British
Geological Survey
NATURAL ENVIRONMENT RESEARCH COUNCIL

The potential for resources of the critical metals in Scotland

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Nottingham

Talk outline

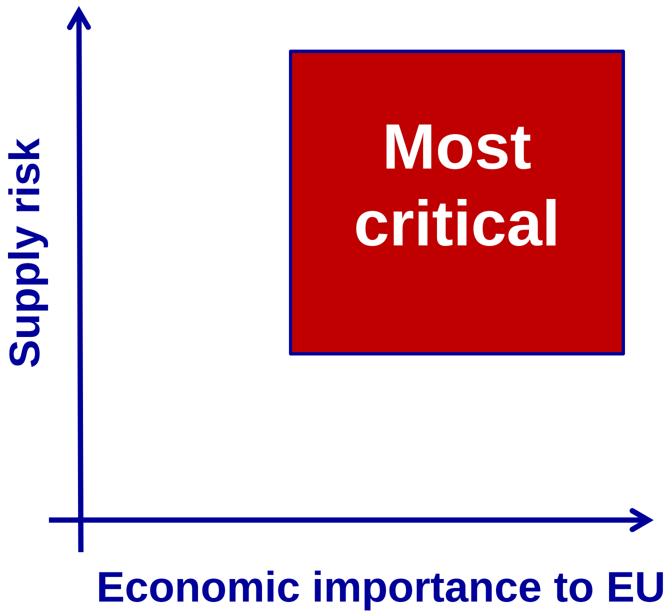
- Critical metals definitions and background
- EU Raw Materials Initiative
- Current work by BGS on critical metals – focus on REE
- Critical metal occurrences in Scotland
- Conclusions and recommendations

What are the critical metals?

The EU is highly dependent on imports of mineral raw materials

The critical metals are those which have the greatest supply risk and are of the most economic importance

Critical metals have low recycling rates and are not readily substituted



Most critical

Supply risk

Economic importance to EU

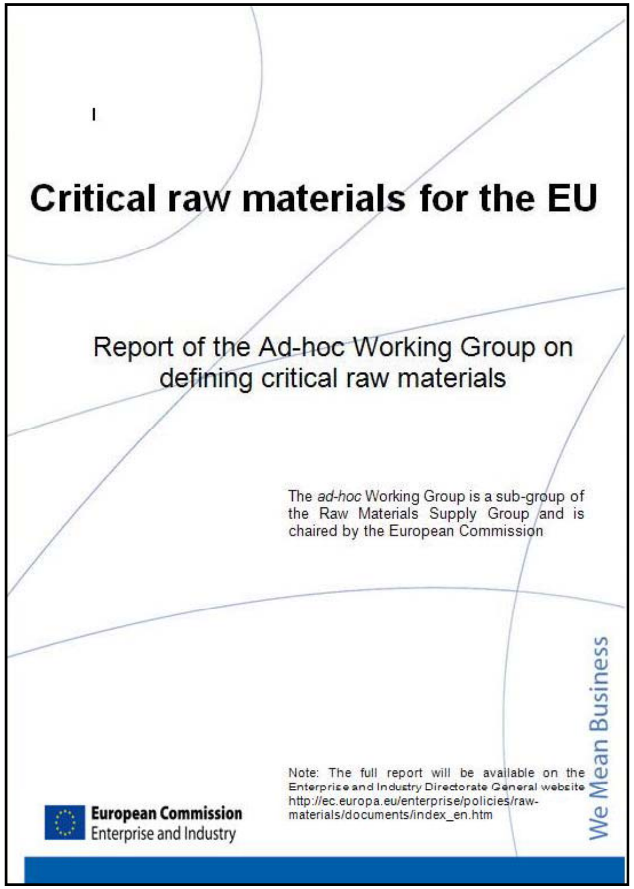
EU Raw Materials Initiative

EU Raw Materials Initiative 2008

- Securing sustainable supplies from within the EU
- Securing access to raw materials overseas
- Reduce consumption through recycling and improved resource efficiency

41 materials assessed on:

- Economic importance
- Supply risk



Critical raw materials for the EU

Report of the Ad-hoc Working Group on defining critical raw materials

The *ad-hoc* Working Group is a sub-group of the Raw Materials Supply Group and is chaired by the European Commission

Note: The full report will be available on the Enterprise and Industry Directorate General website http://ec.europa.eu/enterprise/policies/raw-materials/documents/index_en.htm

European Commission
Enterprise and Industry

We Mean Business

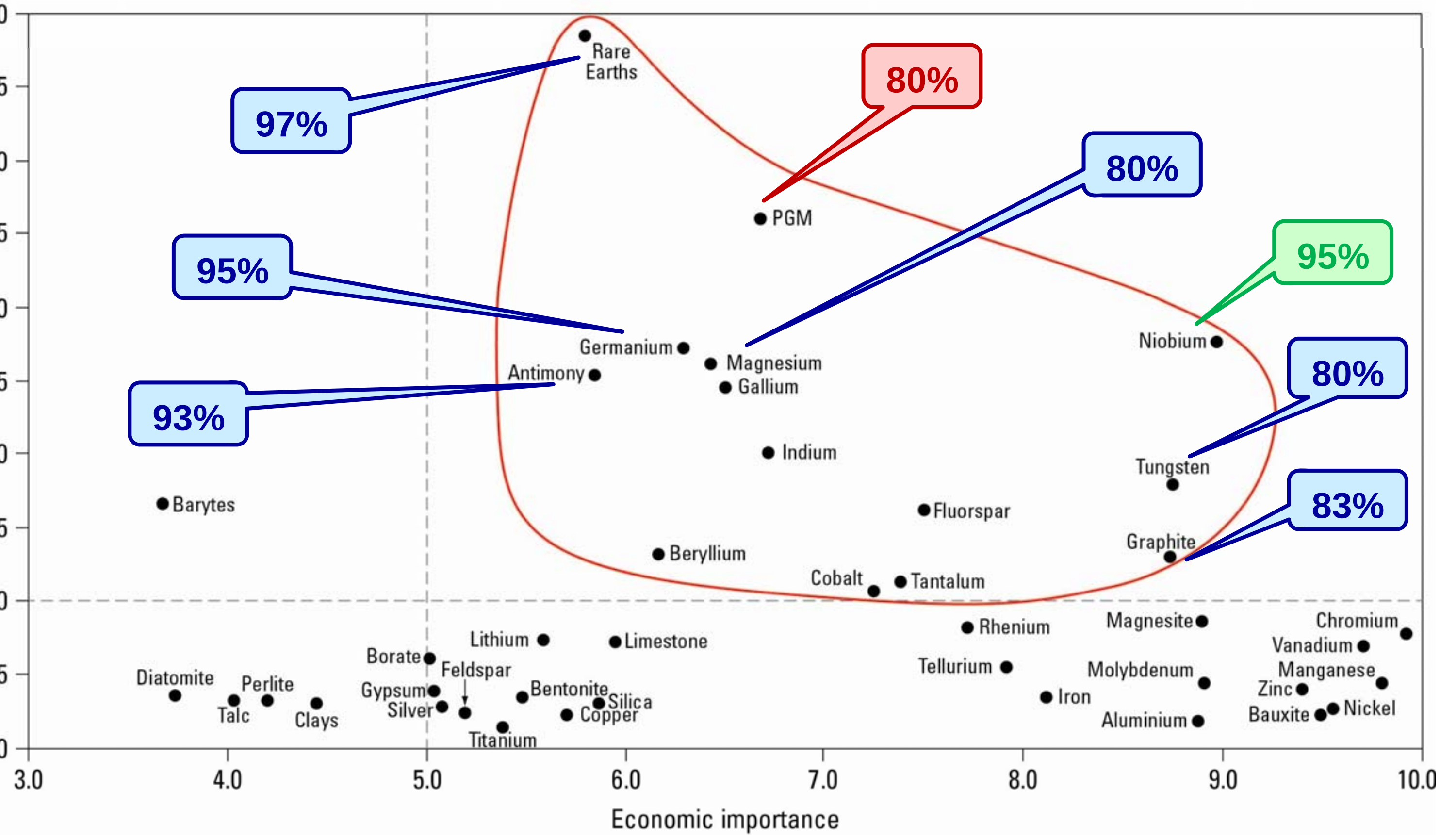
Results of analysis

- Antimony
- Beryllium
- Cobalt
- Fluorspar
- Gallium
- Germanium
- Graphite

- Indium
- Magnesium
- Niobium
- Platinum group metals (6 PGM)
- Rare earths (17 REE)
- Tantalum
- Tungsten



Results of analysis

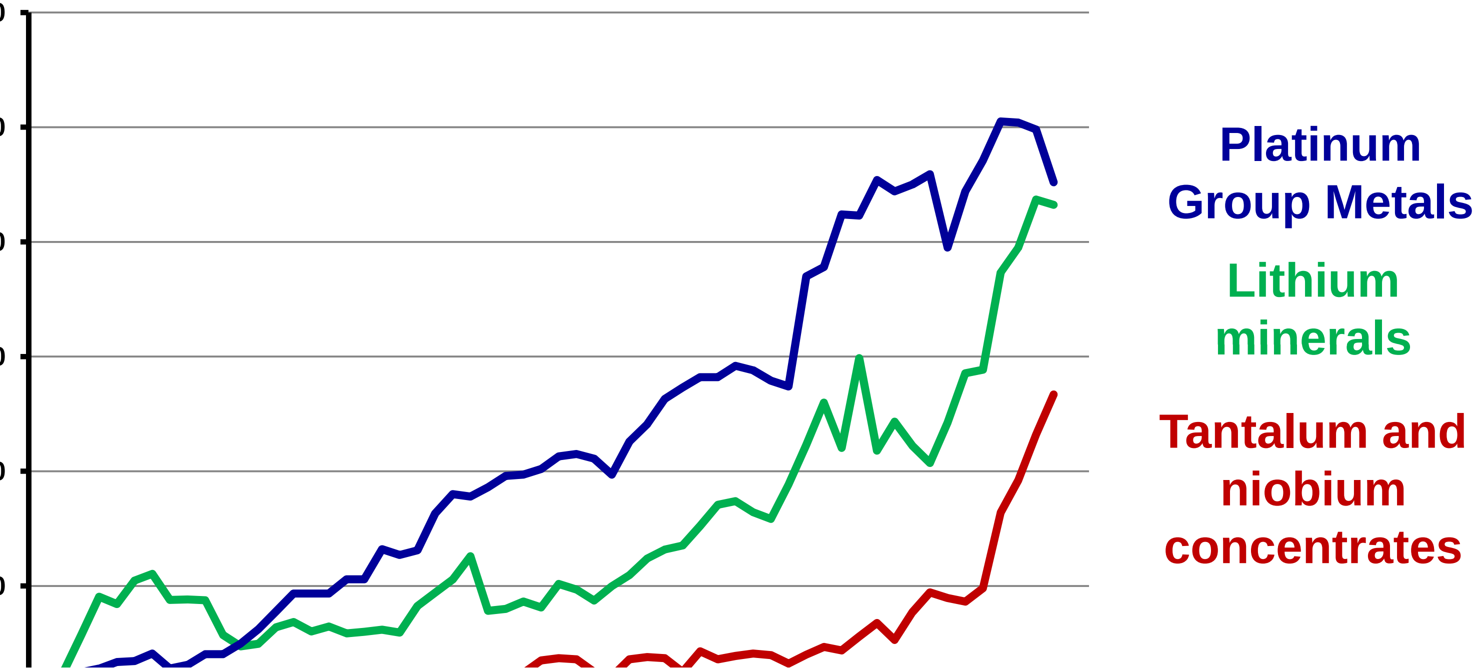


Proportion of global production from:

ncreasing demand for critical metals

istorically production of the critical metals has been low

emand is growing steadily due mainly to their use in emerging chnologies, such as those required for clean energy



cal metal occurrences in Scotland

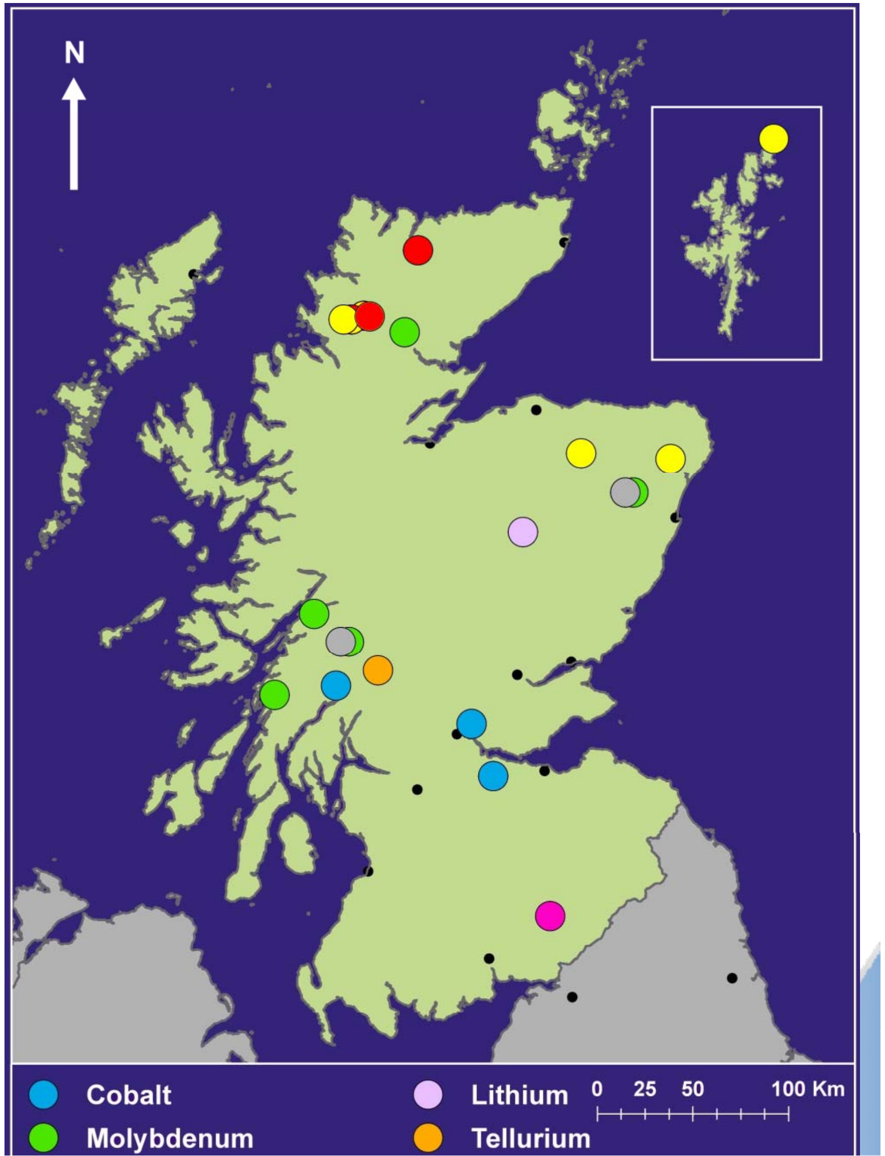
important to evaluate the ential for indigenous resources

ere has been little investigation esources in Scotland

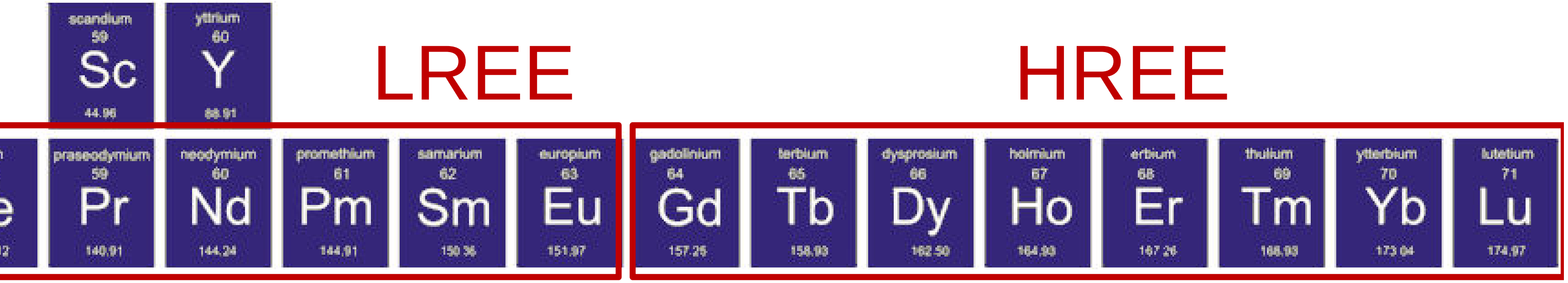
me metals are known to occur number of geological settings

ese occurrences are highly able in amount of information ilable and work done

eir economic potential is



Rare earth elements



oup of 17 elements with similar properties

verse range of uses, specifically in green technologies

ina dominates global production (~97% in 2010) and
bal reserves (~37%)

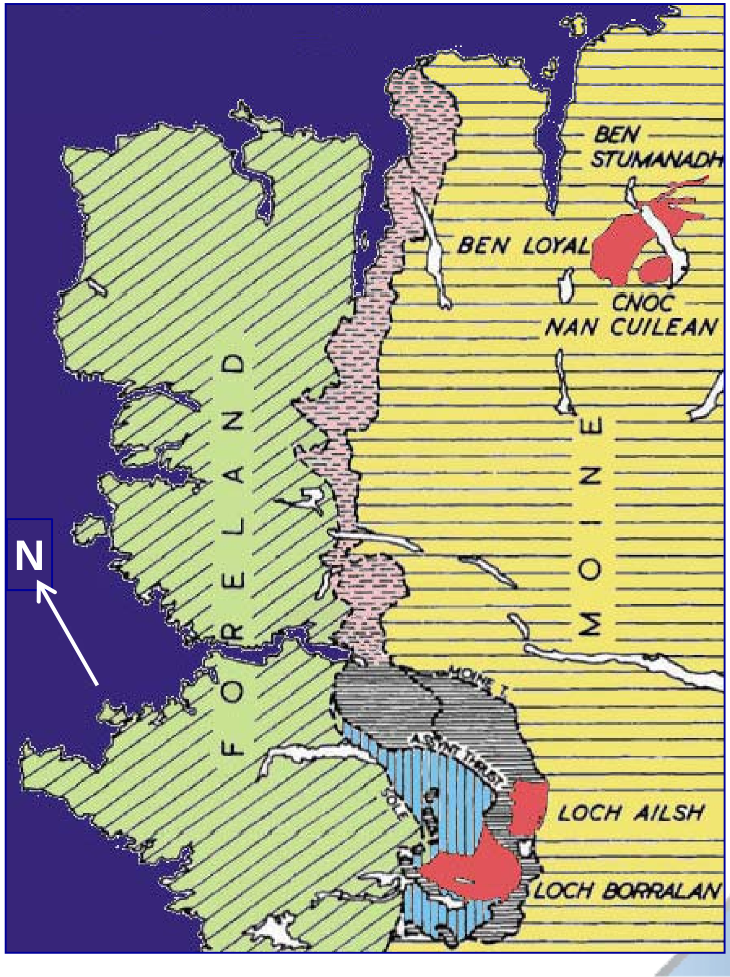
creased global exploration to enhance security of supply

REE in NW Scotland

Caledonian igneous intrusions - Loch Ailsh, Loch Borralan and Loch Loyal

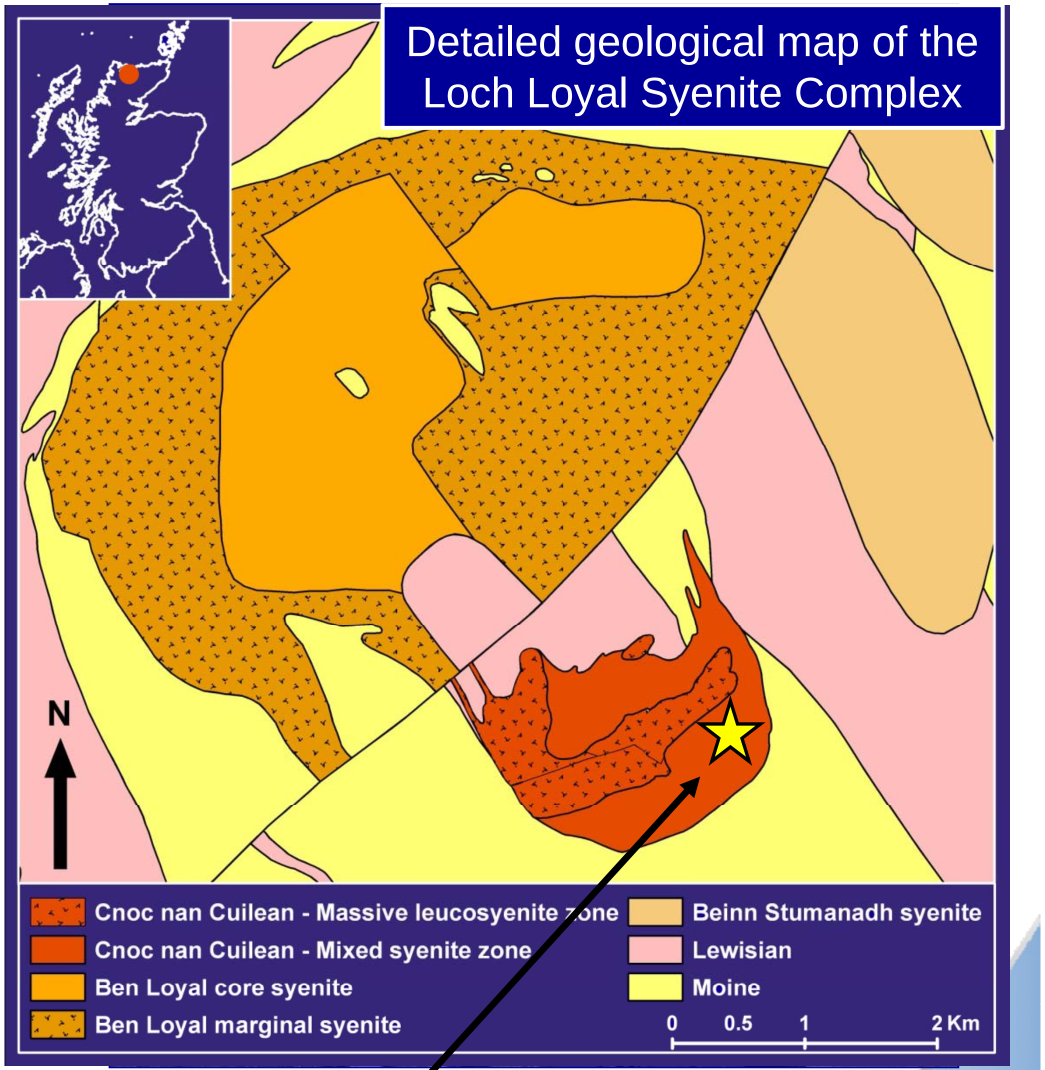
Previous limited investigations by BGS in 1980s identified elevated REE contents

Ongoing metallogenic studies by BGS in these areas



ch Loyal Syenite Complex

- GS programme of mapping d surface rock sampling 10-2011
- ntrusions: Ben Loyal, Beinn umanadh and Cnoc nan ilean, poorly exposed
- oc nan Cuilean intrusion 3km^2) is made up of 2 main nes: a Mixed Syenite Zone d a Massive Leucosyenite ne


Detailed geological map of the Loch Loyal Syenite Complex

hest REO values found in biotite-magnetite hydrothermal

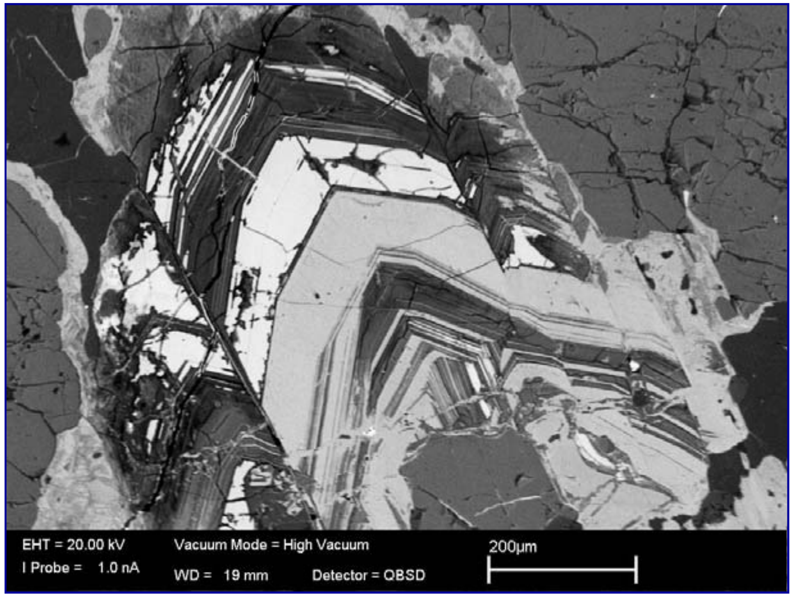
Cnoc nan Cuilean

EO contents:

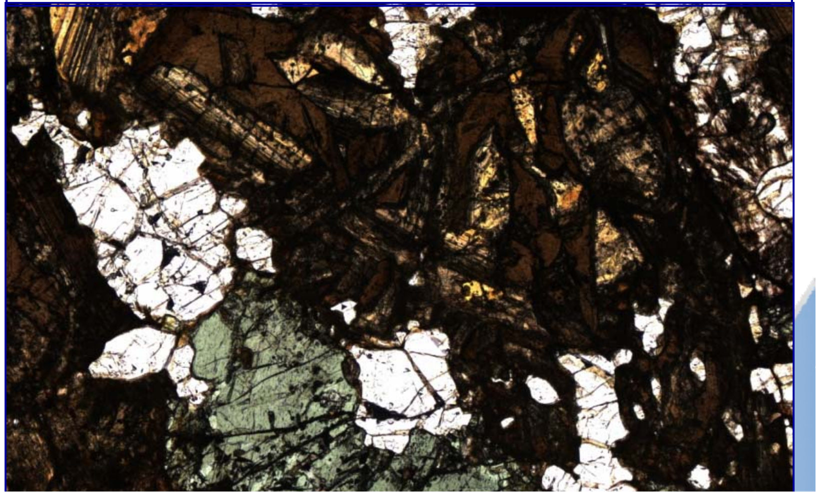
- 20 000 ppm (2%) in hydrothermal veins (maximum)
- 3800 ppm in mafic syenites (average)
- 1400 ppm in leucosyenites (average)

e dominant REE-bearing phase esent is allanite

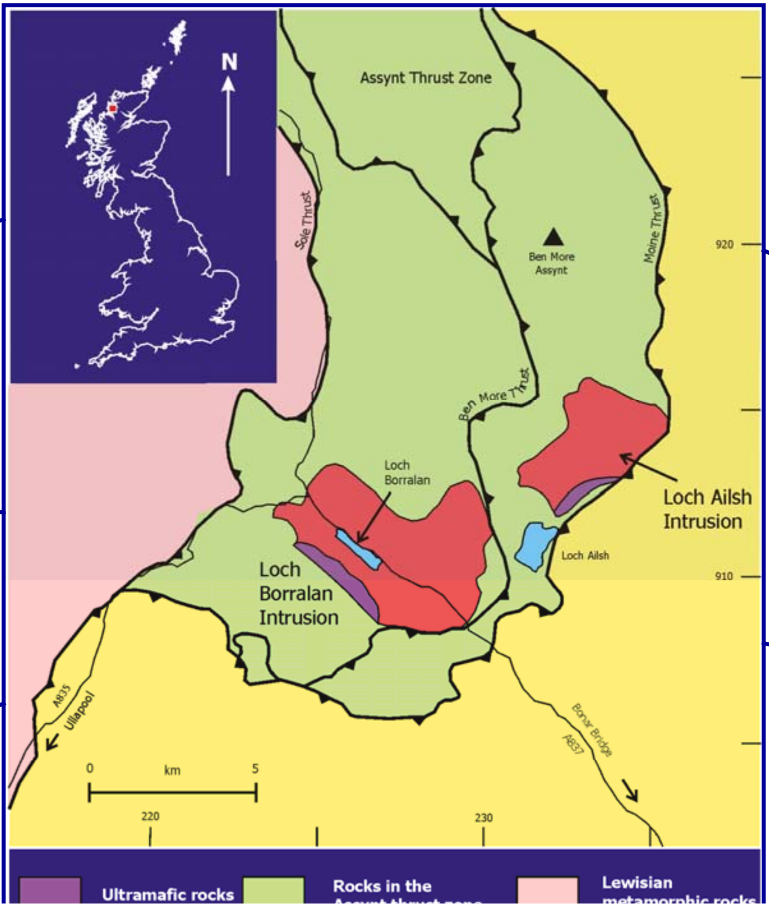
etallogenic model is under velopment and may be a basis for ther exploration in NW Scotland



BSEM image of allanite



och Borralan Complex: potential for several commodities



hosphate
5 million
onnes of
apatite at
2% P_2O_5

ase metals

are earths
p to 5000
pm TREO

Vanadium and titanium
Up to10%
titaniferous
magnetite at
0.3% V

PGMs
Up to 878 ppb
Pt + Pd

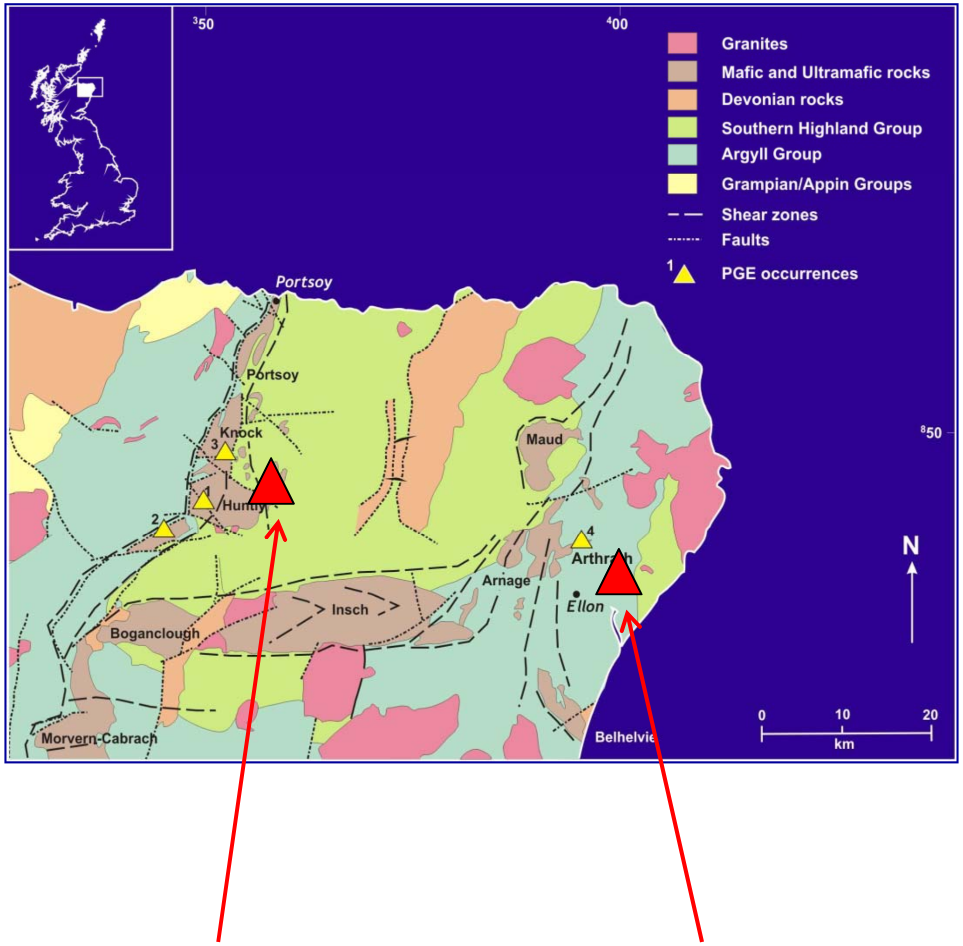
Platinum group metals

st ophiolite, Shetland

- Very high PGM concentrations identified at several stratigraphic levels
- Small, high grade deposits

ledonian mafic-ultramafic rusions of north-east otland

- Values of up to 500 ppb Pt + Pd in magmatic copper-nickel sulphide deposits in the Knock intrusion and at Arthrath, near Ellon



Knock

Arthrath

balt and antimony

- nor occurrences – no modern estigation for cobalt
- ver Glen Mine in Alva, rthshire
  - Fracture-controlled mineralisation in Lower Devonian volcanics
- ille-Braghad Mine near Inverary
  - Stratabound mineralisation within Dalradian metasediments
- derston Mine near Linlithgow
  - Polymetallic hydrothermal veins

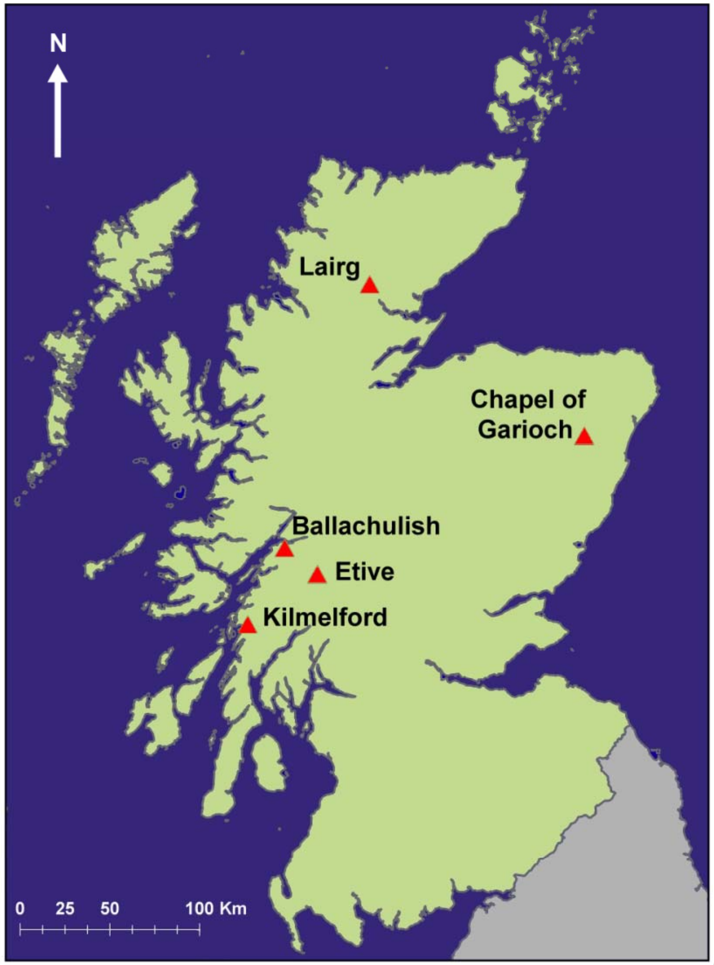
- in antimony mineralisation in urian greywackes at

olybdenum (rhenium)

ossible rhenium enrichment ssociated with molybdenum?

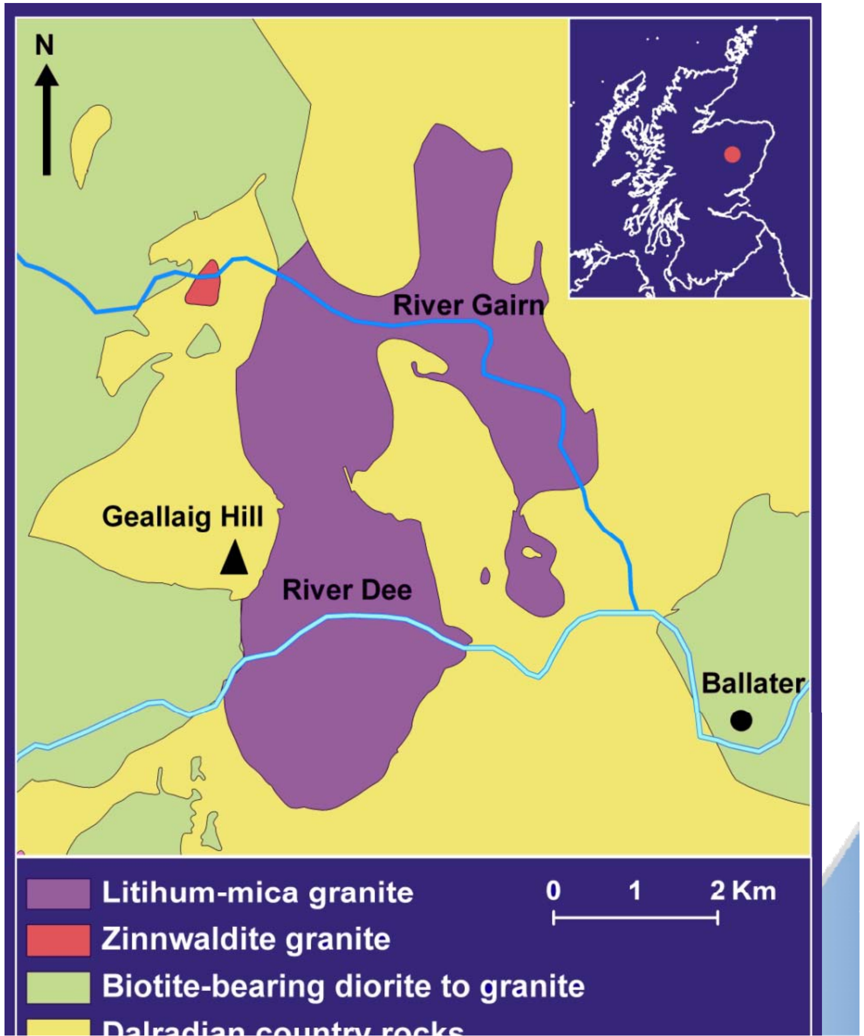
olybdenum occurrences nvestigated by BGS in the 1970s nd 1980s

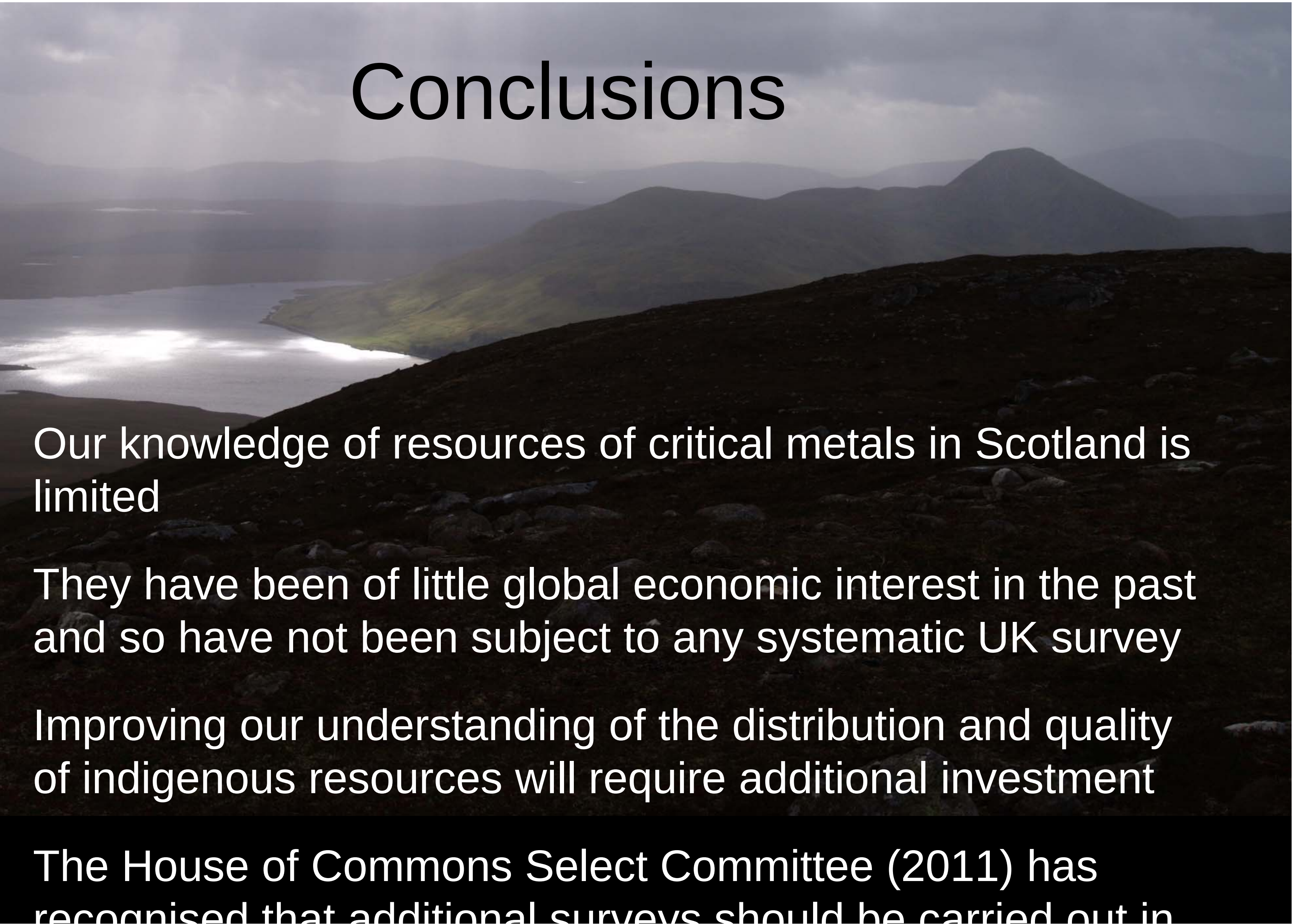
- Kilmelford, Argyllshire
- Ballachulish Igneous Complex, Western Highlands
- Lairg, Sutherland
- Etive plutonic complex, Western Highlands
- Chapel of Garioch, Inverurie



llurium, lithium, tungsten and tantalum

- lurium
  - High values at Scotgold's Cononish gold and silver deposit
- ew minor occurrences of lithium, gsten and tantalum but no stematic study
- hium
  - Lithium-mica granite in the Glen Gairn Complex
- ngsten
  - Chapel of Garioch, Etive pluton
- ntalum
  - Chiapaval pegmatite, South Harris





Conclusions

Our knowledge of resources of critical metals in Scotland is limited

They have been of little global economic interest in the past and so have not been subject to any systematic UK survey

Improving our understanding of the distribution and quality of indigenous resources will require additional investment

The House of Commons Select Committee (2011) has recognised that additional surveys should be carried out in

Tellus project, N Ireland

- gh resolution geochemical and geophysical surveying of rthern Ireland 2004-2006
- newed interest in mineral exploration

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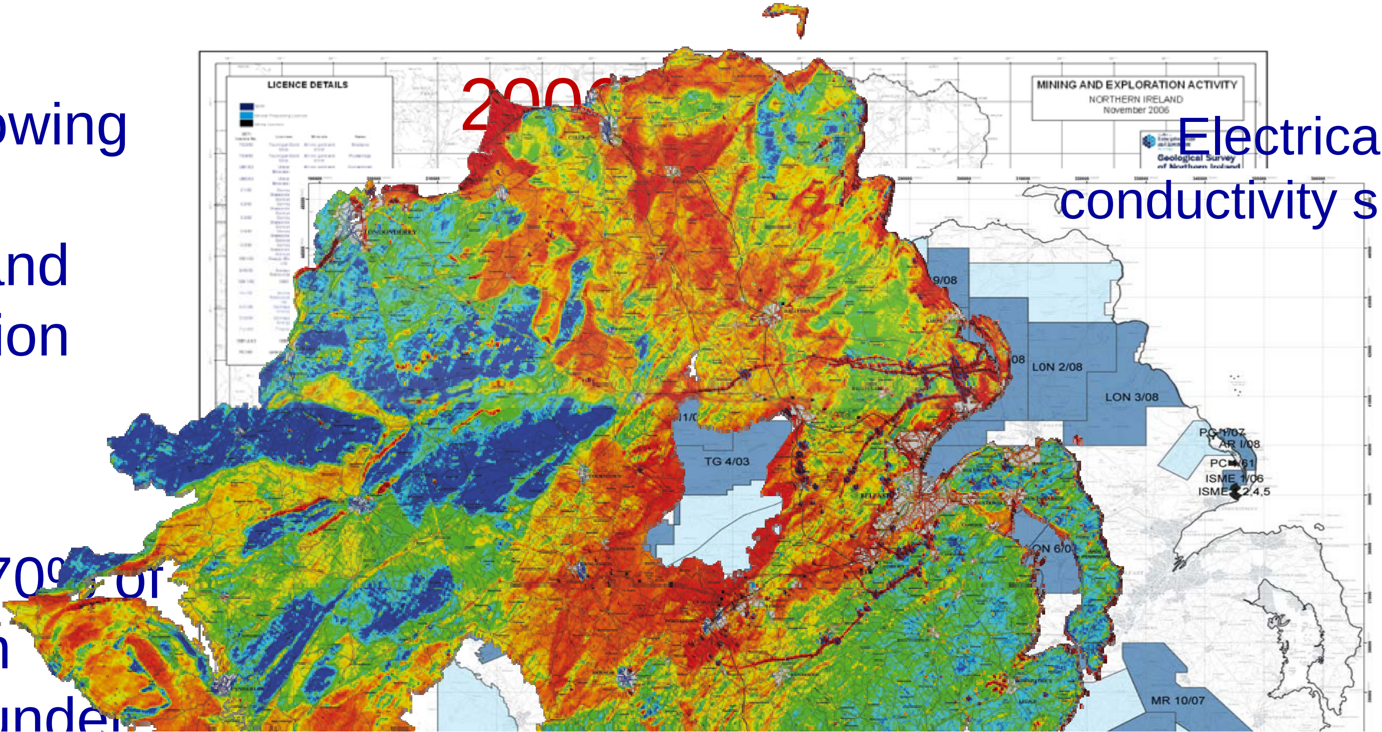
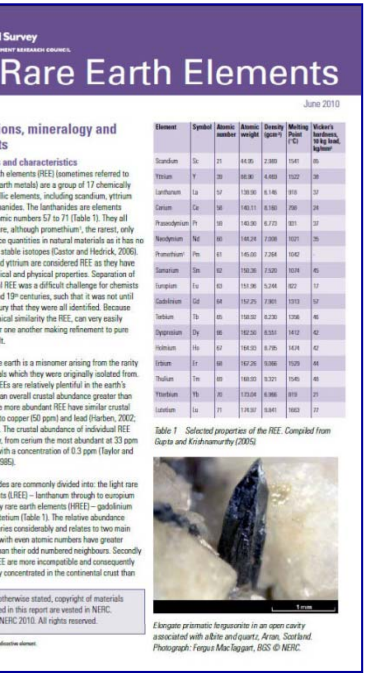
8: ~70% of
thern
and under



Electrical conductivity survey

Thank you for listening



Survey

Rare Earth Elements

June 2010

ions, mineralogy and
ts

and characteristics
h elements (REE) (sometimes referred to
arth metals) are a group of 17 chemically
llic elements, including scandium, yttrium
anides. The lanthanides are elements
mic numbers 57 to 71 (Table 1). They all
re, although promethium[1], the rarest, only
ce quantities in natural materials as it has no
stable isotopes (Castor and Hedrick, 2006).
d yttrium are considered REE as they have
ical and physical properties. Separation of
l REE was a difficult challenge for chemists
d 19th centuries, such that it was not until
ury that they were all identified. Because
ical similarity the REE, can very easily
r one another making refinement to pure
lt.

e earth is a misnomer arising from the rarity
als which they were originally isolated from.
EEs are relatively plentiful in the earth's
an overall crustal abundance greater than
e more abundant REE have similar crustal
to copper (50 ppm) and lead (Harben, 2002;
. The crustal abundance of individual REE
, from cerium the most abundant at 33 ppm
with a concentration of 0.3 ppm (Taylor and
985).

des are commonly divided into: the light rare
ts (LREE) – lanthanum through to europium
y rare earth elements (HREE) – gadolinium
tetium (Table 1). The relative abundance
ries considerably and relates to two main
with even atomic numbers have greater
han their odd numbered neighbours. Secondly
E are more incompatible and consequently
y concentrated in the continental crust than

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dioactive element

Element	Symbol	Atomic number	Atomic weight	Density (gcm⁻³)	Melting Point (°C)	Vicker's hardness, 10 kg load, kg/mm²
Scandium	Sc	21	44.95	2.989	1541	85
Yttrium	Y	39	88.90	4.469	1522	38
Lanthanum	La	57	138.90	6.146	918	37
Cerium	Ce	58	140.11	8.160	798	24
Praseodymium	Pr	59	140.90	6.773	931	37
Neodymium	Nd	60	144.24	7.008	1021	35
Promethium[1]	Pm	61	145.00	7.264	1042	-
Samarium	Sm	62	150.36	7.520	1074	45
Europium	Eu	63	151.96	5.244	822	17
Gadolinium	Gd	64	157.25	7.901	1313	57
Terbium	Tb	65	158.92	8.230	1356	46
Dysprosium	Dy	66	162.50	8.551	1412	42
Holmium	Ho	67	164.93	8.795	1474	42
Erbium	Er	68	167.26	9.066	1529	44
Thulium	Tm	69	168.93	9.321	1545	48
Ytterbium	Yb	70	173.04	6.966	819	21
Lutetium	Lu	71	174.97	9.841	1663	77

Table 1 Selected properties of the REE. Compiled from Gupta and Krishnamurthy (2005)

1 mm

Elongate prismatic fergusonite in an open cavity associated with albite and quartz, Arran, Scotland. Photograph: Fergus MacTaggart, BGS © NERC.

MineralsUK
Centre for sustainable mineral development

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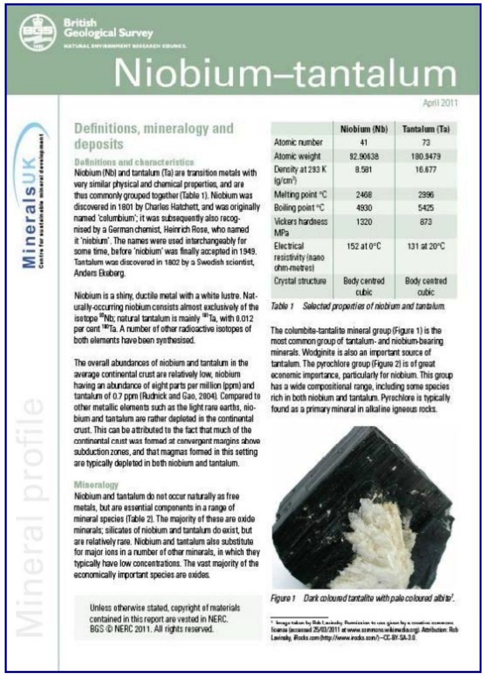

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Niobium–tantalum

April 2011

MineralsUK
Centre for sustainable mineral development

Mineral profile

Definitions, mineralogy and deposits

Definitions and characteristics

Niobium (Nb) and tantalum (Ta) are transition metals with very similar physical and chemical properties, and are thus commonly grouped together (Table 1). Niobium was discovered in 1801 by Charles Hatchett, and was originally named 'columbium'; it was subsequently also recognised by a German chemist, Heinrich Rose, who named it 'niobium'. The names were used interchangeably for some time, before 'niobium' was finally accepted in 1949. Tantalum was discovered in 1802 by a Swedish scientist, Anders Ekeberg.

Niobium is a shiny, ductile metal with a white lustre. Naturally-occurring niobium consists almost exclusively of the isotope ^{93}Nb; natural tantalum is mainly ^{181}Ta, with 0.012 per cent ^{180}Ta. A number of other radioactive isotopes of both elements have been synthesised.

The overall abundances of niobium and tantalum in the average continental crust are relatively low, niobium having an abundance of eight parts per million (ppm) and tantalum of 0.7 ppm (Rudnick and Gao, 2004). Compared to other metallic elements such as the light rare earths, niobium and tantalum are rather depleted in the continental crust. This can be attributed to the fact that much of the continental crust was formed at convergent margins above subduction zones, and that magmas formed in this setting are typically depleted in both niobium and tantalum.

Mineralogy

Niobium and tantalum do not occur naturally as free metals, but are essential components in a range of mineral species (Table 2). The majority of these are oxide minerals; silicates of niobium and tantalum do exist, but are relatively rare. Niobium and tantalum also substitute for major ions in a number of other minerals, in which they typically have low concentrations. The vast majority of the economically important species are oxides.

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	Niobium (Nb)	Tantalum (Ta)
Atomic number	41	73
Atomic weight	92.90638	180.9479
Density at 293 K (g/cm³)	8.581	16.677
Melting point °C	2468	2996
Boiling point °C	4930	5425
Vickers hardness MPa	1320	873
Electrical resistivity (nano ohm-metres)	152 at 0°C	131 at 20°C
Crystal structure	Body centred cubic	Body centred cubic

Table 1 Selected properties of niobium and tantalum.

The columbite-tantalite mineral group (Figure 1) is the most common group of tantalum- and niobium-bearing minerals. Wodginite is also an important source of tantalum. The pyrochlore group (Figure 2) is of great economic importance, particularly for niobium. This group has a wide compositional range, including some species rich in both niobium and tantalum. Pyrochlore is typically found as a primary mineral in alkaline igneous rocks.

Figure 1 Dark coloured tantalite with pale coloured albite[1].

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[1] Image taken by Rob Lavinsky. Permission to use given by a creative commons license (accessed 25/03/2011 at www.commons.wikimedia.org). Attribution: Rob Lavinsky, iRocks.com (http://www.irocks.com/) – CC-BY-SA-3.0.

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