U3A Geology

Skarns

Introduction

- Skarns are calc-silicate rocks that form through contact or regional metamorphism or metasomatism from crystallising granite intrusion
- Skarns can form in almost any lithology (granite, shale, basalt) but, the majority are found through replacement of calcitic or dolomitic marble

There are two genetic classes:

(1) Reaction skarns – formed in response to increasing temperature with diffusion between contrasting rock types

(2) Metasomatic skarns (ore skarns) – formed through mass transport by hot saline evolving fluids, derived in part from a crystallising magma

Skarn definition

- Skarns defined by mineral assemblage → feature wide range of calc-silicate minerals usually dominated by garnet and pyroxene
- Mg and Ca skarns describe the dominant composition of the protolith that is commonly carbonate (limestone, dolomite)
- calc-silicate hornfels → describes fine-grained rocks formed from the metamorphism of impure carbonate units (marls)
- skarns can be classified according to rocks that they replace:

  Exoskarn – replacement of country rocks outside intrusion

  Endoskarn – refers to skarn mineralisation within intrusion

Classification of skarns

Skarns can be classified on the basis of descriptive features:

(1) protolith composition e.g. calcic skarns, magnesian skarns

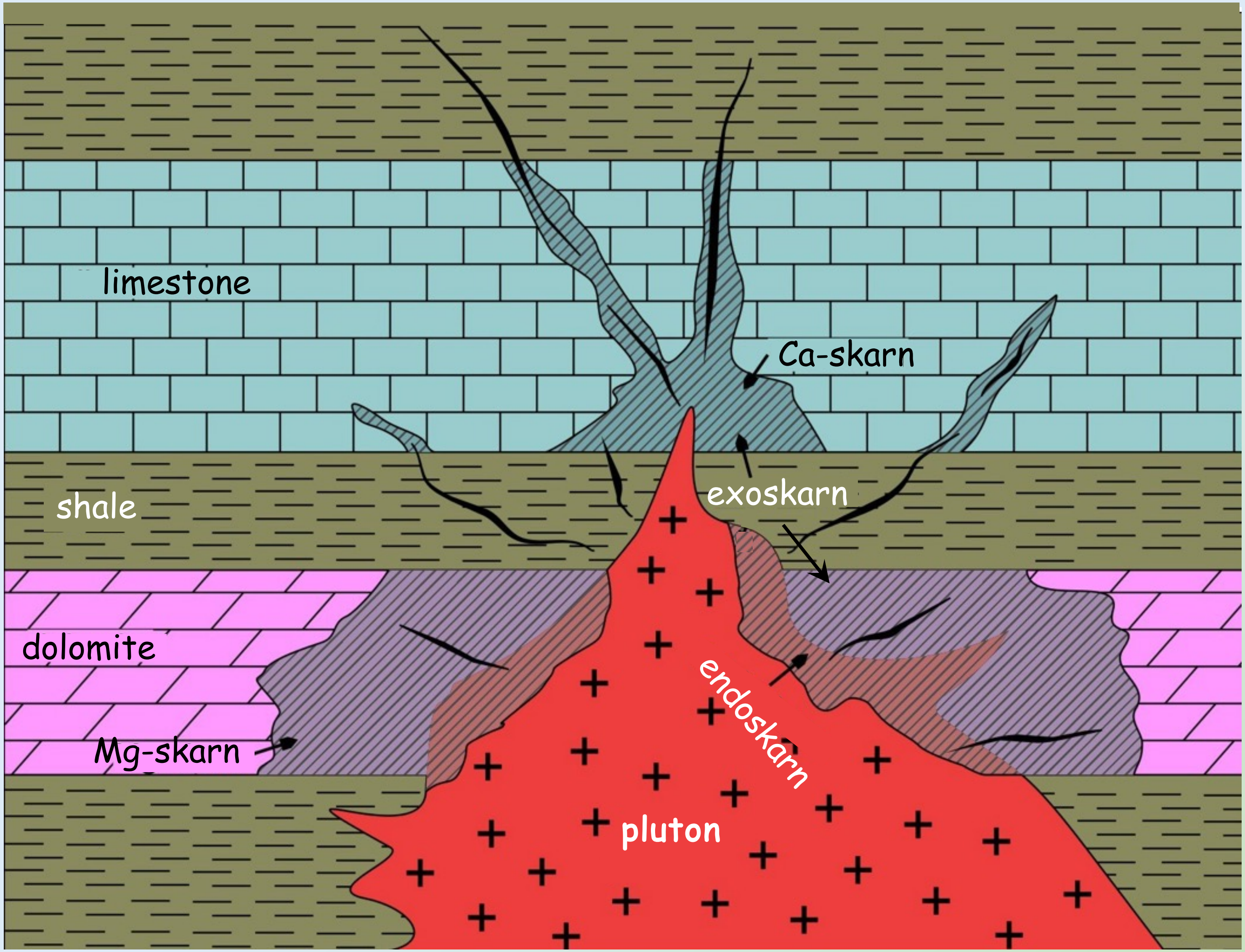
(2) rock type e.g. andradite-wollastonite skarn, diopside skarn

(3) dominant ore minerals present e.g. tungsten skarn, copper skarn, magnetite skarn

Skarn evolution

- Skarns are found adjacent to intrusions, along fractures and major shear zones, in shallow geothermal systems and deeply buried regional metamorphic terrains
- they can form during contact or regional metamorphism from a variety of metasomatic processes involving fluids of magmatic, metamorphic or meteoric origin
- in many skarns there is a transition from early formation of reaction skarn → later metasomatism → metasomatic skarn
- late metasomatism → produces coarse-grained, ore-bearing skarns
- complex metasomatic fluids containing magmatic components e.g. Fe, Si, Cu etc produce a continuum between purely metamorphic and purely metasomatic processes

Skarn evolution



Skarn mineral characteristics

Skarn mineral assemblages reflect the composition of the protolith and any added ionic species

Mineralogy

Calcic skarns: diopside, hedenbergite, grossular and andradite garnet, wollastonite, vesuvianite, calcite, amphiboles, epidote

Magnesian skarns: forsterite, humite, chondrodite, talc, tremolite, serpentine

Ores

Tungsten, iron, talc, copper, molybdenum, lead, zinc, tin (?)

Common skarn gangue minerals

Diopside ($CaMgSi_2O_6$)

Grossular garnet [$Ca_3Al_2(SiO_4)_3$]

Wollastonite ($CaSiO_3$) and vesuvianite [$Ca_{19}Fe(Mg,Al)_8(SiO_4)_{10}(Si_2O_7)_4(OH)_{10}$]

Common skarn gangue minerals

andradite garnet [$Ca_3Fe_2(SiO_4)_3$] with wollastonite and diopside

actinolite [$Ca_2(Mg,Fe)_5Si_8O_{22}(OH)_2$]

epidote [$Ca_2FeAl_2(Si_2O_7)(SiO_4)(O,OH)_2$]

forsterite (Mg_2SiO_4) in marble

Reaction skarn

- Reaction skarns form from contact or regional metamorphism
- heat from metamorphism can cause a chemical reaction between certain contrasting rock layers
- reaction skarns can form from isochemical metamorphism (i.e. no addition of elements to bulk composition)
- there is metasomatic transfer of components between adjacent lithologies on a small scale
- e.g. diffusion reaction $CaCO_3 + SiO_{2(aq)} \rightarrow CaSiO_3 + CO_2$

  calcite   wollastonite

Formation of reaction skarns

- Where thin adjacent beds of limestone and mudstone are contact metamorphosed → some elements diffuse across the boundary aided by pore water

- diffusion produces reaction skarn zonation between marble and hornfels

- the typical zonation is a wollastonite zone bordering the marble graduating into grossular garnet then diopside bordering the hornfels

Reaction skarn, King Island, Tas.

m = marble

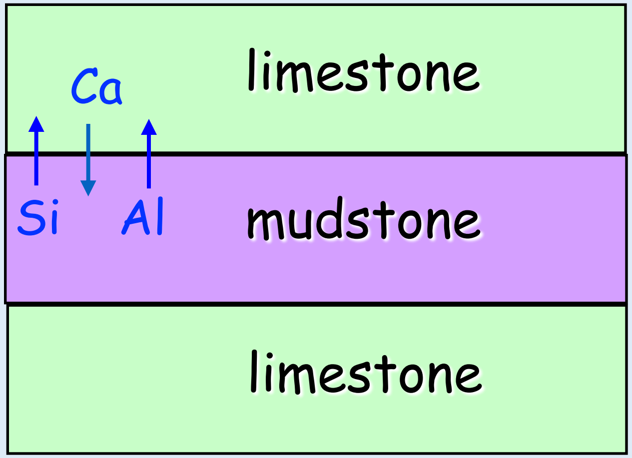
w = wollastonite

d = diopside

g = grossular garnet

h= hornfels

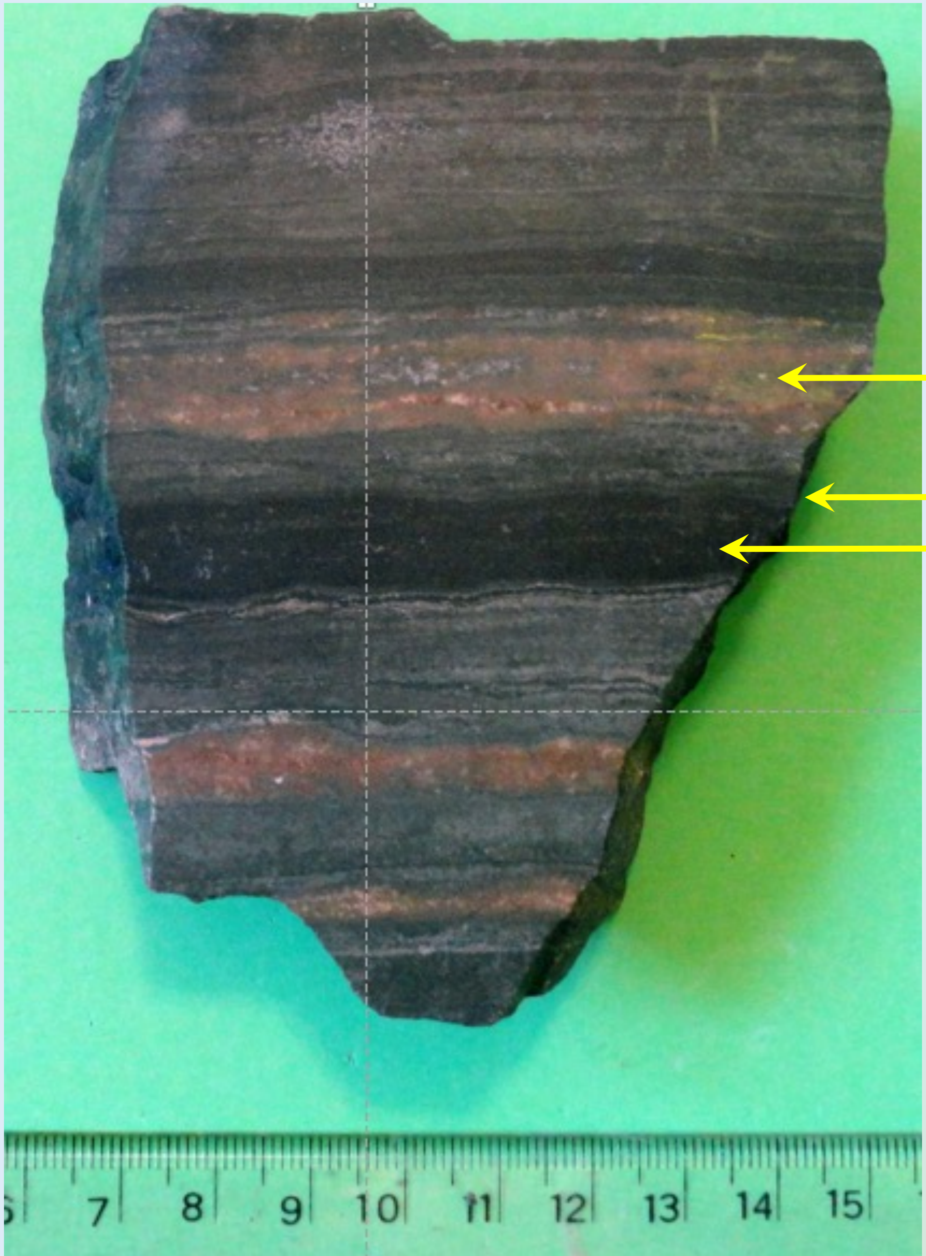
Formation of a reaction skarn



metamorphism

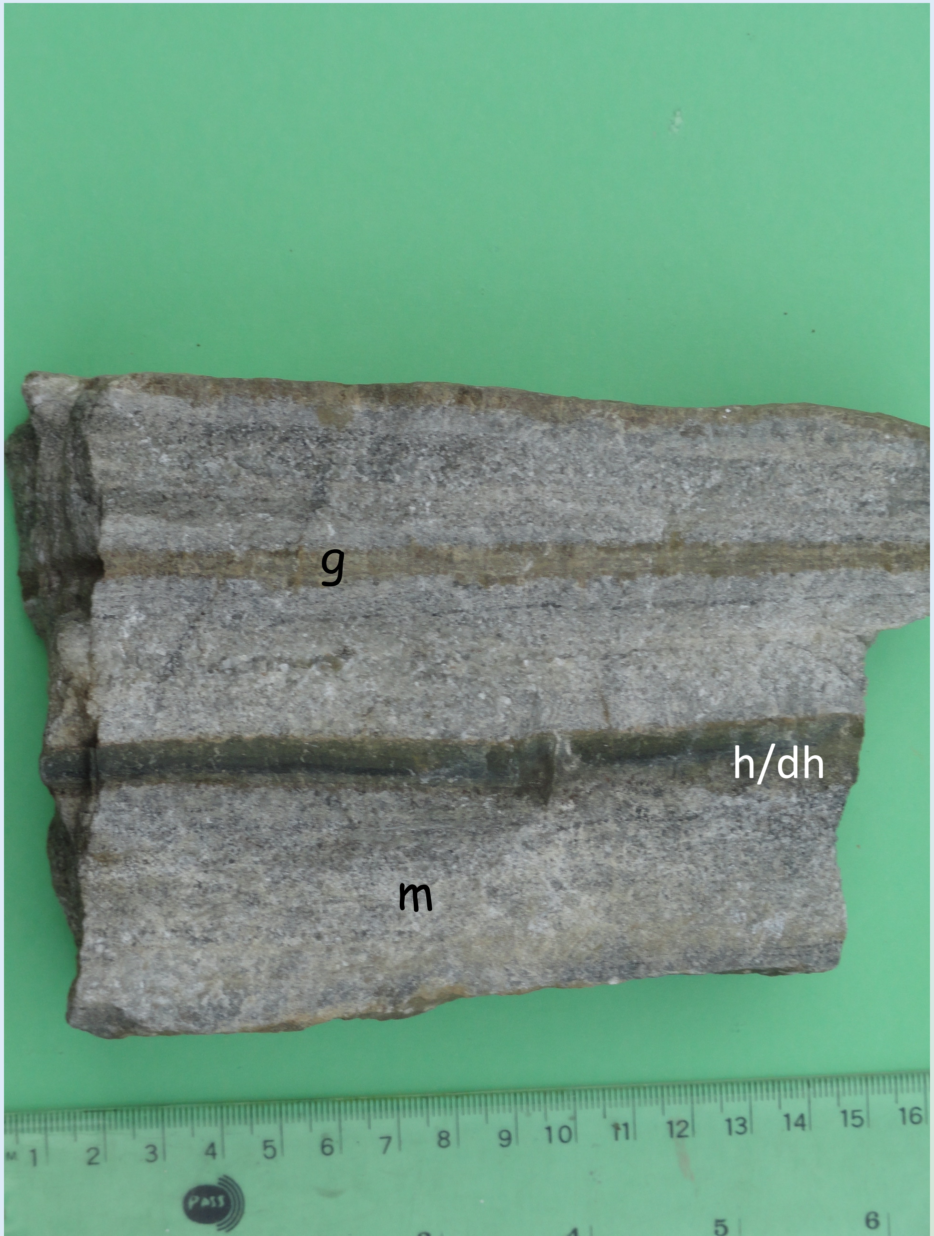
Zonation in skarns

AR1387 Zoned hornfels, King Island



AR1334 Diopside hornfels, King Is.

AR1393 Skarnised marble, King Is.

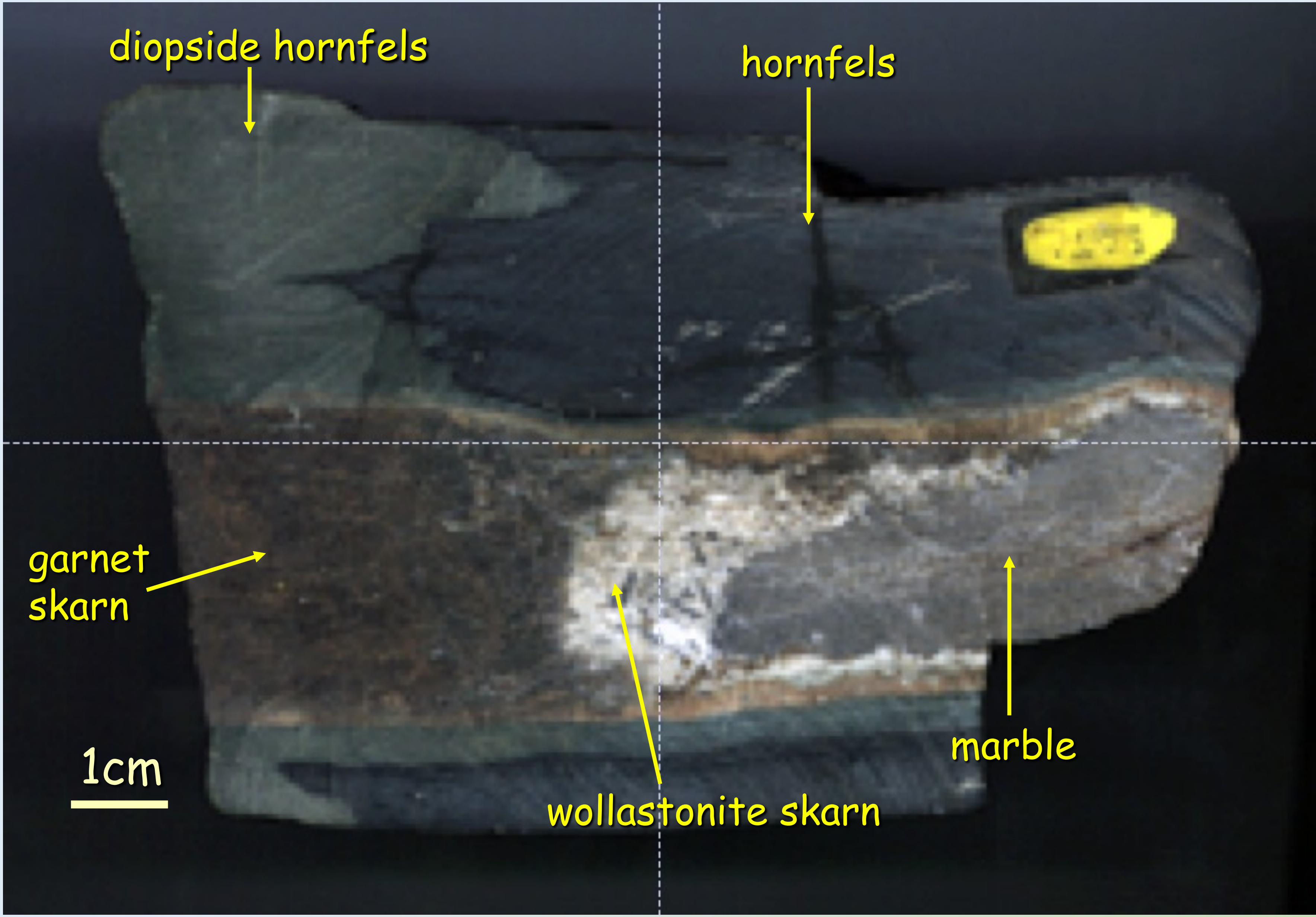


m = marble

g = grossular garnet

h/dh = hornfels/diopside hornfels

Skarn zonation



Effect of depth of formation of skarn

- A fundamental control on skarn size, geometry and alteration is the depth of formation
- ambient wallrock temperature at 2km depth would be 70°C, whereas at 12km → 420°C
- with added influx of heat produced by igneous activity → volume of rock is larger and longer lived than at shallower depths
- strong hydrofracturing associated with shallow intrusions greatly increases permeability of host rocks for metasomatic and later meteoric fluids
- retrograde alteration during cooling and possible reaction with meteoric water is more intense at shallower depths

Metasomatic skarn

- Metasomatic skarns form when hydrothermal fluids originating from magmatic, metamorphic or meteoric sources infuse ions into the skarn
- the resulting skarn may consist of a variety of different minerals
- composition of these minerals depend on the composition of the hydrothermal fluids and the original composition of the protolith
- magmatic metasomatic fluids may introduce metallic ion species into the primary skarn forming ore skarns

Geochemistry of skarn deposits

- Fluid inclusion studies have determined high temperatures (up to 700°C) and high salinities (up to 50% NaCl equivalent?)
- later fluids associated with ore mineralisation are (300-500°C)
- fluid inclusions commonly contain daughter minerals (NaCl, KCl, $CaCl_2$, $FeCl_2$, $CaCO_3$, CaF_2, Fe_2O_3 etc)
- magmatic fluids have KCl > $CaCl_2$ whereas high $CaCl_2$ indicates interaction more with sedimentary wall rocks
- most large scale skarn deposits form from diverse fluids. Later alteration indicates at least partial mixing with meteoric waters

Skarn genesis

Stages recognised in the evolution of skarn deposits:

1. Shallow intrusion into carbonate sediments (700 – 900°C)
2. Contact metamorphism (500 – 700°C) little or no chemical reaction between intrusion and limestone. Impurities in marble react to form minor calc-silicate minerals plus CO_2
3. Metasomatism and iron-rich skarn formation (400 – 600°C). Early magmatic fluids dominated by Fe-chloride complexes Ca-Fe silicates precipitating along with magnetite
4. Superposition of oxides and sulphides at (300 - 500°C). Scheelite and magnetite normally form prior to the formation of sulphides
5. Late hydrothermal stage (200 – 400°C). During this stage, skarn minerals may be intensely altered (influx of meteoric water) e.g. calcite, hematite, quartz, pyrite, epidote, chlorite, other sulphides, amphibole, serpentine ,

Major skarn minerals (non-ore)

Skarn mineral assemblages reflect the composition of the protolith and added ionic species

garnet – grossularite [$Ca_3Al_2(SiO_4)_3$], andradite [$Ca_3Fe_2(SiO_4)_3$]

pyroxene – diopside ($CaMgSi_2O_6$), hedenbergite ($CaFeSi_2O_6$)

olivine – forsterite (Mg_2SiO_4)

pyroxenoid – wollastonite ($CaSiO_3$)

amphibole – tremolite [$Ca_2Mg_5Si_8O_{22}(OH)_2$], ferroactinolite [$Ca_2Fe_5Si_8O_{22}(OH)_2$]

epidote – epidote [$Ca_2(Fe,Al)_3(SiO_4)_3(OH)$, allanite [$(Ca,REE)_2(Fe,Al)_3(SiO_4)_3(OH)$]

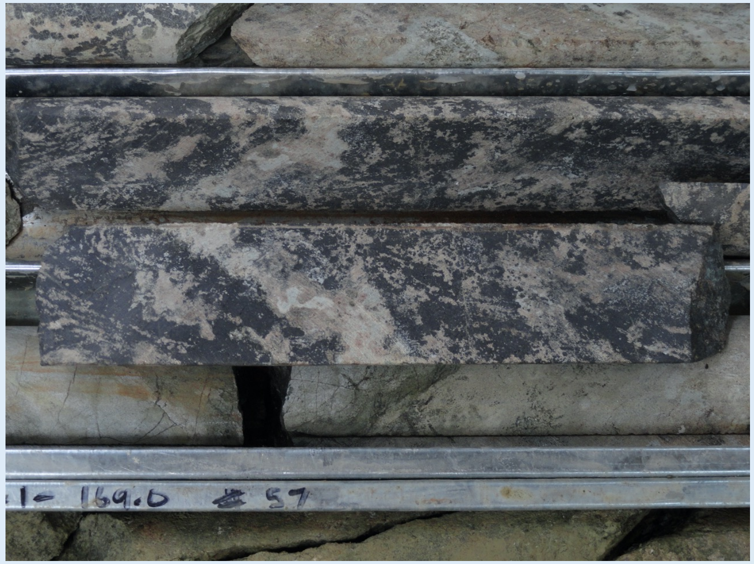
other – axinite [$(Ca,Mn,Fe,Mg)_3Al_2BSi_4O_{15}(OH)$],

vesuvianite [$Ca_{10}(Mg,Fe,Mn)_2Al_4Si_9O_{34}(OH, Cl, F)_4$]

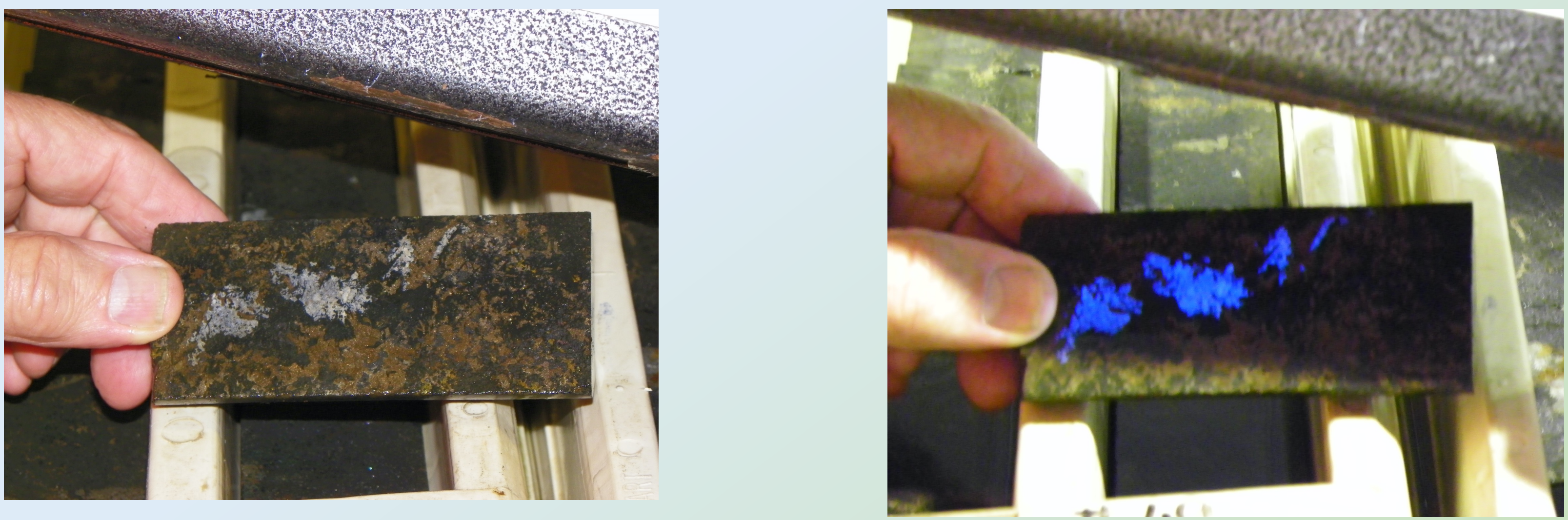
Ore skarn deposits

- The majority of skarns are devoid of economic mineralisation
- the majority of the world's economic skarn deposits occur in calcic exoskarns (replacement of limestone)
- Ores of W, Mo, talc, Cu, Au, Fe, Pb, Zn, and Sn (?) occur in skarns
- deposits are generally smaller than other deposit types but are important sources of W and Fe ores

Common ore minerals in ore skarns



Magnetite (Fe_3O_4) skarn, Kara, Tas.



Scheelite ($CaWO_4$) – magnetite skarn, Mt Lindsay, Tas

King Island scheelite deposits

- >14Mt of ore at 0.8% WO_3 and 0.3% MoO_3
- protoliths were carbonate and pelitic rocks of Late Proterozoic age
- high temperature (600 – 800°C) metasomatic, saline fluids
- orebodies stratabound 5-40m thick
- Skarn types:

  diopside-grossular garnet hornfels

  pyroxene-biotite-grossular garnet hornfels

  biotite-pyroxene-actinolite hornfels

  banded andradite skarn

  andradite-diopside-quartz-epidote-actinolite-zoisite skarn

- all skarn types are mineralised with scheelite ($CaWO_4$)

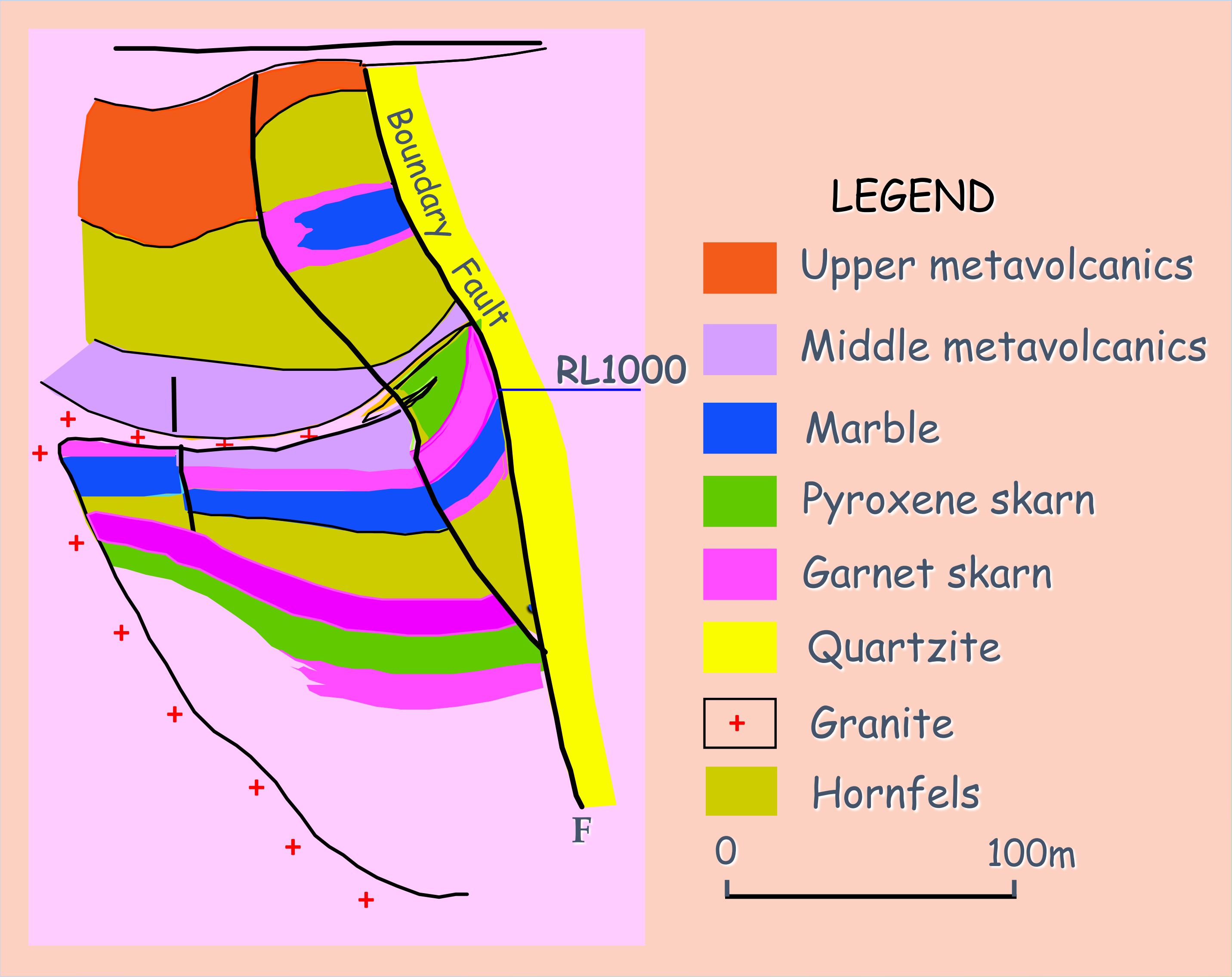
Geological setting, King Island

- Deposit located at Grassy on SE coast of King Island
- hosted by a (±200m thick) Neoproterozoic to Lower Cambrian unit of dolomite, shale and tillite overlying ~7000m thick Neoproterozoic pelitic sequence
- this sequence forms a narrow strip along coast and is overlain to SE by >250m of Cambrian basic lavas, tuffs and agglomerate
- further west → more intensely metamorphic sequence cut by Proterozoic granites
- whole sequence intruded by Late Devonian to Lower Carboniferous granites

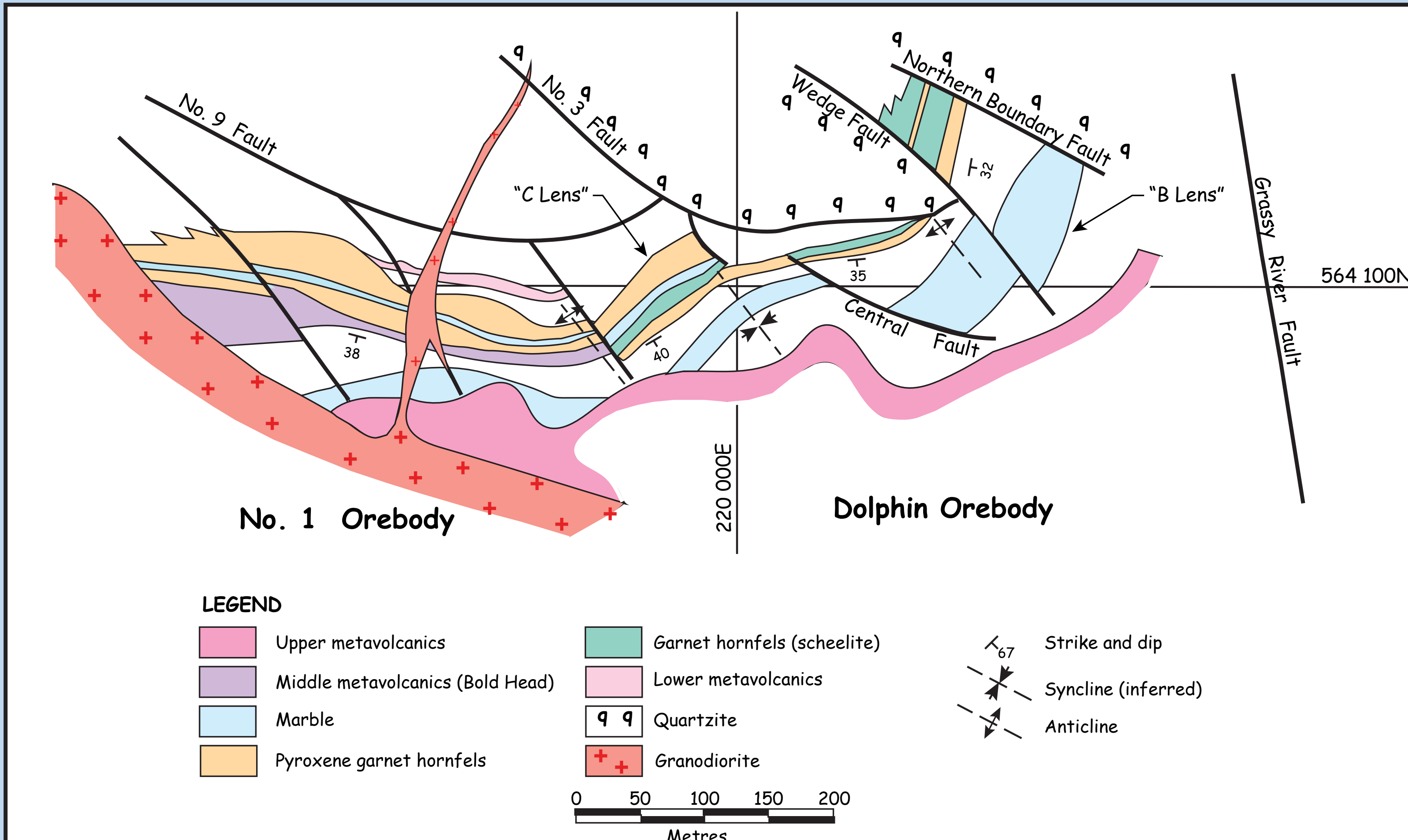
Mineralisation

- Mineralisation → occurs as series of pods and lenses in a skarn composed of actinolite-biotite and actinolite hornfels, marble, blotchy and banded diopside-grossularite hornfels and massive andradite skarn
- scheelite occurs as finely disseminated grains → highest grades associated with andradite garnet [($Ca_3Fe_2(SiO_4)_3$]
- grossular-rich lenses only carry low grades of scheelite
- majority of scheelite is powellite ($CaMoO_4$) rich

X-section 10525N, North Bold orebody, King Island (after Brown 1990)



No. 1 and Dolphin orebodies (Danielson & Brown 1976)



AR1386 andradite-diopside skarn, King Is.

Kara Fe-W skarn deposit

- Kara deposit → small open cut ~40km south of Burnie NW Tas.
- mine products magnetite (Fe_3O_4) and scheelite ($CaWO_4$)
- to north of deposit → a few magnetite skarns hosted by dolostone
- pit contains series of skarns related to Devonian Housetop Granite intruding Ordovician Gordon limestones
- a quartz-epidote endoskarn is developed in the granite contact zone

Skarn zonation, Kara

- The skarn is zoned, four stages recognised in the development of skarn:

(1) hedenbergite ± andradite ± vesuvianite ± wollastonite ± scheelite

(2) andradite-vesuvianite-magnetite ± scheelite ± apatite ± quartz

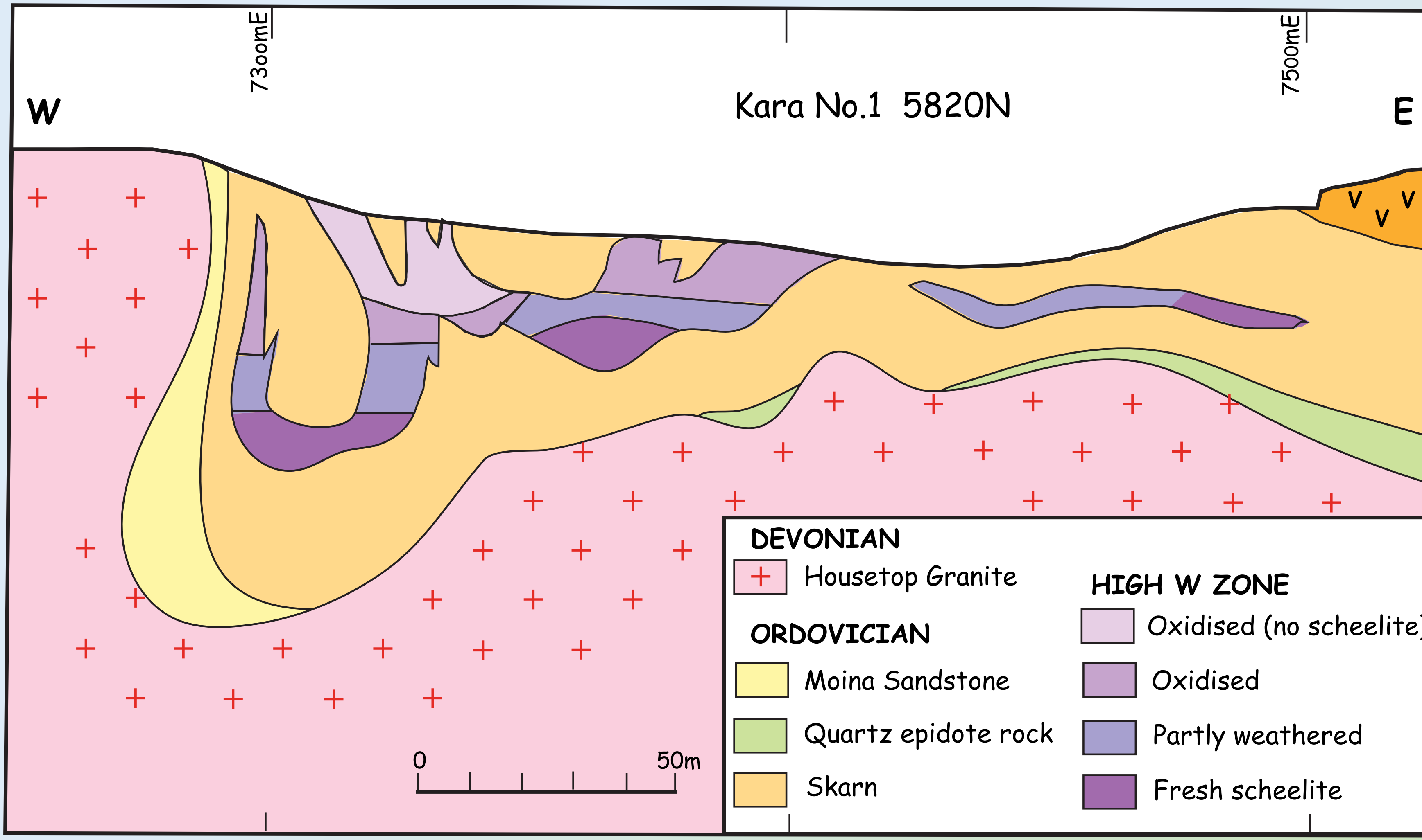
(3) magnetite-amphibole-epidote-fluorite-quartz ± scheelite ±
± carbonate ± pyrite ± cpx

(4) hematite ± calcite ± quartz

Kara skarn development

- Stages 1 and 2 mineral assemblages → early hydrous skarn formation dominated by hedenbergite and garnet
- Stages 3 and 4 minerals represent late skarn-forming phases and pervasively replace early mineral assemblages
- scheelite occurs in Stages 1-3 and is disseminated mostly in magnetite-rich skarn
- minor sulphides are present in skarns and include pyrite, molybdenite, chalcopyrite, arsenopyrite, bismuthinite (Bi_2S_3) and galena
- skarn weathering zones → produce some unusual secondary Fe, W and Cu minerals

X-section 5820N Kara NO.1



AR1265 Magnetite skarn, Kara, W. Tas.

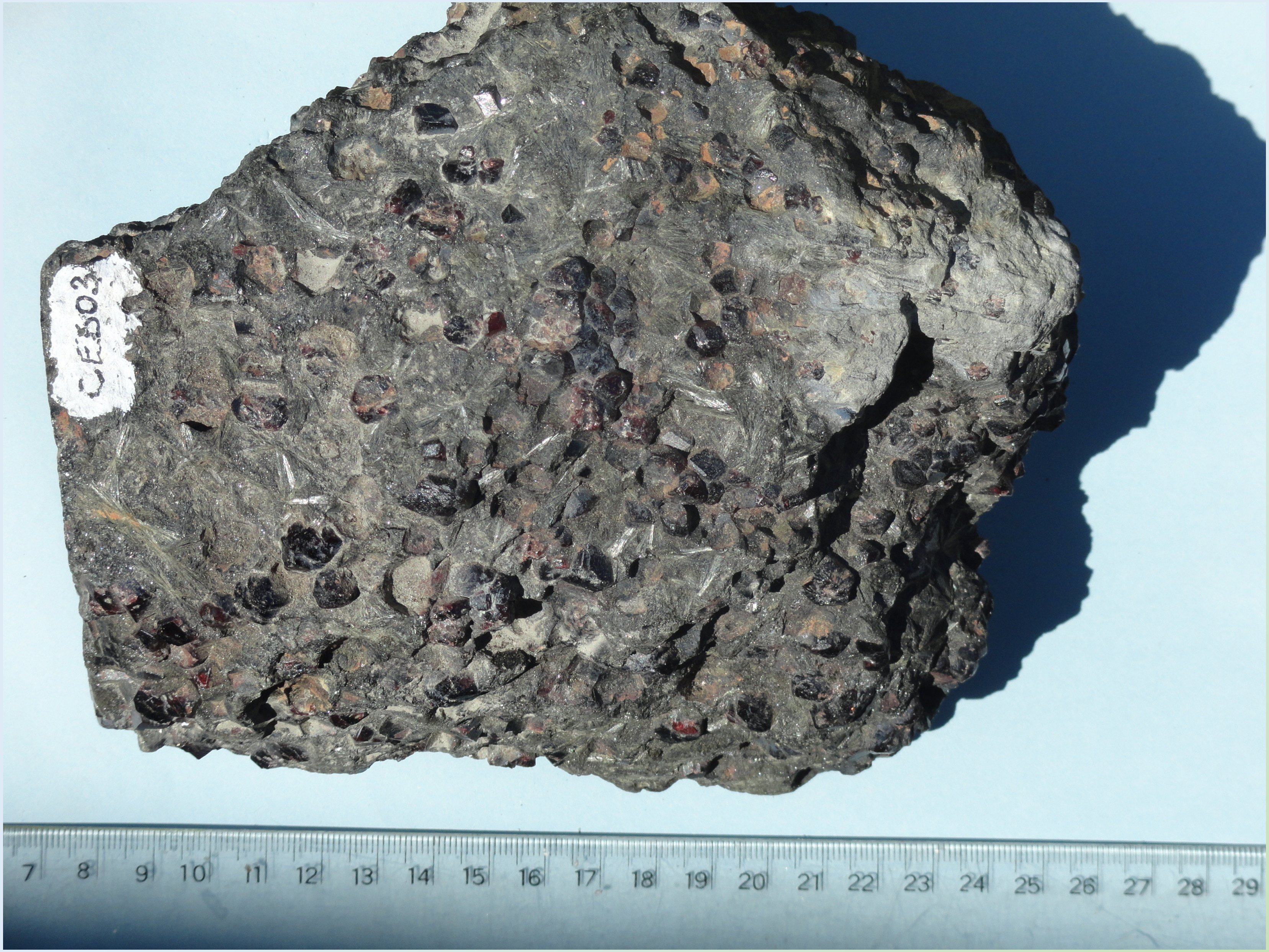
Fluid studies -Kara

- Filling temperatures of primary fluid inclusions show → systematic decrease from 460-620°C in Stage 1 to 230-360°C in Stage 3
- salinities vary from 8-12% NaCl equivalent in Stage 1 to 12-18% in Stage 2
- stable isotope data indicates magmatic hydrothermal fluids were responsible for Stage 1 and 2
- Stages 1 and 2 were succeeded by convective circulation of mixed magmatic hydrothermal fluids and heated groundwater

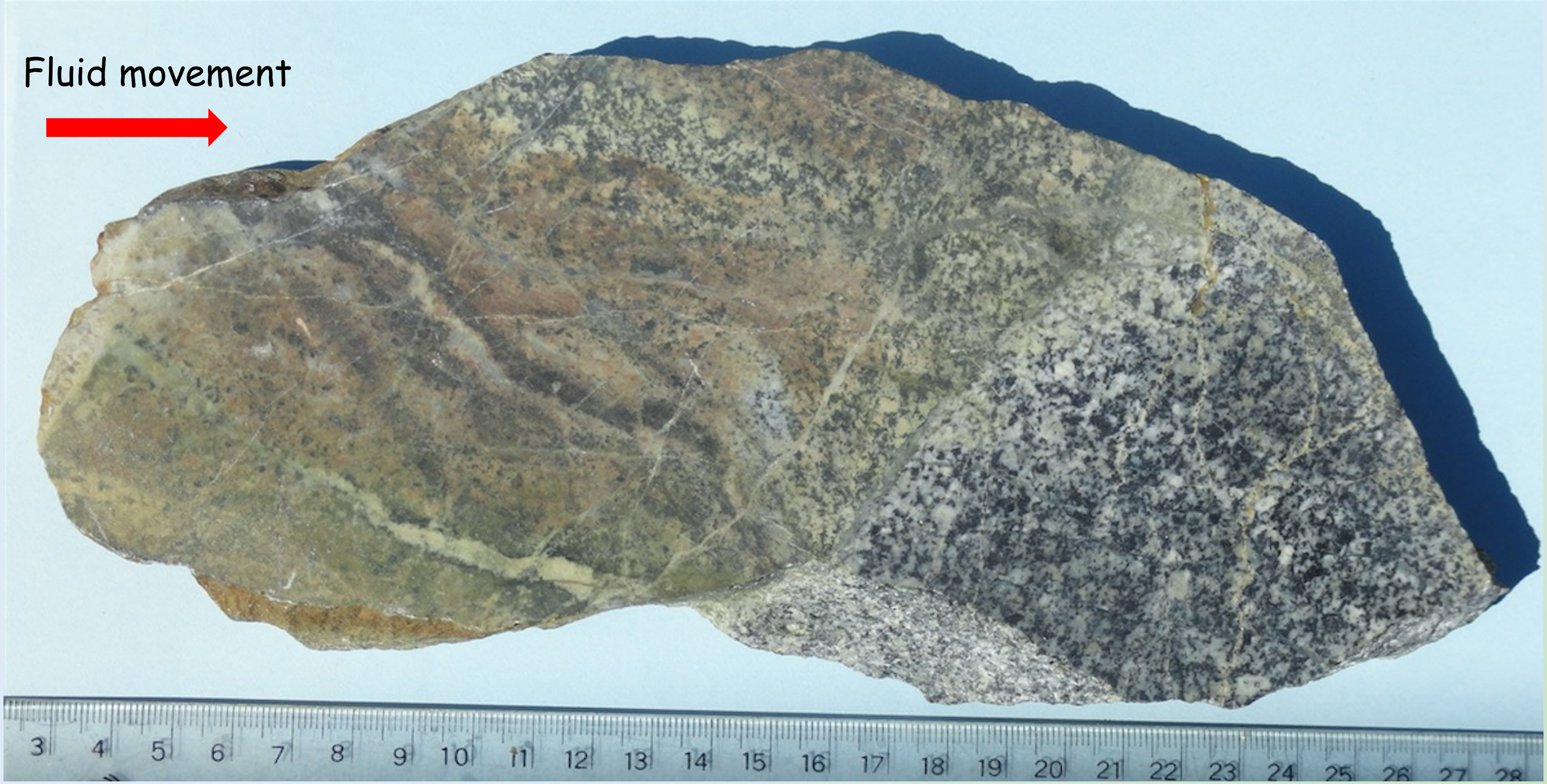
Brown's Creek Au-Cu skarn

- The Brown's Creek Au-Cu skarn deposit is located ~40km south of Orange, NSW
- the main skarn rock in the deposit is wollastonite marble, highly mineralised by metallic sulphides, native gold and tellurides
- related alteration included metasomatised Ordovician Blayney volcanics and marblised interbedded Cowigra limestone
- magmatic fluids were derived from Carcoar granodiorite and the Mine Dyke Group, a more felsic phase

Garnet-actinolite skarn Brown's Creek, NSW



AR1343 endoskarn Brown's Creek, NSW



Colebrook Hill ferro-axinite skarn

- Colebrook Hill is located near Rosebery in W. Tasmania
- location of an axinite-actinolite-arsenopyrite skarn
- metasomatic boron-rich fluids reacted with carbonate to form skarn
- violet-brown ferroaxinite [$Ca_2(Fe,Mn)Al_2BSiO_4O_{15}(OH)$] and actinolite are the most abundant minerals present
- other minerals include datolite [$CaBSiO_4(OH)$], danburite [$CaB_2(SiO_4)_2$], arsenopyrite (FeAS) and calcite

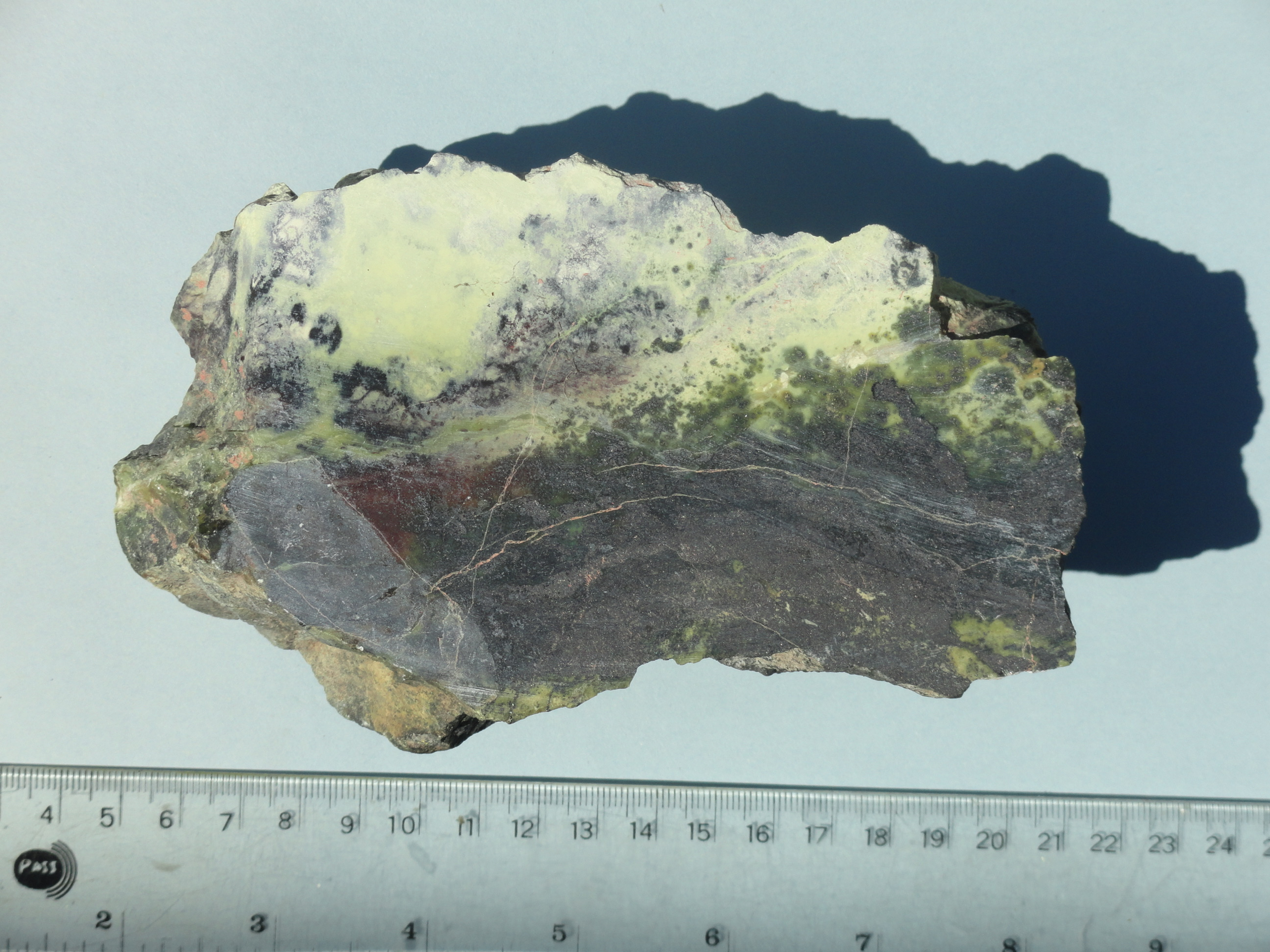
Colebrook Hill

Colebrook Hill, Tas.

axinite-actinolite skarn, Colebrook Hill, Tas.

Tenth Legion Fe-skarn

- Tenth Legion Fe-skarn near Zeehan, W. Tas. → hosted by Proterozoic Oonah Formation quartzites and carbonates
- these rocks pass up into Cambrian sediments and volcanics
- all rocks are intruded by Devonian Heemskirk Granite
- deposit is magnesian carbonate-hosted magnetite skarn, hosted within the Oonah Formation
- ore bodies extend ~500m along strike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Mary Kathleen uranium skarn

- Mary Kathleen is a uranium deposit located ~60km east of Mt Isa, Qld
- the former mine produced 10,000tonnes of U_2O_3 and 200,000tonnes of rare earth oxides
- uranium ore was hosted by garnetiferous calc-silicates (garnetites) with micaceous schists, quartzite, scapolite-diopside, granulites and marbles
- intrusive gabbro, porphyry and dolerite dykes were produced over a period of ~500myr
- U mineralisation occurs as uraninite (UO_2) present as fine disseminations in allanite [$(Ca(Ce,La)(Al,Fe)_3(SiO_4)_3(OH)$] that usually replaces garnet

Mary Kathleen geological setting

- Main sequence within mine comprises the Mary Kathleen Group overlain by Mount Albert Group
- both groups intruded by 1740-1720Ma Wonga Granite
- Mary Kathleen Group >3000m thick → sandstone, siltstone, and shale that are commonly calcareous with greywacke, calcareous breccia, minor felsic and mafic volcanics, BIF and conglomerate (hosts skarn mineralization)
- Mount Albert Group composed of >300m of sandstone, dolomite, shale, limestone and conglomerate

AR1554 allanite-garnetite, Mary Kathleen, Qld

When is a skarn not a skarn?

- Many deposits that are described as skarns are really greisen associated deposits
- true ore skarns are calc-silicates and are formed by early Cl-rich fluids → pyroxenes, garnets, amphiboles, magnetite, scheelite
- with the evolution of later stage high temperature F-B enriched solutions → the rocks through which the fluids pass are strongly leached
- leachates and greisen fluids react with skarn minerals to form new mineral assemblages that include fluorite, muscovite, biotite and tourmaline
- K, Al, Sn,Th are leached from endogreisen

Lost River, Alaska, Sn-W deposit

- The Lost River deposit, Alaska has been described as a Sn-W-Be-Zn-Pb-Cu-Ag
- within the carbonate-replaced bodies → five principal assemblages:

  (1) andradite garnet

  (2) fluorite + magnetite + vesuvianite

  (3) biotite + fluorite + tourmaline + cassiterite

  (4) sulphides

  (5) carbonate + chlorite
- potassic and borosilicate overprint atypical of skarns (and Sn)
- granite source of fluids → strongly greisenised
- deposit should be classified as an exogreisen deposit