



## CHAPTER FOUR

# PRINCIPAL FEATURES OF RARE-EARTH-ELEMENT MINERAL SYSTEMS

### 4.1. WHAT IS A MINERAL SYSTEM?

In general, current schemes for the classification of ore deposits and most ore deposit models used in both exploration and resource assessment are largely empirical (Cox and Singer, 1986; Eckstrand et al., 1995). An alternative mineral-system approach to classify deposits conceptually is to focus on mineral deposits as a mineralising process and/or event. A mineral-system-based concept has some clear parallels with the petroleum systems approach which has proven to be a useful in oil and gas exploration. Such an approach provides a framework that is applicable at both basin and prospect scales and, unlike the empirical concept, can be used for frontier basins (Bradshaw et al., 1998).

A mineral system is generally defined by its constituent elements, which include:

1. sources of energy driving the system;
2. sources of fluids, metals, and ligands;
3. pathways along which melt or fluid move;
4. chemical and/or physical traps in proximity to pathways;
5. outflow zones for discharge of residual fluids (Wyborn et al., 1994; Knox-Robinson and Wyborn, 1997; Jaques et al., 2002); and
6. preservation.

The mineral-systems framework has been used to develop process based conceptual models of ore systems (e.g., Skirrow et al., 2009) and to create flexible probabilistic structures for conducting quantitative risk analysis in mineral exploration (Kreuzer et al., 2010). It has also been used to map essential ingredients of fertile mineral systems and conduct prospectivity analysis (e.g., Wyborn et al., 1994; Barnes et al., 1999). A similar approach was used to describe ore-forming processes in volcanic-associated massive sulphide deposits (Huston et al., 1997) and Archean lode-gold deposits (Phillips et al., 1996; Hagemann and Cassidy, 2000).

A classification of REE mineral deposits based on a general mineral-systems framework was discussed in [Chapter 3](#). In that chapter, a type example of a particular Australian deposit was discussed in detail. In this chapter we summarise principal features of significant REE-forming mineral systems.

In tables presented in this chapter the original concept of the mineral system has been expanded to include information about geological setting, age, relative timing of mineralisation, and preservation. The focus in [Chapter 3](#) was on type examples of Australian deposits, whereas in this chapter the description includes information from deposits outside Australia.

In compiling these tables, individual mineral systems have been grouped into larger categories represented by association types, such as those associated with the regolith ([Table 4.1](#)), heavy minerals ([Table 4.2](#)), alkaline rocks ([Table 4.3](#)), carbonatites ([Table 4.4](#)), pegmatites ([Table 4.5](#)), and skarns ([Table 4.6](#)). A separate table ([Table 4.7](#)) for REE-bearing iron-oxide breccia complexes is included because deposits of the type could be economically significant. A summary for phosphorites ([Table 4.8](#)) concludes the association types.

The genetic association of fluorapatite veins at the Nolans Bore deposit (NT) is at this point unknown. Such vein deposits can be formed from fluids generated by alkaline, carbonatite, and even pegmatitic melts, the mineral-system features of which are described in [Tables 4.3, 4.5, and 4.6](#).

**Table 4.1.** Mineral-system features of rare-earth-element deposits associated with the regolith (deposit types: residual REE related to carbonatite; residual scandium related to ultramafic-mafic igneous rocks).

#### Geological setting

- Carbonatite and associated alkaline complexes and metasomatic rocks (for setting see Table 4.4)
- Mafic-ultramafic igneous rocks (for scandium). Phanerozoic 'alpine'- and 'Alaskan'-type mafic-ultramafic igneous rocks
- Blanket-like layers draped over weathered surface of carbonatite
- Humid tropical climate with moderate to high rainfall

#### Source (melt/fluid, metal, energy)

##### Fluids

- Surficial and/or/shallow ground water

##### Metals and ligands

- REE-enriched carbonatite and/or associated alkalic and metasomatic rocks
- Fluorine, CO<sub>2</sub>, PO<sub>4</sub> and Cl sourced from carbonatite and/or associated alkalic rocks
- Scandium sourced from mafic/ultramafic igneous rocks

##### Energy

- Hydrostatic head for shallow ground water

#### Fluid pathway

- Aquifers, faults, joints, fractures, karstic cavities

#### Depositional processes (Trap)

##### Structural/mechanical

- Faults, fractures, joints, cavities
- Topographic lows associated with karstic terranes are favourable for eluvial accumulations of REE-bearing minerals; such terranes are not conducive for significant concentrations of secondary REE minerals
- In areas without karst development internal drainage and basin-type topography create favourable traps for eluvial accumulations

##### Chemical

- Dissolution of carbonates leaves REE-enriched residual material with minerals, such as apatite, magnetite, pyrochlore, ilmenite, rutile, and zircon (eluvial)
- Decalcification of perovskite
- Changes in the concentration of dissolved fluoride, carbonate, and phosphate ions are important for the formation of secondary REE-bearing carbonates and phosphates, such as monazite, xenotime, parisite, and churchite
- LREE-bearing minerals concentrate in the upper part of the regolith, whereas HREE and Y are more prominent in the deeper parts of the regolith

#### Age

- Mesozoic to Cenozoic

#### Relative timing of mineralisation

- Mineralisation post carbonatite and alkalic rocks, but generally synchronous with karst formation and related supergene processes

#### Preservation

- Preservation is important. In the east Yilgarn Craton, regional glaciation during the Permian scoured pre-existing regolith and superficial deposits (e.g., Ponton Creek carbonatite). Post-mineralisation topography determines the preservation of supergene zones (zone of low hills are eroded)
- Preservation of eluvial accumulation is controlled by the chemistry of surficial water (concentration of CO<sub>2</sub> and sulphate) and nature of internal drainage

#### References

Richardson and Birkett (1995b); Duncan and Willett (1990)

**Table 4.2.** Mineral-system features of rare-earth-element-bearing placers (deposit types: heavy-mineral sands: beach; high dune; offshore shallow marine; channel).

<p><b>Geological setting</b></p> <ul style="list-style-type: none"> <li>• Coastal regions with stable crustal margins</li> <li>• Lower shoreface/inner shelf area with low-energy conditions (for offshore shallow marine deposits)</li> <li>• Transverse dune sands (for dune sand-type deposits)</li> <li>• Braided river sand</li> </ul>
<p><b>Source (melt/fluid, metal, energy)</b></p> <p>Heavy minerals</p> <ul style="list-style-type: none"> <li>• REE-enriched minerals are derived from igneous and high-grade metamorphic rocks. For heavy minerals in dune sands the REE-bearing minerals are sourced from beach sands</li> </ul> <p>Energy</p> <ul style="list-style-type: none"> <li>• Wind, wave, fluvial</li> </ul>
<p><b>Fluid pathway</b></p> <p>Not significant</p>
<p><b>Depositional processes (Trap)</b></p> <p>Structural/mechanical</p> <ul style="list-style-type: none"> <li>• Topography of coastal region. 'J' curved shoreline preceding headlands, which trap heavy minerals (for beach sands)</li> <li>• Changes in wave and wind energy, sea-level changes</li> <li>• Transverse dune sand (dune-type)</li> <li>• Sorting of heavy minerals by wind action from previous heavy-mineral beach concentrations formed by wave action</li> <li>• For channel placer-type deposits: zones of changes in water flow in fluvial system. Sands bounded by clay-rich sediments (formed in quiet swamp environment)</li> </ul>
<p><b>Age</b></p> <ul style="list-style-type: none"> <li>• Miocene to Holocene, but generally Pleistocene to Holocene. Some as old as Eocene. Mesozoic for channel deposits</li> </ul>
<p><b>Relative timing of mineralisation</b></p> <ul style="list-style-type: none"> <li>• Sorting and upgrading in many cycles. Monazite initially trapped with zircon, rutile, and ilmenite, but sorted in subsequent cycles</li> <li>• In REE-bearing heavy minerals in dune sands, sorting of initial beach sands by wind</li> </ul>
<p><b>Preservation</b></p> <ul style="list-style-type: none"> <li>• Tectonically stable regions are important for preservation</li> </ul>
<p><b>References</b></p> <p>McKellar (1975); Wallis and Oakes (1990); Stitt (1999); Williams (1990); Roy (1999); Hou (2005)</p>

**Table 4.3.** Mineral-system features of rare-earth-element deposits associated with (per)alkaline rocks (deposit types: orthomagmatic; volcanic; hydrothermal (vein); metasomatic (albitite)).

#### Geological setting

- Cratonic, anorogenic setting with magma generation and intrusion possibly associated with crustal extension; intraplate
- Igneous complexes are often bimodal (basaltic and rhyolitic). In some cases, (per)alkaline magmas are spatially related to peraluminous magmas
- Shallow-level environment: ring complexes of intrusive and volcanic rocks along ring fractures

#### Source (melt/fluid, metal, energy)

##### Melt/fluids

- Source of the melt: fractional crystallisation of alkali basaltic magma formed from small degree of partial melting of the mantle
- Source of fluids for hydrothermal and metasomatic (albitite) deposits: melt

##### Metals and ligands

- The first-stage source of REE is mantle; partial melting of which produces a REE-bearing melt
- For magmatic deposits: the source melt is of (per)alkaline composition
- For hydrothermal and metasomatic deposits: the source melt is (per)alkaline
- Fluorine and CO<sub>2</sub> sourced from melt

##### Energy

- High-geothermal gradient
- Intrusive and intrusive-volcanic complexes

#### Fluid pathway

- For igneous complexes: major deep crustal (lithospheric?) structures. At shallow levels, complexes are controlled by ring fractures
- For fluids: structures within and in proximity to igneous complexes

#### Depositional processes (Trap)

##### Structural

- Faults and ring fractures within igneous complexes

##### Chemical

- Cooling of melt and crystal fractionation
- Reaction of residual fluids with the pre-crystallised zones of the complex
- For metasomatic and hydrothermal deposits: cooling, and changes in pH could be significant
- In some deposits, such as Lovozero (Russia), bituminous substances could have played some role in forming hydrothermal mineralisation within pegmatites

#### Age

- Any age from Proterozoic to Cenozoic. A large number are Proterozoic

#### Relative timing of mineralisation

- Mineralisation is generally associated with the final phase of a multiple-stage batholith
- In deeper level settings mineralisation associated with small satellite phases of the main pluton
- Metasomatic and hydrothermal mineralisation either late, or postdates, magmatic phase

#### Preservation

- Post-emplacement tectonic history is important to preserve shallow intrusive-volcanic ring complexes

#### References

Mungall (2007); Jaques et al (1985); Jaques (2008); Richardson and Birkett (1995c)

**Table 4.4.** Mineral-system features of rare-earth-element deposits associated with carbonatites (deposit types: orthomagmatic; hydrothermal (vein and replacement); metasomatic (skarn, fenite); regolith-related).

<p><b>Geological setting</b></p> <ul style="list-style-type: none"> <li>• Continental (anorogenic) rift zones. Some carbonatites are near plate margins (collisional as well as divergent)</li> <li>• Near margins of cratons</li> <li>• Carbonatitic complexes invariably occur in association with alkalic rocks</li> <li>• Spatially related to deep crustal (lithospheric?) structures controlling multiple intrusion events</li> <li>• Mineralisation in lava, flows, and plugs, cone sheets, dykes, and rare sills, but never in large homogeneous plutons</li> </ul>
<p><b>Source (melt/fluid, metal, energy)</b></p> <p>Melt/fluids</p> <ul style="list-style-type: none"> <li>• Source of the melt: partial melting of carbonate-rich peridotite mantle; partial melting of carbonate-rich eclogite in subducted oceanic crust; liquation (i.e., separation of metals) and segregation from CO<sub>2</sub>-rich alkaline melts in the crust; fractional crystallisation of alkali basaltic magma formed from small degree of partial melting of the mantle</li> <li>• Source of fluids for hydrothermal and metasomatic (skarn, fenite) deposits: carbonatitic melt</li> </ul> <p>Metals and ligands</p> <ul style="list-style-type: none"> <li>• The first-stage source of REE is mantle; partial melting of which produces a REE-bearing melt</li> <li>• For magmatic deposits: the source is carbonatitic melt. REE-bearing carbonatite deposits are strongly enriched in LREE</li> <li>• For hydrothermal and metasomatic deposits: the source is carbonatitic melt</li> <li>• For regolith-related deposits: the source is mineralised carbonatite</li> <li>• Fluorine and CO<sub>2</sub> sourced from melt</li> </ul> <p>Energy</p> <ul style="list-style-type: none"> <li>• High-geothermal gradient</li> <li>• Intrusive and intrusive-volcanic complexes</li> </ul>
<p><b>Fluid pathway</b></p> <ul style="list-style-type: none"> <li>• For igneous complexes: major deep crustal (lithospheric?) structures. At shallow level complexes controlled by ring fractures</li> <li>• For fluids: structures within and in proximity to igneous complex</li> </ul>
<p><b>Depositional processes (Trap)</b></p> <p>Structural</p> <ul style="list-style-type: none"> <li>• Faults and fractures within igneous complexes</li> </ul> <p>Chemical</p> <ul style="list-style-type: none"> <li>• Cooling of melt and fractionation. REE-bearing minerals formed in the cumulates during the early stages of crystallisation of carbonatitic melt, or from the late residual melt enriched in F, Ba, Sr, U, and Th</li> <li>• Reaction of residual fluids with the pre-crystallised zones of the complex</li> <li>• For metasomatic and hydrothermal deposits: cooling, changes in the concentration of CO<sub>2</sub>, dissolved phosphorus and fluorine could be important</li> </ul>
<p><b>Age</b></p> <ul style="list-style-type: none"> <li>• Any age from Archean to Cenozoic. More abundant in Proterozoic, Mesozoic, and Cenozoic</li> </ul>
<p><b>Relative timing of mineralisation</b></p> <ul style="list-style-type: none"> <li>• Orthomagmatic REE mineralisation formed with cumulates in the early stages of crystallisation of carbonatitic melt and is tied up with minerals, such as perovskite, pyrochlore, apatite, and calcite. Main REE-mineralisation formed from the late residual melt enriched in REE, F, Ba, Sr, U, and Th. Mineralised ferrocarbonatites (dykes and veins) crosscut and replace early phases of carbonatite</li> <li>• Metasomatic and hydrothermal mineralisation either late, or postdates, magmatic phase</li> <li>• Carbonatite melts may be related to major extensional events (such as breakup of Rodinia)</li> </ul>
<p><b>Preservation</b></p> <ul style="list-style-type: none"> <li>• Post-emplacment tectonic history is important for preservation of shallow intrusive-volcanic ring complexes</li> </ul>
<p><b>References</b></p> <p>Mungall (2007); Jaques (2008); Richardson and Birkett (1995a)</p>

**Table 4.5.** Mineral-system features of rare-earth-element-bearing pegmatites (some REE-bearing apatite/fluorite veins may be related to pegmatite system).

<p><b>Geological setting</b></p> <ul style="list-style-type: none"> <li>• Late tectonic stages of compressive dynamo-metamorphic event in orogenic zones. Collisional environments: continent–continent collision, continent–island arc, island arc–island arc, closures of ensialic rift</li> <li>• Archean pegmatites in greenstone belts and mobilised sedimentary troughs</li> <li>• Proterozoic pegmatites in belts marginal to the Archean basement</li> <li>• Phanerozoic pegmatites within granite belts in orogens</li> <li>• Anorogenic related to long-lived rift systems</li> <li>• Structures formed during continuing compression and thickening after peak metamorphism</li> </ul>
<p><b>Source (melt/fluid, metal, energy)</b></p> <p>Pegmatitic melt/fluids</p> <ul style="list-style-type: none"> <li>• For NYC<sup>1</sup>-type: peraluminous to metaluminous (rarely (per)alkaline); A- and I-type felsic melts</li> <li>• For mixed NYC- and LCT<sup>1</sup>-types: subaluminous to peraluminous</li> <li>• Felsic melts are mildly fractionated. REE abundances show depletion in HREE</li> <li>• Source of felsic melts: for NYF-type: depleted middle to lower crustal granulites. For mixed pegmatites: either mixed protoliths, or melts formed from assimilation of supracrustal rocks by NYF-type granites</li> <li>• Fluids are sourced from the pegmatitic melt</li> </ul> <p>Metals and ligands</p> <ul style="list-style-type: none"> <li>• REE: pegmatitic melt and associated fluid. From breakdown of ferromagnesian minerals and accessory minerals, such as ilmenite, monazite, zircon, and titanite during melting of protolith</li> <li>• Ligands: pegmatitic melt and associated fluid</li> <li>• LCT-type: pegmatite with Li, Rb, Cs, Be, Sn, Ga, Ta &gt; Nb (B, P, F); NYF-type: pegmatite with Nb &gt; Ta, Ti, Y, Sc, REE, Zr, U, Th, F</li> </ul> <p>Energy</p> <ul style="list-style-type: none"> <li>• Compressive dynamo-metamorphism in orogenic zones;</li> <li>• Steep thermal gradients established after peak (Abukama-type) metamorphism</li> <li>• Felsic melts</li> </ul>
<p><b>Fluid pathway</b></p> <ul style="list-style-type: none"> <li>• Regional faults formed during continuing compression and thickening after peak metamorphism. Faults along boundaries of metamorphic zones</li> </ul>
<p><b>Depositional processes (Trap)</b></p> <p>Structural</p> <ul style="list-style-type: none"> <li>• Faults, folds for pegmatites</li> <li>• Fractures and cavities within pegmatites</li> </ul> <p>Chemical</p> <ul style="list-style-type: none"> <li>• Cooling and fractionation of pegmatitic melt</li> <li>• Cooling of pegmatitic fluid</li> </ul>
<p><b>Age</b></p> <ul style="list-style-type: none"> <li>• Any age</li> </ul>
<p><b>Relative timing of mineralisation</b></p> <ul style="list-style-type: none"> <li>• NYF-type mostly post-orogenic to anorogenic</li> <li>• Hydrothermal REE mineralisation late- and/or post-pegmatitic</li> </ul>
<p><b>Preservation</b></p> <ul style="list-style-type: none"> <li>• As pegmatites are formed at pressures (4 to 1.5 kbar) generally similar to the pressures at which the host rocks of upper-greenschist to lower-amphibolite facies metamorphism are formed, the pegmatites are generally well preserved</li> </ul>
<p><b>References</b></p> <p>Cerny (1991a); Cerny (1991b)</p>

<sup>1</sup> These types of pegmatites are defined in Tables 3.9 and 3.10.

**Table 4.6.** Mineral-system features of rare-earth-element deposits associated with skarn.

<p><b>Geological setting</b></p> <ul style="list-style-type: none"><li>• Orogens with metaluminous to peraluminous felsic rock intruding calcareous (meta)sedimentary rocks</li><li>• Skarn associated with alkaline and (per)alkaline rock (see Table 4.3 for general setting)</li><li>• Skarn associated with carbonatite complexes (see Table 4.4 for general setting)</li></ul>
<p><b>Source (melt/fluid, metal, energy)</b></p> <p>Fluids</p> <ul style="list-style-type: none"><li>• Alkaline, peralkaline, carbonatite melts</li><li>• For Mary Kathleen-style deposits multiple sources: metaluminous to peraluminous felsic melt and fluid generated during regional metamorphism</li></ul> <p>Metals and ligands</p> <ul style="list-style-type: none"><li>• Alkaline, peralkaline, carbonatite melts</li><li>• For Mary Kathleen-style deposits multiple sources which include felsic melts and (meta)sedimentary rocks</li></ul> <p>Energy</p> <ul style="list-style-type: none"><li>• High-geothermal gradient</li><li>• Intrusive and intrusive-volcanic complexes</li><li>• Regional metamorphism</li></ul>
<p><b>Fluid pathway</b></p> <ul style="list-style-type: none"><li>• Fault within and in proximity to igneous complex. For metamorphic fluids regional faults and other penetrative structures could be significant</li></ul>
<p><b>Depositional processes (Trap)</b></p> <p>Structural</p> <ul style="list-style-type: none"><li>• Faults and fractures within igneous complexes and calcareous (meta)sedimentary rocks</li></ul> <p>Chemical</p> <ul style="list-style-type: none"><li>• Cooling and changes in pH and locally redox state</li><li>• Changes in the concentration of ligands, such as carbonate, phosphate, chloride, and fluoride, could be important. This change caused by reaction with paragenetically early skarns</li></ul>
<p><b>Age</b></p> <ul style="list-style-type: none"><li>• Any age. The relative age is constrained by the age of the intrusive complexes</li></ul>
<p><b>Relative timing of mineralisation</b></p> <ul style="list-style-type: none"><li>• In skarn deposit, REE-bearing minerals either synchronous or post-date skarn</li><li>• In regions where skarn formation is followed by deformation and metamorphism, REE mineralisation can be remobilised</li><li>• Weathering and regolith-formation can also remobilise REE</li></ul>
<p><b>Preservation</b></p> <ul style="list-style-type: none"><li>• Post-emplacment tectonic history is important to preserve skarns formed with intrusive-volcanic complexes, such as carbonatite and (per)alkaline rocks</li></ul>
<p><b>References</b></p> <p>Oliver et al. (1999); Wu et al. (1996); Zhao et al. (2005)</p>

**Table 4.7.** Mineral-system features of rare-earth-element-bearing iron-oxide breccia complex.

**Geological setting**

- Pre-deposit: continental margin, extensional basin along margin
- Syn-deposit: 'far-field' back-arc or intracontinental setting
- Coeval mafic and high-temperature I- or A-type intrusive-volcanic complexes. In some regions, no or limited coeval volcanics
- Brecciation at high-crustal level; diatreme/maar volcanic setting; brecciation not prominent in a relatively deeper crustal setting

**Source (fluid, metal, energy)**

Fluids

- Fluid 1: magmatic; high temperature (~400°C), high-salinity (up to 40 to 50 wt% eq. NaCl) fluid (fluorine-rich)
- Fluid 2: evolved meteoric water; moderate temperature (150°C to 250°C) of low to moderate salinity; fluorine-rich, more oxidised than Fluid 1

Metals and ligands

- Copper: magmatic; A-type granites, mafic rocks
- Iron: magmatic; (meta)sedimentary rocks
- Gold: magmatic; A-type granites, mafic rocks
- Uranium: A-type granites, gneiss in basement
- REE: magmatic (granites, and alkaline, mafic, and ultramafic rocks)
- Ligands: magmatic; locally evaporite-bearing sequences

Energy

- High-geothermal gradient
- Intrusive-volcanic complex
- Hydrostatic head for oxidised fluid 2

**Fluid pathway**

- Crust-penetrating shear/fault zones separating crustal blocks or orogens
- District-scale fault networks reactivated during mineralisation event

**Depositional processes (Trap)**

Structural

- Faults, folds
- Diatreme/maar, breccia zones

Chemical

- Redox: mixing of fluids and/or reaction between reduced rocks and oxidised fluid
- Iron-rich host rocks

**Age**

- Any age, but Proterozoic more important for world-class deposits

**Relative timing of mineralisation**

- Related to a switch from compressional to extensional deformation
- Mineralisation closely linked with emplacement of intrusive-volcanic complexes and brecciation

**Preservation**

- Important for shallow-level breccia complexes. Rapid cratonisation during or before mineralisation and/or basin formation is over

**References**

Reeve et al. (1990); Reynolds (2001); Johnson and McCulloch (1995); Skirrow et al. (2007)

**Table 4.8.** Mineral-system features of rare-earth-element-bearing phosphorite.

<p><b>Geological setting</b></p> <ul style="list-style-type: none"><li>• Continental margin</li><li>• Continental shelves and shelf breaks. Atop submarine highs (seamounts and drowned carbonate build ups)</li><li>• Coastal subtidal, intertidal, and supratidal environments</li><li>• Basements highs over and around which phosphorites are deposited</li></ul>
<p><b>Source (fluid, metal, energy)</b></p> <p>Fluids</p> <ul style="list-style-type: none"><li>• Sea water</li></ul> <p>Metals and ligands</p> <ul style="list-style-type: none"><li>• Phosphorus: organic matter, bones and microbial mats. Locally run-off of rivers where phosphorus is adsorbed to iron hydroxides</li><li>• REE: the source unknown (possibly from REE-rich rocks, which also provide the sediments; bedrock of the basin?)</li></ul> <p>Energy</p> <ul style="list-style-type: none"><li>• Wave and currents provide upwelling of phosphorus-rich water</li></ul>
<p><b>Fluid pathway</b></p> <ul style="list-style-type: none"><li>• Continental shelf</li></ul>
<p><b>Depositional processes (Trap)</b></p> <p>Structural</p> <ul style="list-style-type: none"><li>• Shelf-breaks. Shelf topography conducive for mixing of shallow water with upwelling currents</li></ul> <p>Chemical</p> <ul style="list-style-type: none"><li>• Mixing of cold relatively deeper upwelling currents with warmer shallower water and loss of CO<sub>2</sub></li></ul>
<p><b>Age</b></p> <ul style="list-style-type: none"><li>• Favourable ages for phosphorite formation: Neoproterozoic, Cambrian, Permian, Late Cretaceous/Early Cenozoic, and Miocene</li></ul>
<p><b>Relative timing of mineralisation</b></p> <ul style="list-style-type: none"><li>• Timing of REE-minerals in phosphorites is not clear. Some may precipitate with sedimentary apatite. The possibility of enrichment during diagenesis can not be excluded</li></ul>
<p><b>Preservation</b></p> <ul style="list-style-type: none"><li>• Post-depositional tectonics and transgression and regression events important for preservation. Later transgression events may destroy REE-enriched phosphorite</li></ul>
<p><b>References</b></p> <p>Einsele (1992); Howard and Hough (1979)</p>