Multi-disciplinary characterisation of the Callista clay-hosted REE prospect

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AUSTRALIAN
critical
minerals
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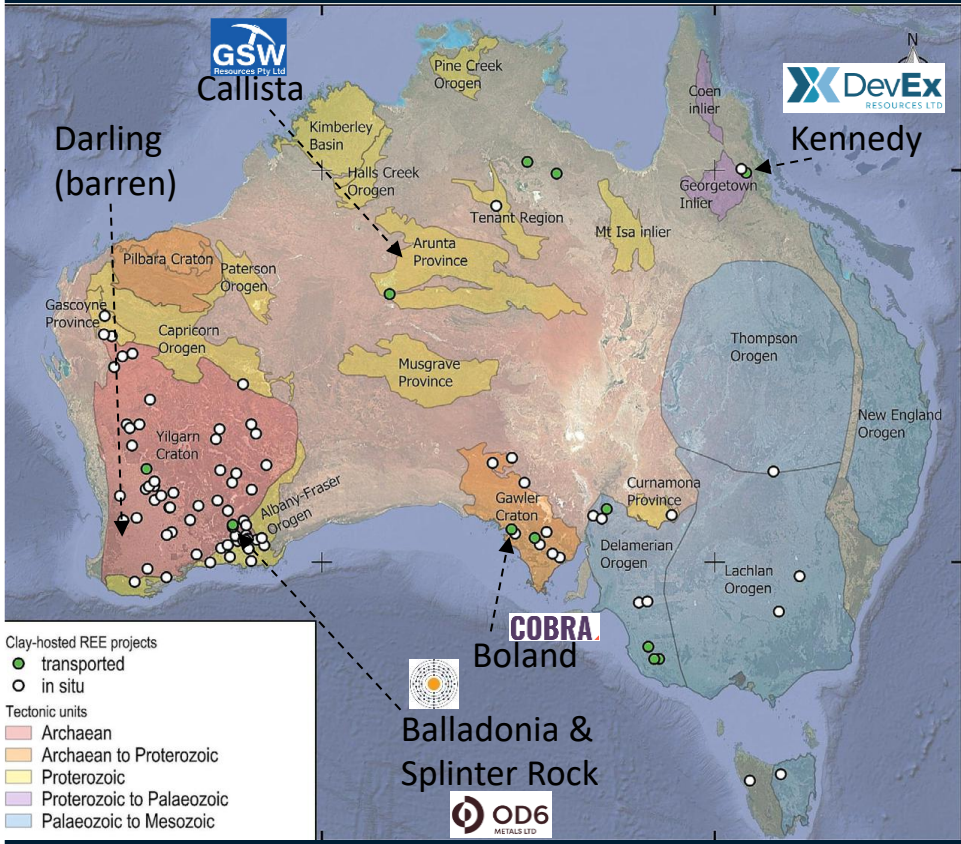
Our project aims

- Understand the formation and deportment of Australian clay-hosted REEs occurrences
- Based on 5 case studies across Australia:
  - Identify commonalities (if any)
  - Identify key parts of CHREE mineral systems
  - Develop prospectivity indicators
- Provide **workflows** and **guidelines** to **industry** for defining exploration criteria, optimizing resources, and targeting **new REE discoveries**

Case studies CSIRO-GA-ANSTO, Critical Minerals Hub



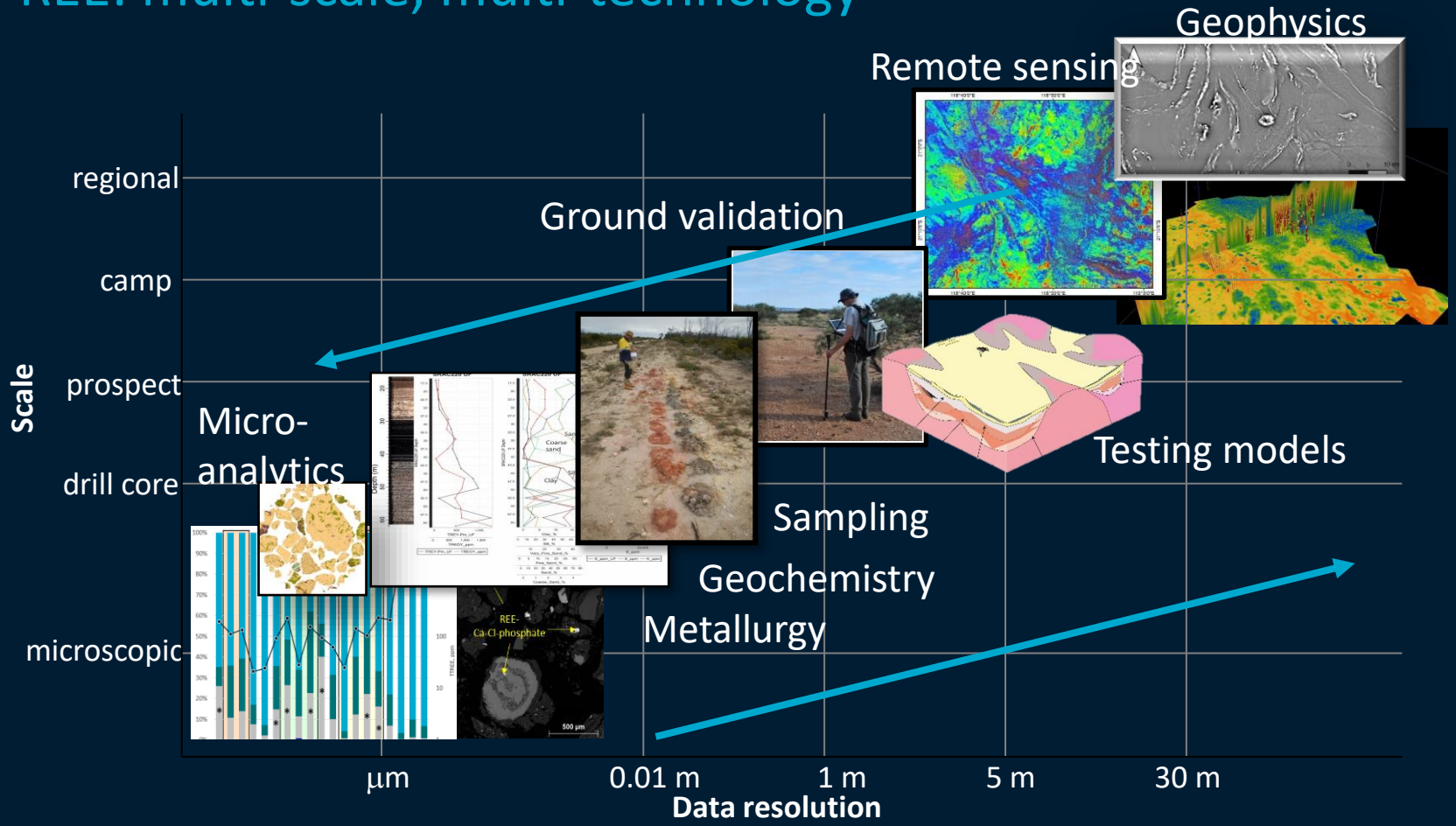
(annotations over Knorsch et al., 2024)

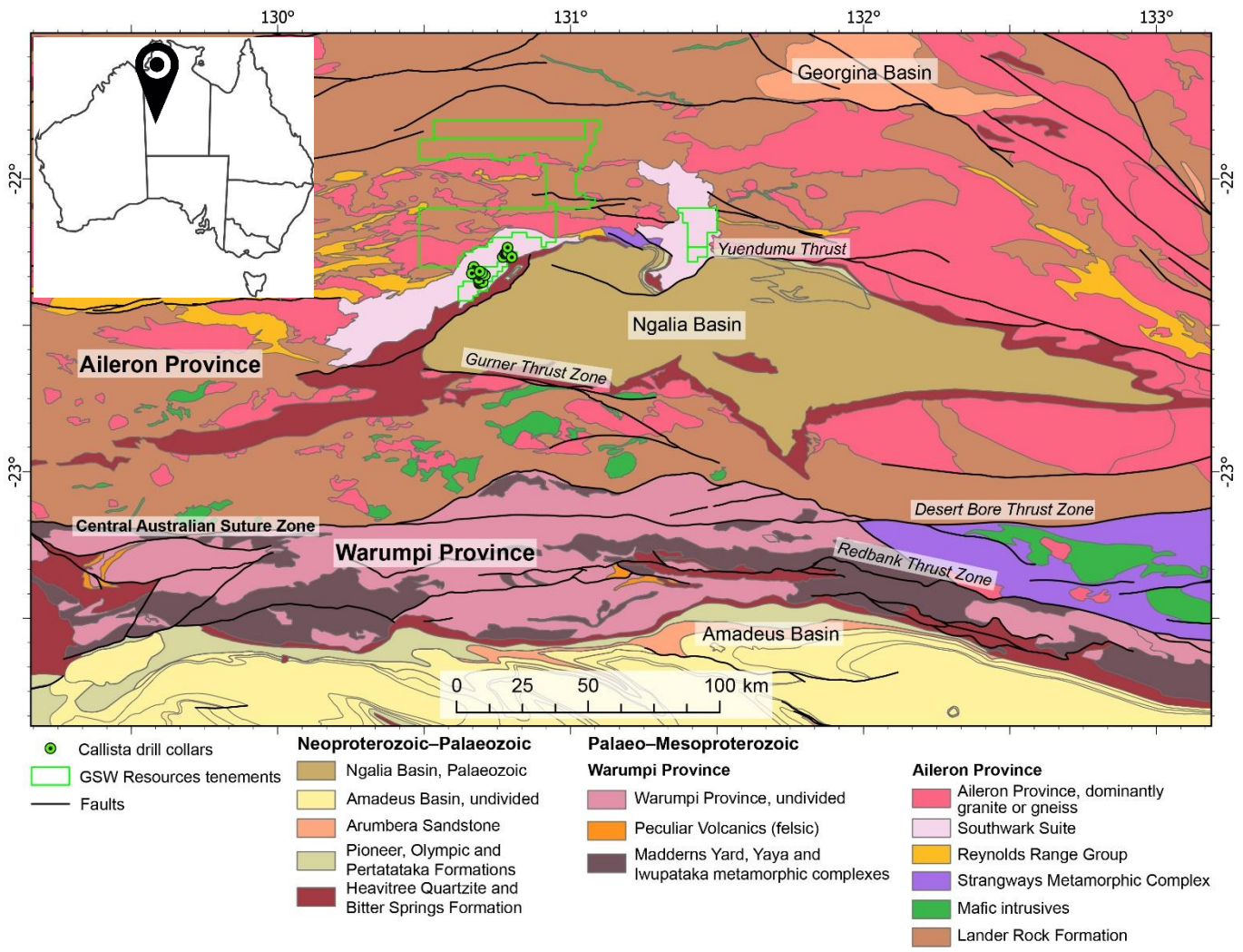
Styles and controls on in situ prospects

Variability of REE mineralogy

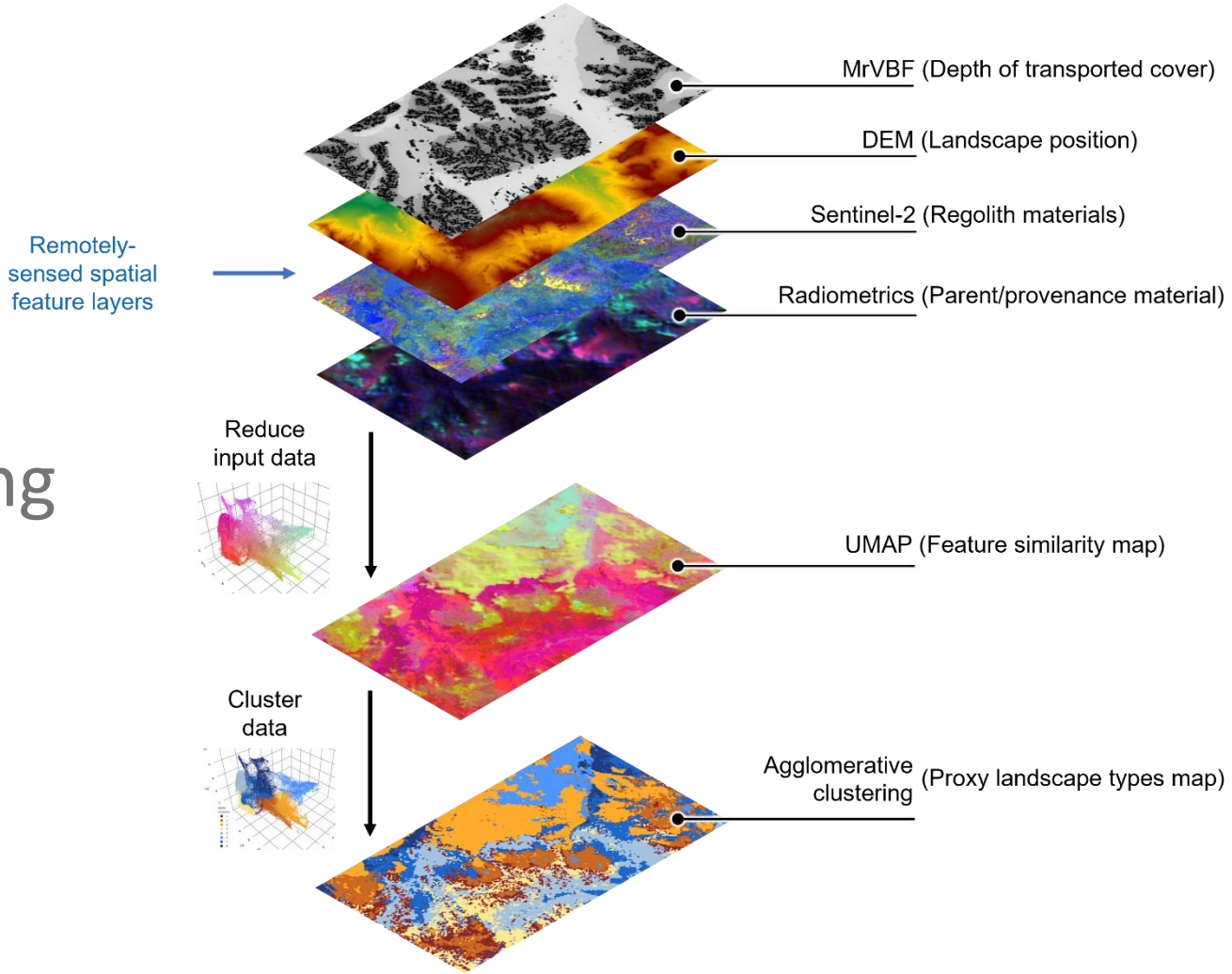
- Primary (pre-weathering) REE-minerals in host granitic rocks:
  - REE-phosphate (Monazite)
  - REE-silicates (Allanite +/- Titanite)
  - REE-carbonates (Bastnasite, Parisite)
  - Amphibole-Clinopyroxene?
- Residual and secondary REE-minerals in saprock/saprolite:
  - Residual (resistant to weathering) primary REE-phosphate: Monazite
  - Secondary REE phosphates: Rhabdophane and Florencite-Crandallite (Al-Ba)
  - Secondary REE carbonates: Bastnasite
  - Ion-adsorbed REE on clays (IAC) = loosely bound to kaolinite or smectite
- Variably reactive to weathering/leaching (controls remobilisation and recovery potential)

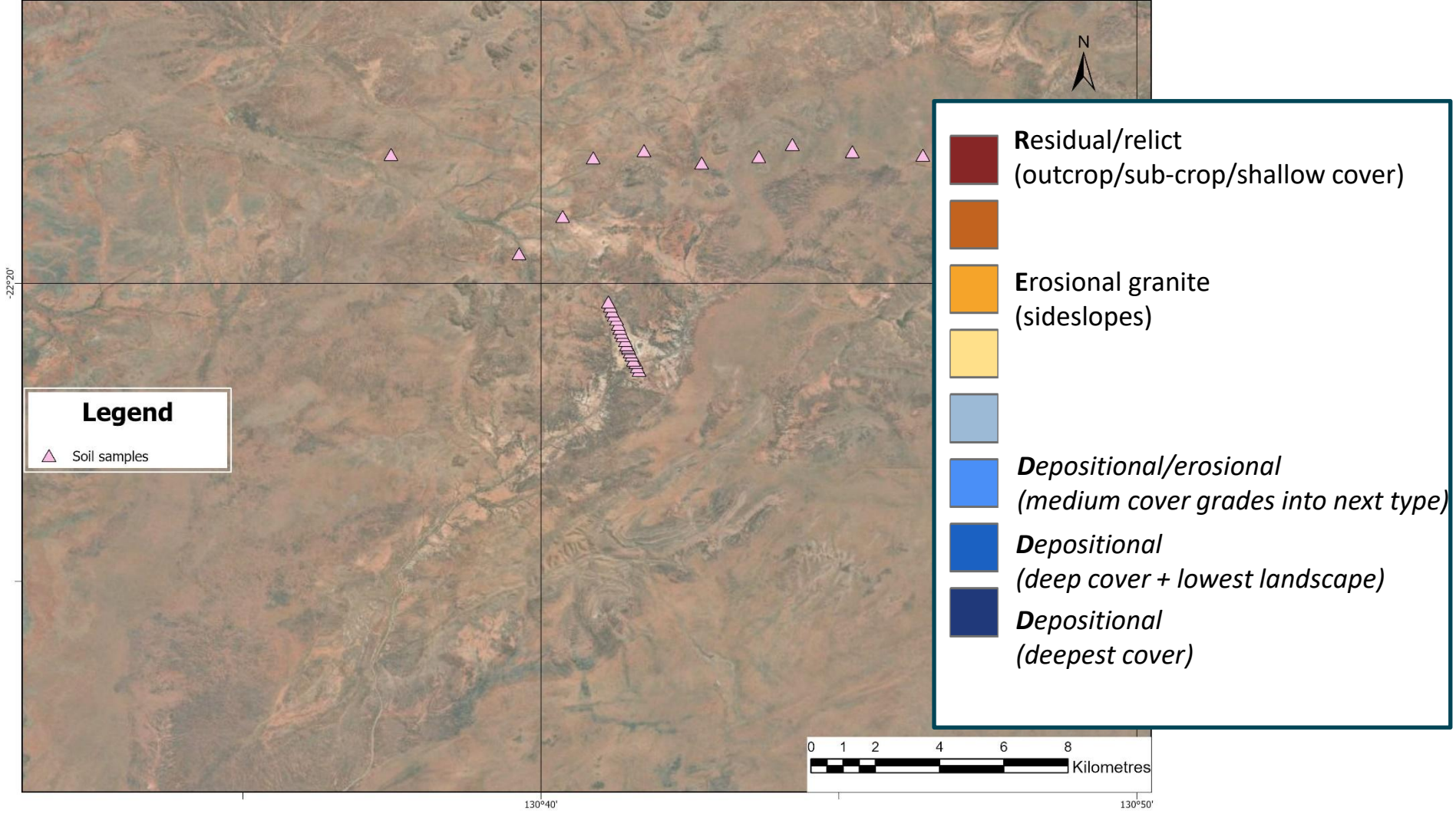
REE: multi-scale, multi-technology

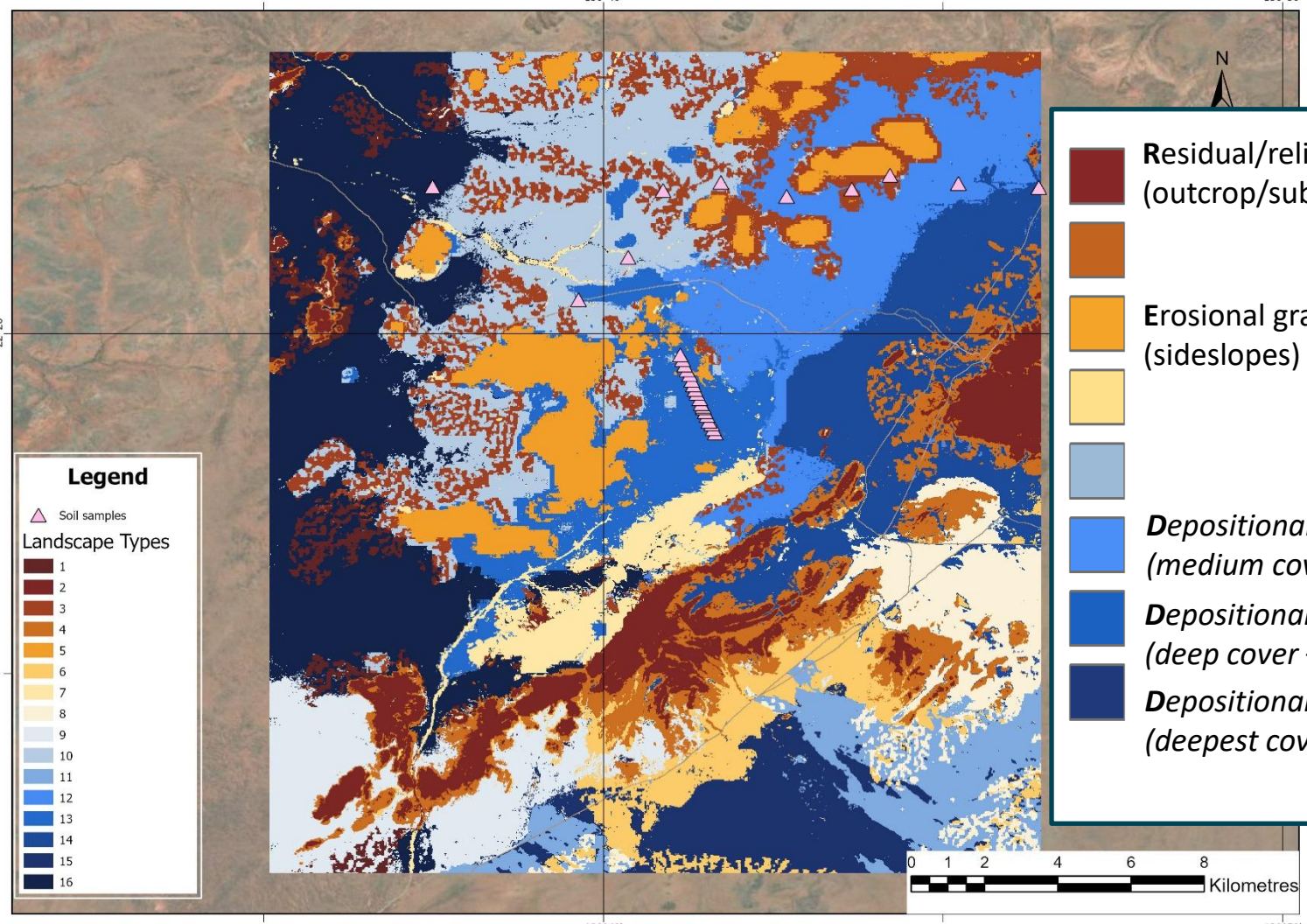



130°
131°
132°
133°
-22°
-23°
Georgina Basin
Yuendumu Thrust
Ngalia Basin
Aileron Province
Gurner Thrust Zone
Central Australian Suture Zone
Warumpi Province
Desert Bore Thrust Zone
Redbank Thrust Zone
Amadeus Basin
0 25 50 100 km
Callista drill collars
GSW Resources tenements
Faults
Neoproterozoic–Palaeozoic
Ngalia Basin, Palaeozoic
Amadeus Basin, undivided
Arumbera Sandstone
Pioneer, Olympic and Pertatataka Formations
Heavitree Quartzite and Bitter Springs Formation
Palaeo–Mesoproterozoic
Warumpi Province
Warumpi Province, undivided
Peculiar Volcanics (felsic)
Madderns Yard, Yaya and Iwupataka metamorphic complexes
Aileron Province
Aileron Province, dominantly granite or gneiss
Southwark Suite
Reynolds Range Group
Strangways Metamorphic Complex
Mafic intrusives
Lander Rock Formation

Regolith mapping – Landscape +




N
Legend
Soil samples
-22°20'
130°40'
130°50'
0 1 2 4 6 8
Kilometres
Residual/relict
(outcrop/sub-crop/shallow cover)
Erosional granite
(sideslopes)
Depositional/erosional
(medium cover grades into next type)
Depositional
(deep cover + lowest landscape)
Depositional
(deepest cover)


130°40'
130°50'
-22°20'
N
Legend
Soil samples
Landscape Types
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
0 1 2 4 6 8
Kilometres
Residual/relict
(outcrop/sub-crop/shallow cover)
Erosional granite
(sideslopes)
Depositional/erosional
(medium cover grades into next type)
Depositional
(deep cover + lowest landscape)
Depositional
(deepest cover)

Landscape

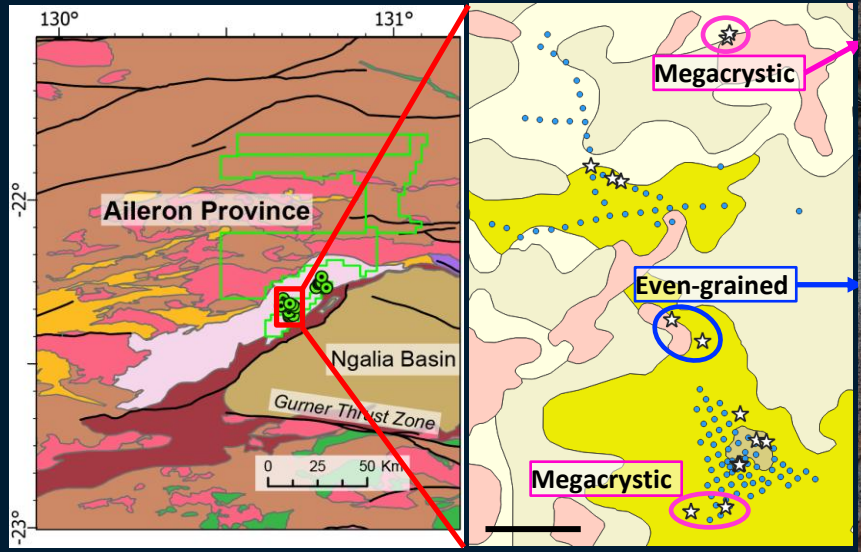

Siliceous hills
Ferricrete
Thin (<1m) colluvial transported cover above saprolite


Southwark Suite granite

Source rocks

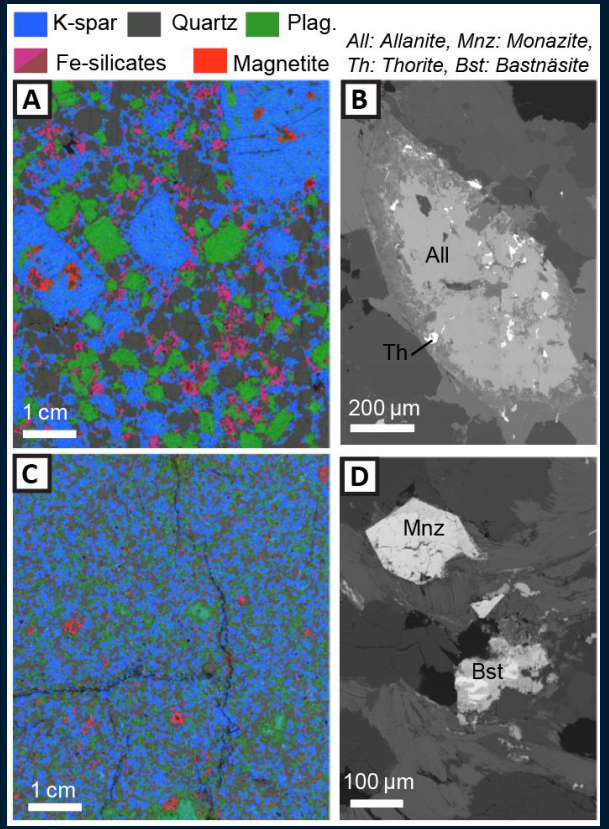
1570–1530 Ma, Southwark Suite granite

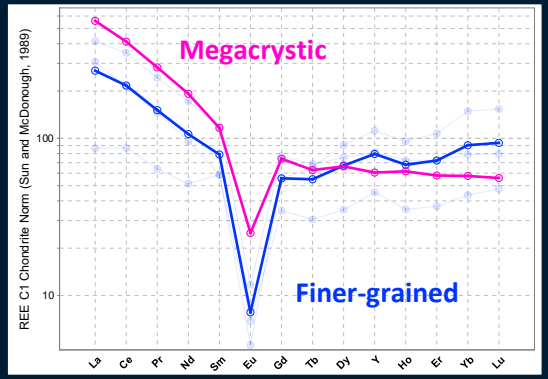
- Biotite and muscovite–biotite granite
- Defined as elevated in SiO_2, K, Th and U and as a high-heat-producing granite suite (Young et al., 1995)
- Megacrystic and even-grained textures



Source rocks

- Similar REE content
- Contrasting REE mineralogy





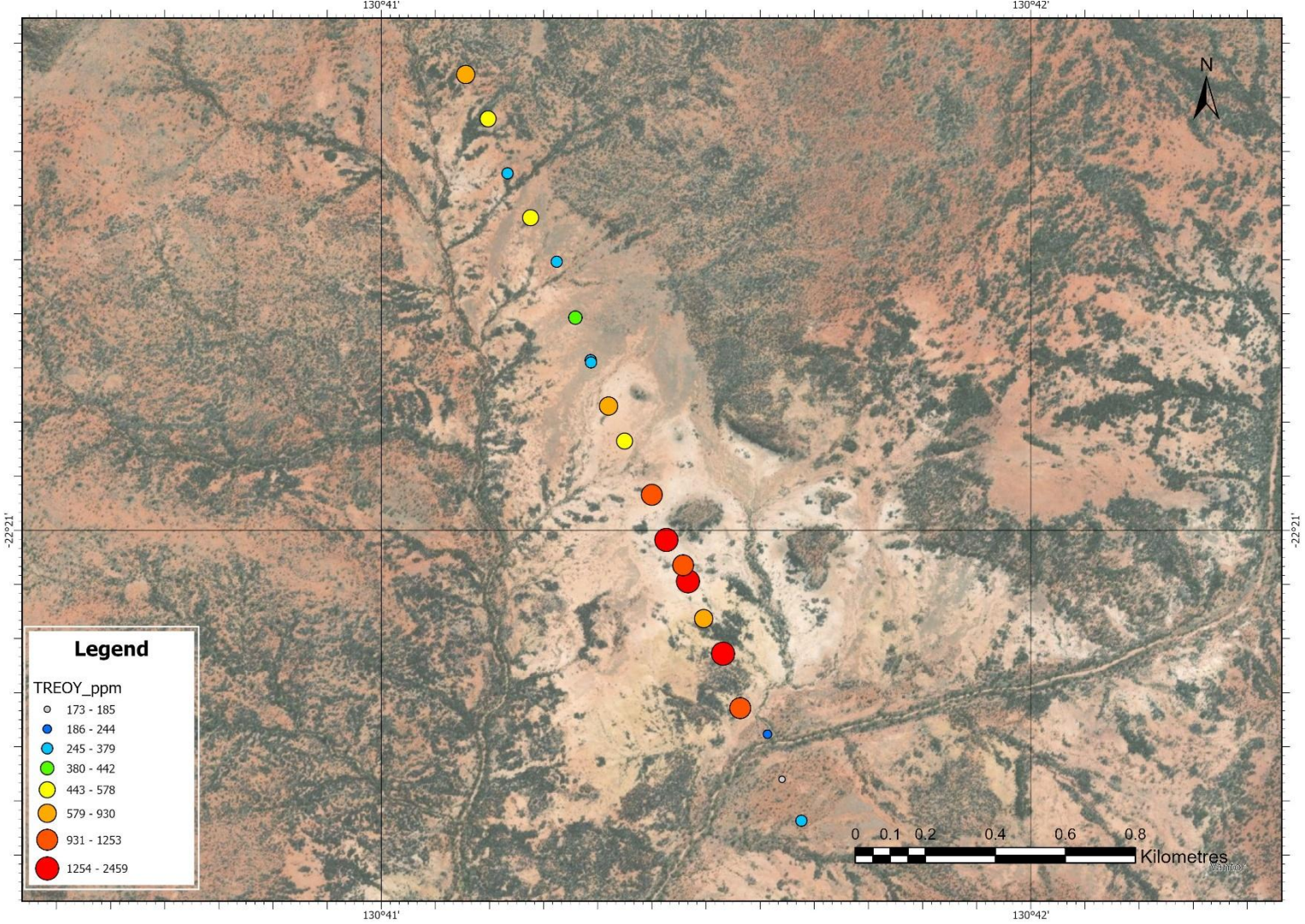
Megacrystic

- Allanite- dominated
- TREO ~800 ppm
- HREO ~250 ppm

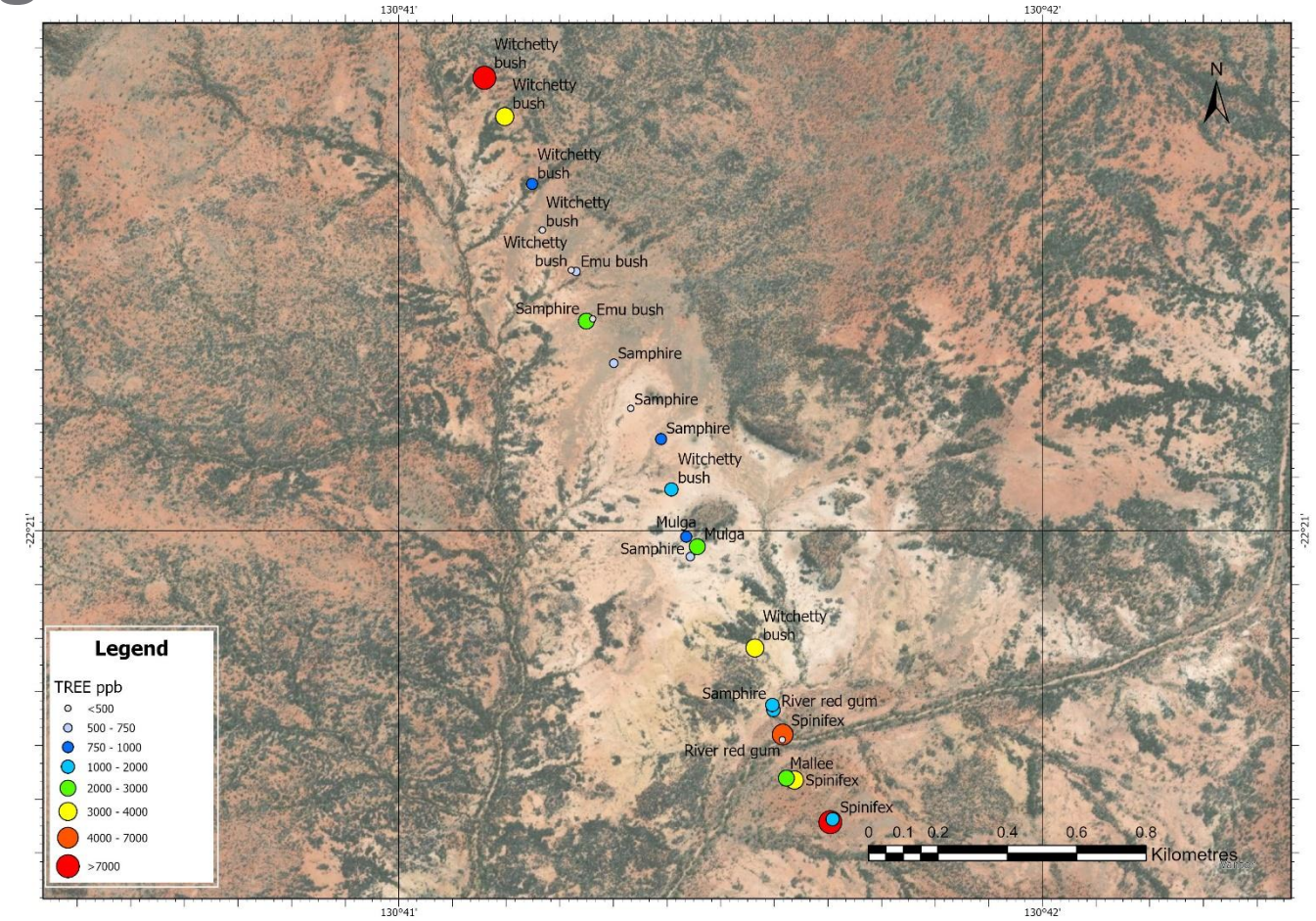
Even-grained

- Monazite-dominated
- TREO ~450-750 ppm
- HREO ~130-330 ppm

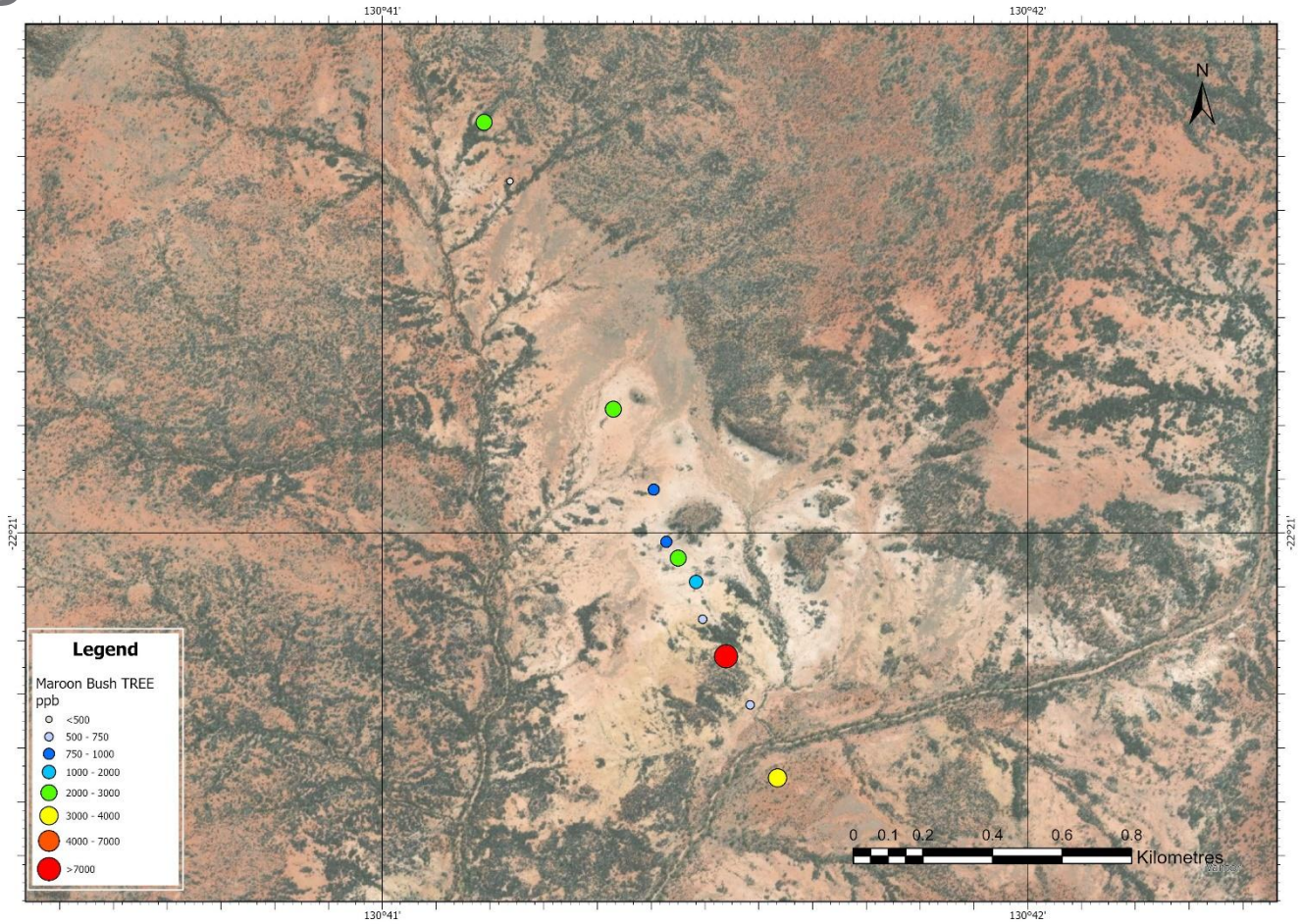
Soils


130°41'
130°42'
-22°21'
N
Legend
TREOY_ppm
173 - 185
186 - 244
245 - 379
380 - 442
443 - 578
579 - 930
931 - 1253
1254 - 2459
0 0.1 0.2 0.4 0.6 0.8
Kilometres

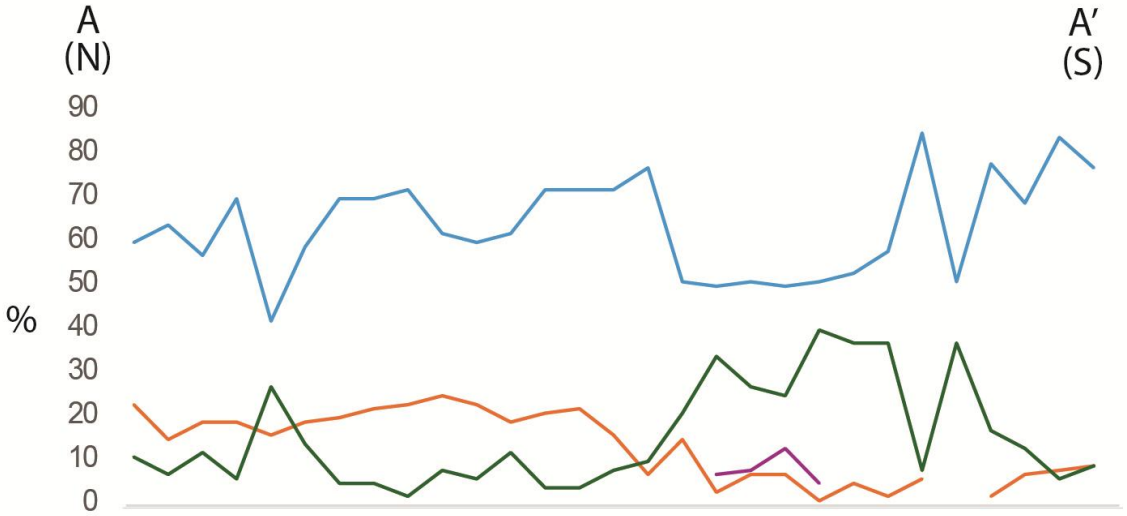
Vegetation


130°41'
130°42'
-22°21'
N
Witchetty bush
Witchetty bush
Witchetty bush
Witchetty bush
Witchetty bush
Emu bush
Samphire
Emu bush
Samphire
Samphire
Samphire
Witchetty bush
Mulga
Mulga
Samphire
Witchetty bush
Samphire
River red gum
Spinifex
River red gum
Mallee
Spinifex
Spinifex
Legend
TREE ppb
<500
500 - 750
750 - 1000
1000 - 2000
2000 - 3000
3000 - 4000
4000 - 7000
>7000
0 0.1 0.2 0.4 0.6 0.8
Kilometres

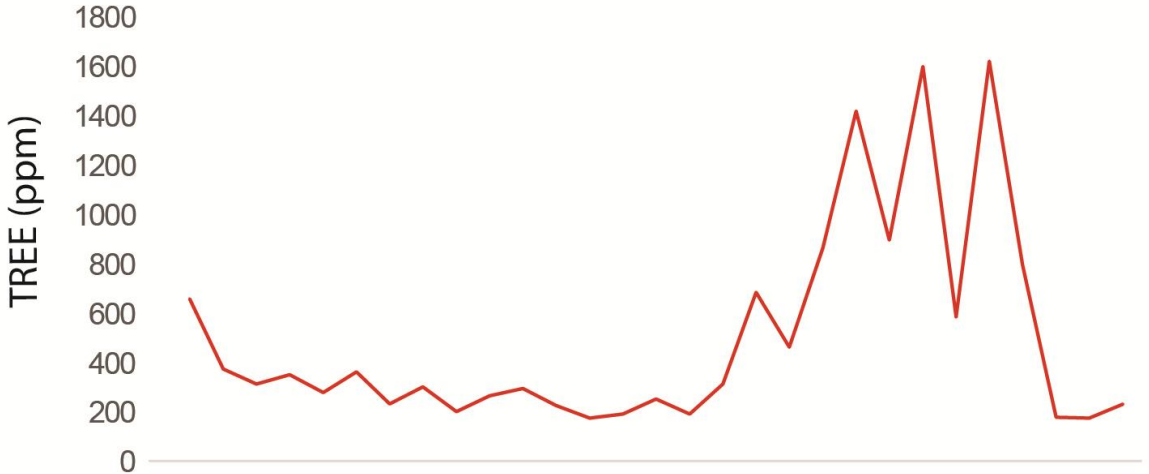
Vegetation

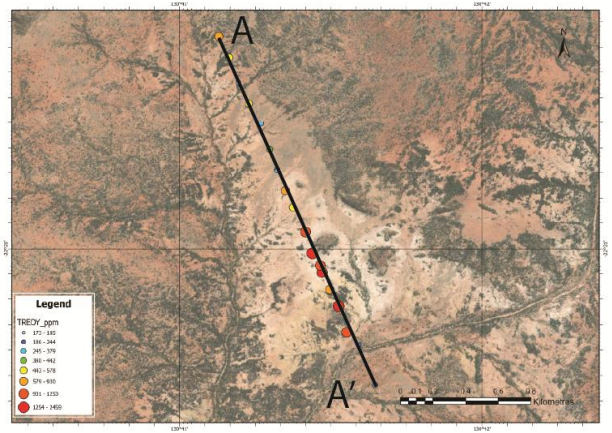

130°41'
130°42'
-22°21'
N
Legend
Maroon Bush TREE
ppb
<500
500 - 750
750 - 1000
1000 - 2000
2000 - 3000
3000 - 4000
4000 - 7000
>7000
0 0.1 0.2 0.4 0.6 0.8
Kilometres

XRD

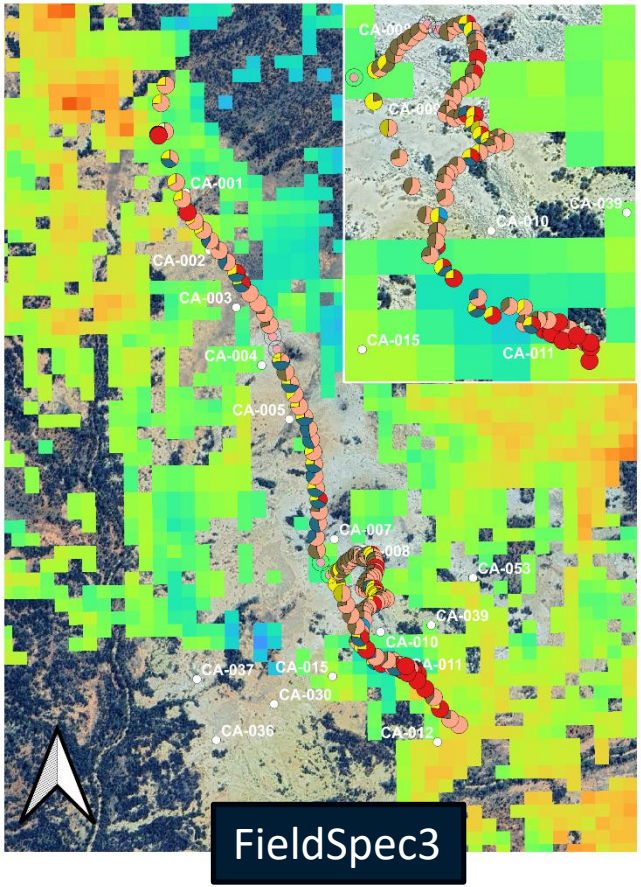

A
(N)
A′
(S)
90
80
70
60
50
40
30
20
10
0
%

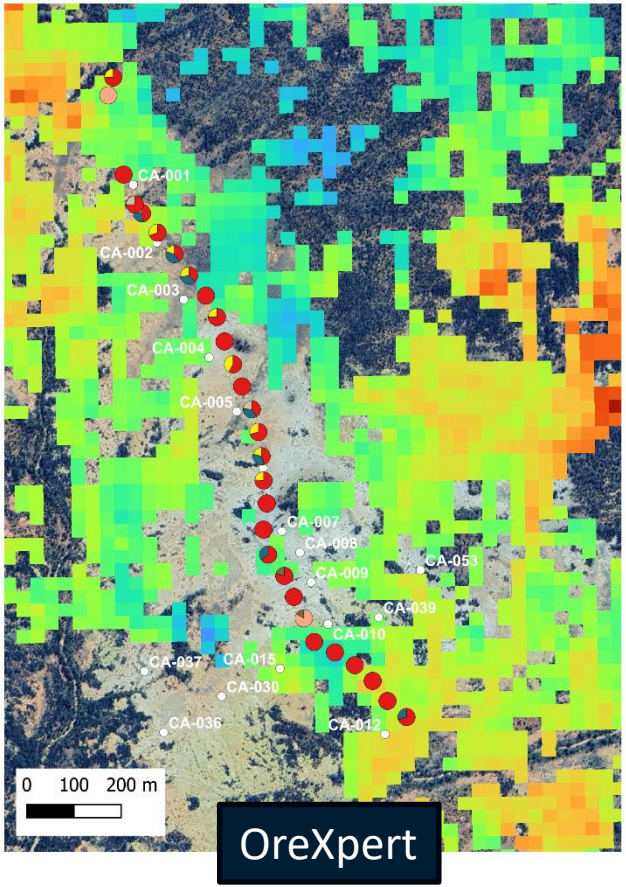

Kaolinite
Muscovite
Quartz
K-feldspar
Montmorillonite


1800
1600
1400
1200
1000
800
600
400
200
0
TREE (ppm)


A
A′
Legend
TREDY_ppm

Hyperspectral surface Kaolin Abundance





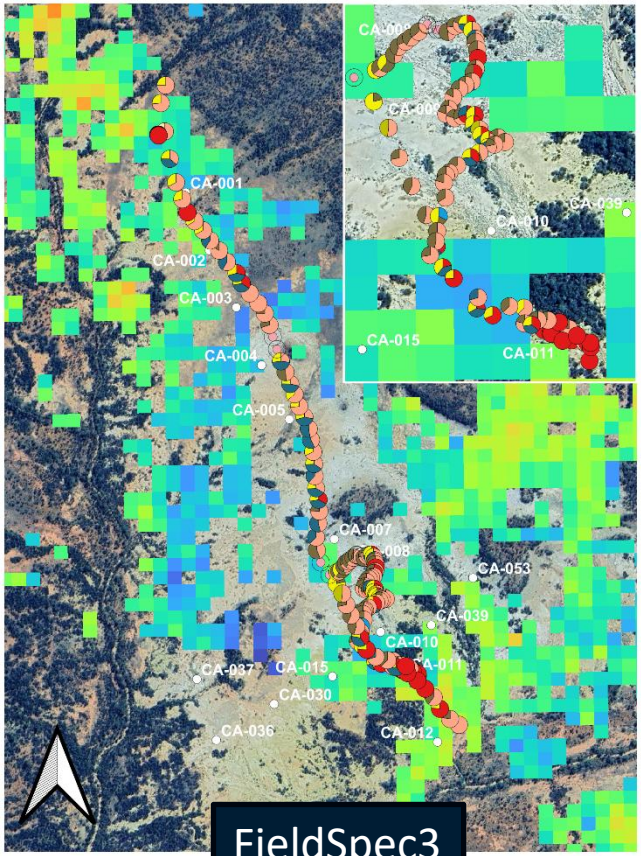
TSG mineral match (SWIR)

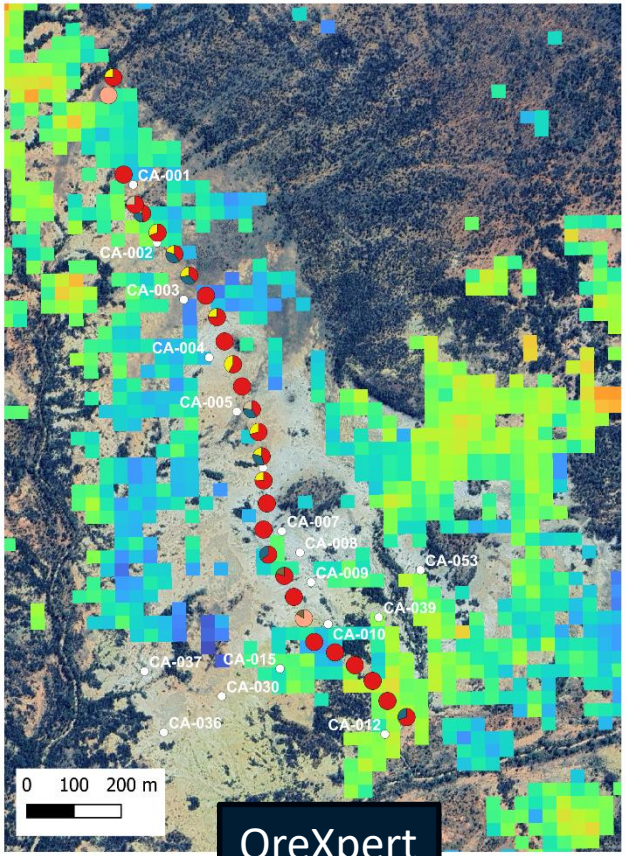
- Kaolinite-PX
- Kaolinite-WX
- Siderite
- Ankerite
- Dolomite
- Magnesite
- Gypsum
- Montmorillonite
- Muscovite
- Phengite
- MuscoviticIllite

Kaolin abundance index EnMAP spectra

low — high

Hyperspectral surface Kaolin Crystallinity





TSG mineral match (SWIR)

- Kaolinite-PX
- Kaolinite-WX
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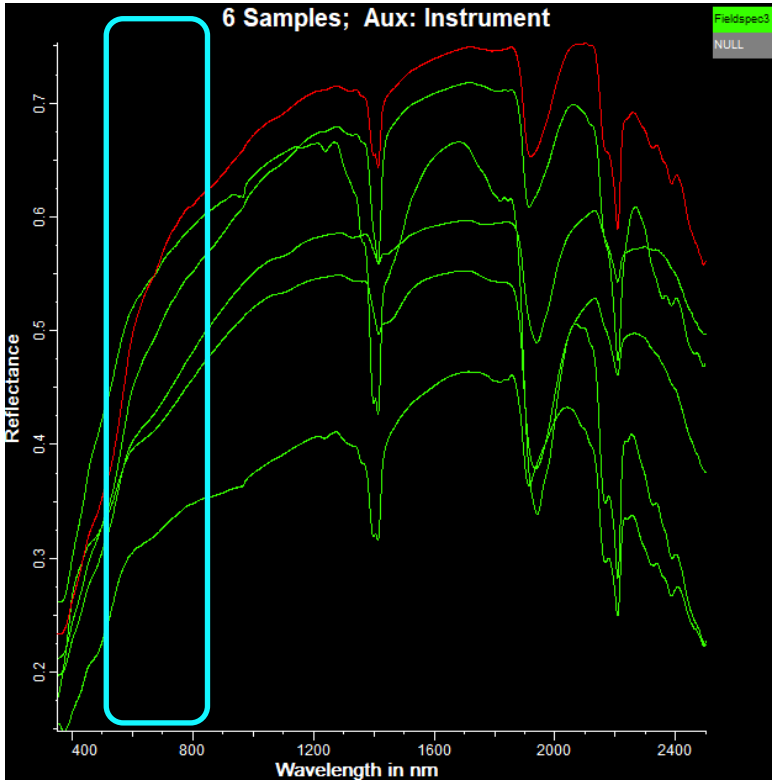
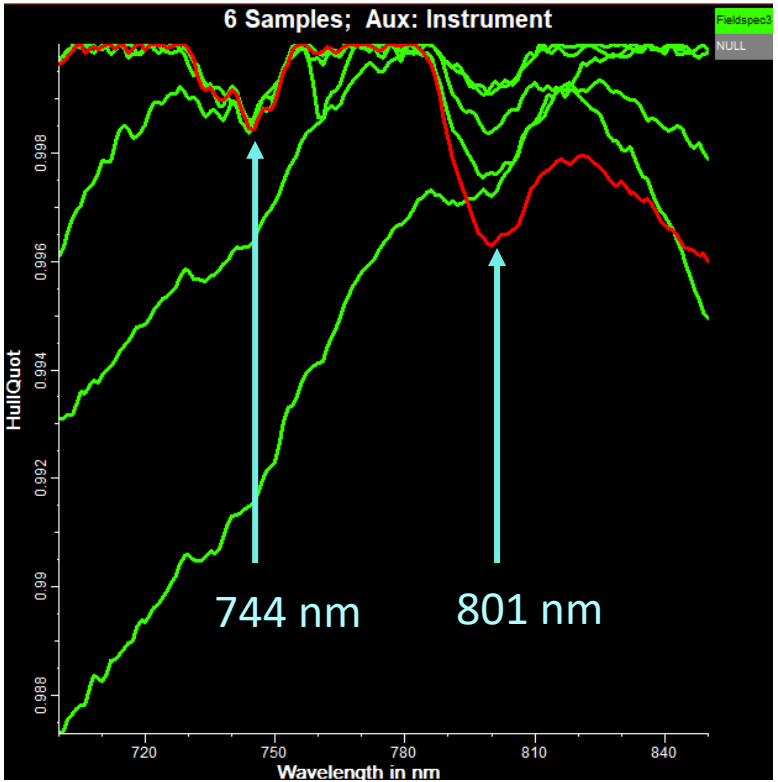
- Ankerite
- Dolomite
- Magnesite
- Gypsum
- Montmorillonite
- Muscovite
- Phengite
- MuscoviticIllite

Kaolin crystallinity index EnMAP spectra

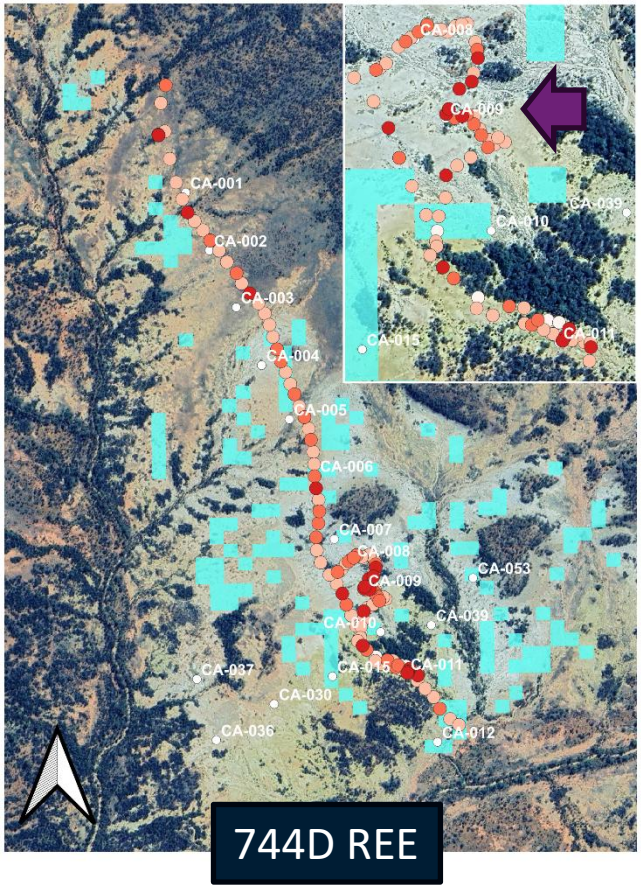
PX WX

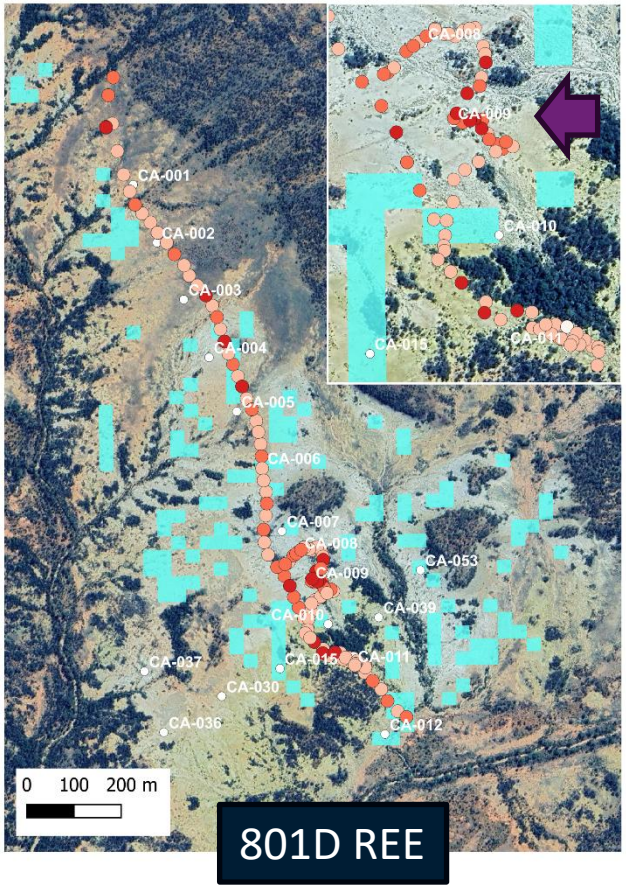
Very Subtle 744 and 801 nm absorptions





Hyperspectral surface Minerals



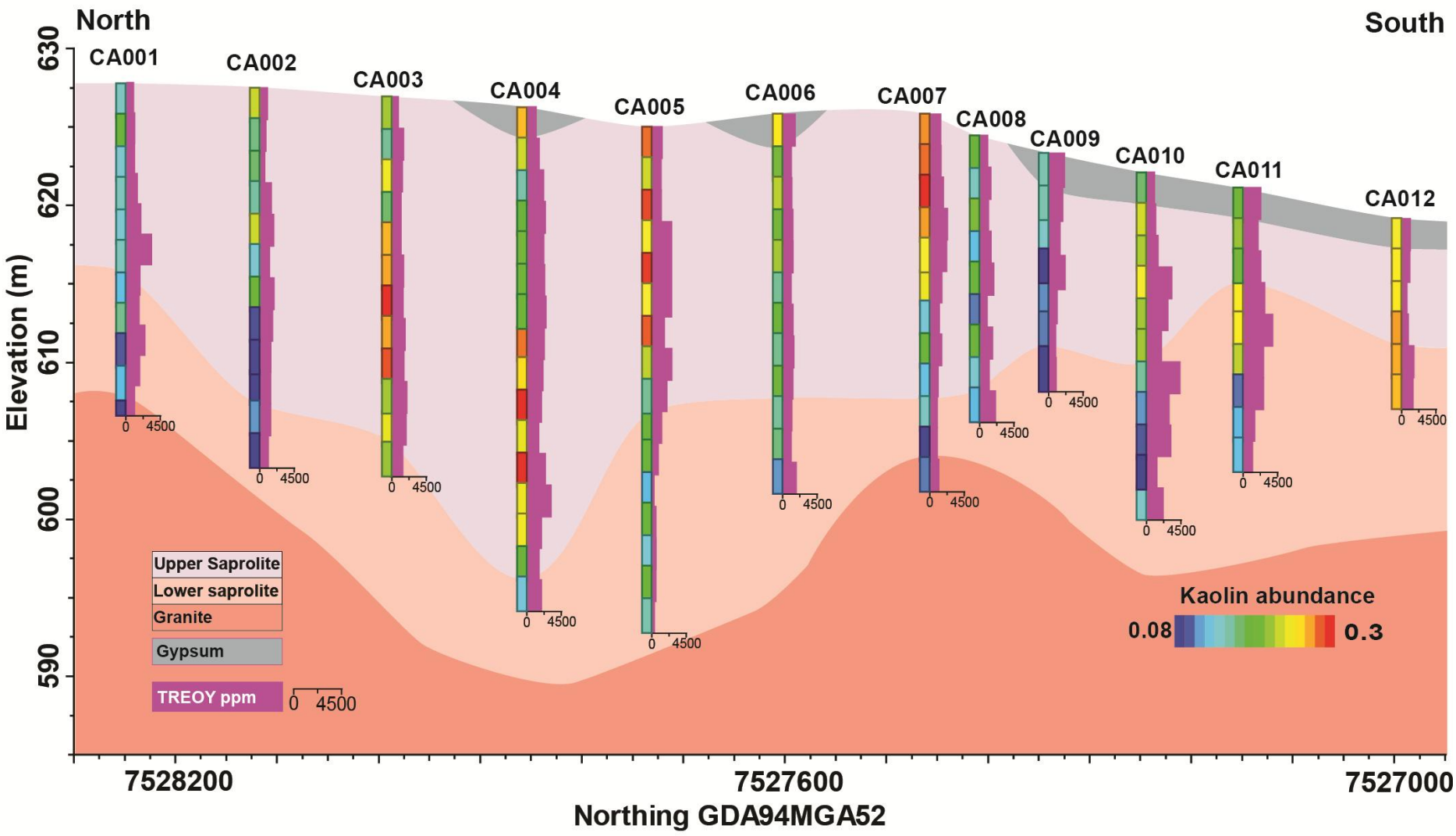


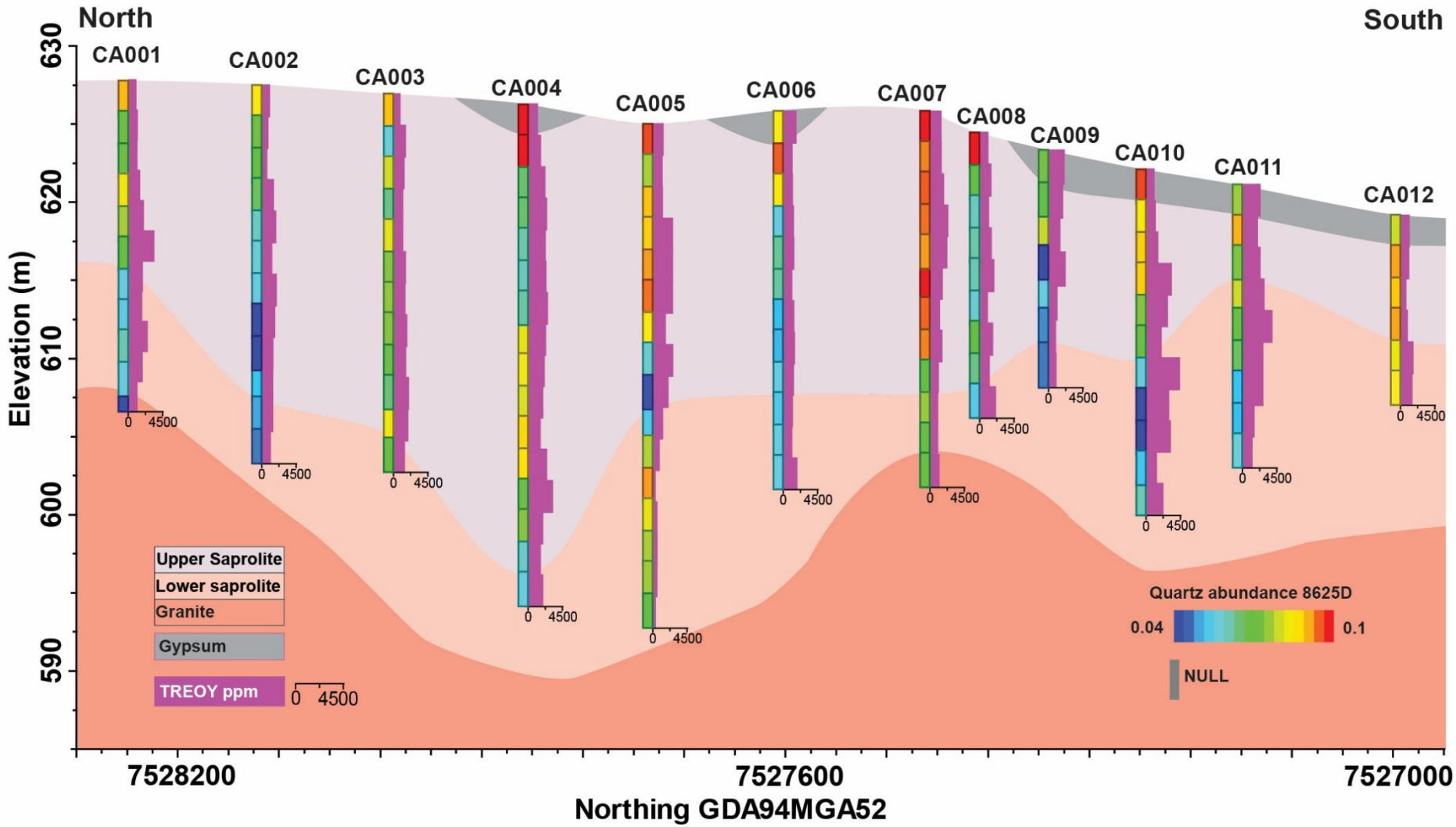
744D and 801D Nd3+ feature depth colour stretch

- 0 - 0.0001 — shallow
- 0.0001 - 0.0005
- 0.0005 - 0.001
- 0.001 - 0.005
- 0.005 - 0.01 — deeper

*features still VERY subtle!

Nd pixels EnMAP spectra


North
South
CA001
CA002
CA003
CA004
CA005
CA006
CA007
CA008
CA009
CA010
CA011
CA012
630
620
610
600
590
Elevation (m)
0 4500
Upper Saprolite
Lower saprolite
Granite
Gypsum
TREOY ppm
Kaolin abundance
0.08
0.3
7528200
7527600
7527000
Northing GDA94MGA52

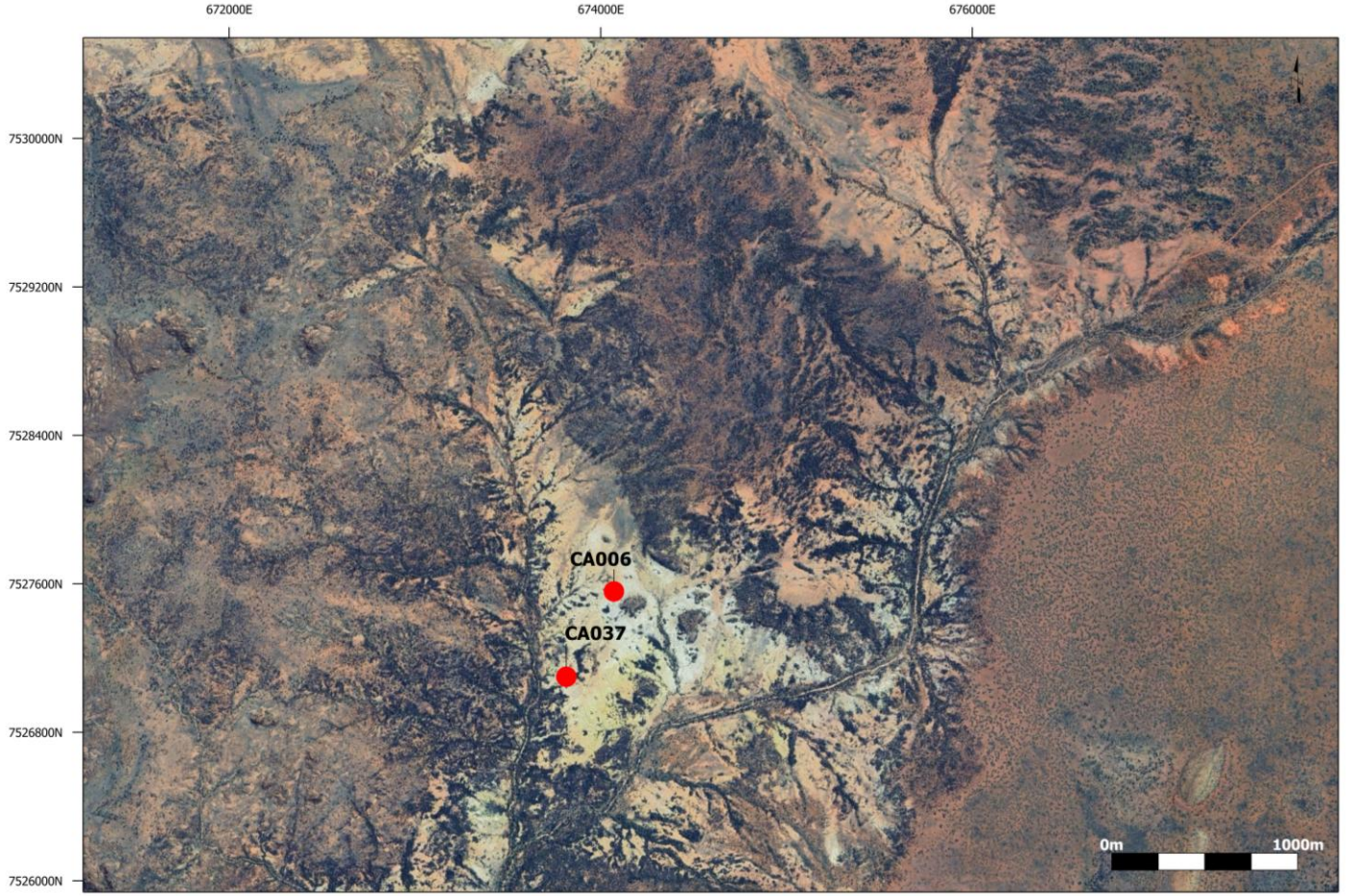

North
South
CA001
CA002
CA003
CA004
CA005
CA006
CA007
CA008
CA009
CA010
CA011
CA012
Elevation (m)
630
620
610
600
590
0 4500
Upper Saprolite
Lower saprolite
Granite
Gypsum
TREOY ppm
Quartz abundance 8625D
0.04
0.1
NULL
7528200
7527600
7527000
Northing GDA94MGA52

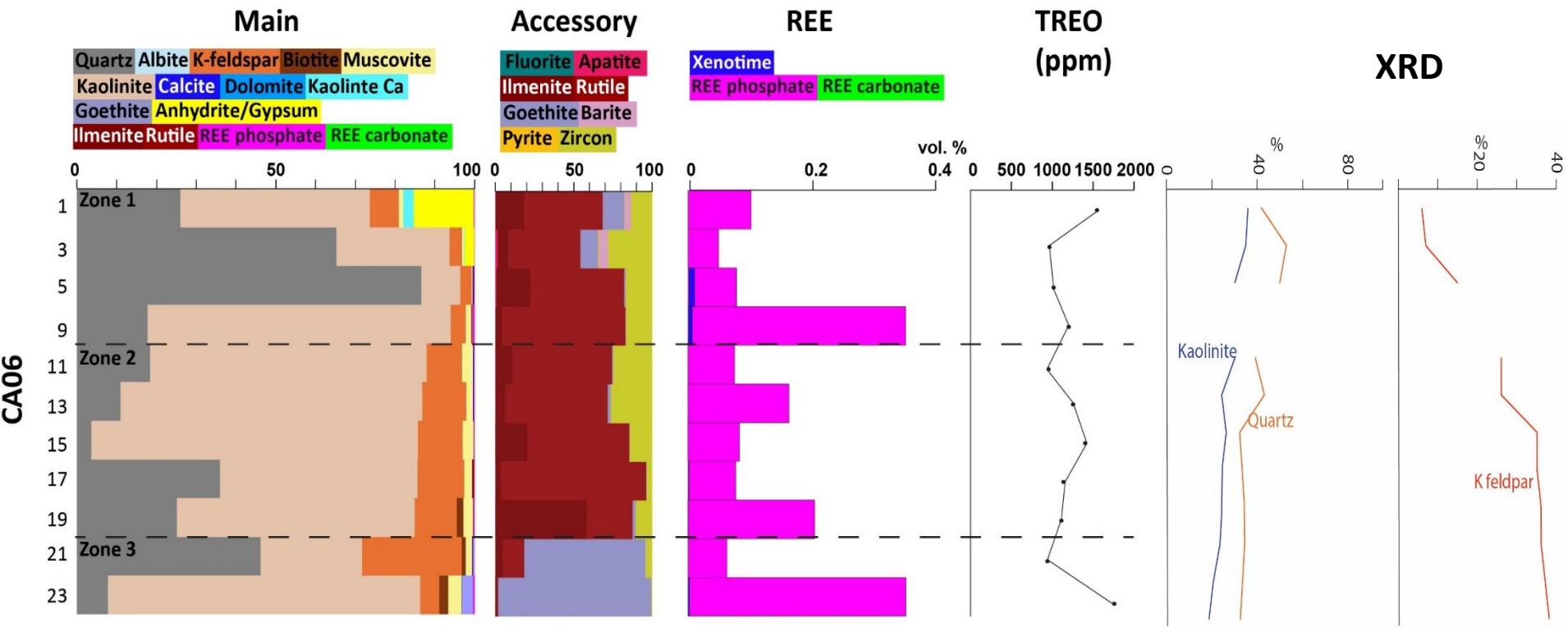
REE bearing Phosphate?

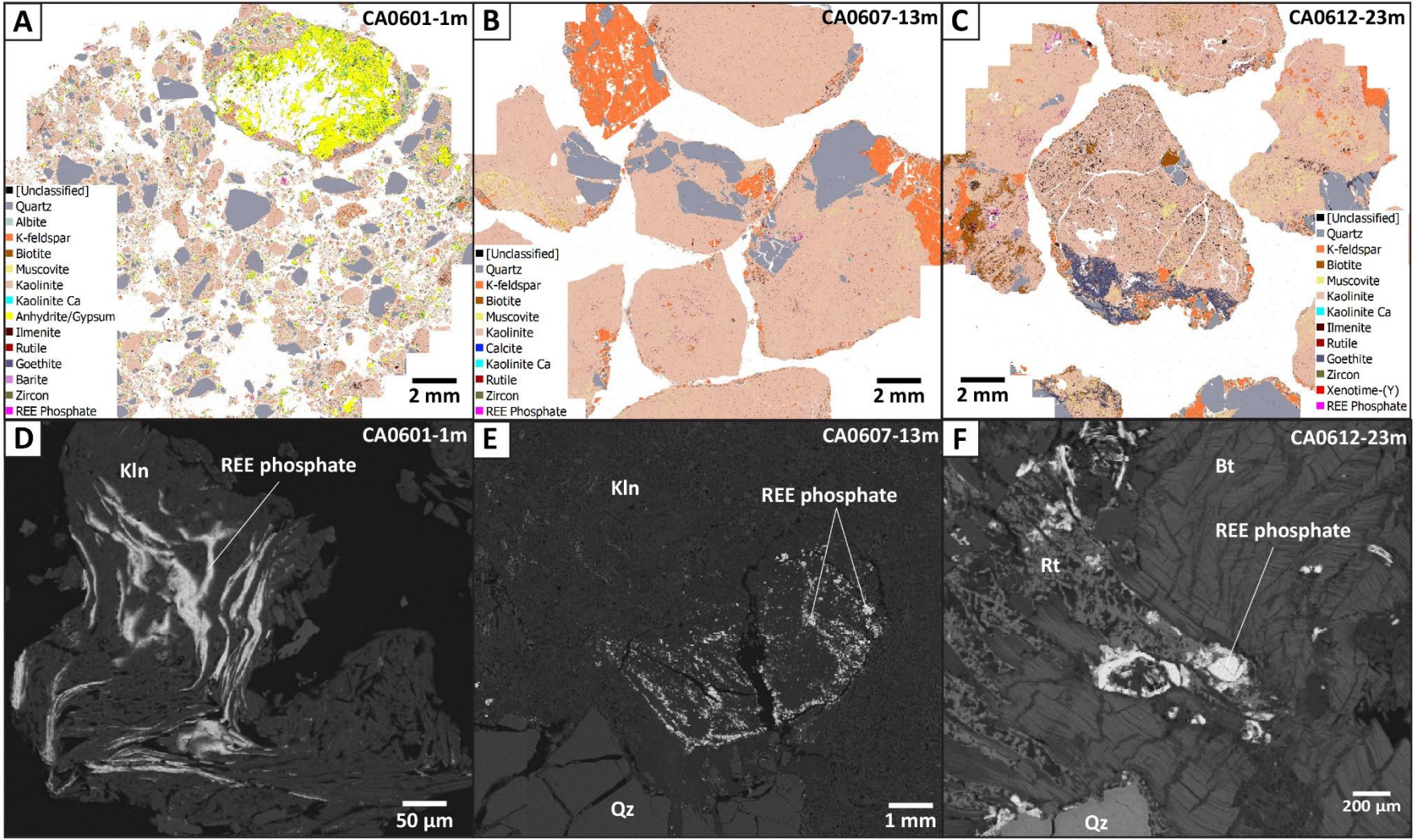
	A	B	C	D
1	Client ID/Schem	P2O5_%	TREOY_pp	K PPM
119	CA01011	0.17	2253.714	16600
120	CA01101	0.13	2163.291	15892
121	CA01102	0.14	1787.673	47900
122	CA01110	0.16	2146.009	54008
123	CA01104	0.18	2713.621	42288
124	CA01105	0.21	3847.024	60992
125	CA01106	0.20	2487.297	44609
126	CA01107	0.17	2564.582	7071
127	CA01108	0.11	1365.918	3968
128	CA01109	0.09	1073.328	6951
129	CA01201	0.08	1034.128	12724
130	CA01202	0.07	930.5988	21875
131	CA01203	0.10	556.6521	52647
132	CA01204	0.06	741.5629	48131
133	CA01205	0.18	1525.86	50027
134	CA01206	0.14	1387.559	4610
135	CA03601	0.20	4162.765	7913
136	CA03602	0.34	5309.017	5151
137	CA03603	0.34	5645.405	4511
138	CA03604	0.26	5520.292	3887
139	CA03610	0.35	5952.813	4963
140	CA03611	0.27	6063.672	4213
141	CA03612	0.25	3860.311	3022
142	CA03608	0.17	2423.117	3851
143	CA03609	0.24	2251.943	2232
144	CA03701	0.02	803.4815	3575
145	CA03702	0.06	883.7516	3442
146	CA03703	0.07	1237.237	8167
147	CA03704	0.10	1813.282	2698
148	CA03705	0.09	1394.51	2339
149	CA03706	0.02	427.6634	3447
150	CA03707	0.08	731.7554	4692
151	CA03708	0.05	1089.47	4995
152	CA03709	0.14	1476.289	9285
153	CA03710	0.05	1095.785	8012
154	CA03711	0.10	1331.155	13619
155	CA03712	0.11	1303.753	7217
156	CA03713	0.04	1620.326	9933
157	CA03714	0.10	1840.585	14289
158	CA03715	0.07	3487.591	16112
159	CA03716	0.06	2521.694	4183
160	CA03717	0.12	4436.464	1771

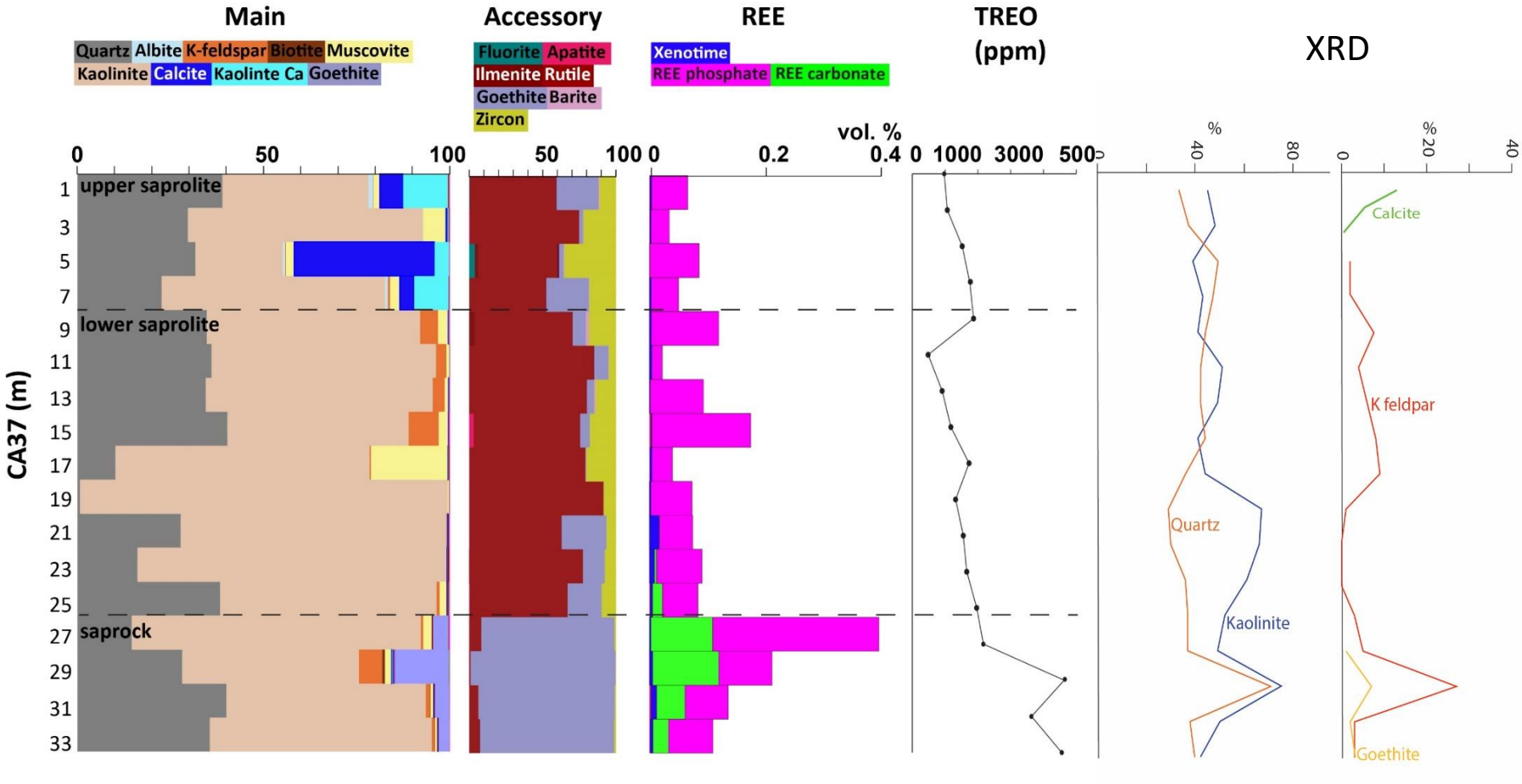
Correlation - 159...	P2O5_pc	TREOY_p...	LREO_ppm	HREOY_...
P2O5_pc	1	0.81	0.8	0.62
TREOY_ppm	0.81	1	0.99	0.78
LREO_ppm	0.8	0.99	1	0.66
HREOY_ppm	0.62	0.78	0.66	1
La2O3_ppm	0.82	0.95	0.96	0.65
CeO2_ppm	0.75	0.96	0.98	0.62
Pr6O11_ppm	0.8	0.96	0.97	0.68
Nd2O3_ppm	0.79	0.97	0.97	0.71
Sm2O3_ppm	0.8	0.97	0.95	0.77
Eu2O3_ppm	0.74	0.96	0.92	0.82
Gd2O3_ppm	0.79	0.96	0.91	0.88
Tb4O7_ppm	0.76	0.93	0.86	0.93
Dy2O3_ppm	0.7	0.86	0.78	0.98
Ho2O3_ppm	0.64	0.8	0.7	1
Er2O3_ppm	0.57	0.75	0.64	0.99
Tm2O3_ppm	0.57	0.73	0.62	0.99
Yb2O3_ppm	0.55	0.72	0.6	0.98
Lu2O3_ppm	0.55	0.7	0.58	0.98
Y2O3_ppm	0.56	0.72	0.6	0.99
Zr_ppm	0.32	0.24	0.24	0.2

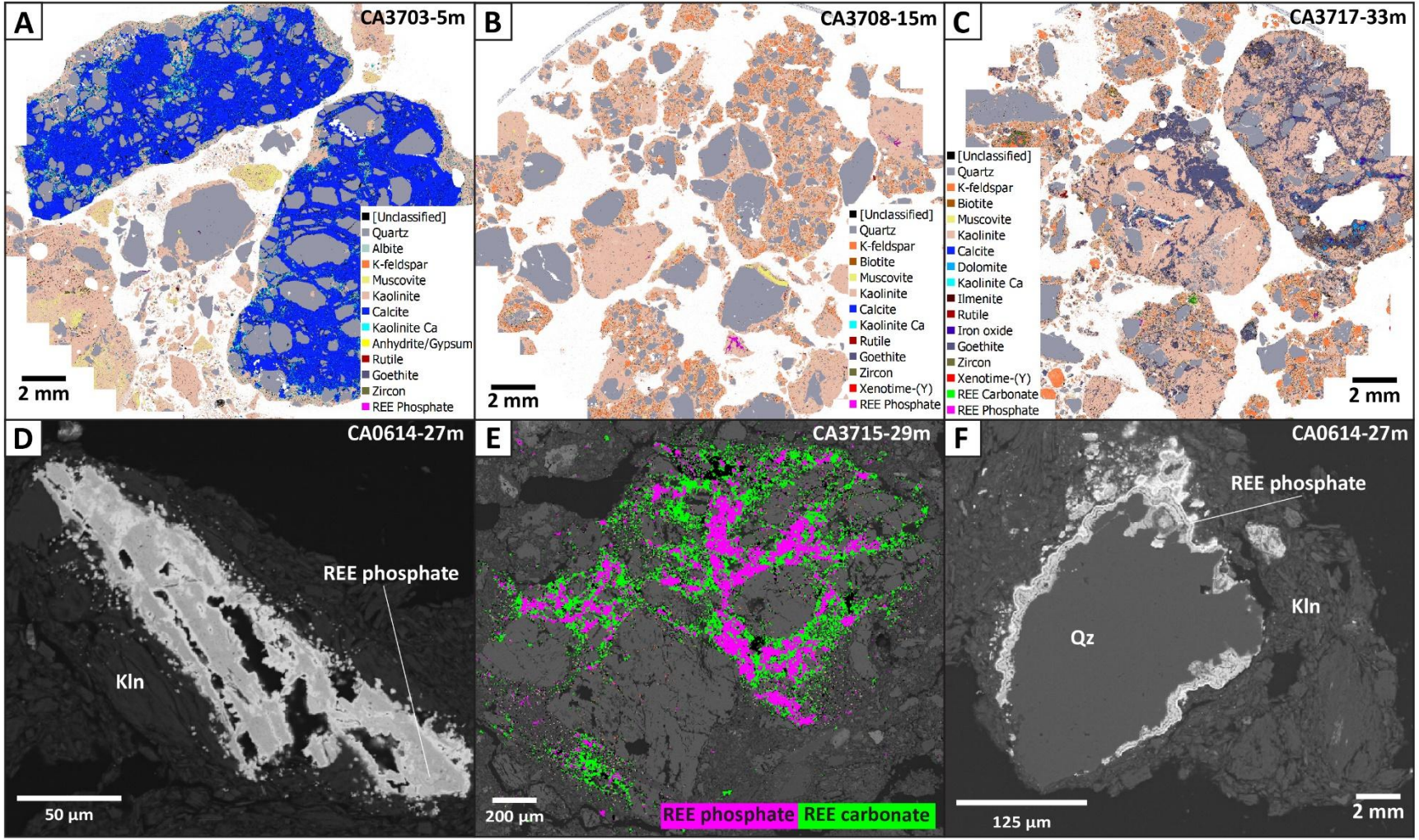
Differences between heavy and light – REE bearing minerals?


672000E
674000E
676000E
7530000N
7529200N
7528400N
7527600N
7526800N
7526000N
CA006
CA037
0m
1000m


Main
Quartz
Albite
K-feldspar
Biotite
Muscovite
Kaolinite
Calcite
Dolomite
Kaolinte Ca
Goethite
Anhydrite/Gypsum
Ilmenite
Rutile
REE phosphate
REE carbonate
Accessory
Fluorite
Apatite
Ilmenite
Rutile
Goethite
Barite
Pyrite
Zircon
REE
Xenotime
REE phosphate
REE carbonate
TREO (ppm)
XRD
vol. %
%
CA06
Zone 1
Zone 2
Zone 3
Kaolinite
Quartz
K feldpar

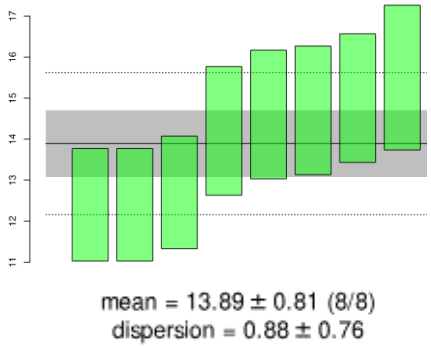

A
CA0601-1m
[Unclassified]
Quartz
Albite
K-feldspar
Biotite
Muscovite
Kaolinite
Kaolinite Ca
Anhydrite/Gypsum
Ilmenite
Rutile
Goethite
Barite
Zircon
REE Phosphate
2 mm
B
CA0607-13m
[Unclassified]
Quartz
K-feldspar
Biotite
Muscovite
Kaolinite
Calcite
Kaolinite Ca
Rutile
Zircon
REE Phosphate
2 mm
C
CA0612-23m
[Unclassified]
Quartz
K-feldspar
Biotite
Muscovite
Kaolinite
Kaolinite Ca
Ilmenite
Rutile
Goethite
Zircon
Xenotime-(Y)
REE Phosphate
2 mm
D
CA0601-1m
Kln
REE phosphate
50 µm
E
CA0607-13m
Kln
REE phosphate
Qz
1 mm
F
CA0612-23m
Bt
REE phosphate
Rt
Qz
200 µm


Main
Quartz
Albite
K-feldspar
Biotite
Muscovite
Kaolinite
Calcite
Kaolinte Ca
Goethite
Accessory
Fluorite
Apatite
Ilmenite
Rutile
Goethite
Barite
Zircon
REE
Xenotime
REE phosphate
REE carbonate
TREO (ppm)
XRD
vol. %
CA37 (m)
upper saprolite
lower saprolite
saprock
Calcite
K feldpar
Quartz
Kaolinite
Goethite


A
CA3703-5m
[Unclassified]
Quartz
Albite
K-feldspar
Muscovite
Kaolinite
Calcite
Kaolinite Ca
Anhydrite/Gypsum
Rutile
Goethite
Zircon
REE Phosphate
2 mm
B
CA3708-15m
[Unclassified]
Quartz
K-feldspar
Biotite
Muscovite
Kaolinite
Calcite
Kaolinite Ca
Rutile
Goethite
Zircon
Xenotime-(Y)
REE Phosphate
2 mm
C
CA3717-33m
[Unclassified]
Quartz
K-feldspar
Biotite
Muscovite
Kaolinite
Calcite
Dolomite
Kaolinite Ca
Ilmenite
Rutile
Iron oxide
Goethite
Zircon
Xenotime-(Y)
REE Carbonate
REE Phosphate
2 mm
D
CA0614-27m
REE phosphate
Kln
50 µm
E
CA3715-29m
200 µm
REE phosphate
REE carbonate
F
CA0614-27m
REE phosphate
Kln
Qz
125 µm
2 mm

Dating – Ferricrete Middle Miocene

Sample code	WATCH code - grain number	^{232}Th (ng)	± (%)	^{238}U (ng)	± (%)	^{147}Sm (ng)	± (%)	^{4}He (ncc)	± (%)	TAU (%)	Th/U	Raw He date (Ma)	±1σ (Ma)	Ft	± (%)	Cor. He date (Ma)	±1σ (Ma)
CAL-R-14	R14-1	0.448	2.6	0.723	2.9	0.0002009	2.6	1.251	0.5	2.6	0.62	12.4	0.3	1.00	5	**12.4**	**0.7**
	R14-2	1.361	2.7	0.535	2.9	0.0001393	4.2	1.565	0.5	2.1	2.53	15.0	0.3	1.00	5	**15.0**	**0.8**
	R14-3	0.348	2.4	0.586	2.7	0.0001393	2.9	1.260	0.6	2.5	0.59	15.5	0.4	1.00	5	**15.5**	**0.9**
	R14-4	0.249	3.0	0.670	3.3	0.0001393	3.1	1.097	0.5	3.1	0.37	12.4	0.4	1.00	5	**12.4**	**0.7**
	R14-5	0.965	2.4	0.702	2.8	0.0001393	4.1	1.440	0.5	2.3	1.36	12.7	0.3	1.00	5	**12.7**	**0.7**
	R14-6	2.518	2.8	1.304	3.2	0.0003471	2.0	3.396	0.5	2.4	1.92	14.7	0.4	1.00	5	**14.7**	**0.8**
	R14-7	1.430	2.5	0.740	2.9	0.0001393	3.2	1.909	0.5	2.2	1.92	14.6	0.3	1.00	5	**14.6**	**0.8**
	R14-8	4.817	2.4	2.113	2.8	0.0005686	1.7	5.617	0.5	2.1	2.26	14.2	0.3	1.00	5	**14.2**	**0.8**



Formation history

Weathering of the Southwark Suite granite before and during the Miocene

REE remobilisation preferentially from allanite granite compared to monazite-granite material

Combined with apatite (P source) weathering can produce secondary REE phosphates e.g. rhabdophane and florencite

Further intense weathering at depth = REE carbonates, can replace phosphates.

If ionically adsorbed REE formed they are leached in acidic saline conditions

Formation of indurated siliceous horizons = protection from physical erosion