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DEPARTMENT OF GEOLOGY

TOPIC:

SKARN AND SKARN DEPOSITS: A GUIDE TO THE IDENTIFICATION AND DISTRIBUTION OF SKARN OCCURRENCES IN NIGERIA.

BY

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2011/179088

MAY, 2016.

OUTLINE

- OBJECTIVES
- SKARN: DEFINITION AND COMPOSITION
- FORMATION OF SKARN
- SKARN CLASSIFICATIONS
- PROFILE OF SKARN DEPOSITS
- SPECULATIONS OF SKARN OCCURRENCES IN NIGERIA
- OCCURRENCES OF SKARN DEPOSIT MINES IN THE WORLD
- SUMMARY AND CONCLUSION

OBJECTIVES OF THIS TOPIC

- To define skarn and its classifications.
- To describe how skarn is formed.
- To discuss the mineral deposits associated with skarn formation.
- To highlight possible skarn occurrences in Nigeria.

SKARN: DEFINITION AND COMPOSITION

- **Skarn** is
  - a metasomatic rock
  - formed by chemical, alteration
  - of carbonate (dolostone and limestone), calcareo-pelitic and Ca-Mg-rich volcanic rocks
  - by hydrothermal fluids of magmatic (mostly granitic magma) or metamorphic origin.

Skarn Deposits: Metallic deposits associated with skarn rock-forming minerals

Fabrics and Mineral Constituents of Skarn

- Colour: Variable, ranges from green to red but occasionally, grey, black, brown or white.
- Grain size: Medium to coarse-grained with abundant **calc-silicate minerals**.

SKARN: DEFINITION AND COMPOSITION

Mineral compositions:

- **Essential minerals:** garnet, pyroxene, calcic amphibole, quartz, calcite, olivine, phlogopite, spinel, plagioclase felspar.
- **Accessory minerals:** titanite, apatite, allanite, tourmaline, topaz, corundum, fluorite, barite, strontianite, tantalite and anglesite.
- **Secondary minerals:** gypsum, hematite, goethite, pyrolusite, axinite, biotite, prehnite, actinolite, chlorite, stipnomelane, sericite, albite, copiapite, roemerite, epsomite,
- **Ore minerals:** magnetite, chalcopyrite, pyrite, native gold, arsenopyrite, pyrrhotite, galena, sphalerite, cassiterite, scheelite and molybdenite.

FORMATION OF SKARN

- **Isochemical metamorphism**:

- Metasomatic transfer of components between adjacent lithologies on a small scale (argillite and limestone, banded iron formation and limestone) forming reaction skarns.

- **Infiltration metasomatism**:

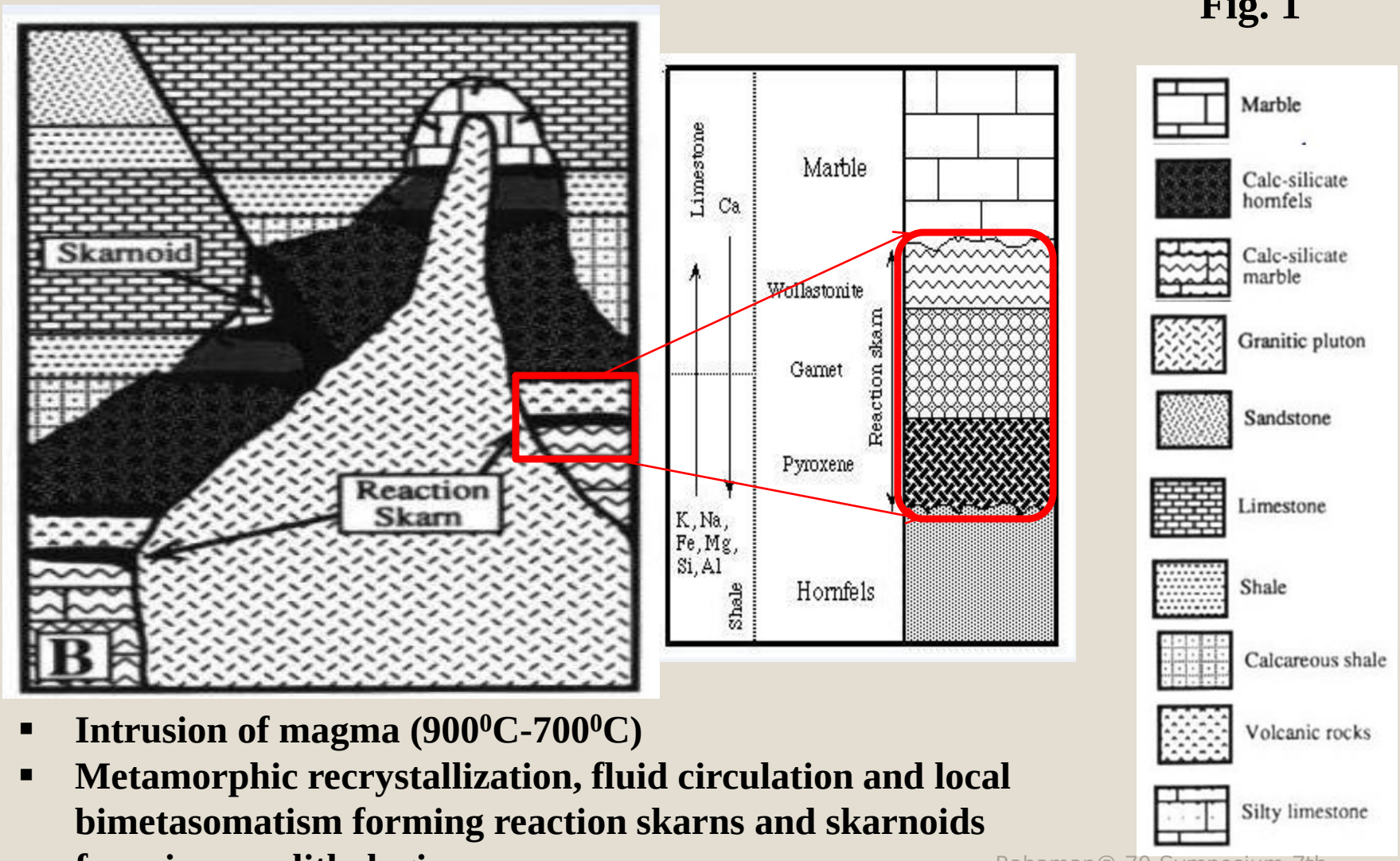
- Hyrdrothermal fluid interaction (magmatic/metamorphic origin) with calcareous rocks forming replacement or infiltration skarns.

(Ray et al. (1997) and Meinert (1992)

FORMATION OF SKARN

ISOCHEMICAL METAMORPHISM

Fig. 1



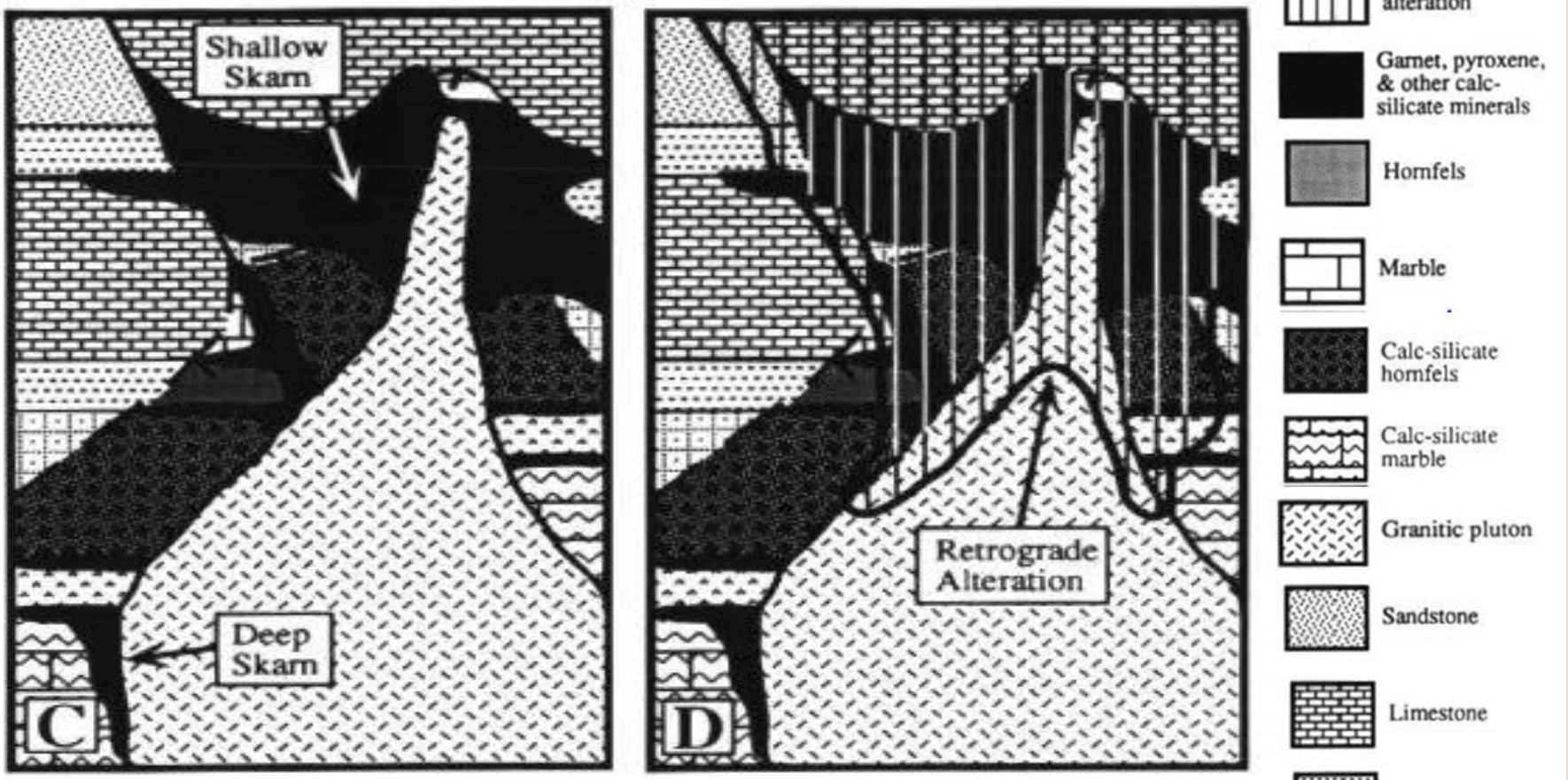
- **Intrusion of magma (900^0C-700^0C)**
- **Metamorphic recrystallization, fluid circulation and local bimetasomatism forming reaction skarns and skarnoids from impure lithologies.**

Meinert (1992)

FORMATION OF SKARN

Fig. 2

INFILTRATION METASOMATISM



▪ Crystallization and release of a separate aqueous phase resulting in fluid-controlled metasomatic skarn (700^0C-500^0C)

Meinert (1992)

▪ Cooling of the pluton and the circulation of cooler oxygenated meteoric waters (600^0C-400^0C) causes retrograde alteration of metamorphic and metasomatic calc-silicate assemblages.

SKARN CLASSIFICATION

- **Based on alteration assemblages**;

Prograde calcic skarn: Replacement of limestone and other calcareous rocks.

- Essential minerals: garnet, clinopyroxene, epidote, calcic amphibole and wollastonite.

- Idealized zonation of minerals in calcic skarns, from the intrusion to the unaltered host rock: **endoskarn >> garnet-dominant exoskarn >> pyroxene-dominant exoskarn >> vesuvianite, wollastonite, bustamite or rhodonite-bearing skarn with abundant carbonate >> marble, with or without silicification >> unaltered wallrock**.
  - If the fluids are undersaturated in Si, too high in CO_2, or too low in temperature, the wollastonite-rich zone is not developed.

Soloviev et al. (2013), and Ray et al. (1997)

SKARN CLASSIFICATION

Prograde magnesian skarn: Replacement of dolomite.

- Essential minerals: olivine, phlogopite, serpentine, spinel, Mg-pargasite and humite group minerals.
- Mineral zonation (between the intrusion and dolomite): **endoskarn >> pyroxene and plagioclase-rich exoskarn >> olivine and spinel-rich exoskarn >> dolomite.**

❑ **Based on type of protolith**:

Exoskarn: Alteration of the wall rock (limestone or dolostone). Describes sedimentary protolith.

Endoskarn: Alteration of the intrusion (igneous protolith).

Meinert (1992) and Ray et al. (1997)

PROFILE OF SKARN DEPOSITS

Seven (7) major classes of metallic skarn deposits:

- Fe Skarn Deposits
- Cu Skarn Deposits
- Au Skarn Deposits
- Pb-Zn Skarn Deposits
- Sn Skarn Deposits
- Mo Skarn Deposits
- W Skarn Deposits

Fe Skarn Deposit

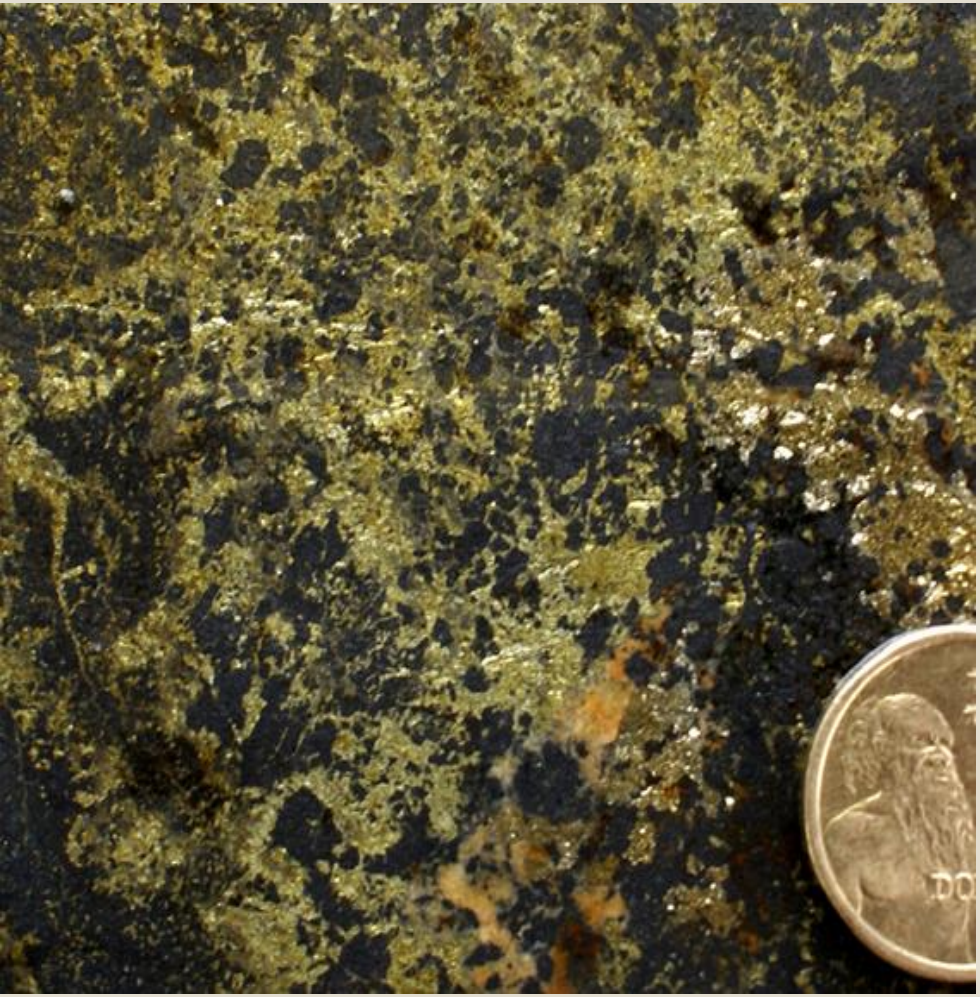
(Compiled from: Jansson *et al.*, 2013; Ray *et al.*, 1997 and Soloviev et al., 2013)

Main metal (By-products)	Fe (Cu, Ag, Au)
Tectonic Setting	Calcic Fe Skarns: Oceanic island arc. Magnesian Fe Skarns: Synorogenic continental margins.
Host/Associated Rock Types	**Calcic Fe skarns:** Fe-rich, Si-poor intrusions (primitive oceanic crust). Dikes of gabbro to syenite (mostly gabbro-diorite) intruding limestone, calcareous clastic sedimentary rocks, tuffs or mafic volcanics at a high to intermediate structural level. **Magnesian Fe skarns:** Granodiorite to granite intruding dolomite and dolomitic sedimentary rocks.
Ore Mineralogy	Principal ore: Magnetite. Subordinate ores: chalcopyrite, bornite, pyrite, pyrrhotite, sphalerite, molybdenite, argentite.
Grade and Tonnage	Grades are typically 40 to 60%. Worldwide, calcic Fe skarns range from 3 to 150 Mt whereas magnesian Fe skarns can be larger (exceeding 250 Mt).

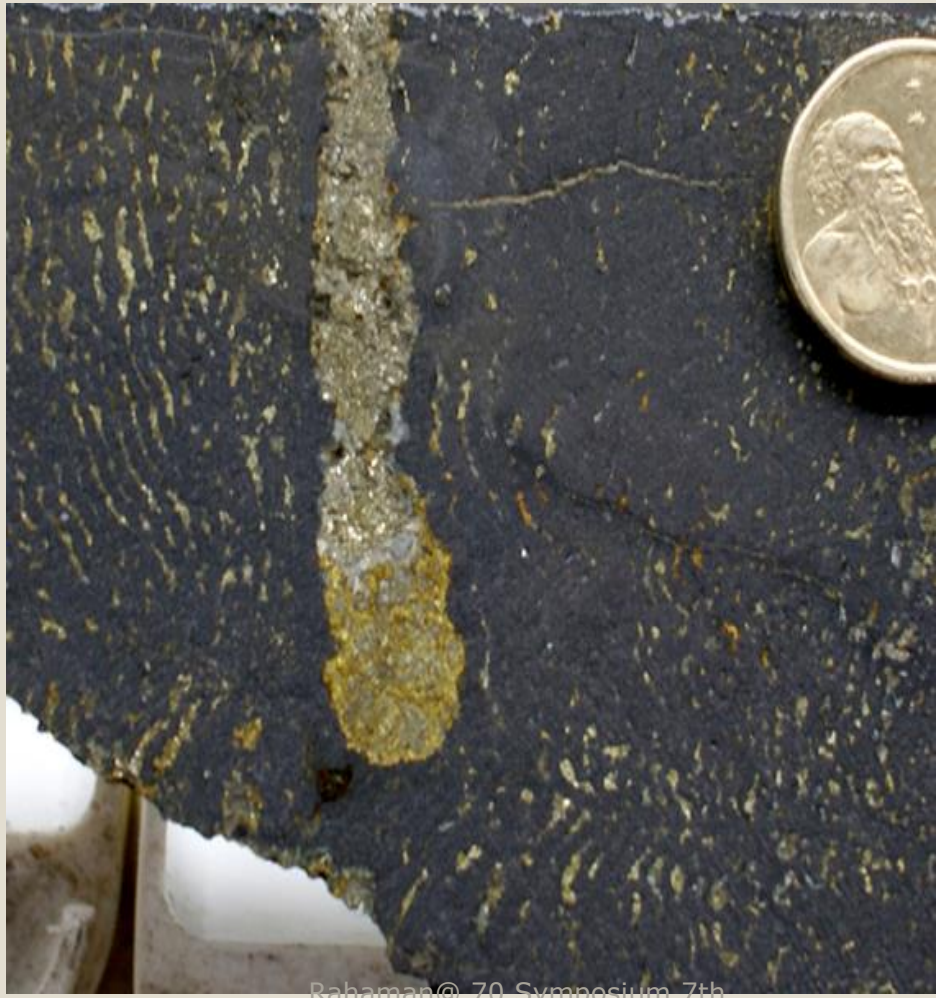
Fig. 3:

A. Disseminated pyrite in magnetite skarn

B. Parallel pyrite and chalcopyrite dissemination through magnetite skarn .



A



B

http://users.monash.edu.au/~weinberg/index.htm

Cu Skarn Deposit

(Compiled from: Nadoll *et al.*, 2015; Ray *et al.*, 1997 and Soloviev, 2015)

Main metal (By-products)	Cu (Au, Ag, Mo, W)
Tectonic Setting	Andean-type plutons intrude older continental-margin carbonate sequences. To a lesser extent, they are associated with oceanic island arc plutonism.
Host/Associated Rock Types	Dikes and breccia pipes of quartz diorite, granodiorite, monzogranite and tonalite composition, intruding carbonate rocks, calcareous volcanics or tuffs. Copper skarns in oceanic island arcs tend to be associated with more mafic intrusions (quartz diorite to granodiorite), while those formed in continental margin environments are associated with more felsic rocks.
Ore Mineralogy	(Moderate to high sulphide content). Chalcopyrite, pyrite, magnetite, sphalerite, hematite, pyrite, pyrrhotite, etc. Distal to the skarn envelope, veins of pyrite, chalcopyrite, galena and sphalerite may occur.
Grade and Tonnage	Average 1 to 2 % Cu. Worldwide, they generally range from 1 to 100 Mt, although some exceptional deposits exceed 300 Mt (the Candelaria deposit in Chile, for example, contains 366 Mt grading 1.08% Cu).

Fig. 4:

A. Copper(gold-silver-molybdenum) skarn from Whitehorse Copper Beli, Yukon.

B. Core sample of copper skarn

A

B

http://www.danieleheon.com/fieldwork-photos-yukon--bc.html

Au Skarn Deposit

(Compiled from: and Ray *et al.*, 1997; Soloviev, 2015 and Soloviev *et al.*, 2013)

Main metal (By-products)	Au (Cu, Ag)
Tectonic Setting	Orogenic belts at convergent plate margins. They tend to be associated with syn- to late intraoceanic island arc intrusions emplaced into calcareous sequences in arc or back-arcs. They are also hosted by platformal carbonates and Archean greenstones (Magnesian Au skarn).
Host/Associated Rock Types	High to intermediate level stocks, sills and dikes of gabbro, quartz diorite or granodiorite intruding carbonate, calcareous clastic or volcaniclastic rocks.
Ore Mineralogy	Principal ores: Native gold, pyrrhotite, chalcopyrite, pyrite, arsenopyrite. Subordinate ores: galena, argentite, magnetite, tellurides, bismuthinite, sphalerite, etc.
Grade and Tonnage	These deposits range from 0.4 to 13 Mt and from 2 to 15 g/t Au. Median Au and Ag grades and tonnage can be 8.6 g/t Au, 5.0 g/t Ag and 213,000 t.

Fig 5:

A. Native gold (yellow) in a quartz vein (white and light grey) with hematite disseminations (brown), garnet (dark green), and pyroxene (light green) in the Nambija skarn, Campanillas Mine, Ecuador.
B. Fracture-fill with chalcopyrite and azurite in a Cu-Au skarn.

A

B

https://cms.unige.ch/sciences/terre/research/Groups/mineral_resources/deposits/deposits_slides_f.php.

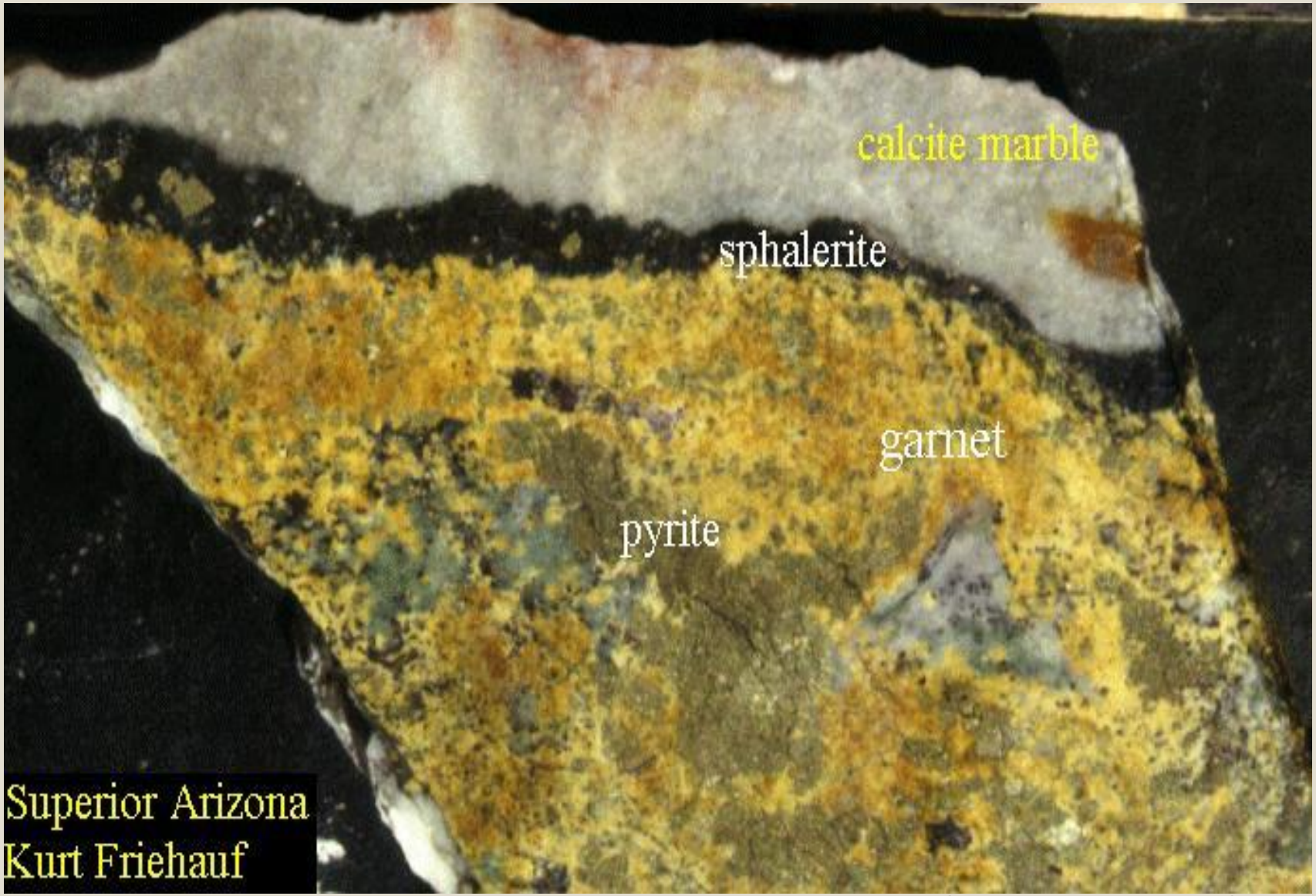
http://www.mikepole.com/skarn-cu-au/4229774

Pb-Zn Skarn Deposit

(Compiled from: Davidheiser-Kroll *et al.*, 2014; Moroskat *et al.*, 2015 and Ray *et al.*, 1997)

Main metals (By-products)	Pb, Zn, Ag, (Cu, W, Au)
Tectonic Setting	Along continental margins where they are associated with late orogenic plutonism.
Host/Associated Rock Types	Thick limestones, calcareous tuffs and sediment associated with granodiorite, leucogranite, diorite and syenite (mostly quartz monzonite).
Ore Mineralogy	Principal ores: Sphalerite , galena. Subordinate ores: pyrite, magnetite, argentite, chalcopyrite, cassiterite, bornite. Other trace minerals reported include scheelite, stannite, cassiterite, tetrahedrite, molybdenite, fluorite, and native gold.
Grade and Tonnage	Lead-zinc skarns tend to be small (< 3 Mt), but can reach 45 Mt, grading up to 15 % Zn, 10 % Pb and > 150 g/t Ag with substantial Cd. Copper grades in Pb-Zn skarn deposits are generally < 0.2 %.

Fig.6: Garnet-amphibole-pyrite (sphalerite) skarn



https://pangea.stanford.edu/research/ODEX/kurt-gsh.html

Sn Skarn Deposit

(Compiled from: Ray *et al.*, 1997)

Main metal (By-products)	Sn (W, Zn, Fe)
Tectonic Setting	Late to post orogenic granites emplaced into thick and deeply buried continental margin sedimentary sequences, or sequences in rifted or stable cratons.
Host/Associated Rock Types	Associated with differentiated (low Ca, high Si and K) ilmenite-series granite, adamellite and quartz monzonitic stocks and batholiths intruding carbonate and calcareous clastic rocks. Tin skarns tend to develop in reduced and deep-level (high depth) environments and may be associated with greisen alteration.
Ore Mineralogy	Principal ore: Cassiterite. Subordinate ores: sphalerite, scheelite, pyrite, pyrrhotite, magnetite.
Grade and Tonnage	Deposits grade up to 1 % Sn, but much of the metal occurring in malayaite, garnet, amphibole and epidote is not economically recoverable. Worldwide, deposits reach 30 Mt, but most range between 0.1 and 3 Mt.

Fig 7: Greisen sample with mica and cassiterite (SnO_2)

www.sandatlas.org

Mo Skarn Deposit

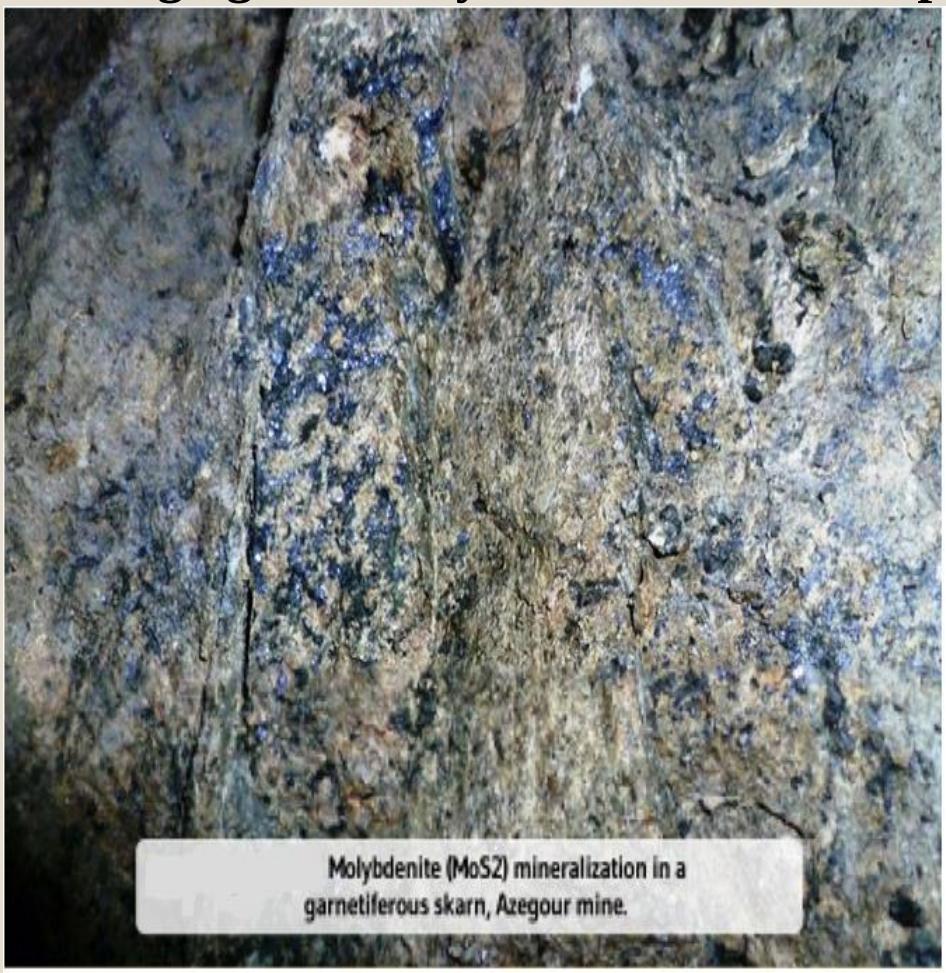
(Compiled from: Ray *et al.*, 1997 and Soloviev, 2015)

Main metal (By-products)	Mo (W, Cu, Pb, Zn, Sn, Au)
Tectonic Setting	Late orogenic plutonism (derived from transitional crust) intruding continental margin carbonate sequences. Also, some are associated with Mo-bearing porphyry systems developed within intra-oceanic island arcs.
Host/Associated Rock Types	Stocks and dikes of leucocratic quartz monzonite to granite (some containing primary biotite and muscovite) intruding calcareous clastic rocks.
Ore Mineralogy	Principal ore: Molybdenite. Subordinate ores: scheelite, chalcopyrite, galena, sphalerite, cassiterite, arsenopyrite, etc.
Grade and Tonnage	Worldwide, grades range from 0.1 to 2 % MoS_2, but can reach 12%, and tonnages between 0.1 and 2 Mt.

Fig 8:

A. Molybdenite (MoS_2) mineralization in garnetiferous skarn

B. High grade molybdenite in skarn. Up to 12% Molybdenum



A

mayagoldsilver.com

B

www.happycreekminerals.com

W Skarn Deposit

(Compiled from: Soloviev, 2015 and Ray *et.al.*, 1997)

Main metal (By-products)	W (Mo, Cu, Sn, Zn)
Tectonic Setting	Continental margin, synorogenic to late orogenic plutonism intruding deeply buried sequences of eugeoclinal carbonate-shale sedimentary rocks. Can develop in tectonically thickened packages in back-arc thrust settings.
Host/Associated Rock Types	Pure and impure limestones, calcareous to carbonaceous pelites intruded by tonalite, granodiorite, quartz monzonite and granite of both I and S-types.
Ore Mineralogy	Principal ore: Scheelite. Subordinate ores: molybdenite, chalcopyrite, cassiterite, sphalerite.
Grade and Tonnage	Grades range between 0.4 and 2 % WO_3 (typically 0.7 %). Deposits vary from 0.1 to >30 Mt.

Fig: 9

A. Scheelite (a calcium tungstate mineral and an important ore of tungsten) found in W-skarn deposits.

Source: http://www.geologyforinvestors.com/skarn-deposits-largest-source-tungsten/.

B. Highest grade W at the base of Ore Limestone and near en-echelon quartz veins, Cantung Tungsten Skarn Deposit, Northwest Territories, Canada.

Source: Rasmussen (2013) .

A

B

OCCURRENCES OF SKARN DEPOSIT MINES IN THE WORLD

- **The Cantung Mine:** The Cantung mine is operated by North American Tungsten in the Northwest Territories of Canada. It is the western world's largest producer of Tungsten concentrate.
- **Ok Tedi Mine:** Located in Western Papua New Guinea. This is a giant porphyry and skarn copper-gold deposit extracting about 20 million tonnes of ore each year.
- **The Pine Creek mine:** Located in California. It hosts one of the world's largest skarn scheelite deposits. Formerly a major source of North America's tungsten supply.
- **The Kamaishi mine:** This is the largest iron skarn orebody in Japan. Measuring 400m long by 80m wide and stretching over half a kilometre deep.

William (2015)

- **CHINA:**

The **Xianglushan Mine** in Jiangxi Province is a tungsten skarn and China's largest tungsten mine in terms of annual output.

The **Shizhuyuan Skarn-Greisen Deposit** in Hunan Province, China. This is one of the largest tungsten deposits in the world and the largest in China in terms of proven reserves.

The **Yaogangxian Mine** in Hunan Province consists of two deposits; a quartz vein-type tungsten-tin deposit related to granite intrusions into sedimentary rocks, and a skarn-type deposit.

- **Nickel Plate Mine** in Hedley District, British Columbia, Canada is the largest and highest grade gold skarn in Canada.
- **Fortitude Deposit**, Battle Mountain District, Nevada, known for various skarn deposit types (Cu, Fe, Au).
- **Junction Reefs** in Australia: Au skarn deposits. Mined from1876 to present.

Kurt (1995)

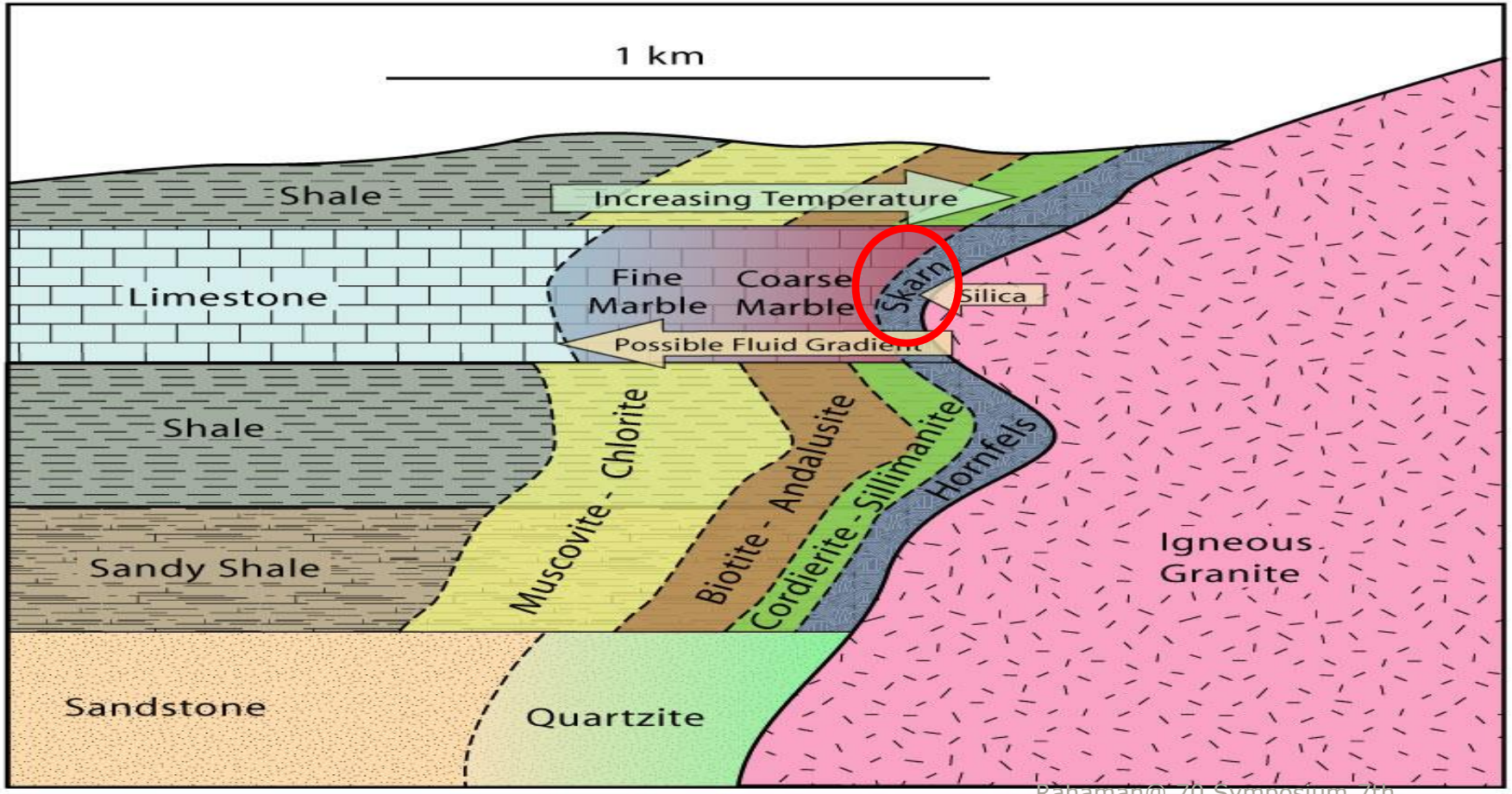
OCCURRENCES (OR SPECULATIONS) OF SKARN IN NIGERIA

- Tin (Cassiterite) Deposits in The Younger Granites Complex of Nigeria:

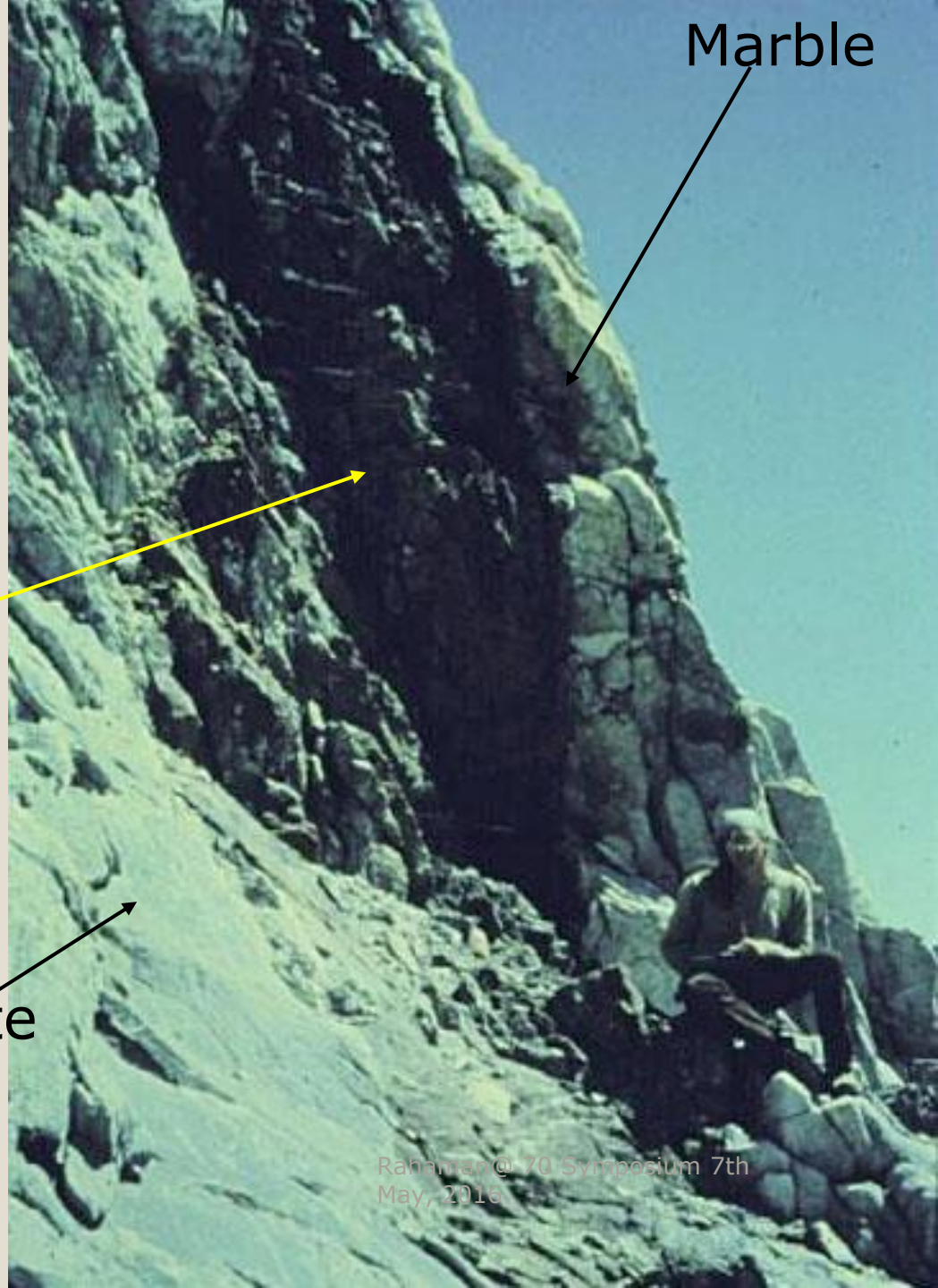
  Endoskarn signature, presence of greisens and its associated high-fluorine activities. The earlier skarn deposits in the igneous rock environment may have been destroyed by the greisen-stage alteration.

- Marble occurrences (Schist Belts) in the Precambrian Basement Complex of Nigeria.

Fig 10: Model for Marble formation from Contact Metamorphism



Pine Creek, California
W skarn



CONCLUSION

- Skarn, as a metasomatic rock is a product of hydrothermal alteration of calcium- and magnesium-rich carbonate rocks. Its formation is associated with the concentrations of metallic deposits (skarn deposits). The most abundant metal determines the skarn deposit type and this is also governed by the source of the hydrothermal fluid, tectonic setting of emplacement, structures on the protolith and the composition of the protolith.
- The Younger Granites Complex and marble-bearing Schist Belts are the possible locations of skarn occurrences in Nigeria. Endoskarn is much likely to occur in the igneous environment (Younger Granites Complex) with the associated greisens and high fluorine activities (suitable conditions for Sn Skarn Deposits). The marble-bearing schist belts in the country are likely to be host to exoskarns rich in Fe, Cu, Au and Mo skarn deposits.

THANK YOU FOR LISTENING

Fig 10: Idealized models of skarn formation in various tectonic settings: **(A)** Oceanic subduction and back arc basin environment **(B)** Continental subduction environment with accreted oceanic terrane **(C)** Low angle subduction environment **(D)** Non-rifted extensional environment. **Modified After Meinert (1992).**

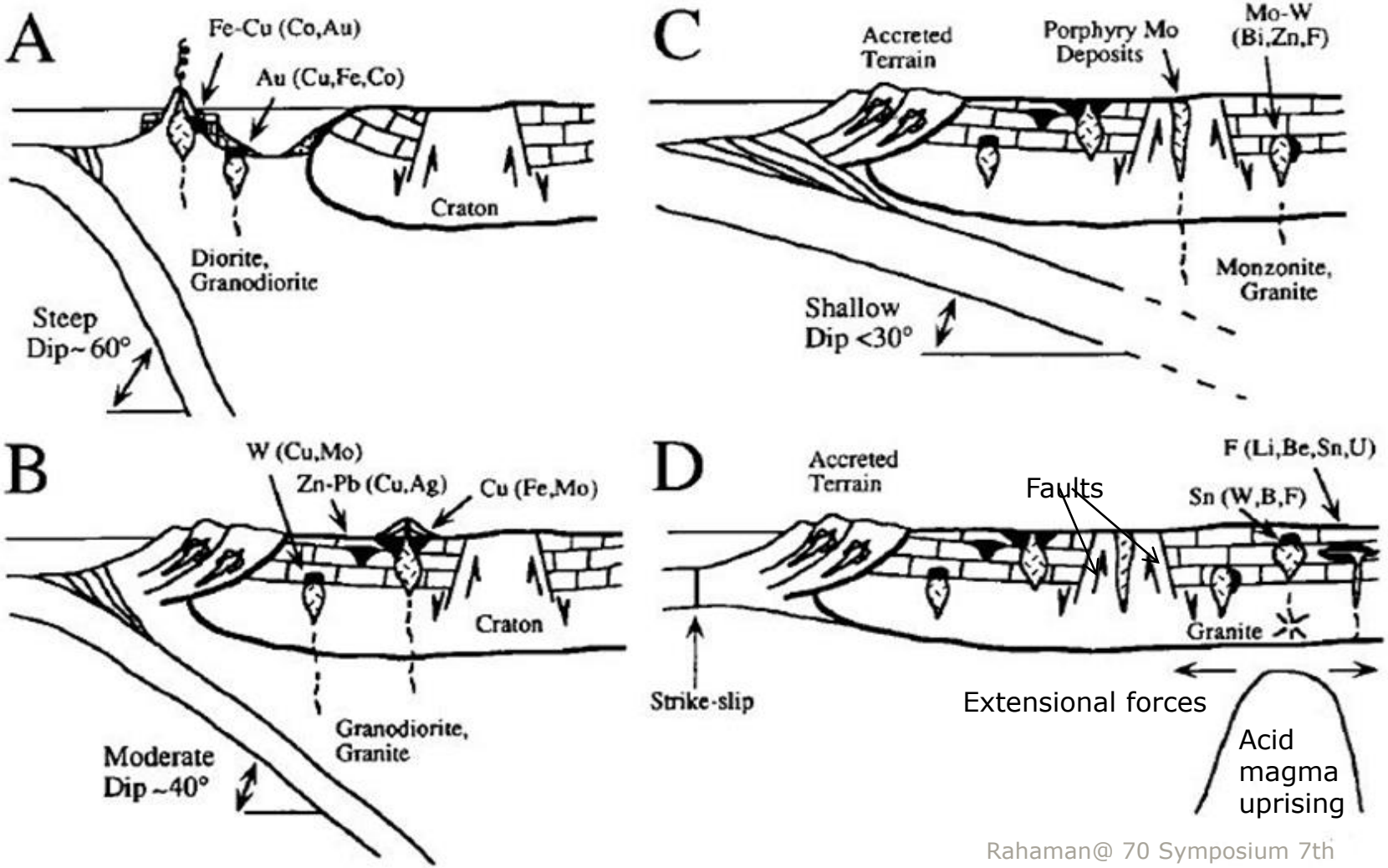
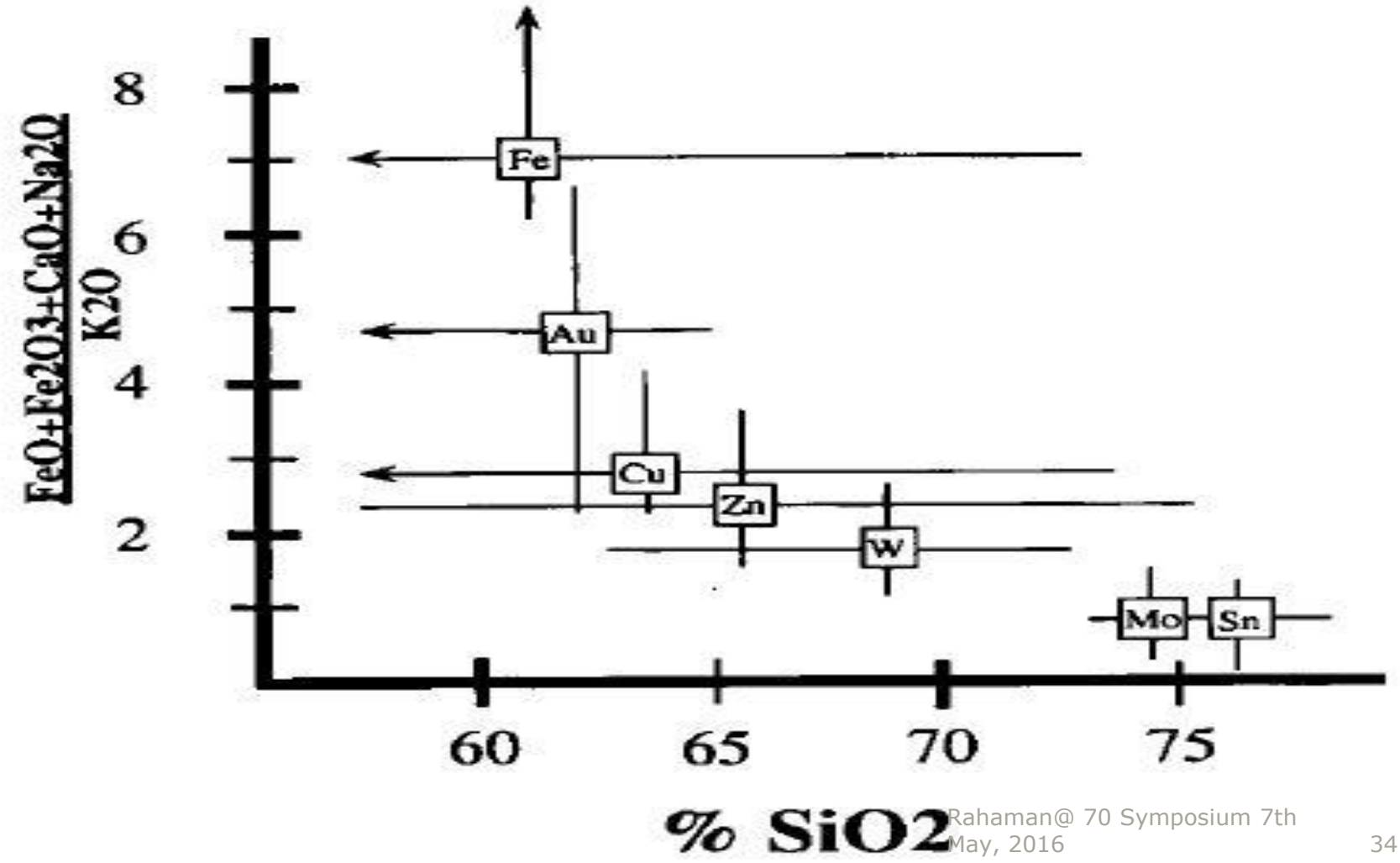


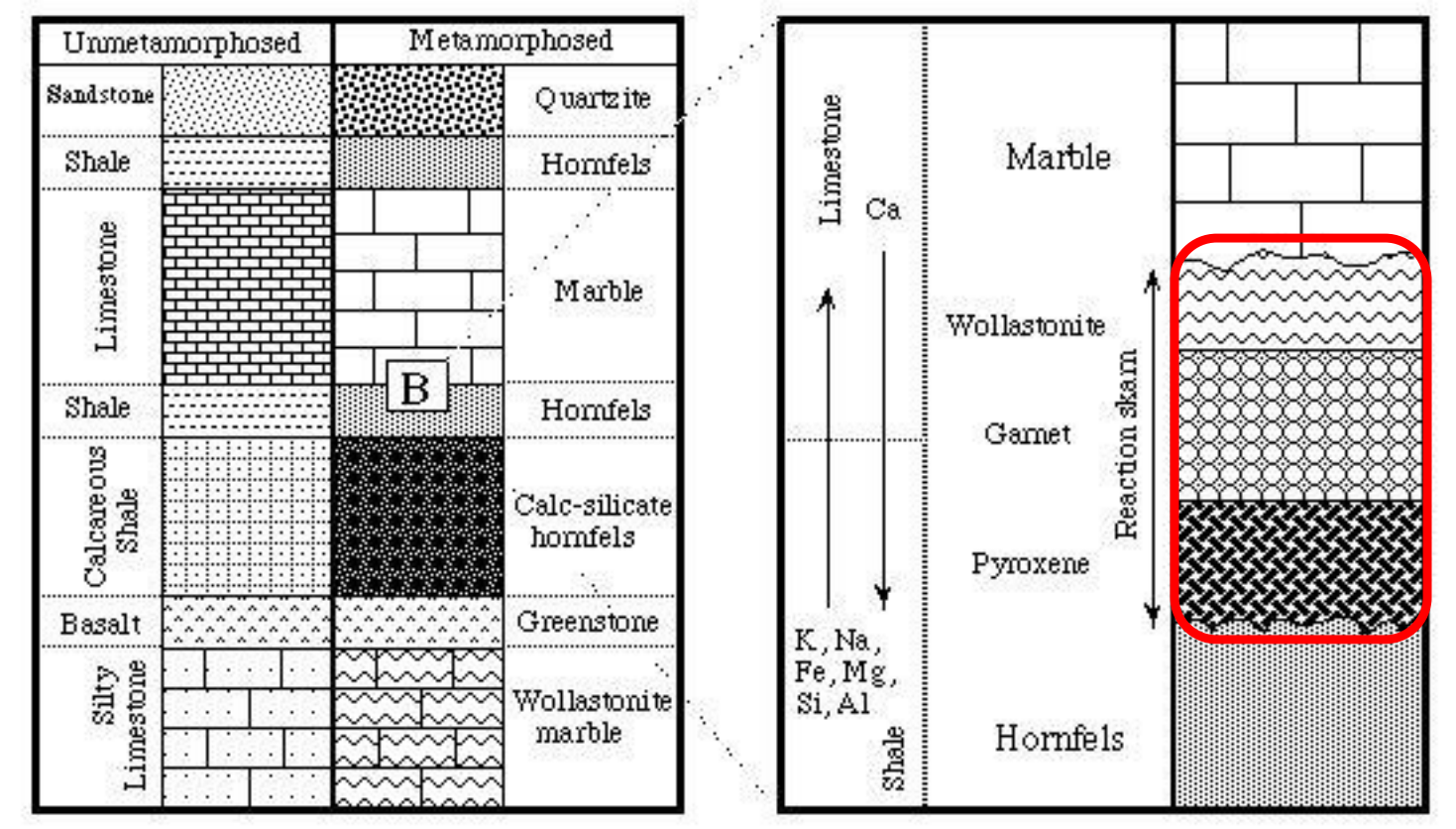
Fig 11. Average composition of plutons associated with different skarn types. **Source: Meinert (1992).**



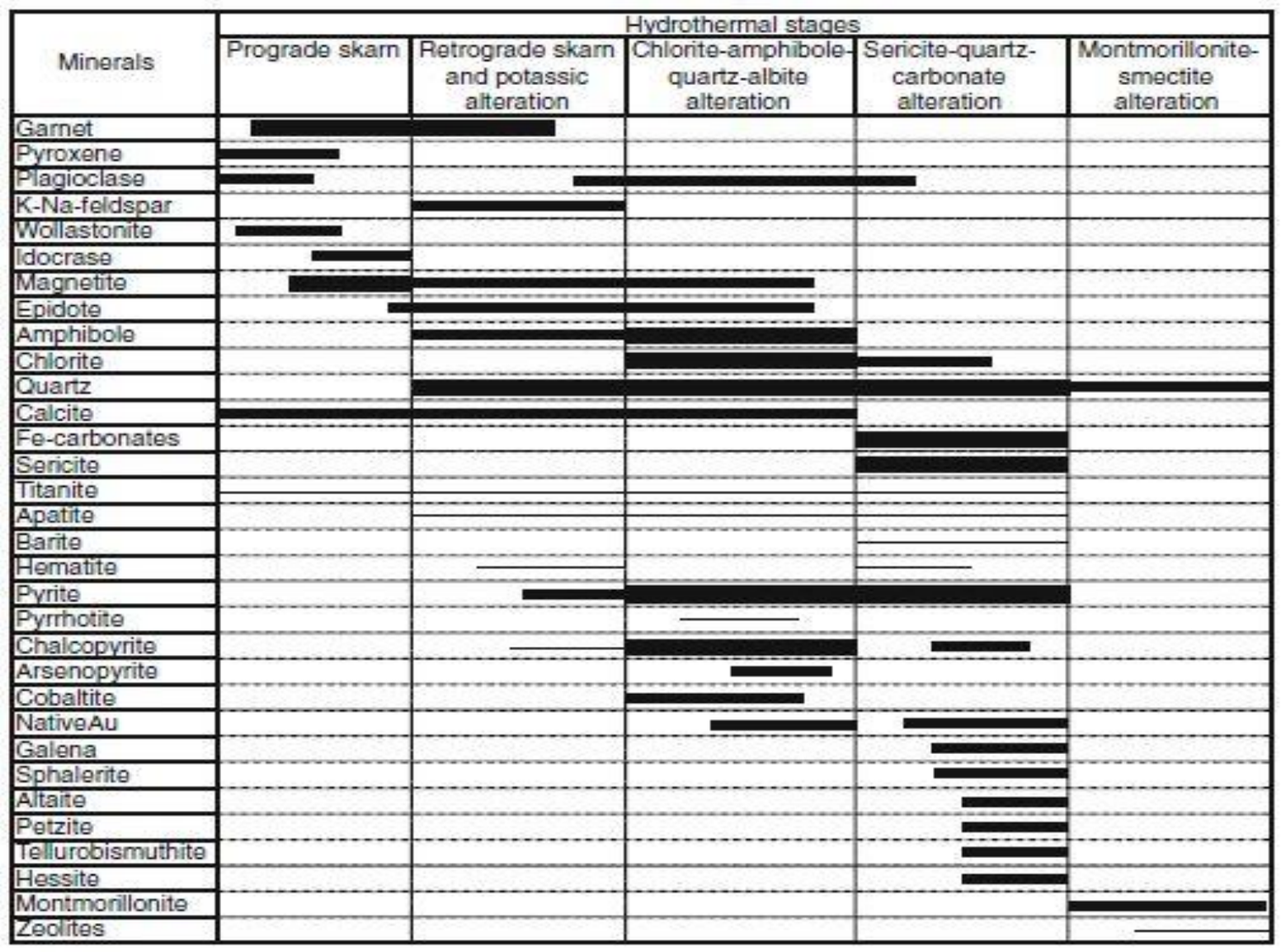
FURTHER DESCRIPTIONS

- The ore in many Fe, Cu, Mo and W skarn deposits tends to form proximal to their related plutons, whereas the ore in many Au, Sn and Pb-Zn skarns develops more distally in the outer parts of the exoskarn envelope.
- The ores are structurally and stratigraphically controlled.
- The skarn deposits can be in the forms of mantos, chimneys, veins, dykes, sills and pipes.
- The mineral assemblage for each skarn type is defined using the phase equilibra, mineral compatibilities and compositional variations in solid solution series.

REACTION SKARN



Mass transfer of cations at a small scale (between adjacent shale and limestone beds forming a skarn rock (reaction skarn) between them.



Paragenesis diagram of alteration assemblages showing sequence of mineralization at the Novogodnee–Monto deposit