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# Appendix 1

## The Rare Earth Resources of Europe and Greenland: Mining Potential and Challenges

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### **A1.1. Table summarizing rare earth deposits listed in the paper written for this book**

The table below illustrates the rare earth minerals found in Europe and Greenland. The data presented here include the type of mineral deposit, its age, the main commodities presented and used there, potentially interesting additional commodities and known or inferred reserves/resources as well as bibliographical references.

Name of the deposit/locality	Country	Type of deposit	Age	Main commodities	Other commodities	Known/inferred reserves/resources	References
Afrikanda	Russia	Ultrabasic-carbonatite complex	Upper Devonian	Fe, Ti, REE	–	34 Mt @ 0.67% REO	(Kalashnikov et al. 2016)
Aghios Ioannis	Greece	Laterite–Bauxite	Upper Jurassic	Al	REE	–	(Maksimović and Pantó 1996)
Alnö	Sweden	Alkaline complex	Neoproterozoic/Ediacaran	REE, Nb, Zr	–	–	(Andersen 1996)
Aksu Dıamas	Turkey	Paleoplacer	Quaternary/Pleistocene	REE, Zr, Ri	–	454 Mt @ 0.07 Mt REO	(EURARE 2017)
Arran	United Kingdom (Scotland)	Felsic plutonism	Palaeogene/Palaeocene	REE	–	–	(Hyslop et al. 1999)
Araxa	Brazil	Carbonatite laterite	Upper Cretaceous	P, Nb	REE	28.3 Mt @ 4.21 Mt REO	(Itafos)
Ardennes	Belgium	Authigenic/placers	Ordovician, Silurian?	REE	–	–	(Burnotte et al. 1989)
Atalandi (Atalanti)	Greece	Laterite–Bauxite	Upper Jurassic	Al	REE	–	(Bárdossy et al. 1976)
Attu	Greenland (Denmark)	Pegmatite	Palaeoproterozoic/Statherian	REE	–	–	(GEUS 2014)
Bailleul	France	Paleoplacer	Lower Ordovician	Ti, Zr, REE	Th	3.5Mt @ 0.45% REO	(Lemarchand 1970)
Bastnäs	Sweden	Skarn	Palaeoproterozoic/Orosirian	Fe, Cu, REE	–	–	(Holtstam 2004)
Bayan Obo	China	Carbonatite	Mesoproterozoic/Ectasian-Calymnian	REE, Nb, Fe	–	118 Mt @ 6% REO	(Verplanck et al. 2016)
Ben Loyal	United Kingdom (Scotland)	Alkaline granite	Silurian/Wenlockian	–	–	–	(Walters et al. 2012)

Name of the deposit/locality	Country	Type of deposit	Age	Main commodities	Other commodities	Known/inferred reserves/resources	References
Biggejav'ri	Norway	Hydrothermal-metasomatic	Lower Palaeoproterozoic	Sc	U, REE	0.05 Mt @ 0.2% REO	(Olerud 1988)
Browns Range	Australia	Hydrothermal vein	Palaeoproterozoic/Statherian	REE	–	9.26 Mt @ 0.67% REO	(Nazari-Dehkordi et al. 2018)
Brtná	Czech Republic	Paleoplacer	Ordovician	Ti, Zr, Th, REE	–	–	(Goliás 2001)
Buckton	Canada	Authigenic/shales	–	Ni-U-Zn-Cu-Co	REE	4544 Mt @ 0.02% REO	(Weng et al. 2015)
Central Wales	United Kingdom (Wales)	Authigenic/placers	Silurian/Pridoli	REE	–	–	(Evans and Zalasiewicz 1996)
Cnoc nan Cuilean	Scotland	Alkaline granite	Silurian/Wenlockian	–	–	–	(Walters et al. 2012)
Cuxhaven	Germany	Beach placer	Quaternary	REE, Ti, Zr	–	–	(Hedrick 1985)
Dalucao	China	Carbonatite	Neogene/Miocene	REE	–	0.76 Mt @ 5% REO	(Weng et al. 2015)
Delitzsch (Storkwitz)	Germany	Carbonatite	Upper Cretaceous	REE	–	4.5 Mt @ 0.45% REO	(Krüger et al. 2013)
Evje-Iveland	Norway	NYF-type pegmatite	Neoproterozoic/Tonian	Ta, Nb, REE	–	–	(Müller et al. 2018)
Fen-Søve	Norway	Alkaline-carbonatite complex	Neoproterozoic/Ediacaran	REE, Nb, Fe	–	83.7 Mt @ 1.08% REO	(Dietzel et al. 2019)
Froland-Gloserheia	Norway	NYF-type pegmatite	Neoproterozoic/Tonian	Ta, Nb, REE	–	4 Mt @ 0.02% REO	(EURARE 2017)

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Galiñeiro	Spain	Alkaline complex	Lower Ordovician	REE, Th	–	–	(Montero et al. 2009)
Gardiner	Greenland (Denmark)	Ultramafic to differentiated alkaline complex	Palaeogene/Eocene	REE	–	–	(Campbell et al. 1997)
Glamsland	Norway	NYF-type pegmatite	Neoproterozoic/Tonian	Ta, Nb, REE	–	–	(Müller et al. 2018)
Grebnik	Kosovo	Laterite–Bauxite	Upper Cretaceous	Al	REE	–	(Bárdossy et al. 1976)
Grønødal-Ika	Greenland (Denmark)	Alkaline complex	Mesoproterozoic/Ectasian	REE	–	–	(Sørensen and Kalvig 2011)
Hanstholm	Denmark	Beach placer	Quaternary	REE, Zr, Ti	–	–	(Orris and Grauch 2002)
Honkilehto	Finland	Hydrothermal-metasomatic	–	REE, Co, U	–	–	(Sarapää et al. 2013)
Iivaara	Finland	Alkaline complex	Upper Devonian	P	REE	–	(Sarapää et al. 2013)
Isle of Skye	United Kingdom (Scotland)	Granite	Palaeogene/Palaeocene–Eocene	REE	–	–	(Exley 1980)
Kaiserstuhl	Germany	Alkaline-carbonatite complex	Neogene/Miocene	Nb, Ta, REE	Th, U	–	(Walter et al. 2018)
Kap Parral	Greenland (Denmark)	Alkaline complex	Palaeogene	Nb, REE	–	–	(Nielsen 2002)
Kap Simpson (Bjørnedal-Trail)	Greenland (Denmark)	Alkaline complex	Palaeogene	Nb, REE	Pb, Zn, Mo	–	(Stembera 2012)

Name of the deposit/locality	Country	Type of deposit	Age	Main commodities	Other commodities	Known/inferred reserves/resources	References
Katajakangas	Finland	Meta-alkaline granite	Palaeoproterozoic/Orosirian	Nb, Zr, Ti	REE, Th, U	0.46 Mt @ 2.71% REO	(Hugg 1985)
Kerala	India	Beach placer	Quaternary	Ti, Zr, REE	Grenats	118 Mt @ 0.09% REO	(Orris and Grauch 2002)
Khibiny (total)	Russia	Alkaline complex	Upper Devonian	P	Sr, REE	3200 Mt @ 0.36% REO	(Kalashnikov et al. 2016)
Kiruna	Sweden	IOA	Palaeoproterozoic/Orosirian	Fe, P	REE	2000 Mt @ 0.5% REO	(EURARE 2017)
Kiruna-Malmberget	Sweden	Mining residue	Quaternary/Anthropocene	P, REE	–	5.6 Mt apatite @ 0.5% REO	(Bru et al. 2015)
Koashva	Russia	Alkaline complex	Upper Devonian	P	Sr, REE	634 Mt @ 0.41% REO	(Kalashnikov et al. 2016)
Kodal	Norway	Ultramafic alkaline complex	Permian/Cisuralian	P, Ti, Fe	REE	49 Mt @ 0.12% REO	(Ihlen et al. 2001)
Kontioaho	Finland	Meta-alkaline granite	Palaeoproterozoic/Orosirian	Nb, Zr, Ti	REE, Th, U	4 Mt @ 0.7% REO	(Kärenlampi et al. 2020)
Korsnäs	Finland	Carbonatite	Palaeoproterozoic/Orosirian	Pb	REE	0.87 Mt @ 0.96% REO	(Tasman Metals Ltd. 2010)
Kortejärvi	Finland	Carbonatite	Lower Palaeoproterozoic	REE	–	–	(Al-Ani et al. 2011)
Kovdor	Russia	Ultrabasic-carbonatite alkaline complex	Upper Devonian	Fe, Zr, P	REE, Sc	500 Mt @ 0.001 to 0.09% REO	(Korsakova et al. 2012)
Kringlerne	Greenland (Denmark)	Alkaline complex	Mesoproterozoic/Stenian	Ta, Nb, REE, Zr	–	4300 Mt @ 0.65% REO	(Sørensen and Kalvig 2011)

Name of the deposit/locality	Country	Type of deposit	Age	Main commodities	Other commodities	Known/inferred reserves/resources	References
Kukisvumchorr	Russia	Alkaline complex	Upper Devonian	P	Sr, REE	415 Mt @ 0.25% REO	(Kalashnikov et al. 2016)
Kvanefjeld	Greenland (Denmark)	Alkaline complex	Mesoproterozoic/ Stenian	U, REE, Zn	–	673 Mt @ 1.09 Mt REO	(GME 2014)
La Monnerie	France	Alluvial placer	Quaternary	REE	–	0.08 Mt @ 0.08% REO	(Cornet and Sapinart 1967)
Laivajoki	Finland	Alkaline-carbonatite complex	Lower Palaeoproterozoic	REE	–	–	(Nykänen et al. 1997)
Langesundfjord-Larvik	Norway	NYF-type pegmatite	Permian/ Cisuralian	REE	Nb, Th	–	(Larsen 2010)
Lesnoe	Russia	Alkaline complex	Neoarchaeon	Zr	REE, Nb	1.51 Mt @ 0.22% REO	(Korsakova et al. 2012)
Loch Ailish	United Kingdom (Scotland)	Ultramafic alkaline complex	Silurian/ Llandoveryian	–	–	–	(Walters et al. 2012)
Loch Borralan	United Kingdom (Scotland)	Ultramafic alkaline complex	Silurian/ Wenlockian	–	–	–	(Walters et al. 2012)
Lofdal	Namibia	Alkaline-carbonatite complex	Neoproterozoic/ Tonian	REE	–	6.16 Mt @ 0.29% REO	(Zhou et al. 2017)
Longnan	China	Ionic clays	Quaternary	REE	–	48 Mt @ 0.1% REO	(Zhou et al. 2017)
Lovozero (total)	Russia	Alkaline complex	Upper Devonian	Nb	REE	1020 Mt @ 0.75% REO	(Kalashnikov et al. 2016)
Lužnice	Czech Republic	Alluvial placer	Quaternary	Ti, Zr, Th, REE, Nb	–	–	(Maòour et al. 1992)
Mäkärä-Vaulo	Finland	Ionic clays	–	Kaolin	REE	–	(Sarapää et al. 2013)

Name of the deposit/locality	Country	Type of deposit	Age	Main commodities	Other commodities	Known/inferred reserves/resources	References
Maoniuping	China	Alkaline-carbonatite complex	Palaeogene/Oligocene	REE, Pb, Ba, F	–	3.17 Mt @ 2.95% REO	(Verplanck et al. 2016)
Marmara	Greece	Laterite–Bauxite	Lower Cretaceous	Al	REE	–	(Maksimović and Pantó 1996)
Marmeiko	Greece	Laterite–Bauxite	Upper Jurassic	Al	REE	–	(Maksimović and Pantó 1996)
Maw	Canada	Hydrothermal-breccia	Mesoproterozoic/Calymanian	REE	–	0.46 Mt @ 0.21% Y <sub>2</sub> O <sub>3</sub>	(Rabiei et al. 2017)
Milne Land	Greenland (Denmark)	Palaeoplacer	Middle Jurassic	REE, Ti, Zr	–	5 Mt @ 0.5–1.9% REO	(Harpoth et al. 1986)
Misværdalen	Norway	Ultramafic alkaline complex	Silurian/Llandoveryian	P	REE	30 Mt @ 0.07% REO	(EURARE 2017)
Mont Parnasos	Greece	Laterite–Bauxite	Upper Jurassic	Al	REE	–	(Maksimović and Pantó 1996)
Monts Mourne	United Kingdom (Scotland)	Granite	Palaeogene/Eocene	REE	–	–	(Green et al. 2005)
Motzfeldt Sø	Greenland (Denmark)	Alkaline complex	Mesoproterozoic/Stenian	Th-U-Nb-Ta-Zr-REE	–	340 Mt @ 0.26% REO	(Ram Resources 2012)
Mount Weld	Australia	Carbonatite laterite	Cretaceous or Palaeogene	REE	–	23.9 @ 7.86 Mt REO	(Zhou et al. 2017)
Mountain Pass	USA	Carbonatite	Mesoproterozoic/Stenian–Ectasian	REE	–	16.7 Mt @ 7.98% REO	(Verplanck et al. 2016)
Nafpactos	Greece	Laterite–Bauxite	Upper Cretaceous	Al	REE	–	(Bárdossy et al. 1976)



Name of the deposit/locality	Country	Type of deposit	Age	Main commodities	Other commodities	Known/inferred reserves/resources	References
Nagyharsány (Villány)	Hungary	Laterite–Bauxite	Lower Cretaceous	Al	REE	–	(Bárdossy et al. 1976)
Nassuttutata tasia	Greenland (Denmark)	Pegmatite	Palaeoproterozoic/Statherian	REE	–	–	(GEUS 2014)
Nazda-Vlasenica	Bosnia-Herzegovina	Laterite–Bauxite	Lower Cretaceous	Al	REE	–	(Bárdossy et al. 1976)
Nea Peramos	Greece	Beach placer	Quaternary	REE	–	–	(Melfos and Voudouris 2012)
Niaqornakassak–NIAQ	Greenland (Denmark)	Metasomatic, carbonatite flow	Palaeoproterozoic/Orosirian	REE	Th	26.3 Mt @ 1.36% REO	(Mott et al. 2013)
Nyorkpakhk	Russia	Alkaline complex	Upper Devonian	P	Sr, REE	58 Mt @ 0.37% REO	(Kalashnikov et al. 2016)
Nisi (Nissi)	Greece	Laterite–Bauxite	Upper Jurassic	Al	REE	–	(Maksimović and Pantó 1996)
Nordre Isortoq	Greenland (Denmark)	Pegmatite	Palaeoproterozoic/Statherian	REE	–	–	(GEUS 2014)
Norra Kärr	Sweden	Alkaline complex	Mesoproterozoic/Calymnian	REE, Zr	–	58.1 Mt @ 0.59% REO	(EURARE 2017)
Oleny Ruchey	Russia	Alkaline complex	Upper Devonian	P	Sr, REE	325 Mt @ 0.38% REO	(Kalashnikov et al. 2016)
Olserum	Sweden	Hydrothermal vein and metasomatic	Palaeoproterozoic/Statherian	REE	–	7.8 Mt @ 0.62% REO	(Tasman Metals Ltd. 2013)
Olympic Dam	Australia	IOCG	Mesoproterozoic/Calymnian	Cu, U, Au, Ag	REE	9576 Mt @ 0.55% REO	(Weng et al. 2015)

Name of the deposit/locality	Country	Type of deposit	Age	Main commodities	Other commodities	Known/inferred reserves/resources	References
Pålång	Sweden	Phosphorite	Paleoproterozoic/ Rhyacian	P, U	REE	6 Mt	(Gustafsson 1979)
Palkiskuru-Palovaara	Finland	Hydrothermal-metasomatic or carbonatite	Unknown	REE, Th, U	–	–	(Sarapää et al. 2013)
Panormos (Skopelos)	Greece	Laterite–Bauxite	Lower Jurassic	Al	REE	–	(Bárdossy et al. 1976)
Partomchorr	Russia	Alkaline complex	Upper Devonian	P	Sr, REE	748 Mt @ 0.2% REO	(Kalashnikov et al. 2016)
Pennines	United Kingdom (England)	Hydrothermal vein	Permian/Cisuralian	Pb, Zn, F, Ba	REE	–	(Kraemer et al. 2019)
Pointe de l'Espiguette	France	Beach placer	Quaternary	REE, Zr	–	–	(Vazquez-Lopez and Jézéquel 2002)
Pretul	Austria	Hydrothermal vein	Upper Cretaceous	–	–	–	(Bernhard et al. 1998)
Pylos	Greece	Laterite–Bauxite	Palaeogene/Eocene	Al	REE	–	(Bárdossy et al. 1976)
Qaqarssuk (Qeqertaasq)	Greenland (Denmark)	Carbonatite	Middle Jurassic	Nb, REE, P	–	–	(Stendal 2014)
Qassarsuk	Greenland (Denmark)	Alkaline-carbonatite complex	Mesoproterozoic/ Stenian–Ectasian	REE	–	–	(Sørensen and Kalvig 2011)
Rasvumchorr	Russia	Alkaline complex	Upper Devonian	P	Sr, REE	340 Mt @ 0.35% REO	(Kalashnikov et al. 2016)
Ría Vigo	Spain	Beach-alluvial placer	Quaternary	REE	–	–	(Prego et al. 2012)

Name of the deposit/locality	Country	Type of deposit	Age	Main commodities	Other commodities	Known/inferred reserves/resources	References
Richards Bay	South Africa	Beach placer	Quaternary/Holocene	Fe, Zr, ti	REE	4980 Mt @ 0.01% REO	(Zhou et al. 2017)
Sæteråsen	Norway	Alkaline volcanism-differentiated	Permian/Cisuralian	Zr, Nb, REE	–	8 Mt @ 0.53% REO	(EURARE 2017)
Sakharjok	Russia	Alkaline complex	Neoarchaean	Zr	REE, Nb	35.8 Mt @ 0.16% REO	(Korsakova et al. 2012)
St Kilda	United Kingdom (Scotland)	Granite	Palaeogene/Eocene	REE	–	–	(Harding et al. 1982)
San Giovanni Rotondo	Italy	Laterite-Bauxite	Upper Cretaceous	Al	REE	–	(Bárdossy and Pantó 1973)
Sarfartog	Greenland (Denmark)	Carbonatite	Neoproterozoic/Ediacarian	P, Nb, Ta, REE	–	8.3Mt @ 1.72% REO	(Druecker and Simpson 2012)
Siilinjärvi	Finland	Alkaline-carbonatite complex	Neoarchaean	P	REE	200 Mt @ 0.06% REO	(Decrée et al. 2020)
Singertåt	Greenland (Denmark)	Alkaline-carbonatite complex	Neoarchaean	Sr, REE	–	–	(Blichert-Toft et al. 1995)
Smerna	Greece	Laterite-Bauxite	Paleogene/Eocene	Al	REE	–	(Bárdossy et al. 1976)
Sokli	Finland	Alkaline-carbonatite complex	Upper Devonian	P	REE, Nb, Ta, Zr, U	–	(Sarpää et al. 2013)
Sørensen	Greenland (Denmark)	Alkaline complex	Mesoproterozoic/Stenian	U, REE, Zn	–	242 Mt @ 1.1 Mt REO	(GME 2014)
Steenkampskraal	South Africa	Hydrothermal vein	Mesoproterozoic/Stenian	REE	Cu	0.6 Mt @ 14.4% REO	(Weng et al. 2015)

Name of the deposit/locality	Country	Type of deposit	Age	Main commodities	Other commodities	Known/inferred reserves/resources	References
Stenis Arahovis	Greece	Laterite-Bauxite	Upper Jurassic	Al	REE	–	(Bárdossy et al. 1976)
Štitovo	Montenegro	Laterite-Bauxite	Upper Cretaceous	Al	REE	–	(Bárdossy et al. 1976)
Strange Lake	Canada	Alkaline complex	Mesoproterozoic/ Ectasian	REE, Zr, Nb	–	492 Mt @ 0.89% REO	(Weng et al. 2015)
Tåsjö	Sweden	Phosphorite	Cambrian–Ordovician	P, U	REE	75/150 Mt @ 0.13/0.28% REO	(Armands 1970)
Tikusaaq	Greenland (Denmark)	Carbonatite	Upper Jurassic	P, REE	–	0.2 Mt @ 1-5% REO	(Stendal 2014)
Timmarmiut	Greenland (Denmark)	Alkaline-carbonatite complex	Archaean	Sr, REE	–	–	(Steensgaard et al. 2010)
Třebíč	Czech Republic	NYF-type pegmatite	Carboniferous/ Mississippian	REE	–	–	(Škoda and Novák 2007)
Trimouns-Luzenac	France	Hydrothermal- metasomatic	Lower Cretaceous	Talc	REE	–	(Močlo et al. 1974)
Tupertalik	Greenland (Denmark)	Carbonatite	Mesoarchaean	Sr, Zr, REE	–	–	(Larsen et al. 1983)
Umiammakku Nunnaa–UMIA	Greenland (Denmark)	Hydrothermal- metasomatic	Palaeoproterozoic/ Orosirian	REE	Th	–	(Mott et al. 2013)
Uuniniemi	Finland	Hydrothermal- metasomatic		P, REE, Nb	–	–	(Sarapää et al. 2011)
Virtasalmi	Finland	Ionic clays	Mesoproterozoic/ Stenian	Kaolin	REE	–	(Sarapää et al. 2011)
Weishan	China	Alkaline-carbonatite complex	Lower Cretaceous	REE, F	–	0.19 @ 4.61% REO	(Jia and Liu 2020)

Name of the deposit/locality	Country	Type of deposit	Age	Main commodities	Other commodities	Known/inferred reserves/resources	References
Ytterby	Sweden	NYF-type pegmatite	–	–	–	–	(Romer and Smeds 1994)
Yukspor	Russia	Alkaline complex	Upper Devonian	P	Sr, REE	540 Mt @ 0.39% REO	(Kalashnikov et al. 2016)
Zagrad	Montenegro	Laterite–Bauxite	Upper Cretaceous	Al	REE	–	(Bárdossy et al. 1976)
Zone 3	Greenland (Denmark)	Alkaline complex	Mesoproterozoic/Stenian	U, REE, Zn	–	95 Mt @ 1.16 Mt REO	(GME 2014)