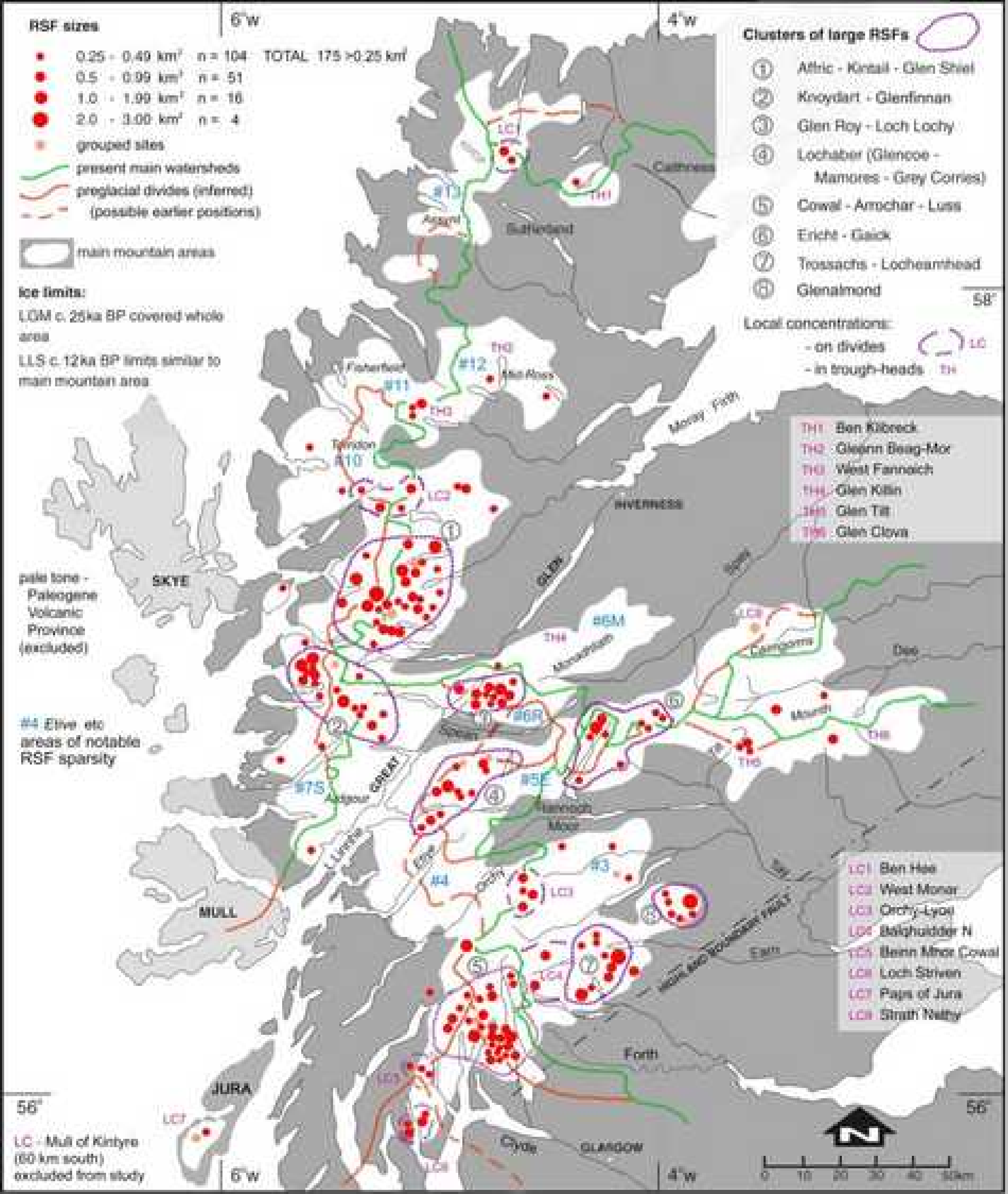

major RSF clusters *density*

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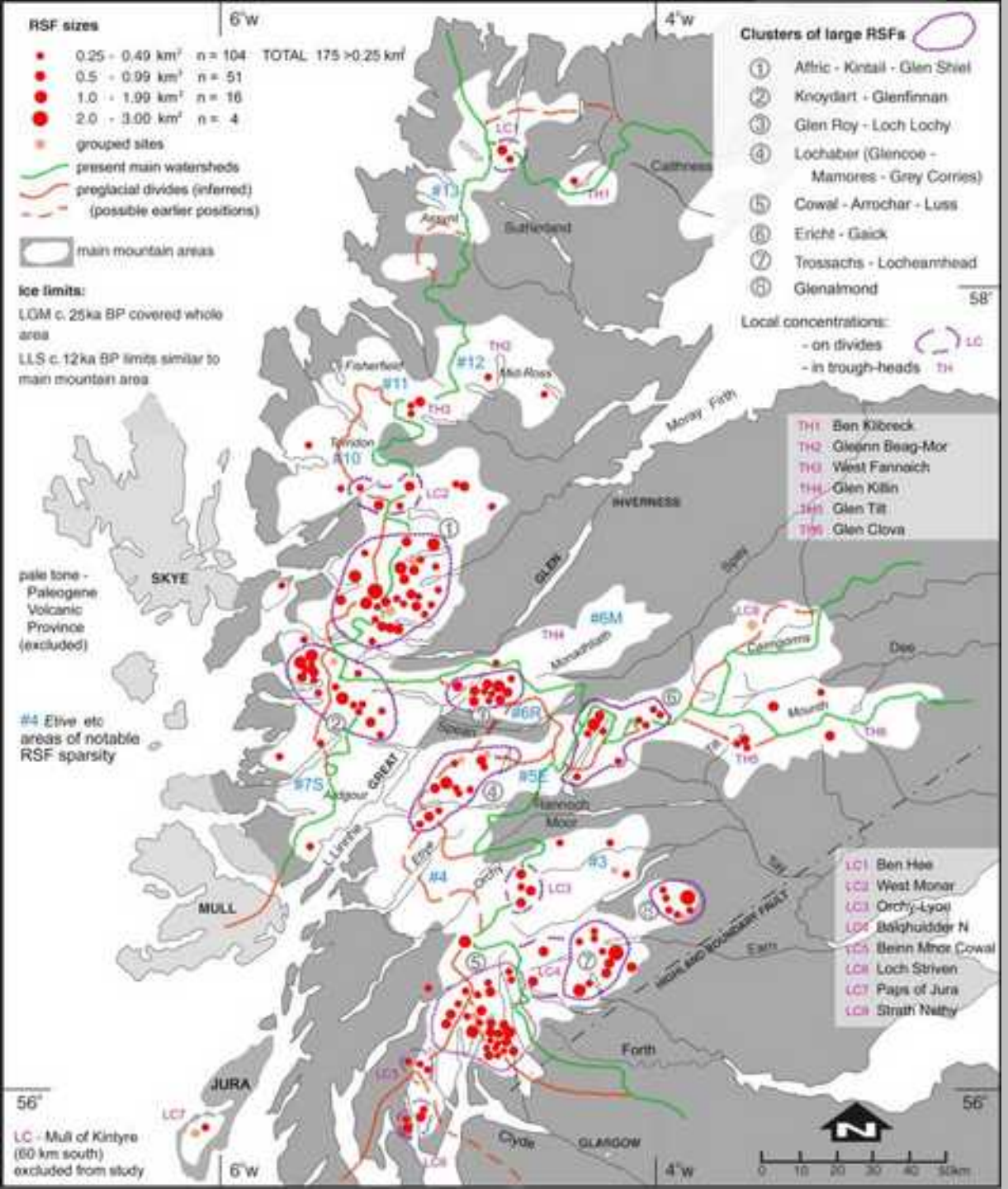
6 groupings ***10-20%***



major RSF clusters

#1 Glen Shiel / Kintail *111*

#5 SW Highlands *130*

Loch Lomond twin breaches

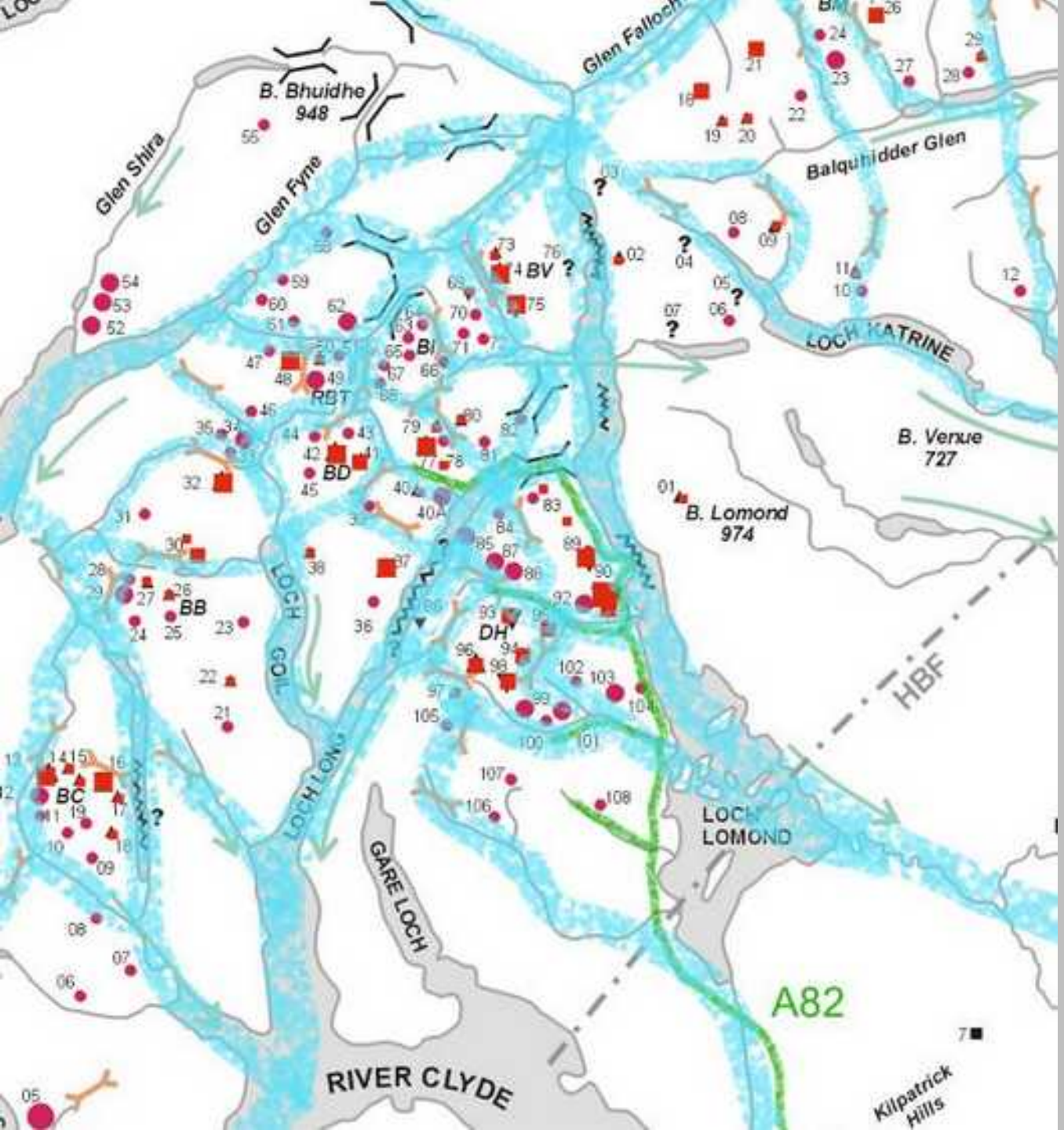
Henry Cadell 1886

David Linton 1960

#1W89-92 Beinn Bhreac

1.40 km²

rock slope deformation

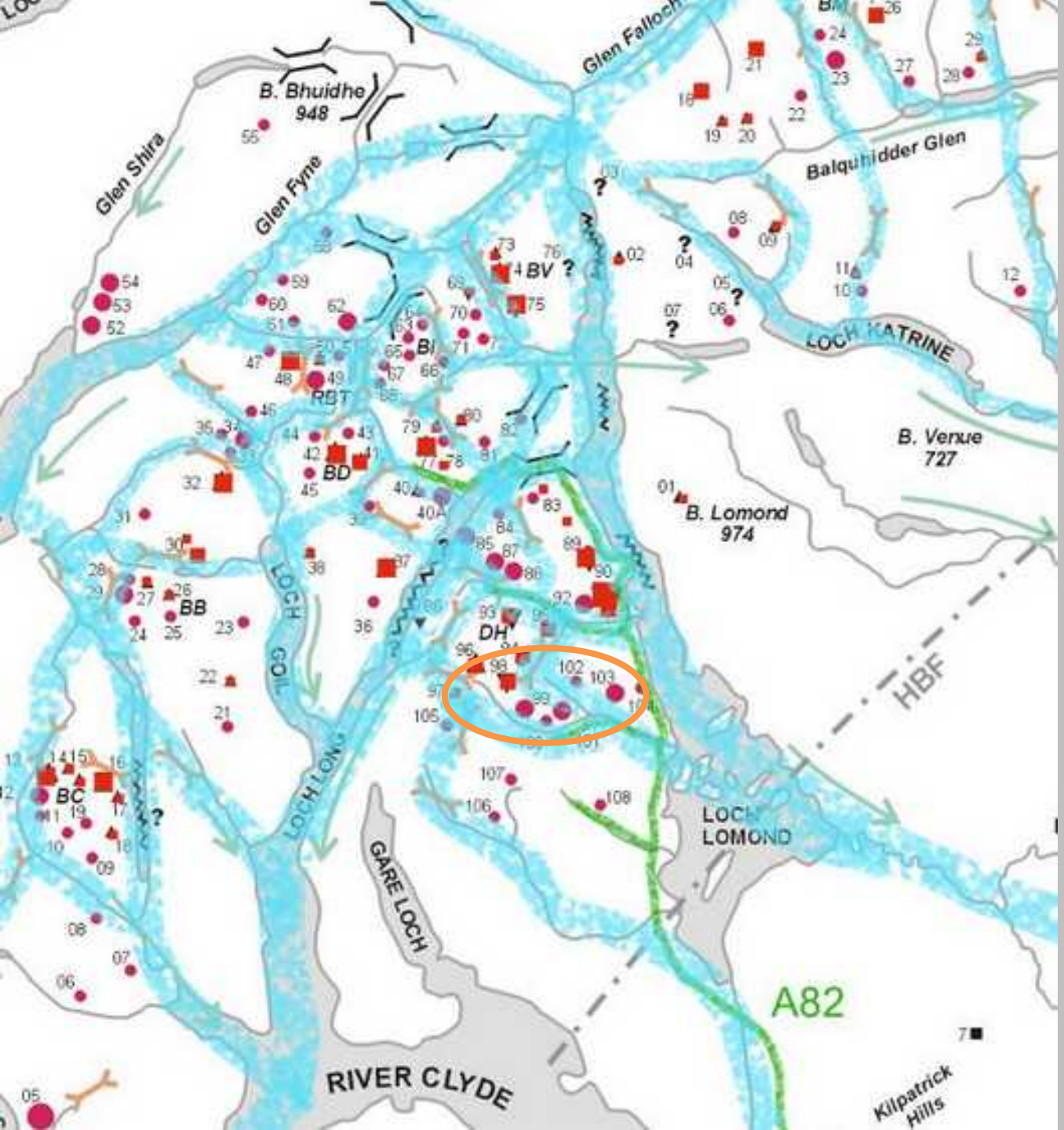


SW Highlands
RSF cluster

Arrochar Alps
Ardgoil
Cowal
Luss Hills

dissected by 'cross-hatched' glacial breaching

oscillating outflows to Clyde -- Forth -- Atlantic



SW Highlands
RSF cluster

Arrochar Alps
Ardgoil
Cowal
Luss Hills

dissected by 'cross-hatched' glacial breaching

50% *north side Glen Luss is RSF*

West Highland Railway - Loch Long

'fjord' loch, local overdeepening

#1W85 Morelaggan RSF

0.55 km²

'hinge'

bulge into loch

'parting' with millimetric creep

West Highland Railway - Loch Long

'fjord' loch, local overdeepening

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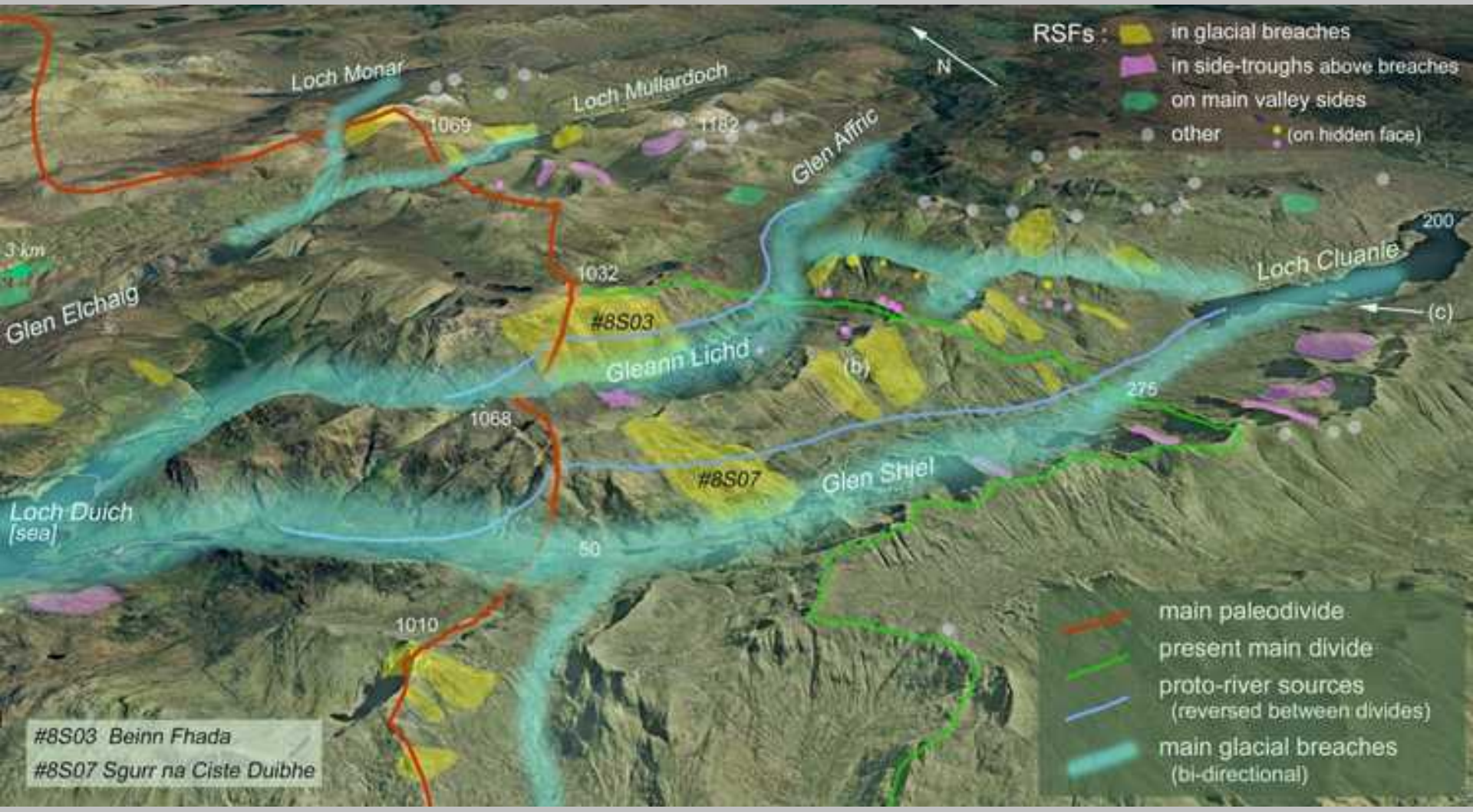
0.55 km²

Glasgow Geological Society

'hinge'

bulge into loch

'parting' with millimetric creep



Glen Shiel - Kintail *RSF cluster*

dissected by glacial breaching

Glen Shiel Five Sisters

#8S07 Sgurr na Ciste Duibhe *1.25 km²*

A 87
Cluanie

landslide dam

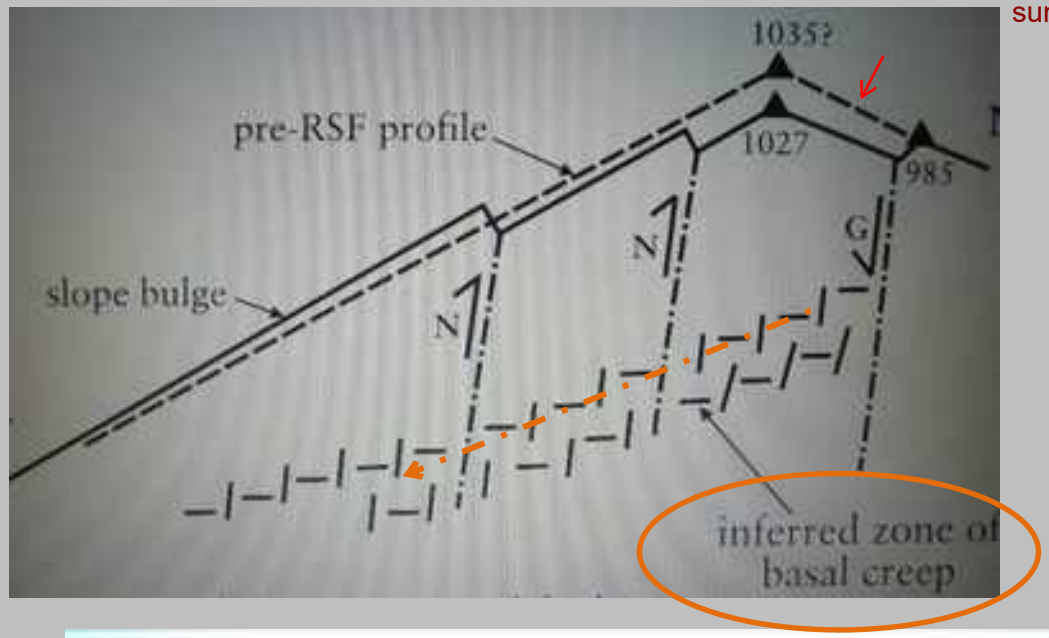
1719 battle site


Sgurr nam Spainteach


Glen Shiel Fault
Red Top


Sgurr na Ciste Duibhe
failed summit
return fracture
Glen Shiel Fault
Red Top

summit lowered 6-8 m



main ridge severed

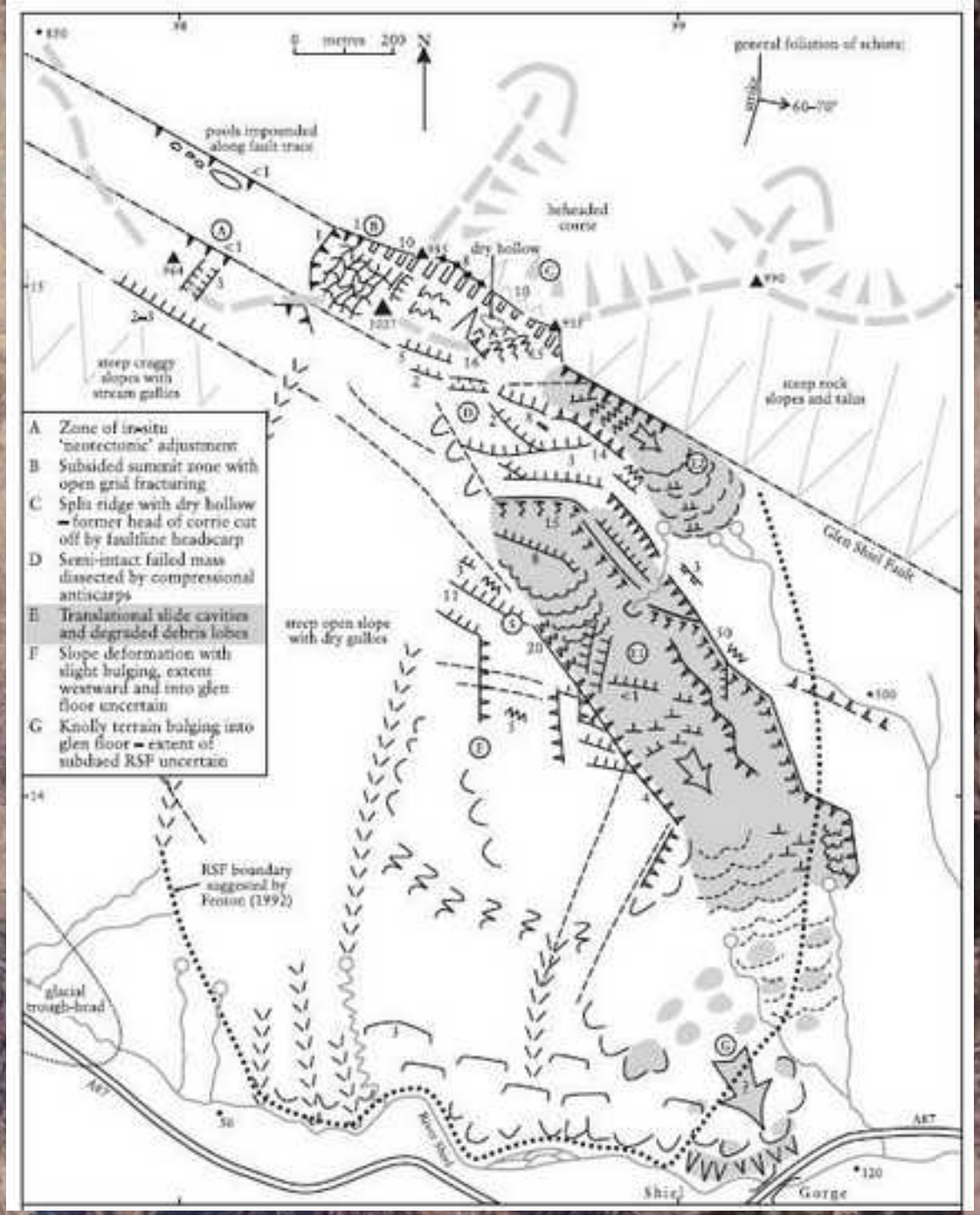
Sgurr na Ciste Duibhe

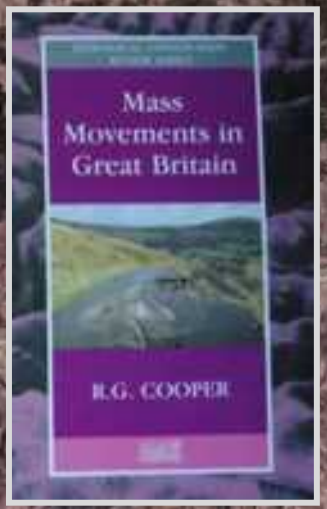
“ black chest “

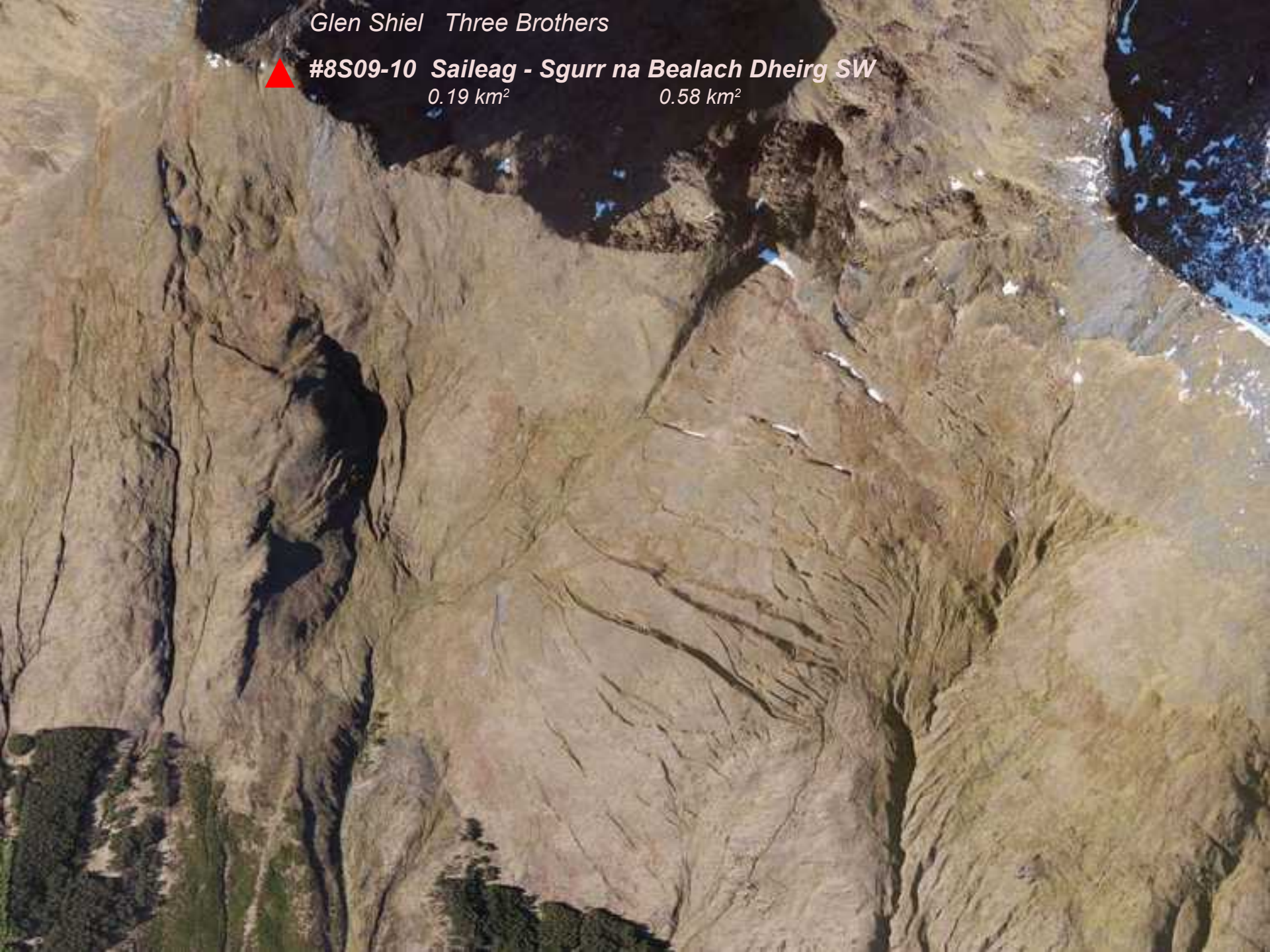
“ false antiscarp ”


A 87
Glen Shiel
X
1719
Pass

A 87
Glen Shiel






Glen Shiel Three Brothers
#8S09-10 Saileag - Sgurr na Bealach Dheirg SW
0.19 km²
0.58 km²


Saileag 959m

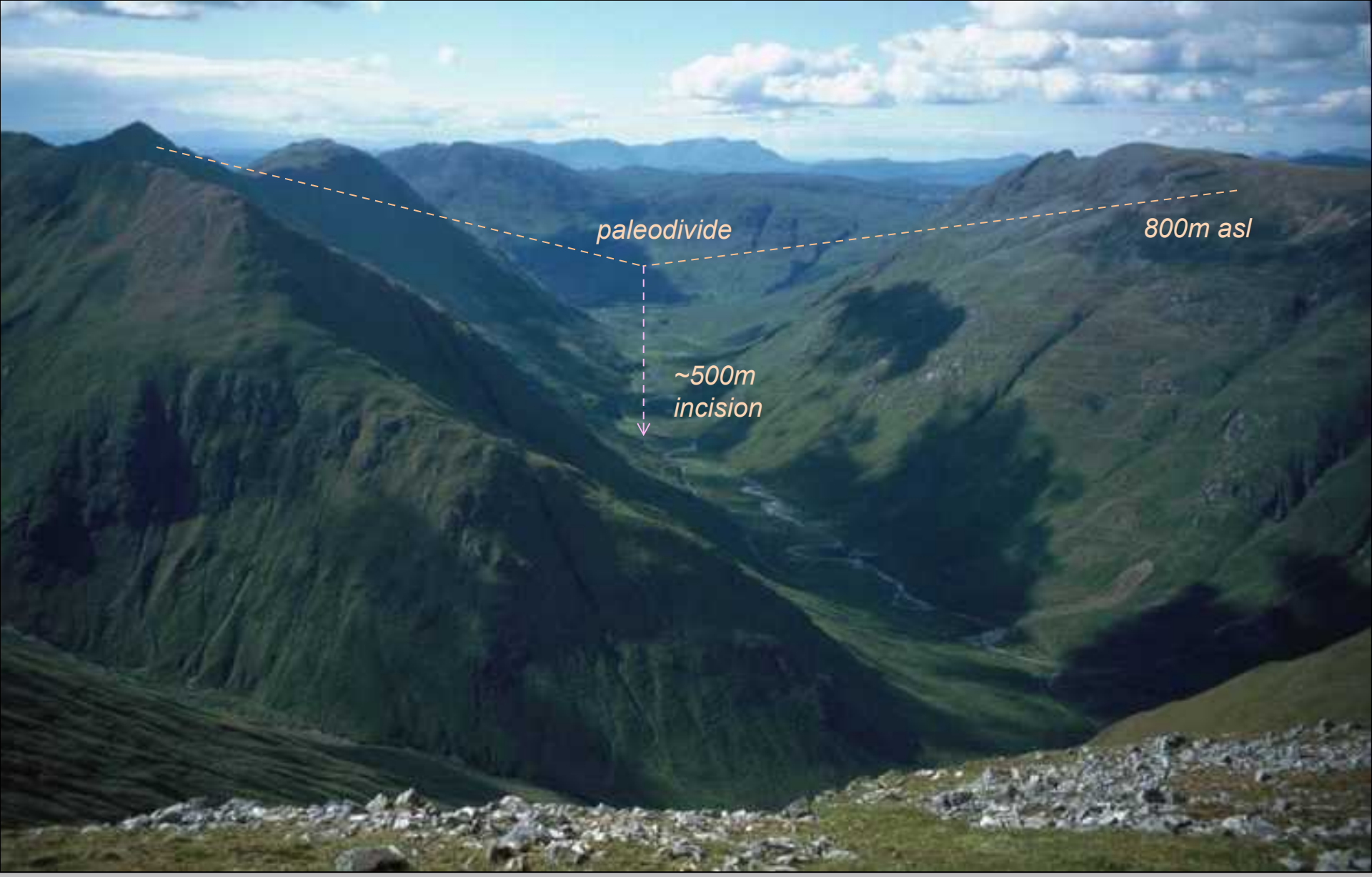
Sgurr a' Bhealaich Dheirg

Five Sisters

Gleann Lichd

3.0 km²

#8S03 *Beinn Fhada*

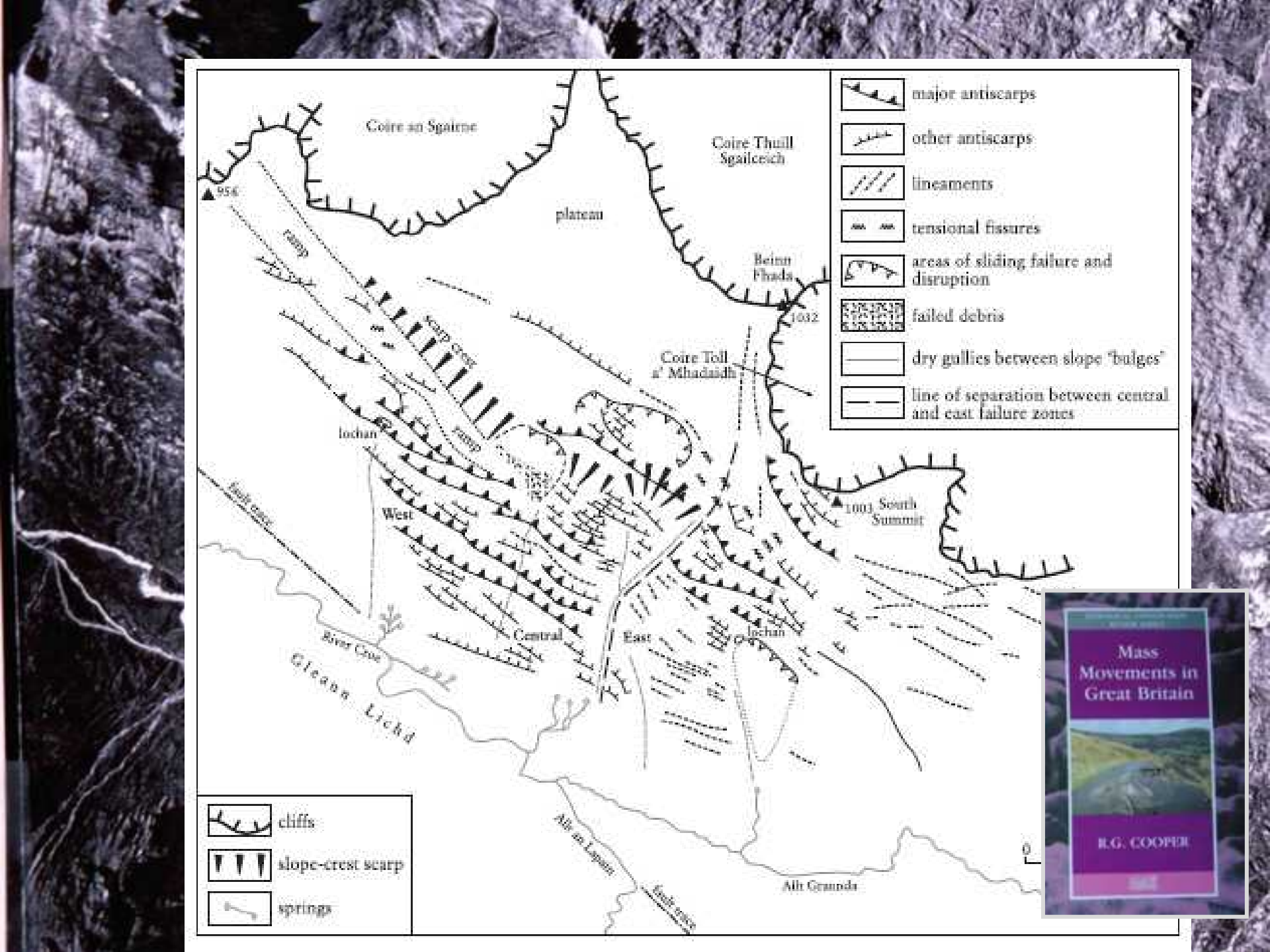


Five Sisters

Gleann Lichd

3.0 km²

#8S03 *Beinn Fhada*


major antiscarps
other antiscarps
lineaments
tensional fissures
areas of sliding failure and disruption
failed debris
dry gullies between slope 'bulges'
line of separation between central and east failure zones
Coire an Sgairne
Coire Thuill Sgailceich
plateau
Beinn Fhada
1032
Coire Toll a' Mhadaidh
1003 South Summit
lochan
West
Central
East
River Cour
Gleann Lichd
Allt an Laoigh
Allt Grannda
cliffs
slope-crest scarp
springs
Mass Movements in Great Britain
R.G. COOPER

#8S03 Beinn Fhada *3.00 km²*
compressional rock slope deformation

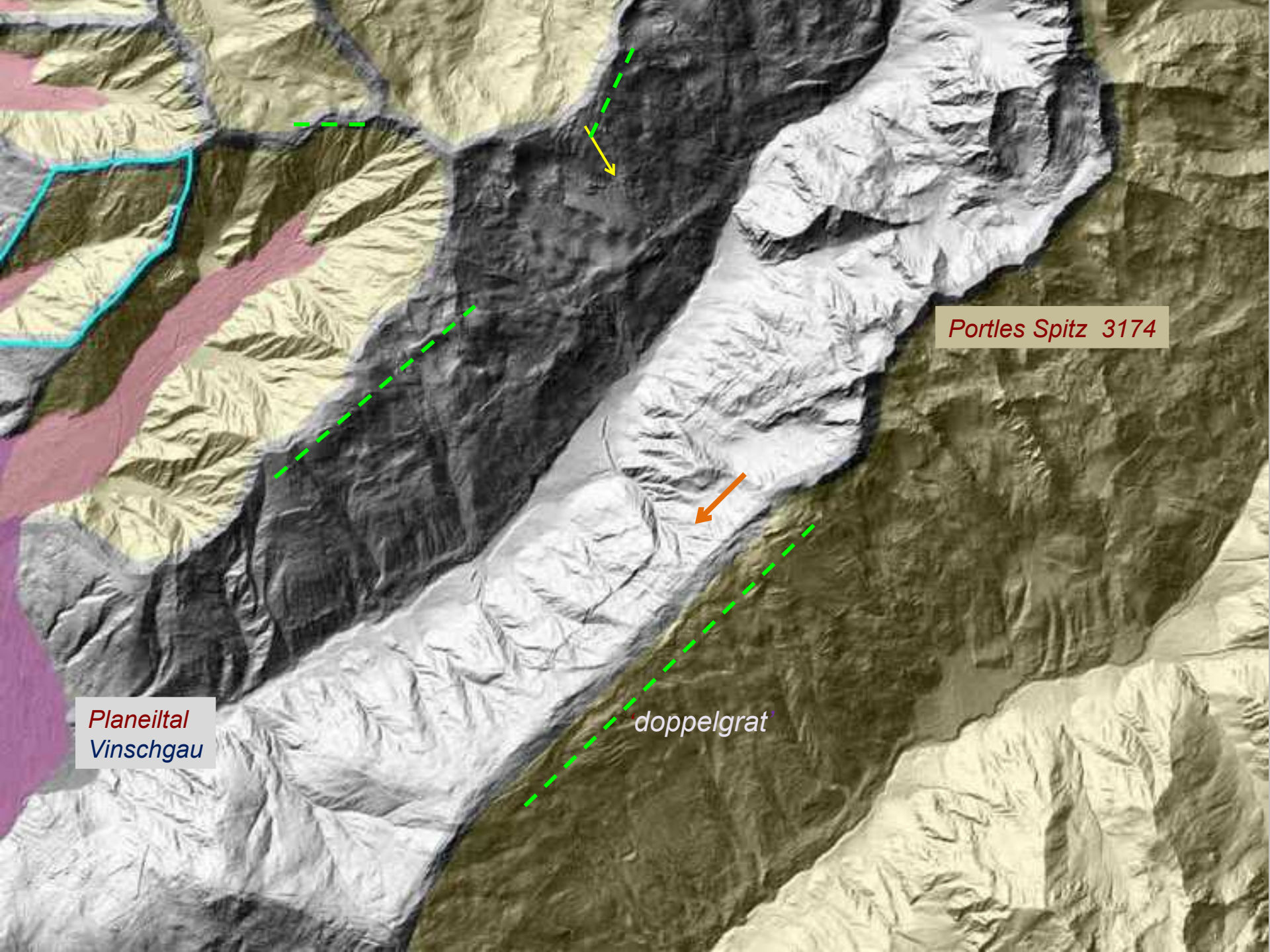
antiscarp array

- *8 main ones, up to 800 m long, 10 m high*
- *largest in British mountains*

antiscarp array -
***Sud-Tirol**, up to 800 m long, 10 m high*


Portles Spitz 3174


Portles Spitz 3174
Planeiltal
Vinschgau


Portles Spitz 3174
Planeiltal
Vinschgau
'doppelgrat'

Parang Mts
Romanian
S Carpathians

Zehnerkopf
Reschenpass Sud-Tirol

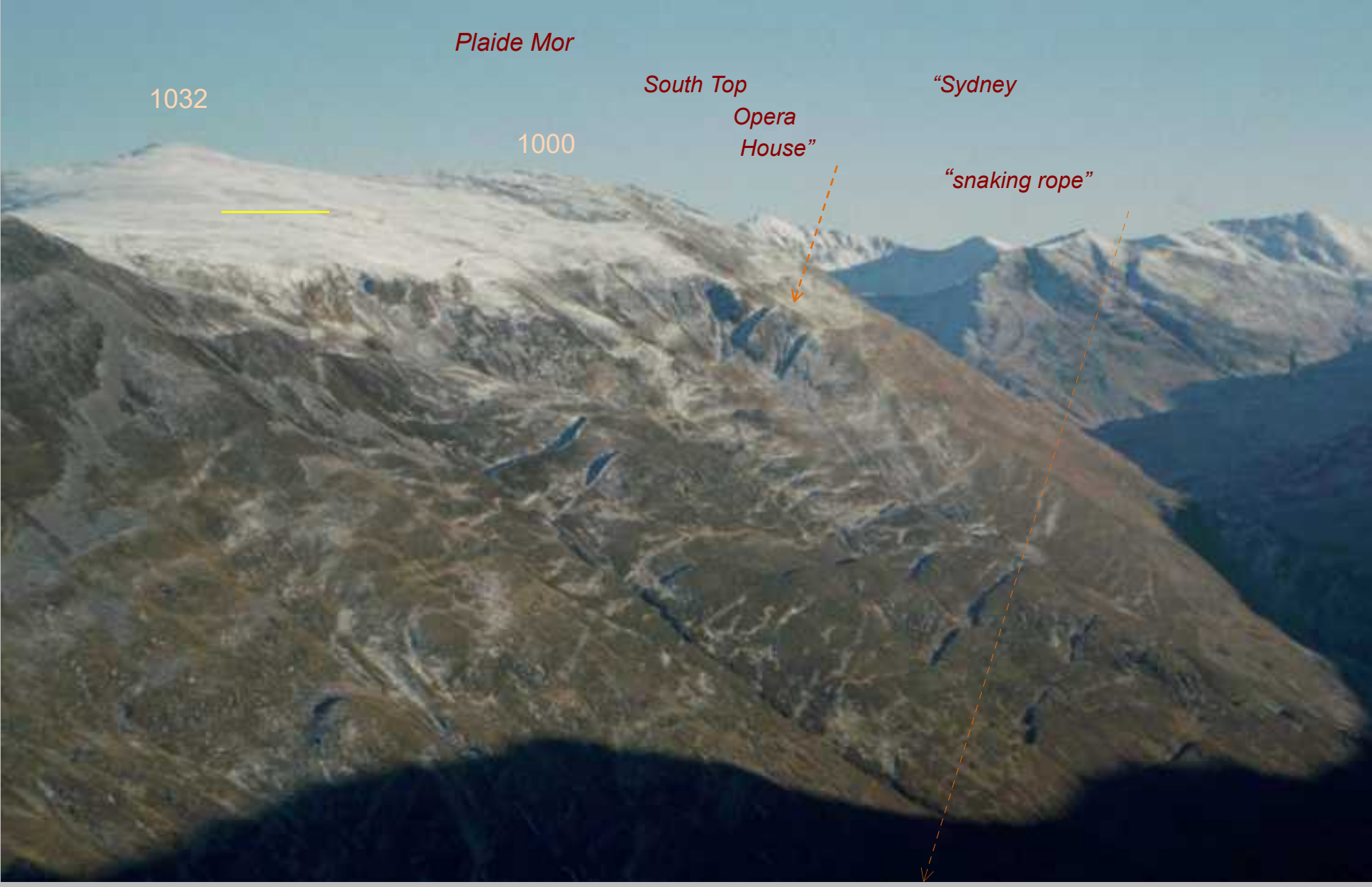
*'doppelgrat' - **split ridges***

'doppelgrat' - split ridges

#7K09 Aonach Sgoilte Ladhar Bheinn Knoydart

#3.01 Ben Challum Tyndrum

Beinn Fhada - diverse antiscarp array



Beinn Fhada - diverse antiscarp array

rebound fractures across plateau

“Sydney Opera House”

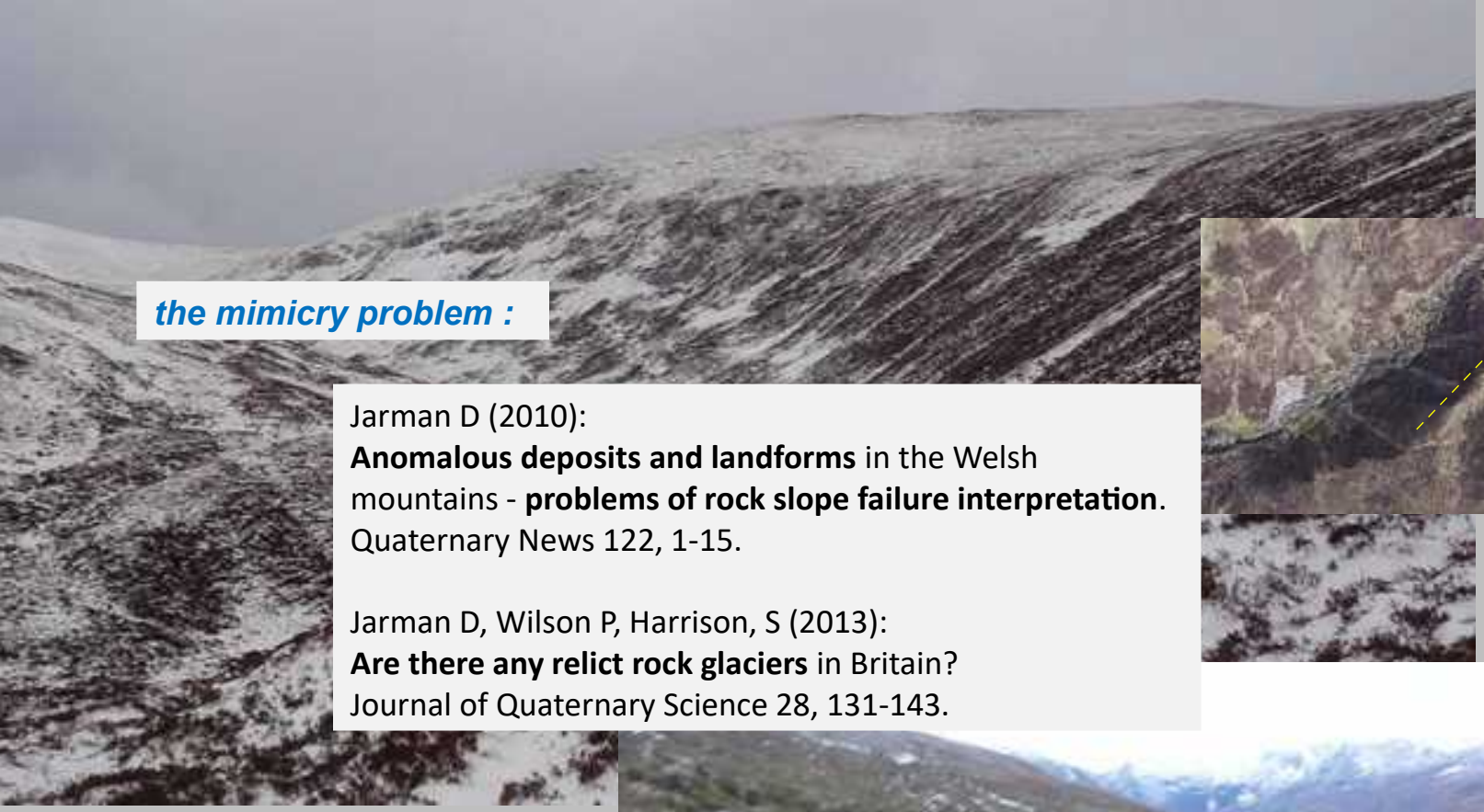
John Gordon SNH

“snaking rope”
lower-slope reactivation

Glen Loy
Gairlochy

Glencalvie
Ardgay

"antiscarp" - true or false ?



Glen Loy
Gairlochy

Glencalvie
Ardgay

the mimicry problem :

Jarman D (2010):
Anomalous deposits and landforms in the Welsh mountains - **problems of rock slope failure interpretation**. Quaternary News 122, 1-15.

Jarman D, Wilson P, Harrison, S (2013):
Are there any relict rock glaciers in Britain? Journal of Quaternary Science 28, 131-143.

"antiscarp" - true or false ?

Loch Loch -- Beinn a' Ghlo

RSF misidentified by

- *cavities with nothing below*
- *bulges / DDAs with nothing above*
- *erosional forms and lineaments*
- *mismapping from imagery*

Loch Loch -- Beinn a' Ghlo RSFs

Loch Loch -- Beinn a' Ghlo

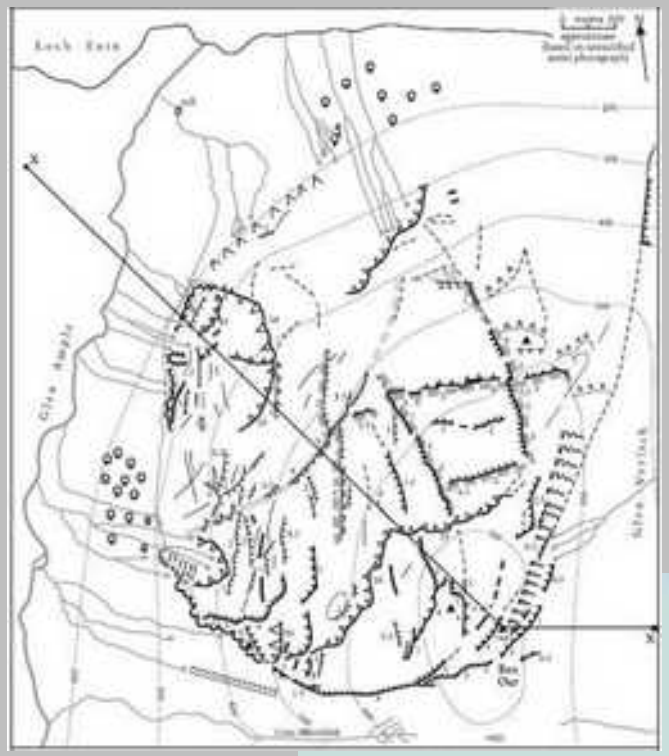
bonus RSF !

Loch Loch -- Beinn a' Ghlo

bonus RSF !

“Beinn Fhada rock slope deformation”

Jarman and Ballantyne *Scottish Geographical Journal 2003*



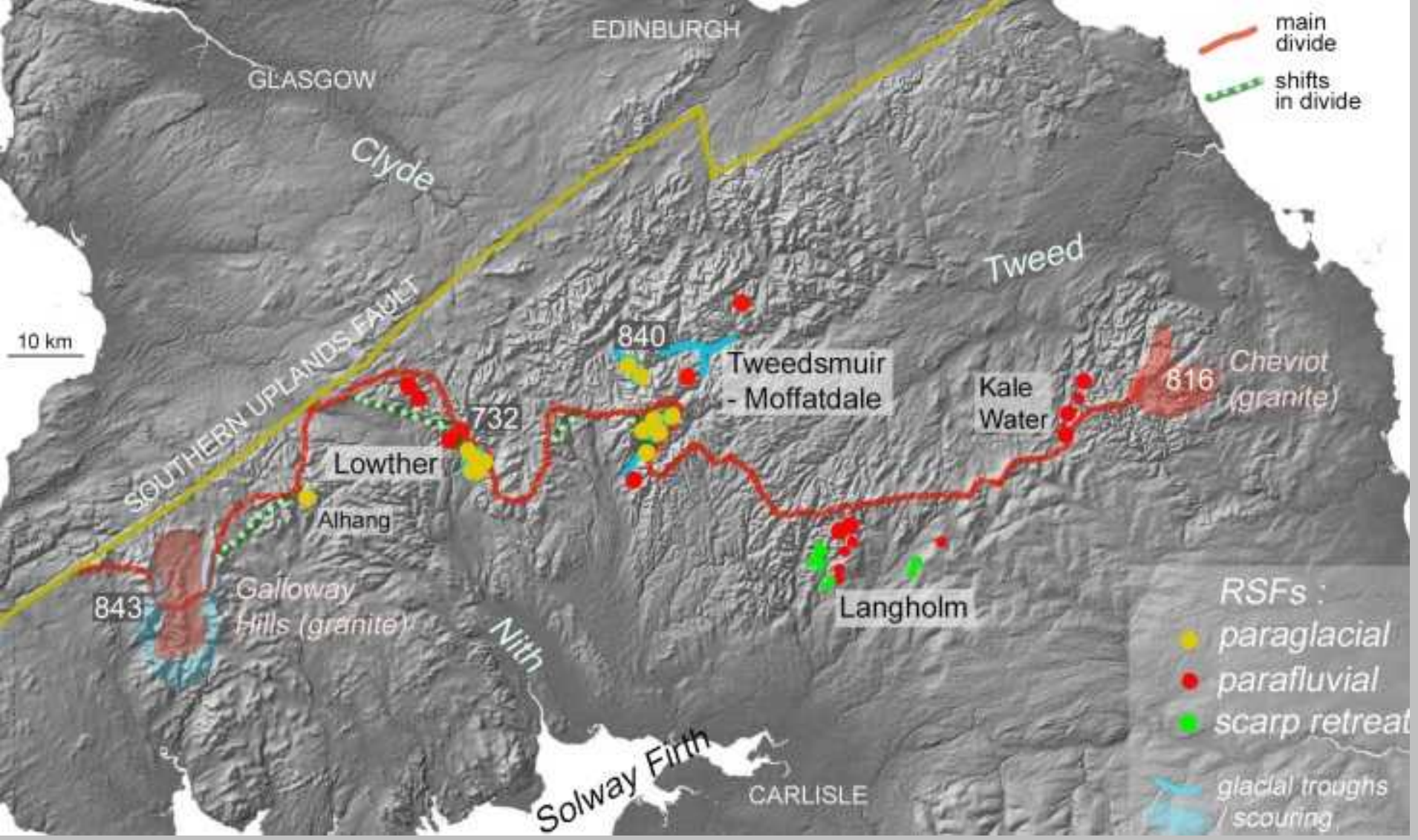
Ben Our

Lochearnhead

2.9 km²


Glen Ample

Ben Vorlich



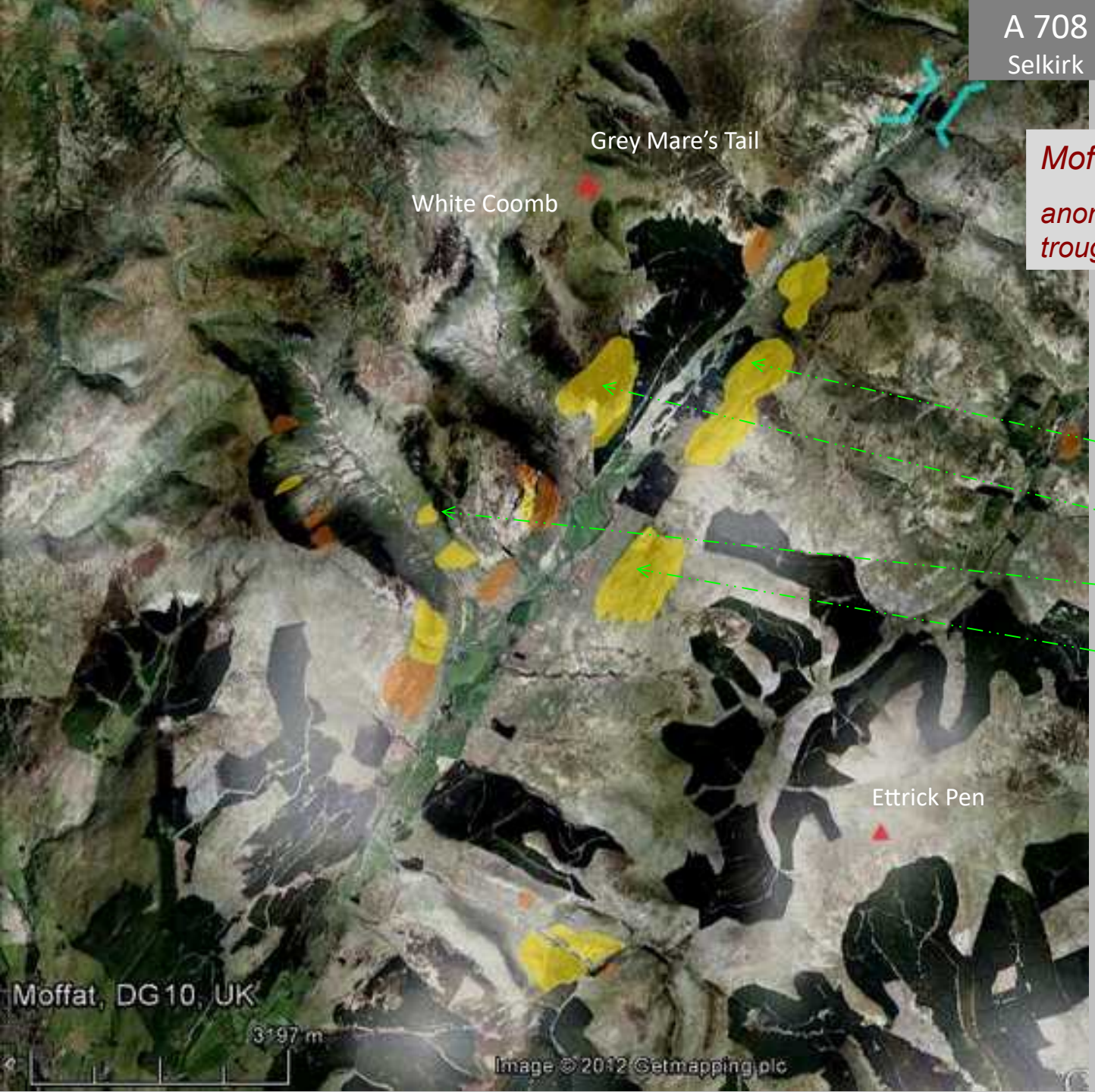
Southern Uplands *- local clusters in enlarging glacial trough heads - and V-ravines*

*- **paraglacial** >>> **parafluvial** >>> Pennine-scarp transition*

Lowther Hills mini-cluster
***Dalveen Pass** paraglacial RSF sequence - **Capel Hill** 0.17 km²*

Lowther Hills mini-cluster

***Enterkin** parafluvial RSF sequence*



Moffatdale cluster

anomalous deep glaciated trough along weak Fault

Bell Craig

Carrifran Gans

Saddle Yoke

Bodesbeck Law

Selcoth valley
(parafluvial meltwater ravine)

Ettrick Pen

(c) Colin K Ballantyne 2010

(c) BING Maps

Moffatdale cluster

#SUE10 Bell Craig

Bodesbeck Law

Saddle Yoke

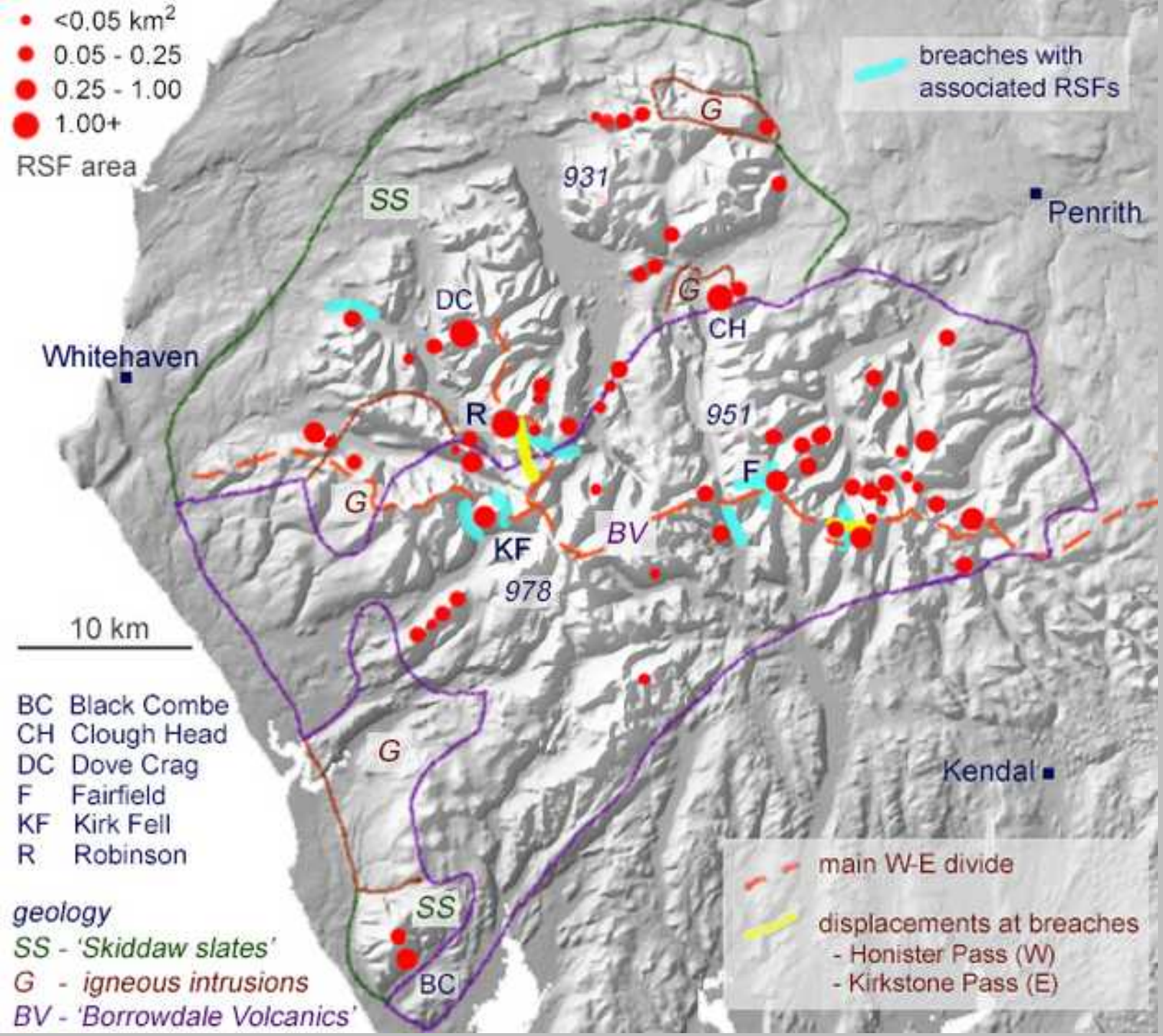
Carrifran Gans

Paper Hill RSF
Chapelhope, Loch of the Lowes

Garelet Hill RSF
Talla Reservoir head
Tweedsmuir

The Glen *paraglacifluvial RSF*

thanks to Wishart Mitchell

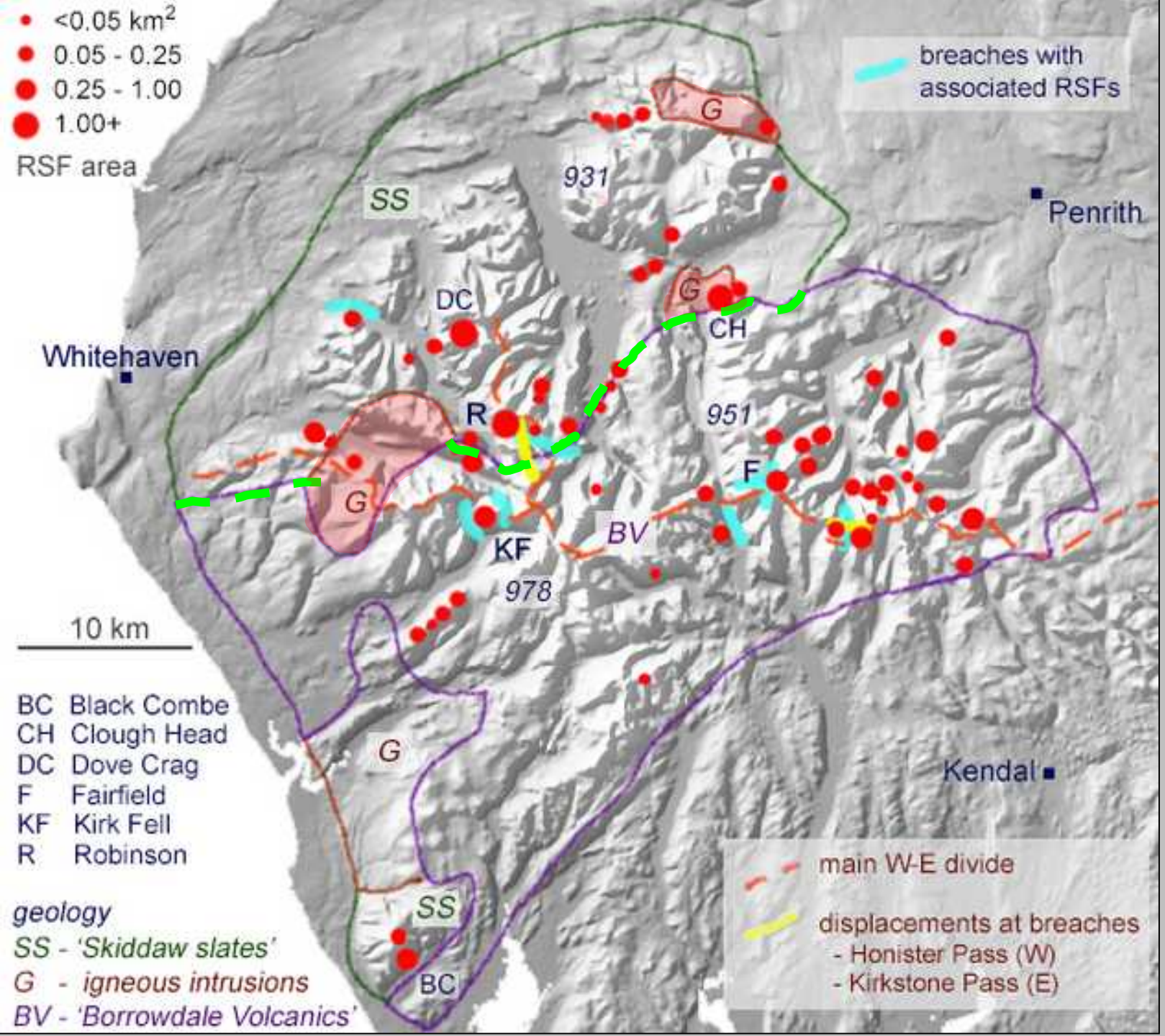


Lake District

clustering

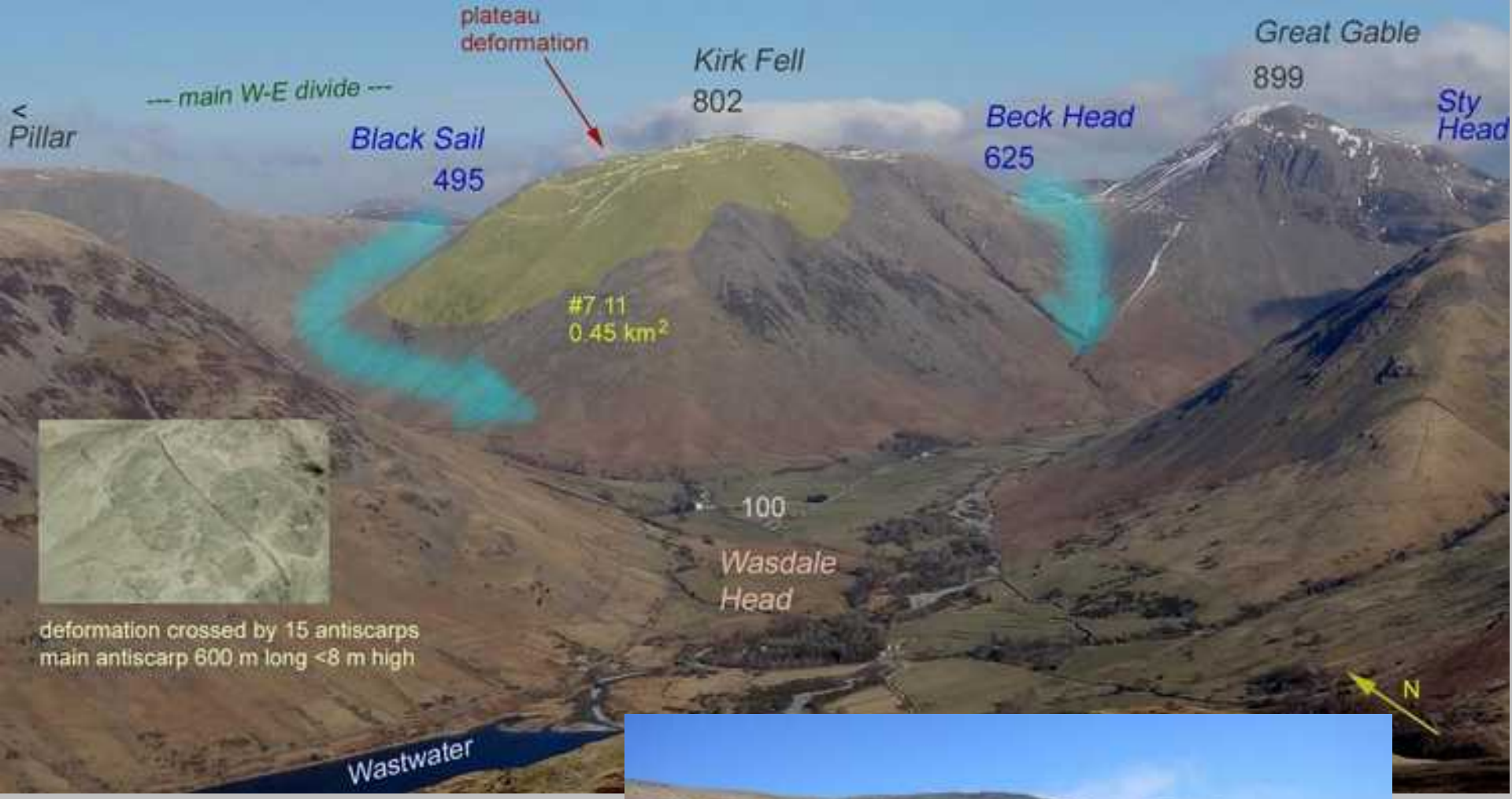
W side breach-related

E side trough-head related



Lake District

no geological control



Lake District

7.11 Kirk Fell
slope deformation

Lake District

7.11 Kirk Fell

slope deformation - quasi-in situ, compressional - asymmetric rebound ?

#1W77 ***The Cobbler*** *0.62 km²*
Arrochar Alps

#1W77 ***The Cobbler*** *0.62 km²*
Arrochar Alps

#1W77 ***The Cobbler***
Arrochar Alps

“great landslip”

#1W77 ***The Cobbler***
Arrochar Alps