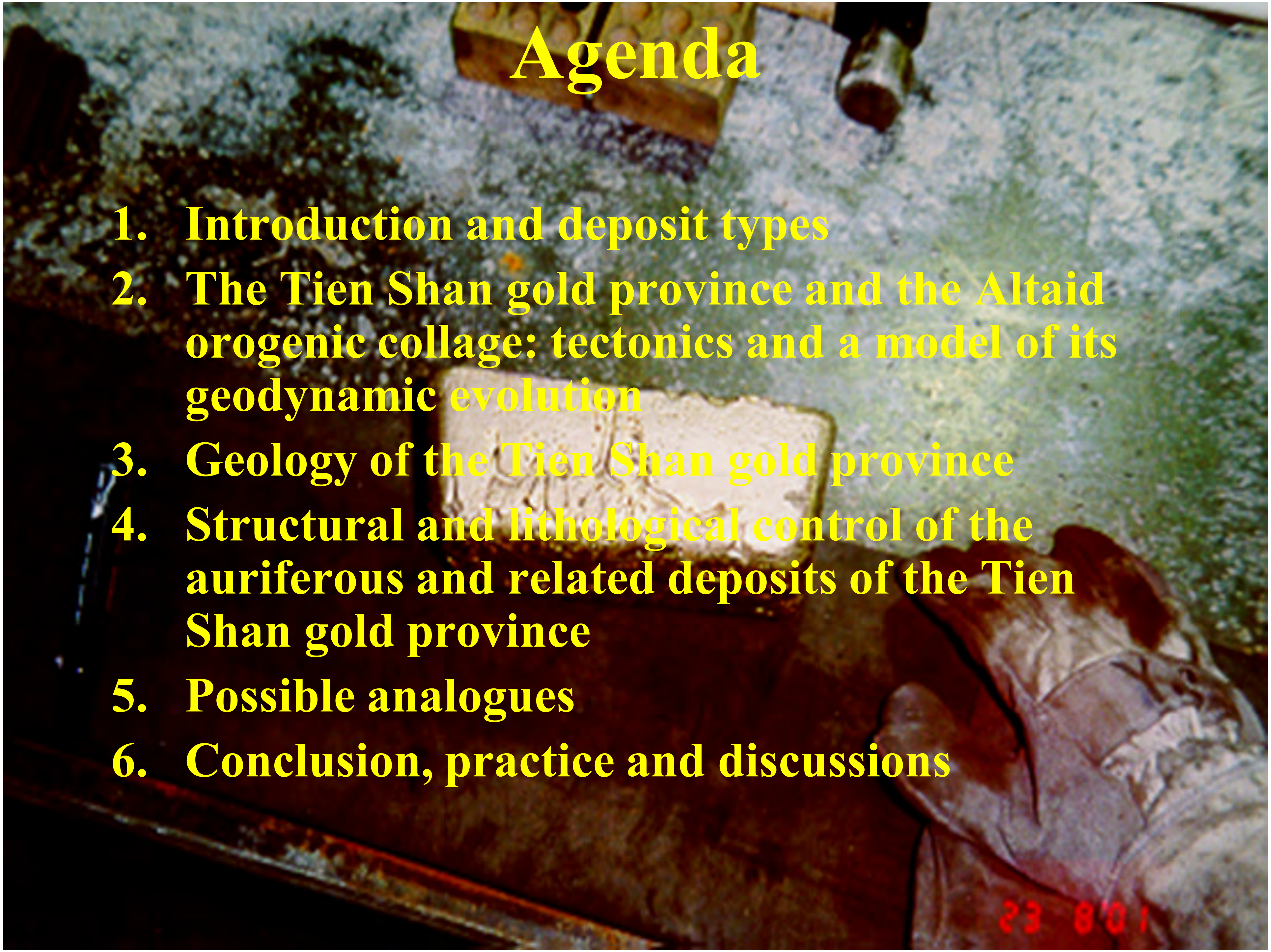

Anatomy of Giants – Gold
Tien Shan Province
Instructors
Alexander Yakubchuk, c/o CERCAMS, NHM, London, UK
Reimar Seltmann, CERCAMS, Natural History Museum, London, UK
With contributions from
Andy Cole, Metal Bulletin Research, London, UK
Vitaly Shatov, All-Russia Geological Institute VSEGEI, Russia,
Torsten Graupner, Freiberg Technical University, Germany


Agenda
1. Introduction and deposit types
2. The Tien Shan gold province and the Altaid orogenic collage: tectonics and a model of its geodynamic evolution
3. Geology of the Tien Shan gold province
4. Structural and lithological control of the auriferous and related deposits of the Tien Shan gold province
5. Possible analogues
6. Conclusion, practice and discussions
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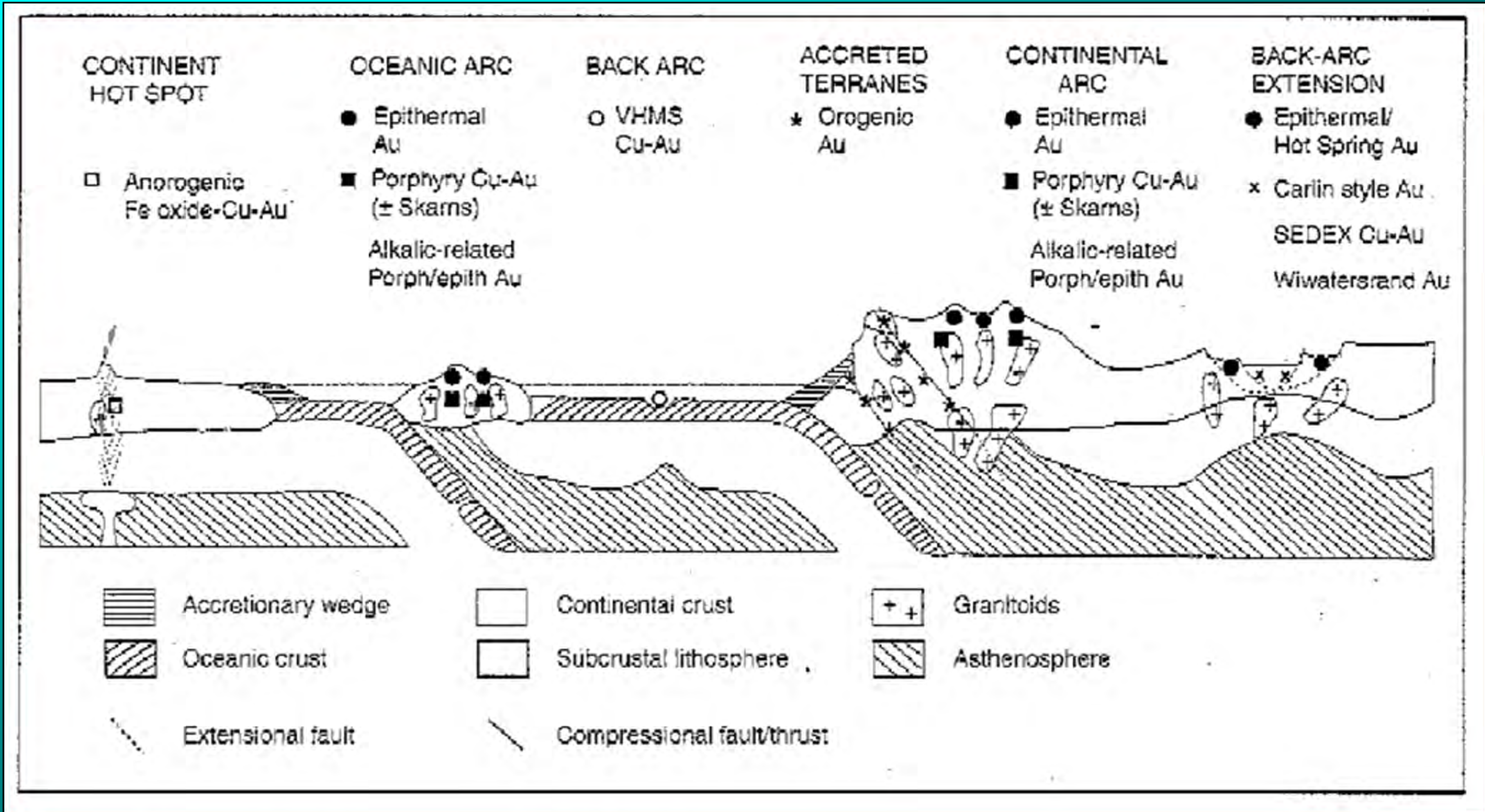
1. Introduction and deposit types

Introduction and deposit types

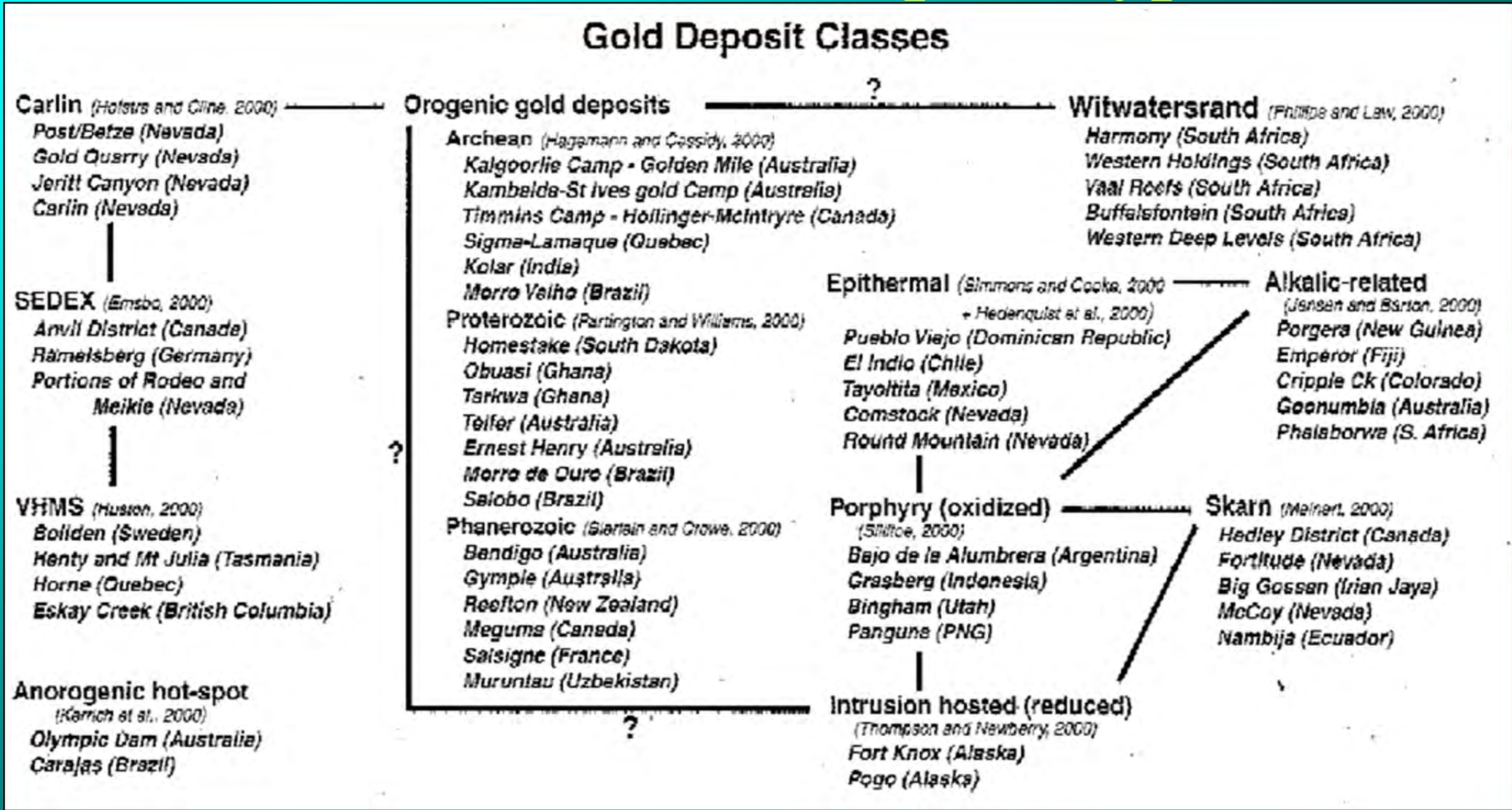
- Arc-related gold deposits
  - Porphyry deposits
  - Epithermal deposits
  - Skarn deposits
- Orogenic gold deposits
  - Sedimentary rock-hosted deposits
  - Intrusion-related deposits
  - Skarn deposits

Introduction and deposit types



Groves et al., 1998

Introduction and deposit types



Groves et al., 1998

Introduction and deposit types

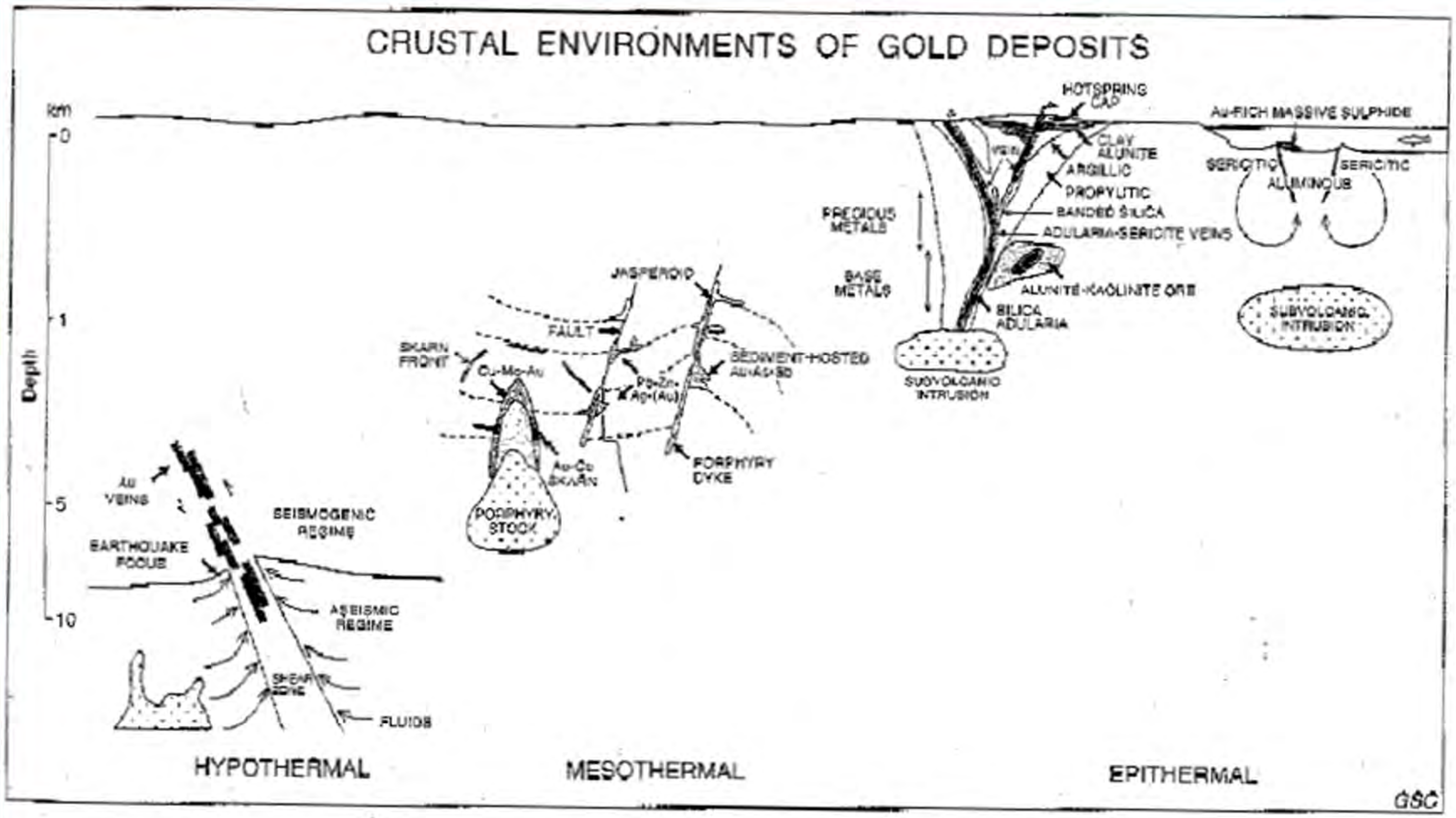
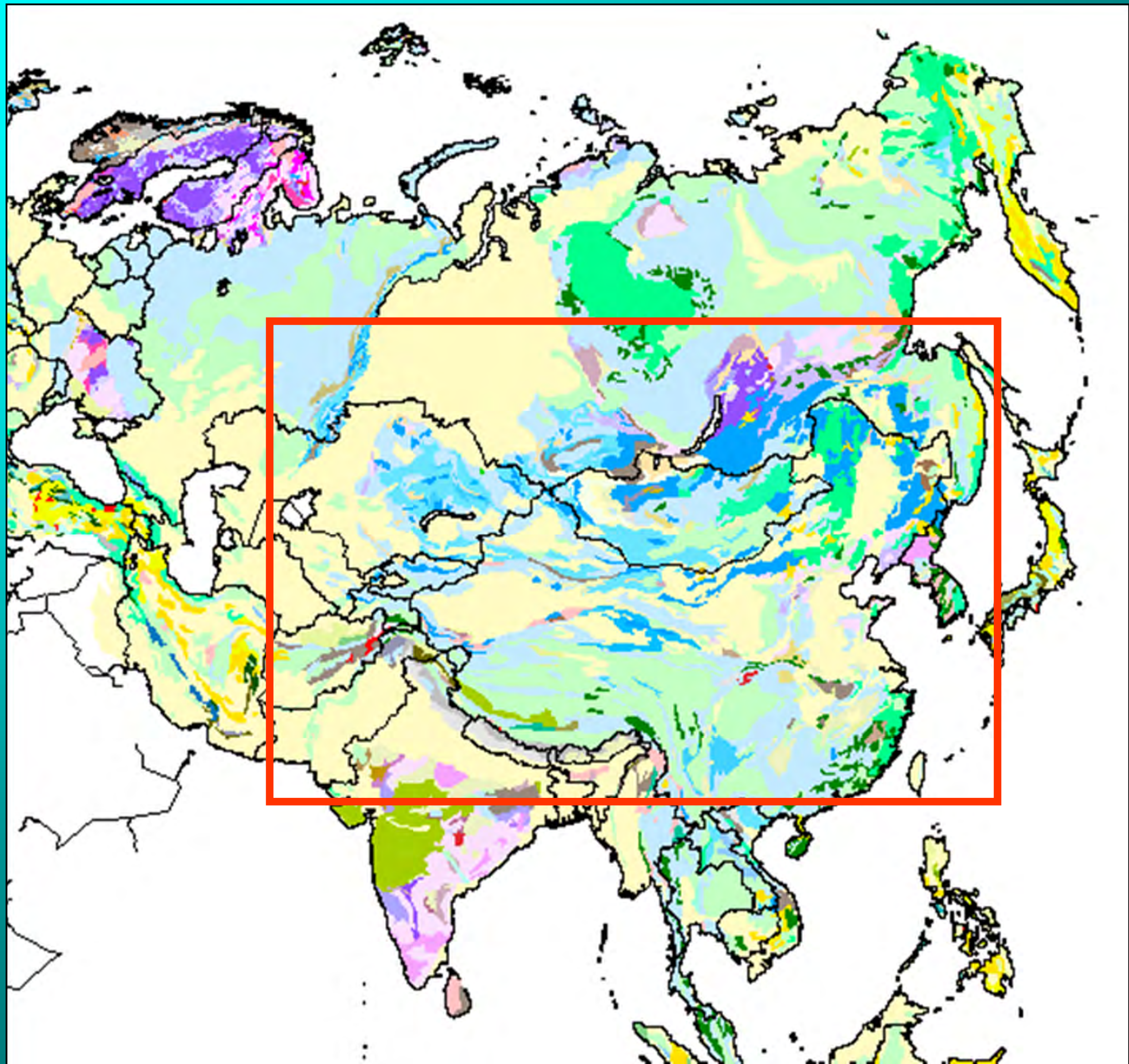


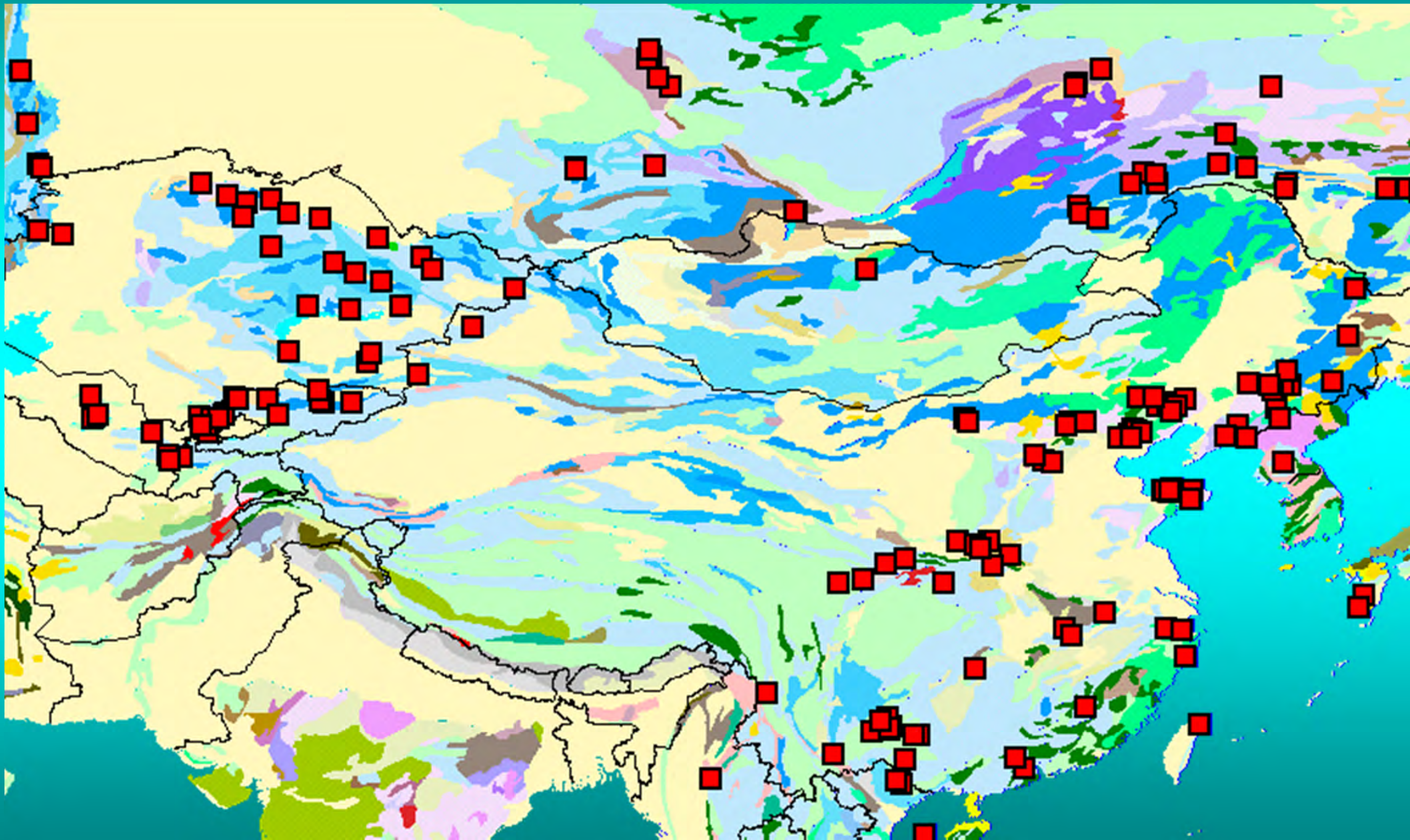
Figure 15-2. Schematic models of the crustal settings of gold deposits. For the deeper "hypothermal" environment a steep shear zone is illustrated to transect the boundary between seismogenic and aseismic crust and as a control on fluid (curved arrows) movement (after Sibson et al., 1988); for a shallower "mesothermal" environment the relative positions of porphyry Cu-Mo-Au, Au-skarn, and distal "Carlin-type" Au-As-Sb mineralization are illustrated (after Sillitoe and Bonham, 1990); for a shallow "epithermal" environment the relative position of subaerial hotspring mineralization is illustrated with respect to deeper epithermal veins (after Buchanan as reproduced in Panteleyev, 1986) as well as a hypothetical shallow marine environment corresponding to the formation of gold-rich volcanogenic massive sulphides.

Geology of Eurasia and its gold endowment



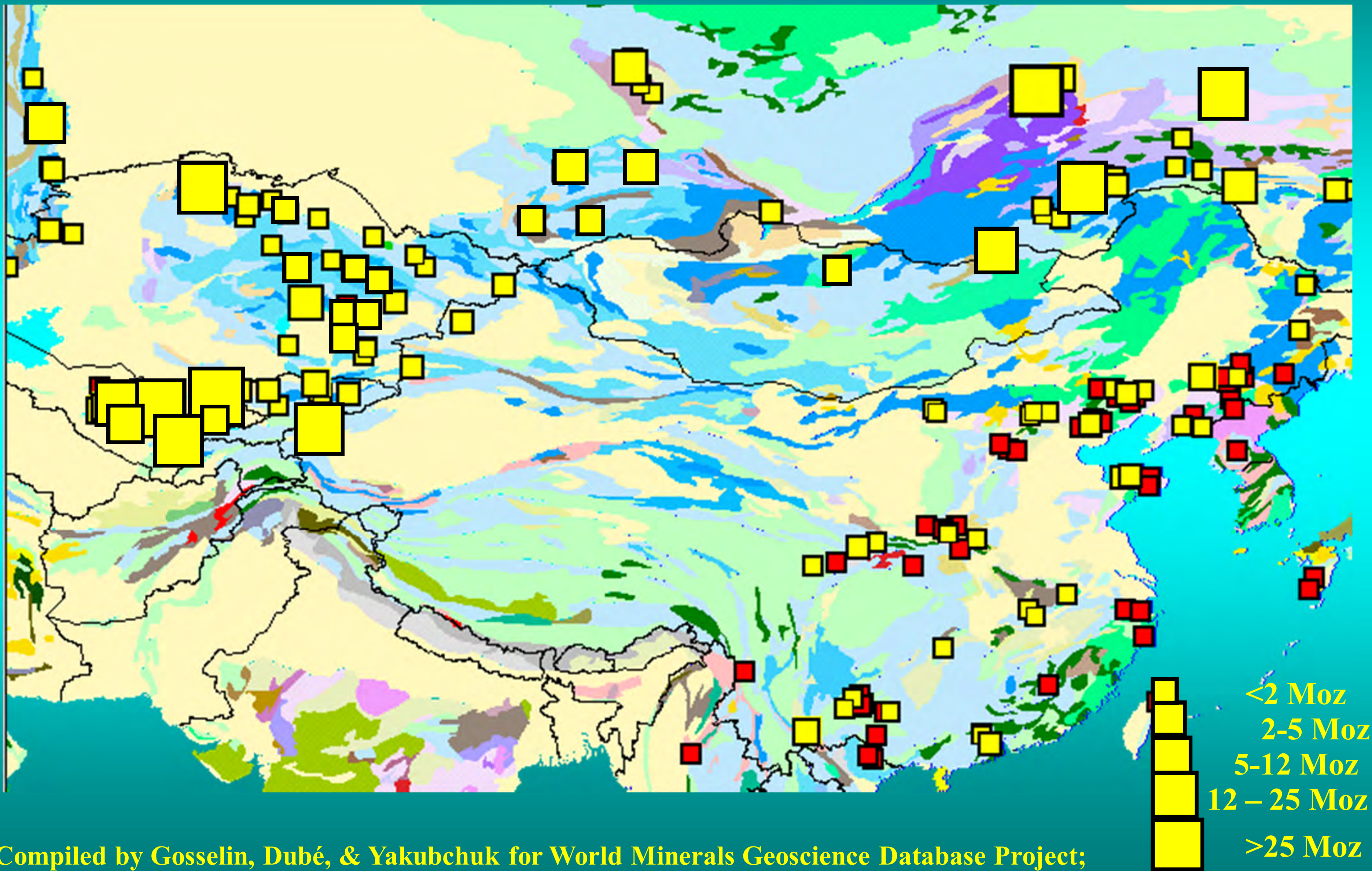
World Minerals Geoscience Database Project;
Geological Survey of Canada. GIS implementation by L.Chorlton

Introduction: >1 Moz gold deposits



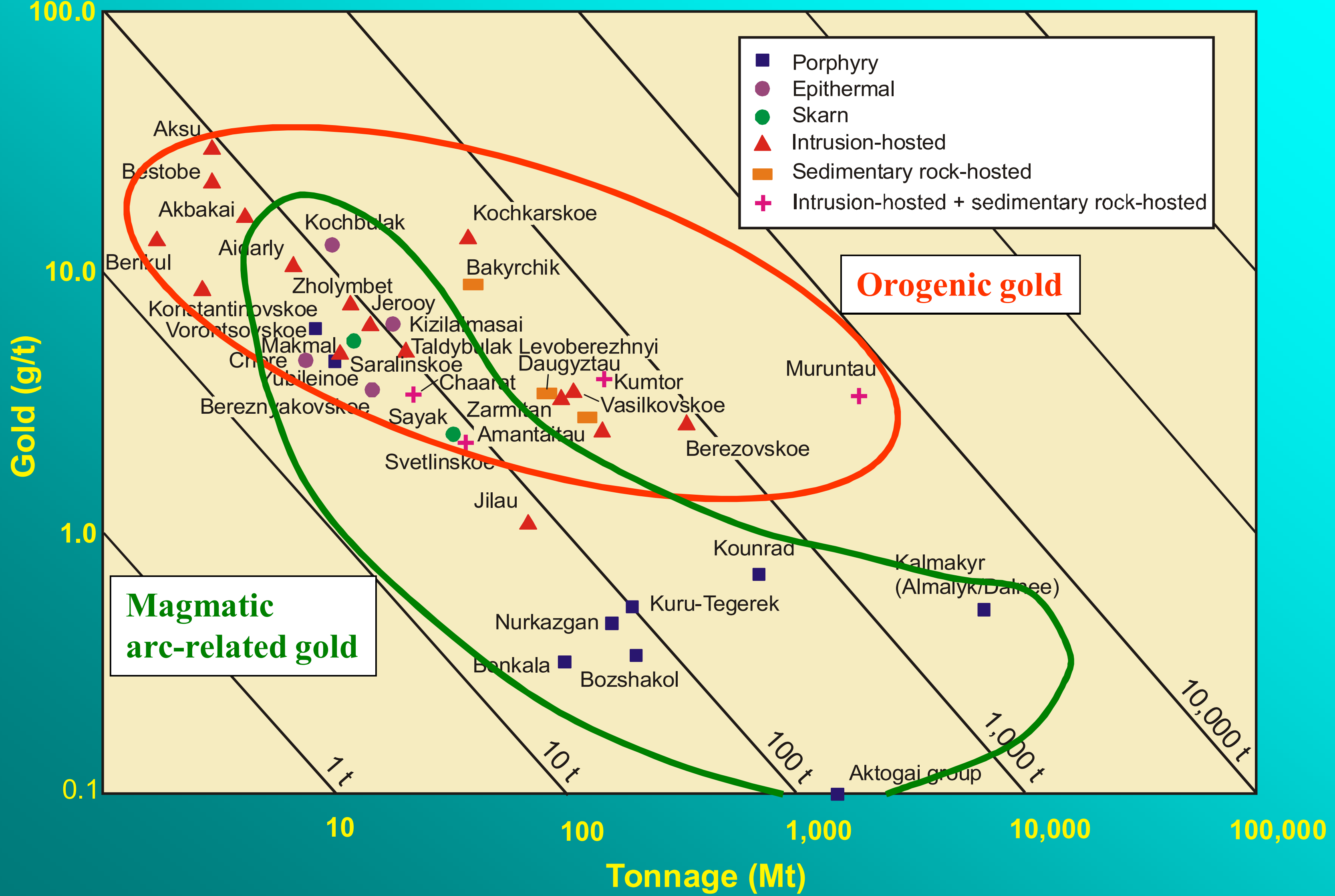
Compiled by Gosselin, Dubé, & Yakubchuk for World Minerals Geoscience Database Project; Geological Survey of Canada. GIS implementation by L.Chorlton

Central Eurasia: relative gold deposit size

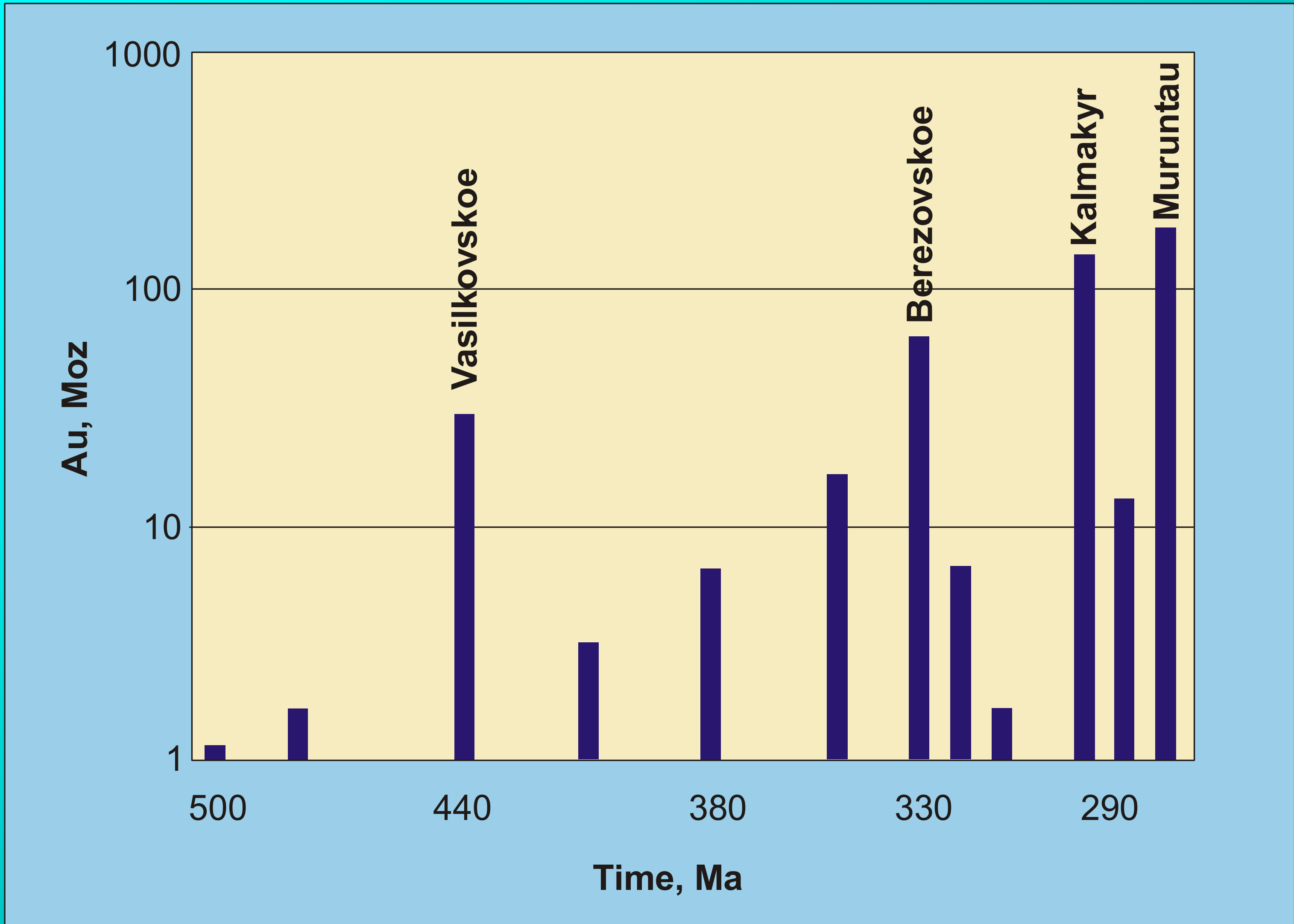


Compiled by Gosselin, Dubé, & Yakubchuk for World Minerals Geoscience Database Project; Geological Survey of Canada. GIS implementation by L.Chorlton

Grade-tonnage diagram for Au-bearing deposits of Kazakhstan and Central Asia

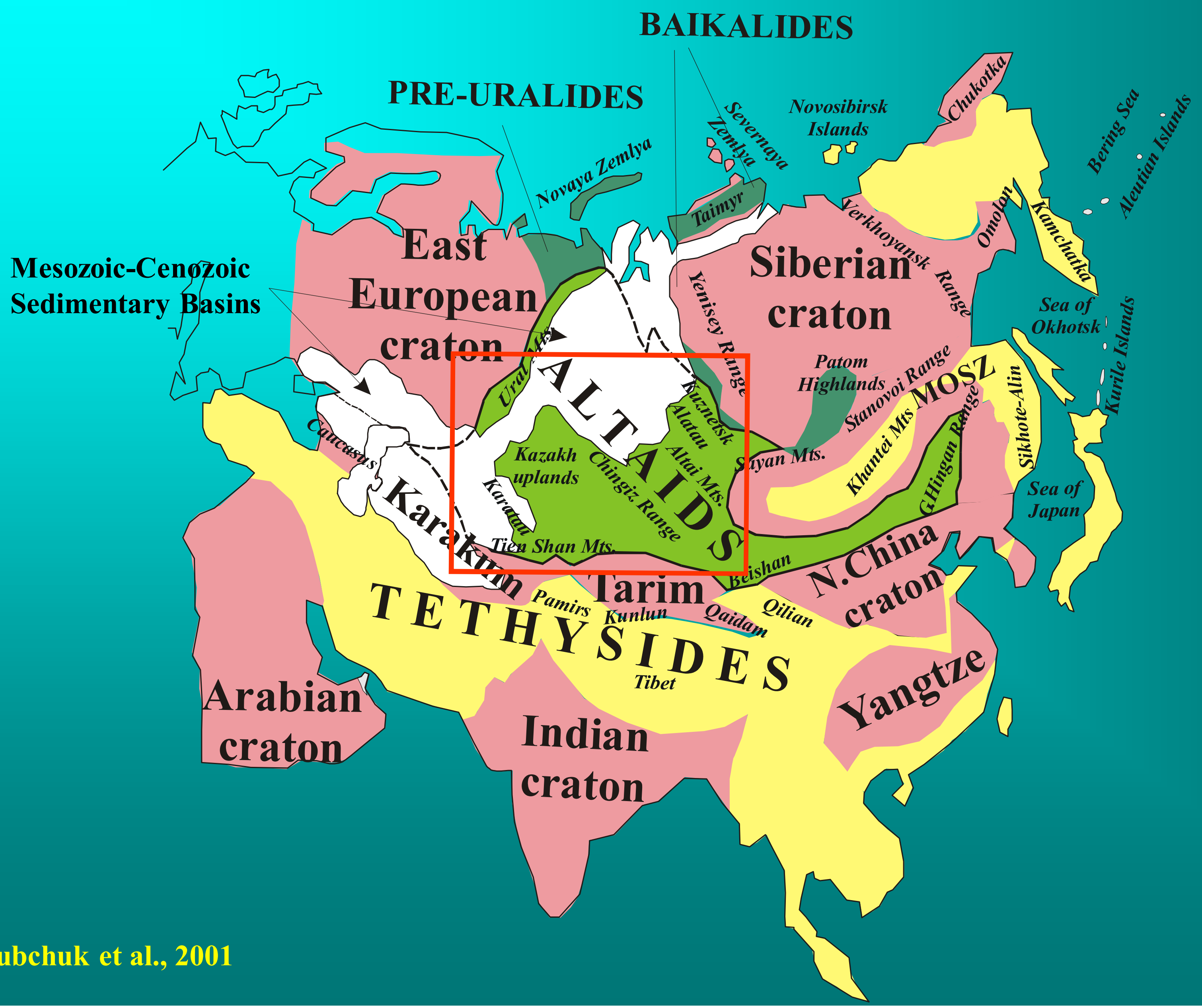


Time distribution of gold deposits in Kazakhstan and Central Asia



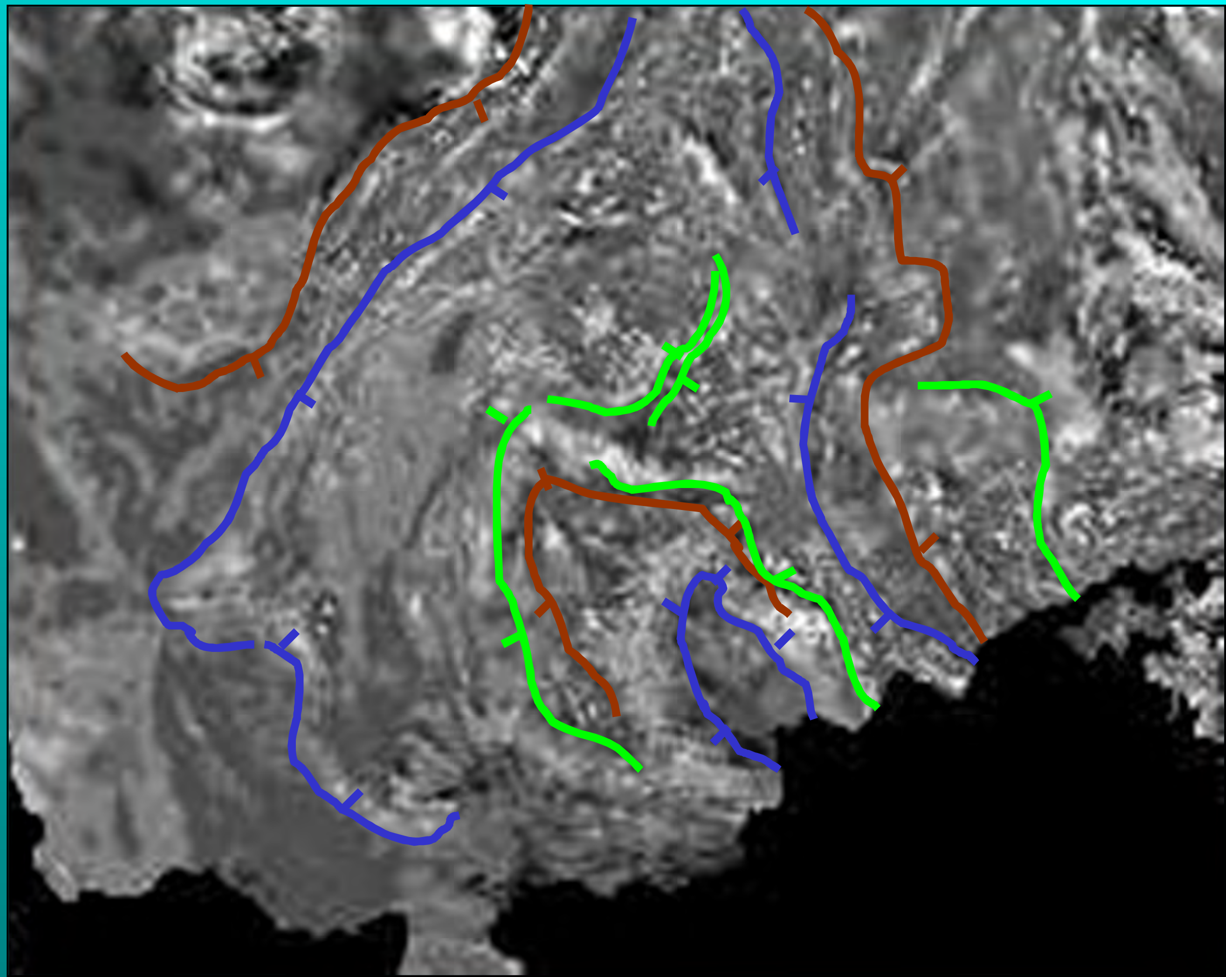
2. The Tien Shan gold province and the Altaid orogenic collage: tectonics and a model of its geodynamic evolution

Tectonic position of the Tien Shan gold province in Eurasia



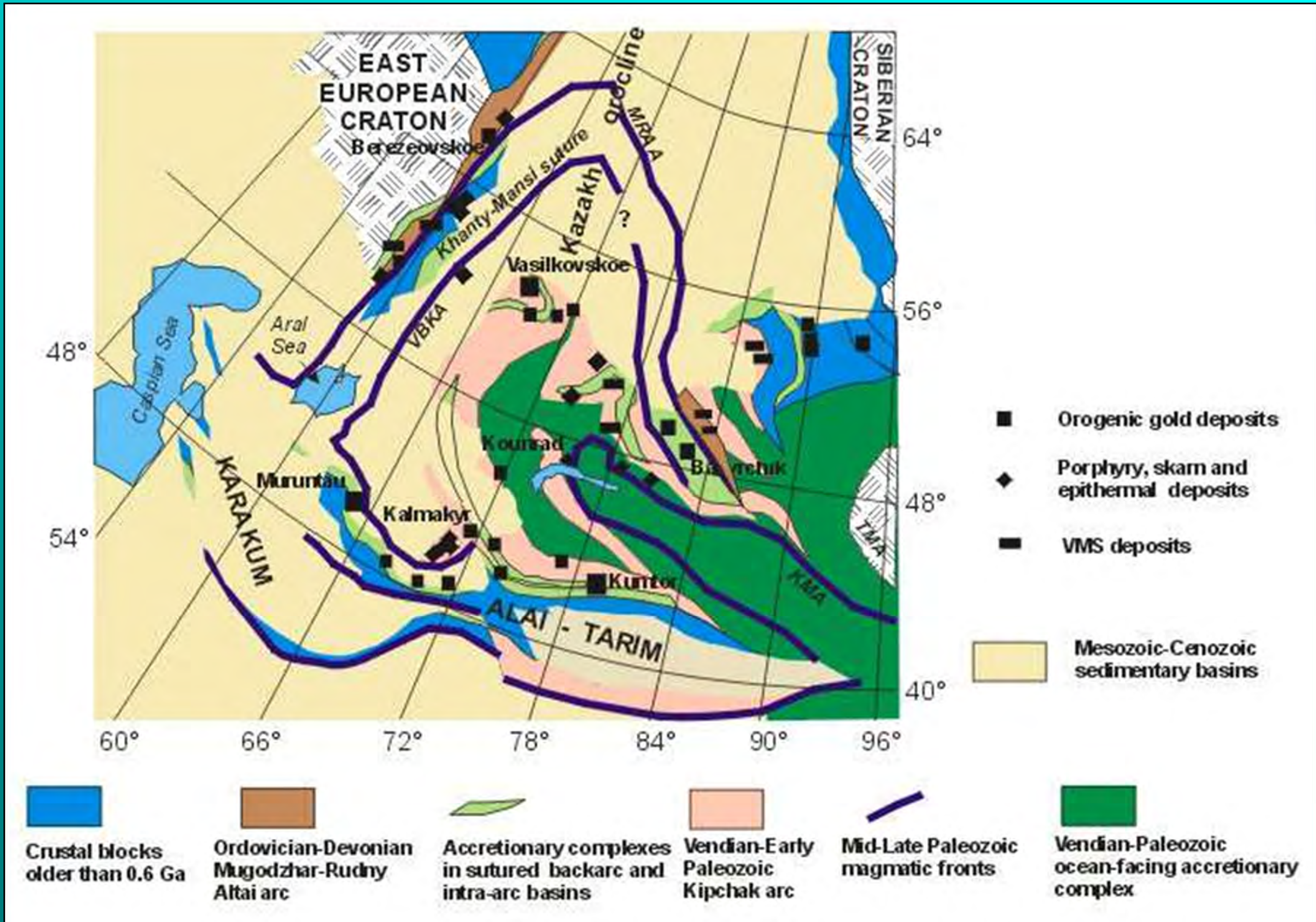
Yakubchuk et al., 2001

Geophysical characteristics: Western Altaids



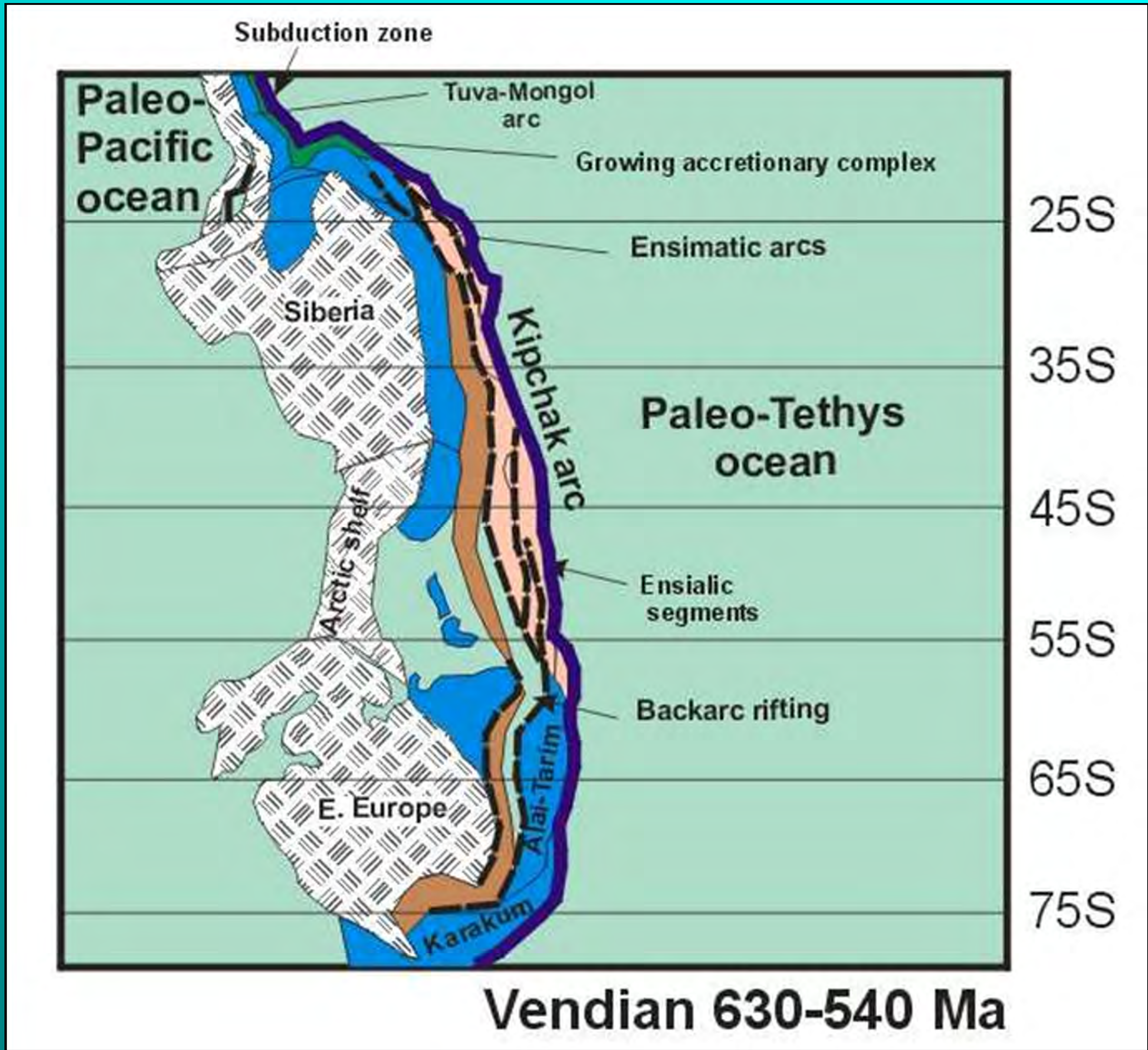
Tracing of the fronts of magnetic magmatic arcs reveals oroclinal structure of the Altaids.

Distribution of gold deposits in the western Altaids



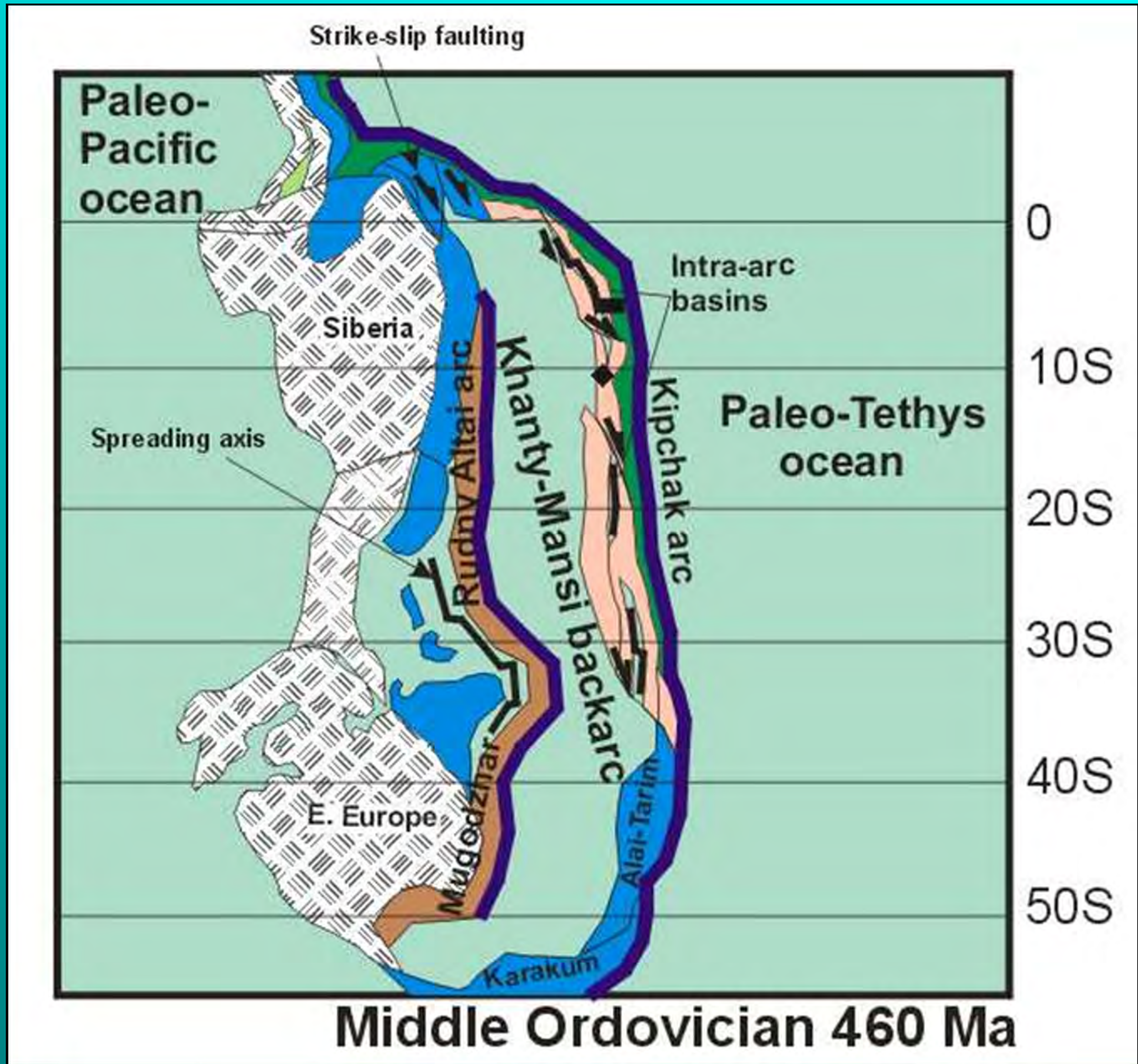
There was significant oroclinal bending of these arcs during the Paleozoic.

Plate tectonic reconstructions



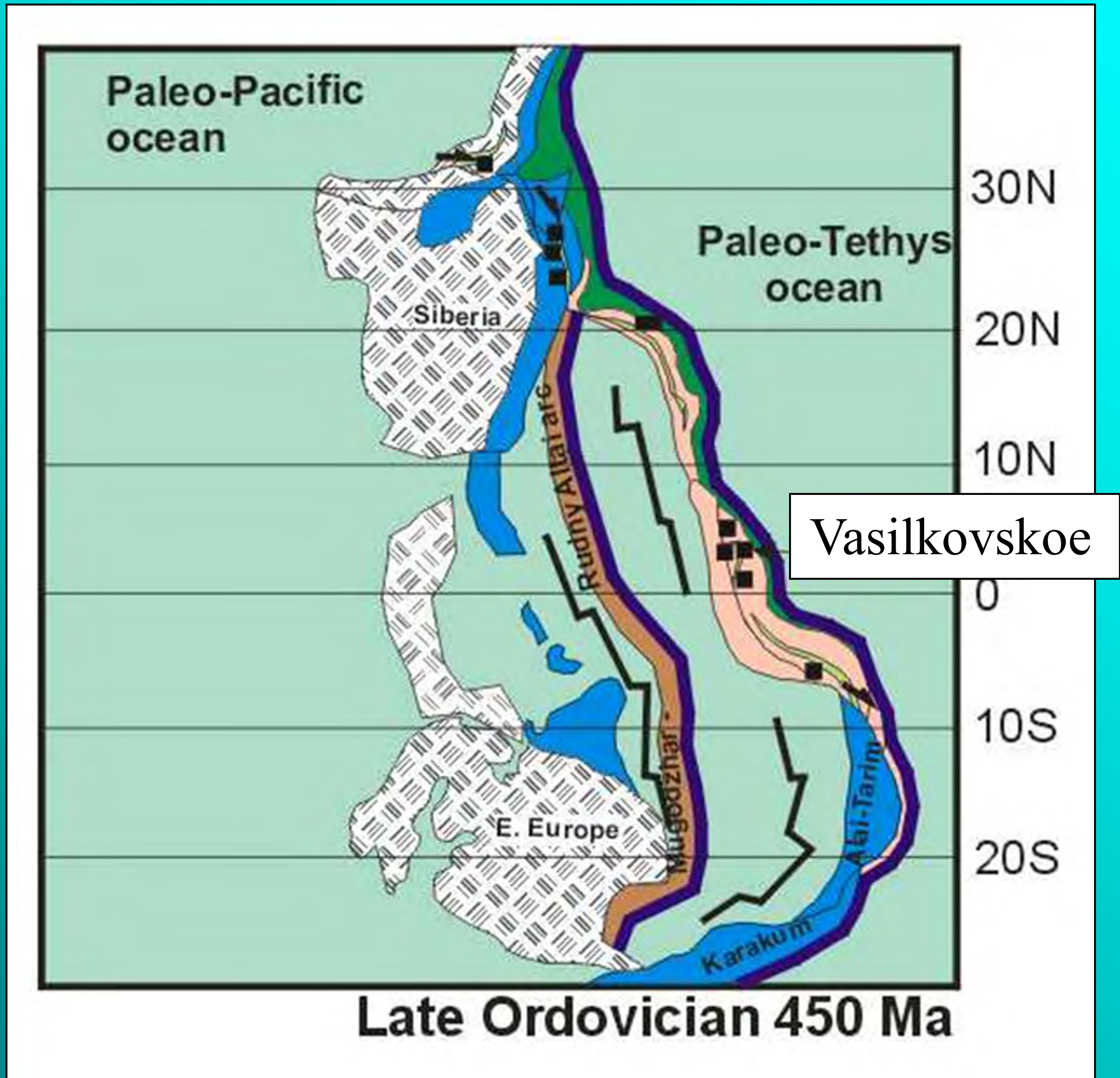
Beginning of backarc spreading between the Kipchak arc and Siberia-E.Europe; Tuva-Mongol arc between the Paleo-Tethys and Paleo-Pacific Oceans

Plate tectonic reconstructions



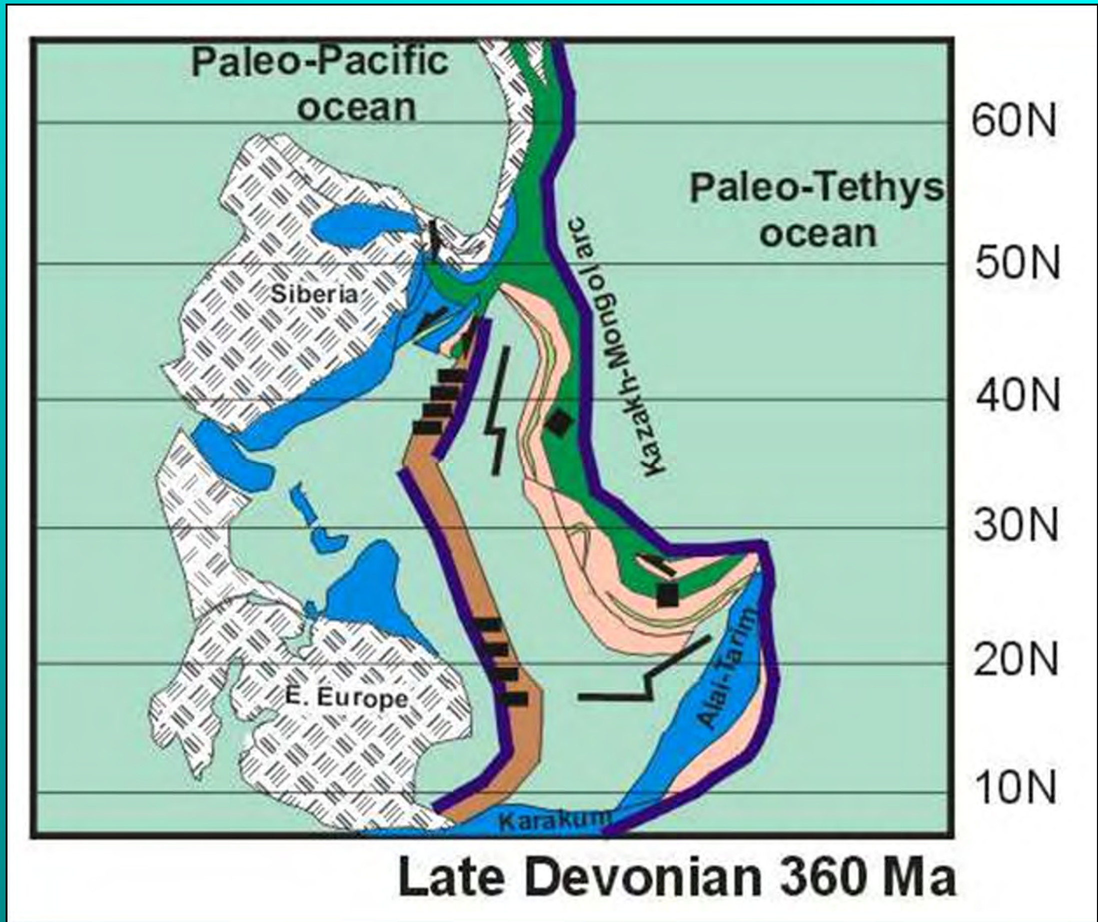
Initiation of the Mugodzhar-Rudny Altai arc behind the Kipchak arc; Intra-arc spreading; VMS deposits

Plate tectonic reconstructions



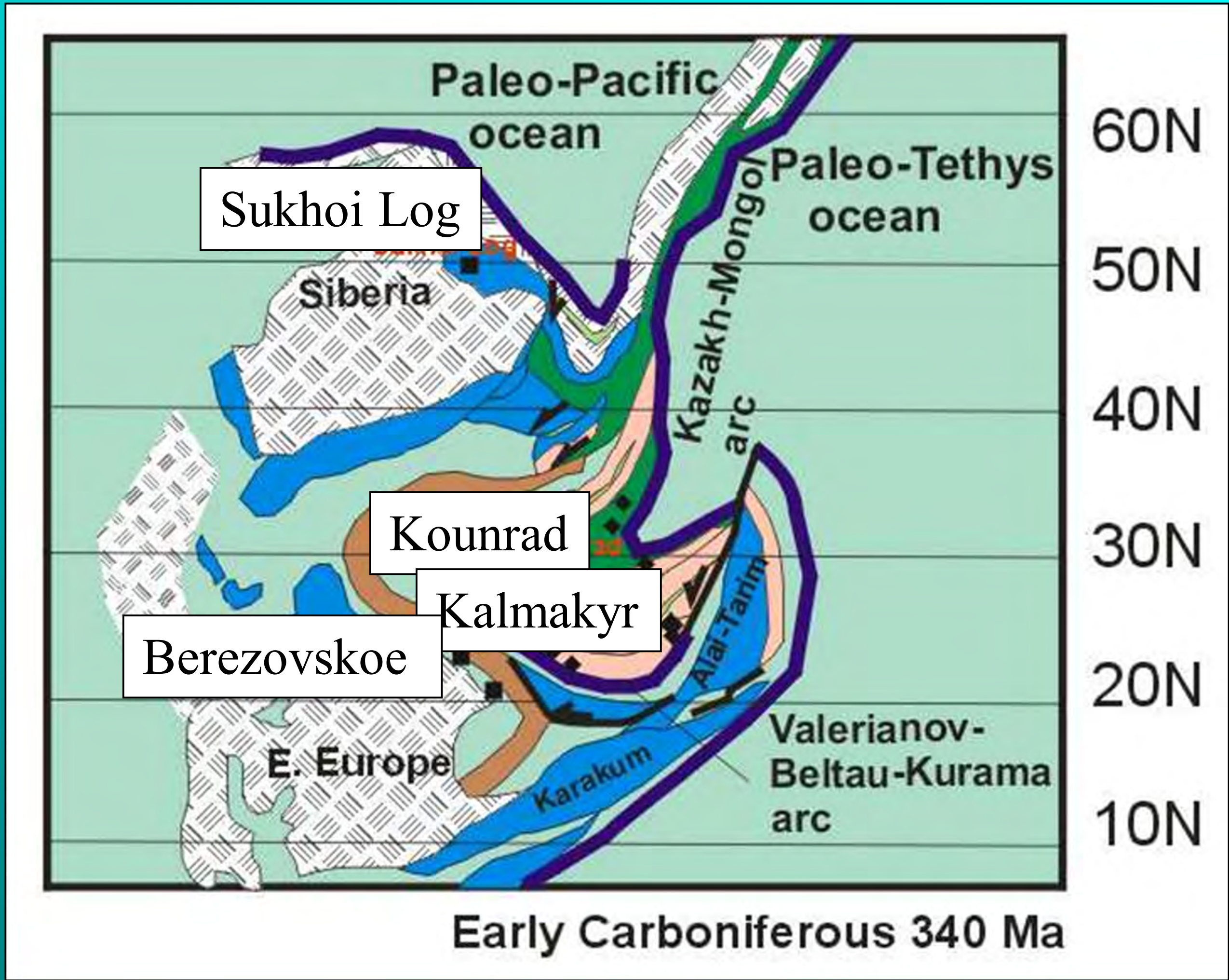
Beginning of clockwise rotation of Siberia, intra-arc collision, emplacement of first orogenic gold deposits, e.g., Vasilkovskoe

Plate tectonic reconstructions



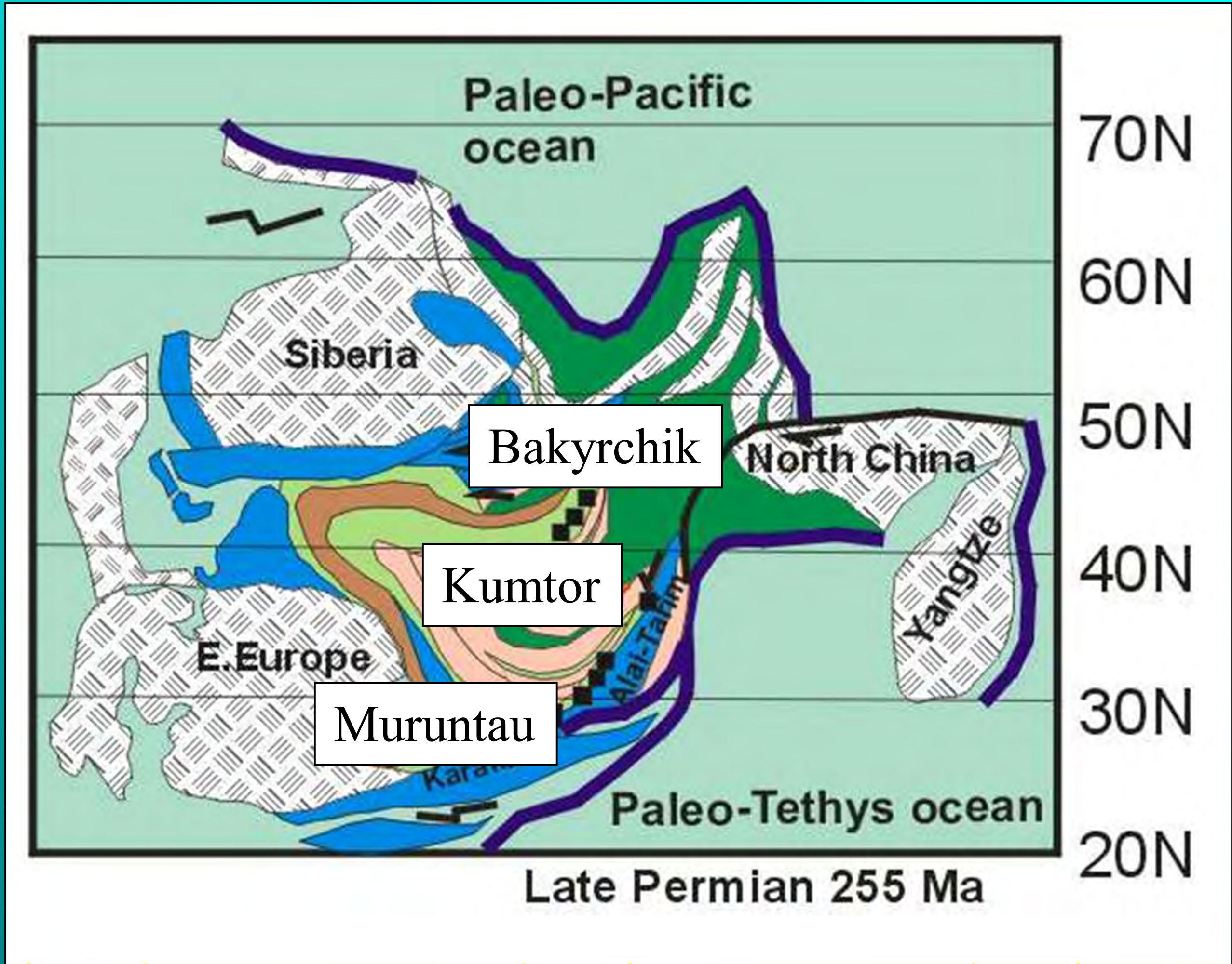
Kazakh-Mongol arc amalgamated fragments of the Kipchak and Tuva-Mongol arcs; cContinuing rotation of Siberia and oroclinal bending of the Kazakh-Mongol arc; Emplacement of porphyry and VMS deposits

Plate tectonic reconstructions



Further rotation, further oroclinal bending of the arcs, and their "intrusion" between Alai-Tarim and Siberia towards Eastern Europe with transform boundary along the Tien Shan; Emplacement of major porphyry and orogenic gold deposits

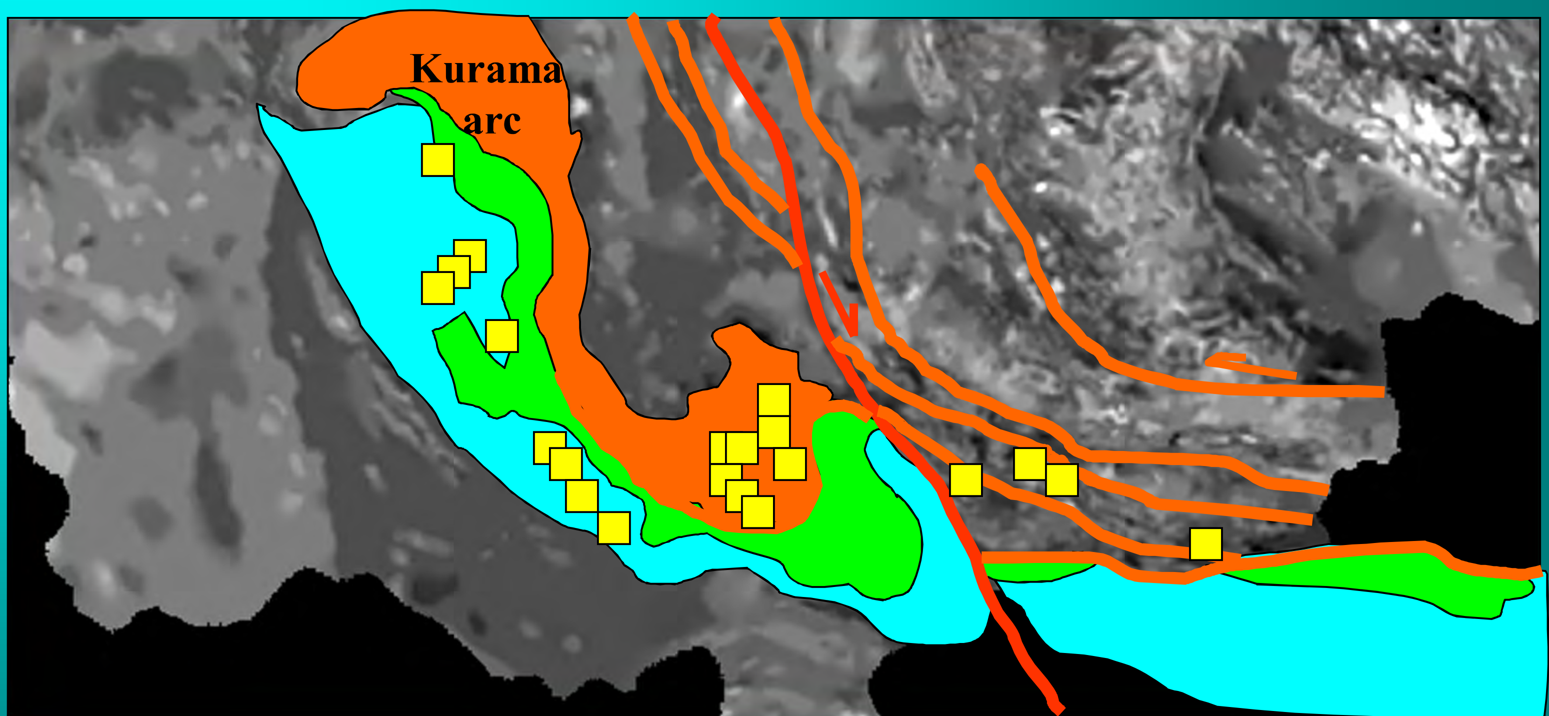
Plate tectonic reconstructions



Termination of rotation and amalgamation of the western portion of the Altaid orogenic collage; Emplacement of Muruntau-style orogenic gold deposits in those parts of the former Backarc basins that formed where the arcs remained attached to their rear continents, in addition to collision a possibility of the slab-window mechanism cannot be ruled out to explain extraordinary Gold endowment of the province

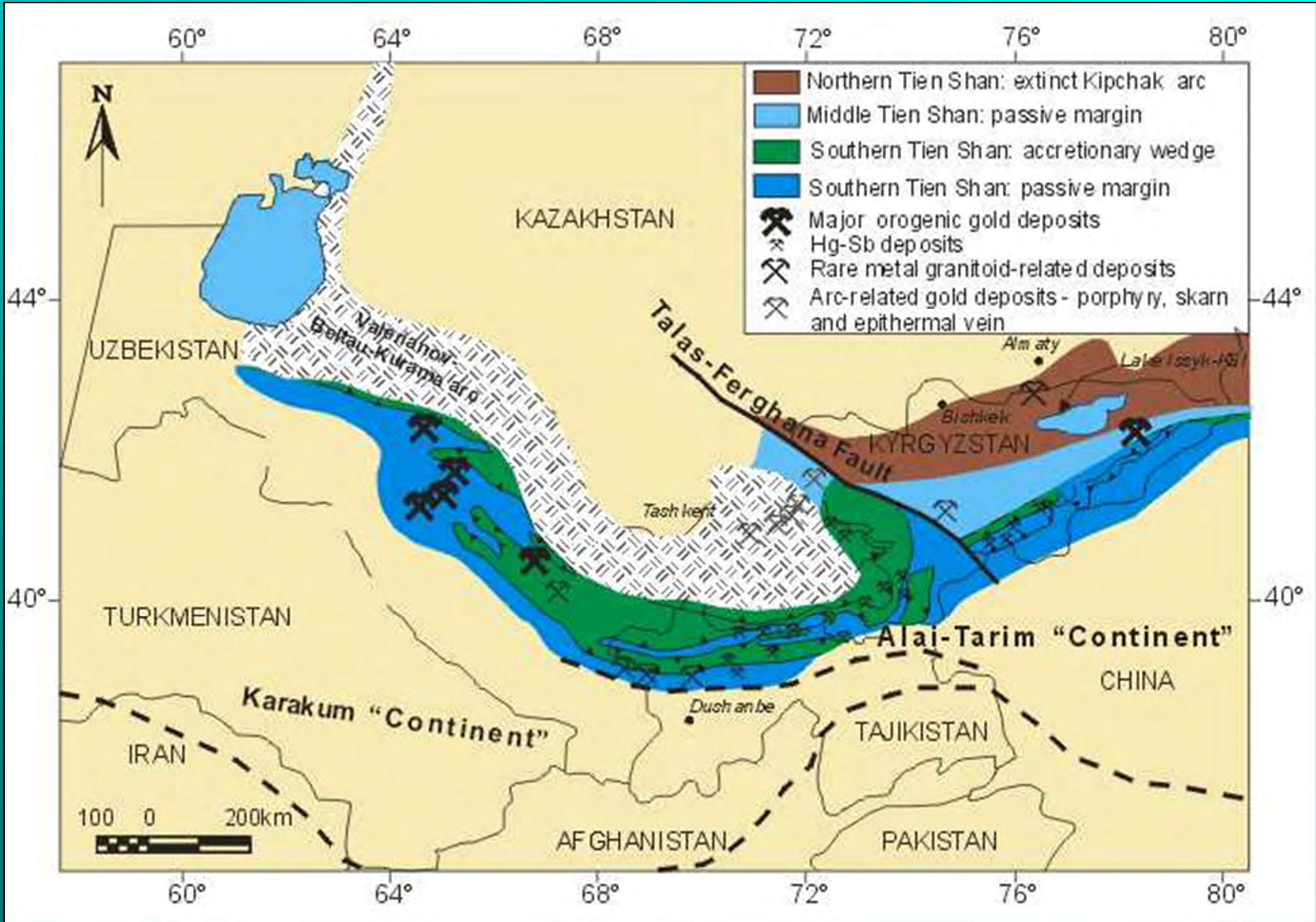
3. Geology of the Tien Shan gold province

Magnetic anomalies and major structural elements of the Tien Shan

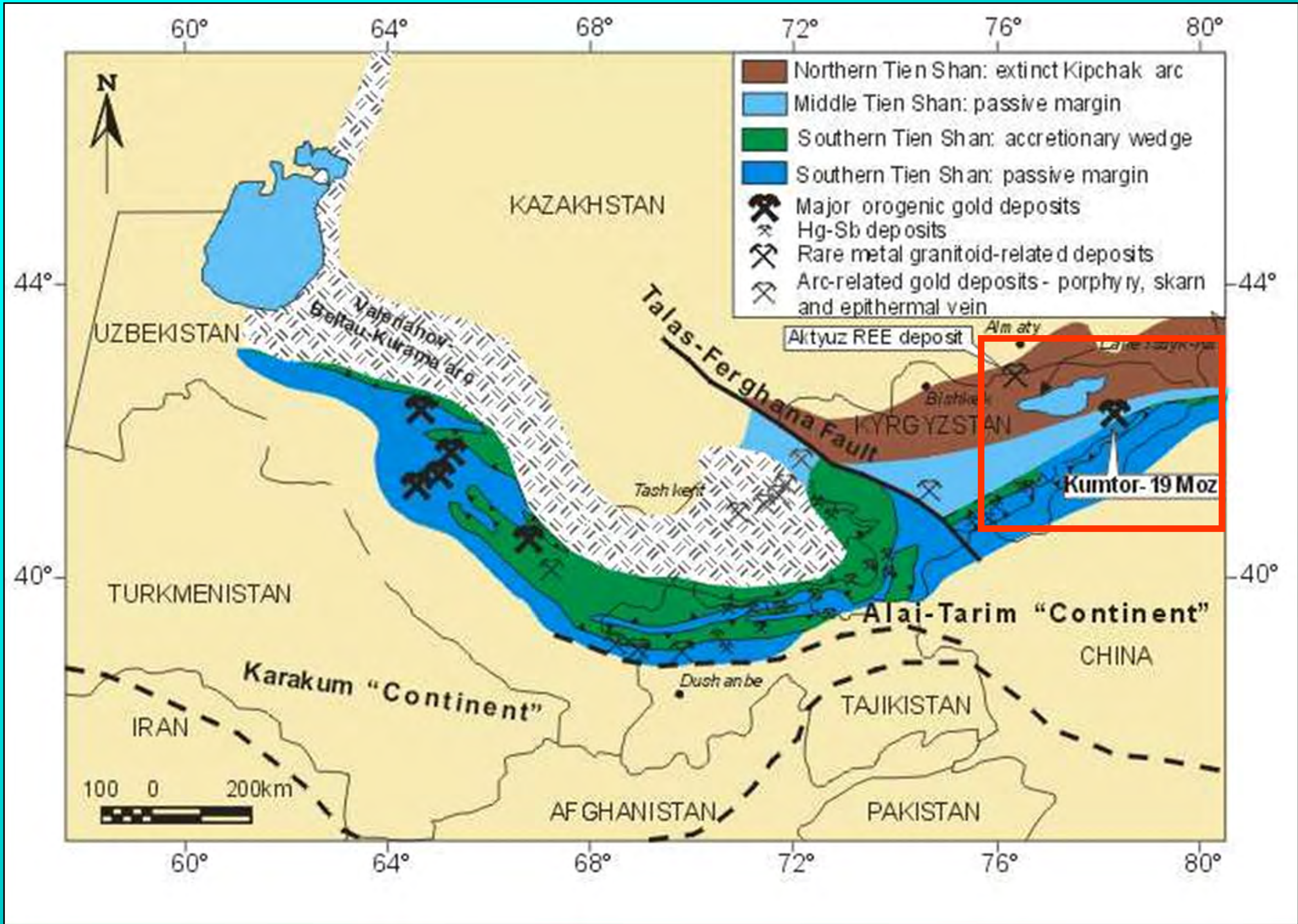


- Middle-Late Paleozoic passive margin rocks, accretionary complex and magmatic arc form a collisional belt of the Tien Shan
- Orogenic gold deposits occur in the passive margin sediments, whereas porphyry and epithermal deposits sit within the magmatic arc
- Mineral trends are controlled by Late Paleozoic sinistral transform-like faults
- Post-mineral Mesozoic-Cenozoic Talas-Ferghana fault offsets all the structures

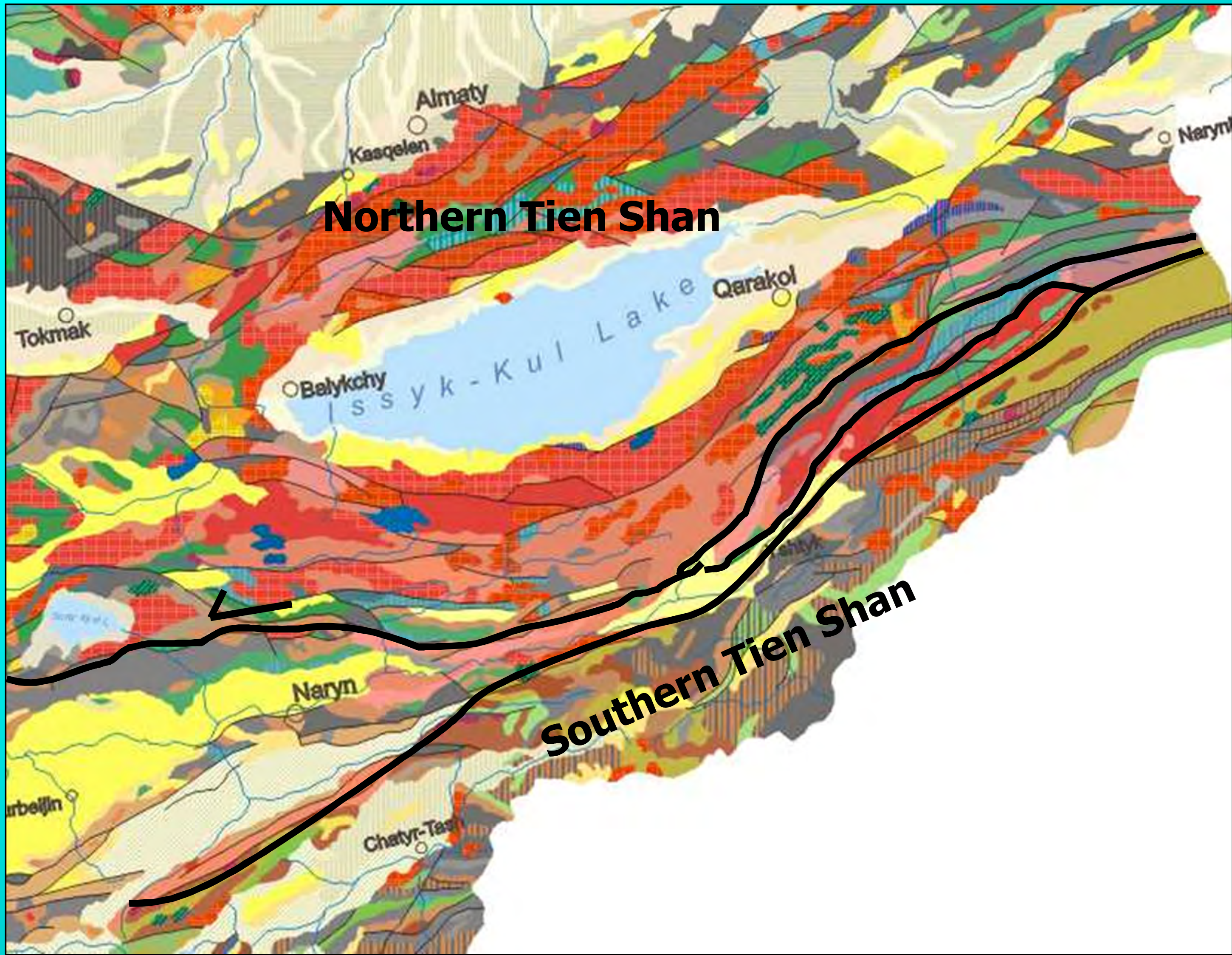
Tectonics, Mineral Districts of the Tien Shan and Deposit Case Studies



Issyk-kol District



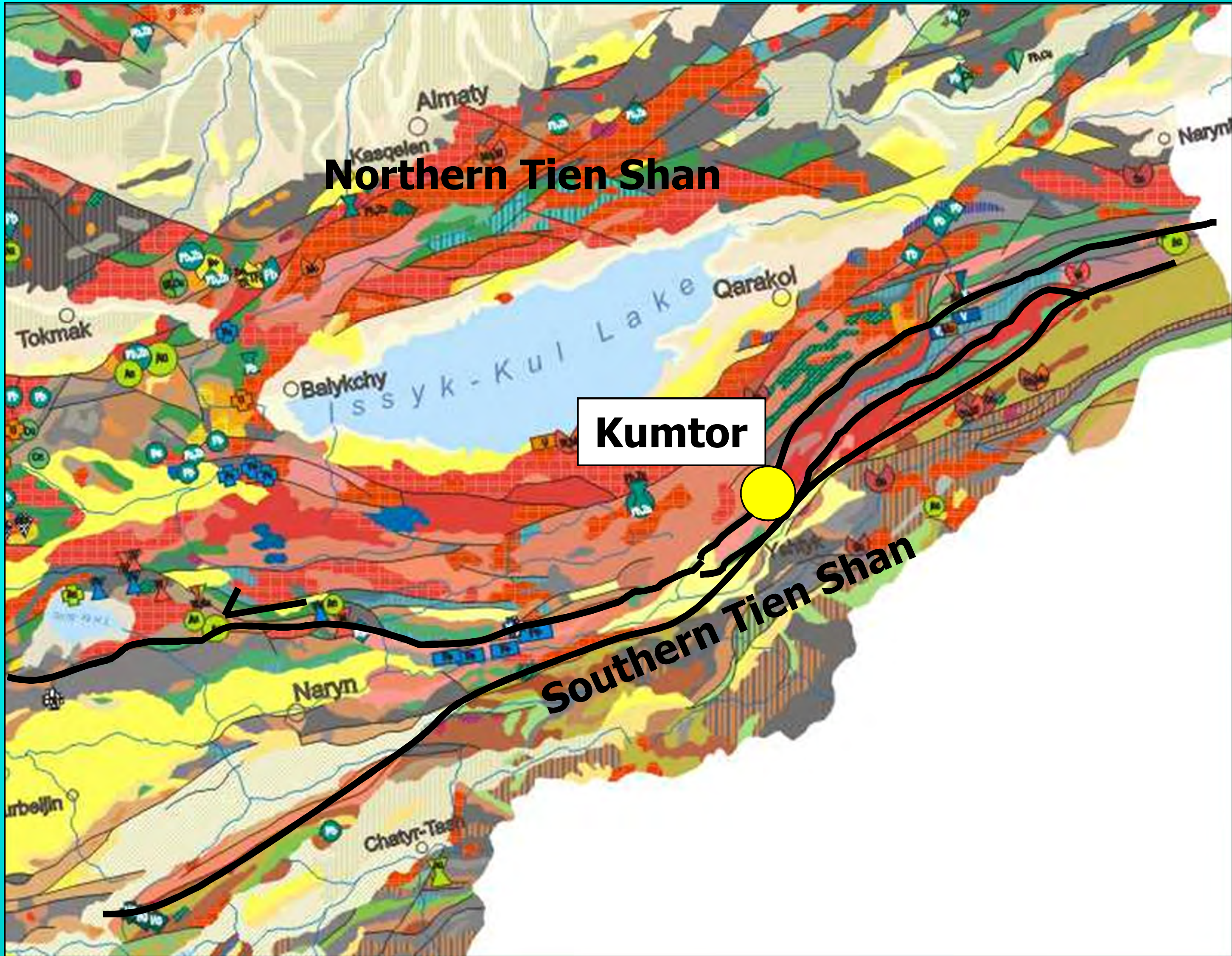
Issyk-kol District



Major shear zone between the northern and southern Tien Shan

Base map: Mineral Deposits Map of Central Asia, Seltmann, Shatov and Yakubchuk (eds), 2001

Issyk-kol District: deposits



Sinistral shear zones may be a principal controlling factor here

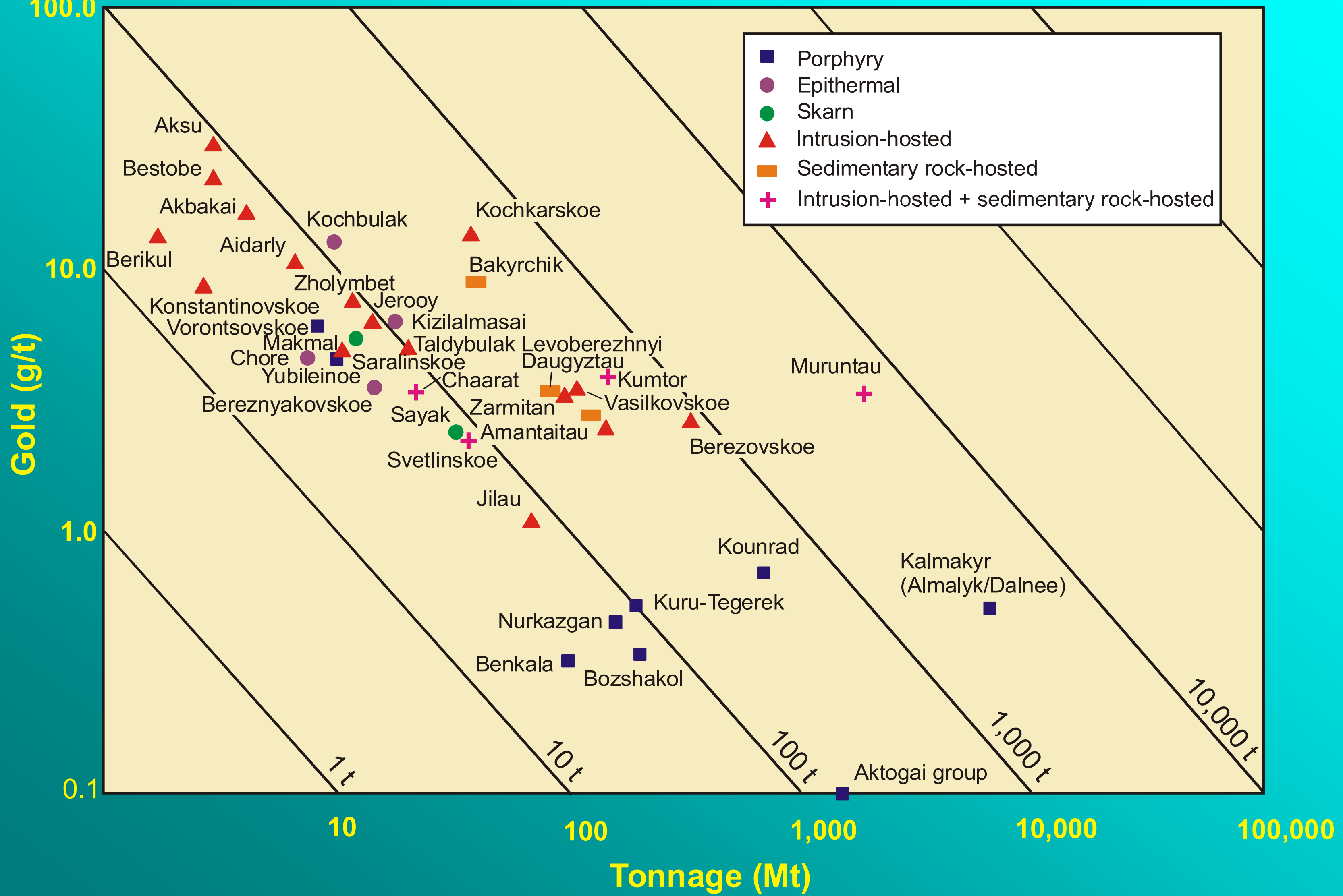
Base map: Mineral Deposits Map of Central Asia, Seltmann, Shatov and Yakubchuk (eds), 2001

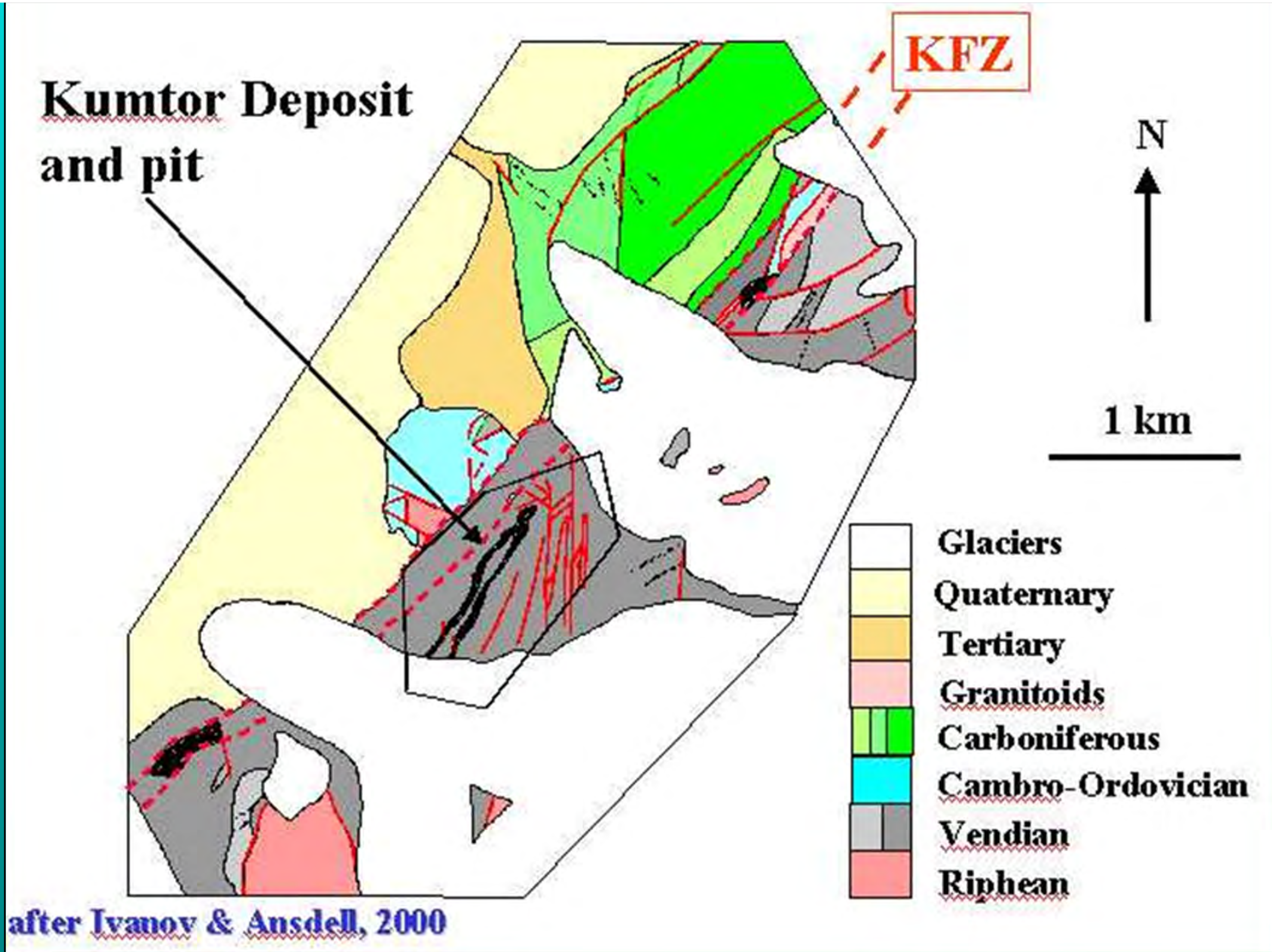
Kumtor Deposit

- First Au-bearing pyritic rocks found in 1978 during regional geophysical works
- Operated by JV between Cameco and Kyrgyzaltyn
- Total resource is 514 t Au
- However economic resource 288 t Au @ 3.57 g/t
- Annual product is approximately 660,000 Oz Au
- 9.3 Mt of this ice has been removed before pit construction

Photo A. Wilde

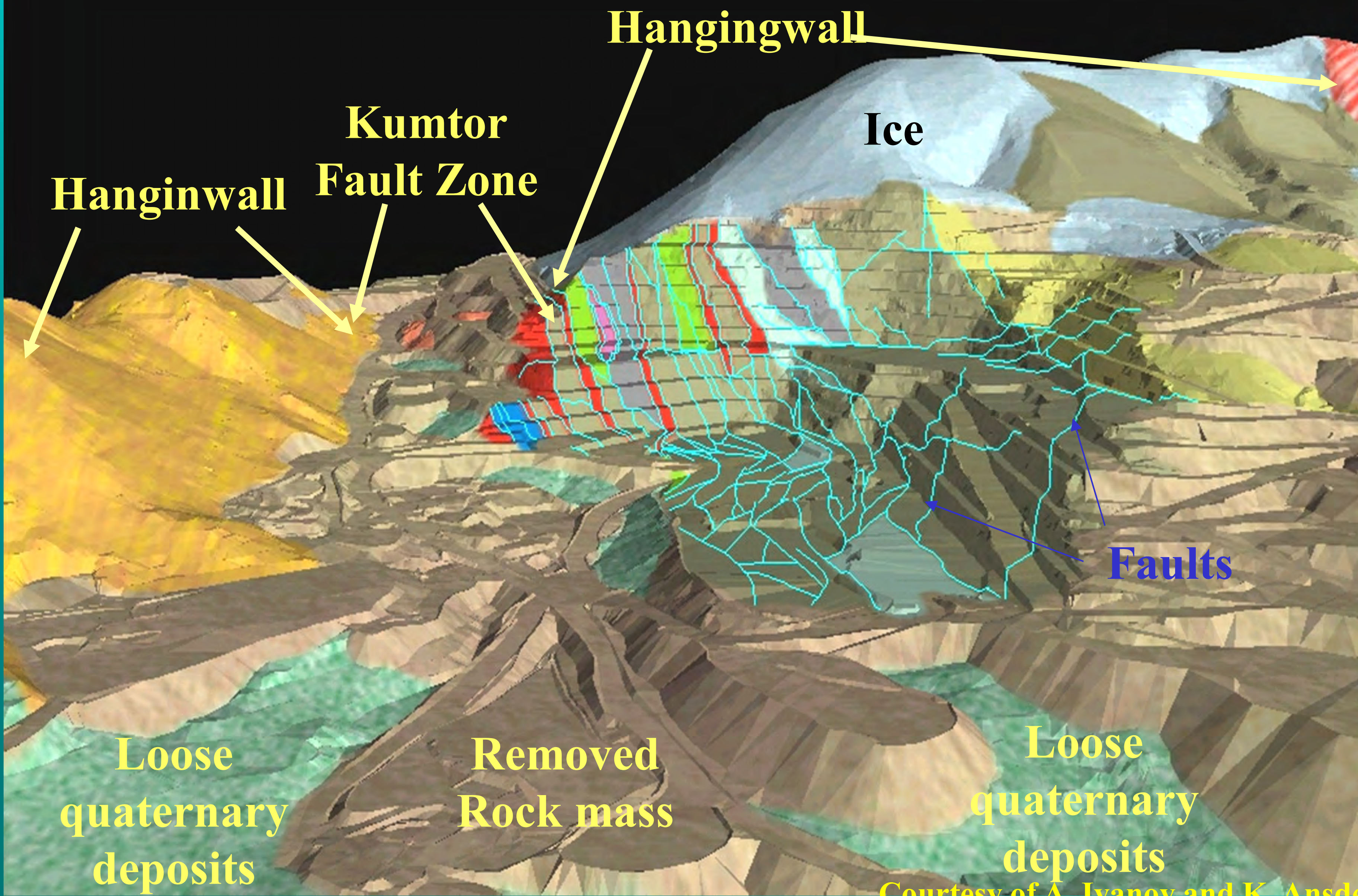
Kumtor deposit





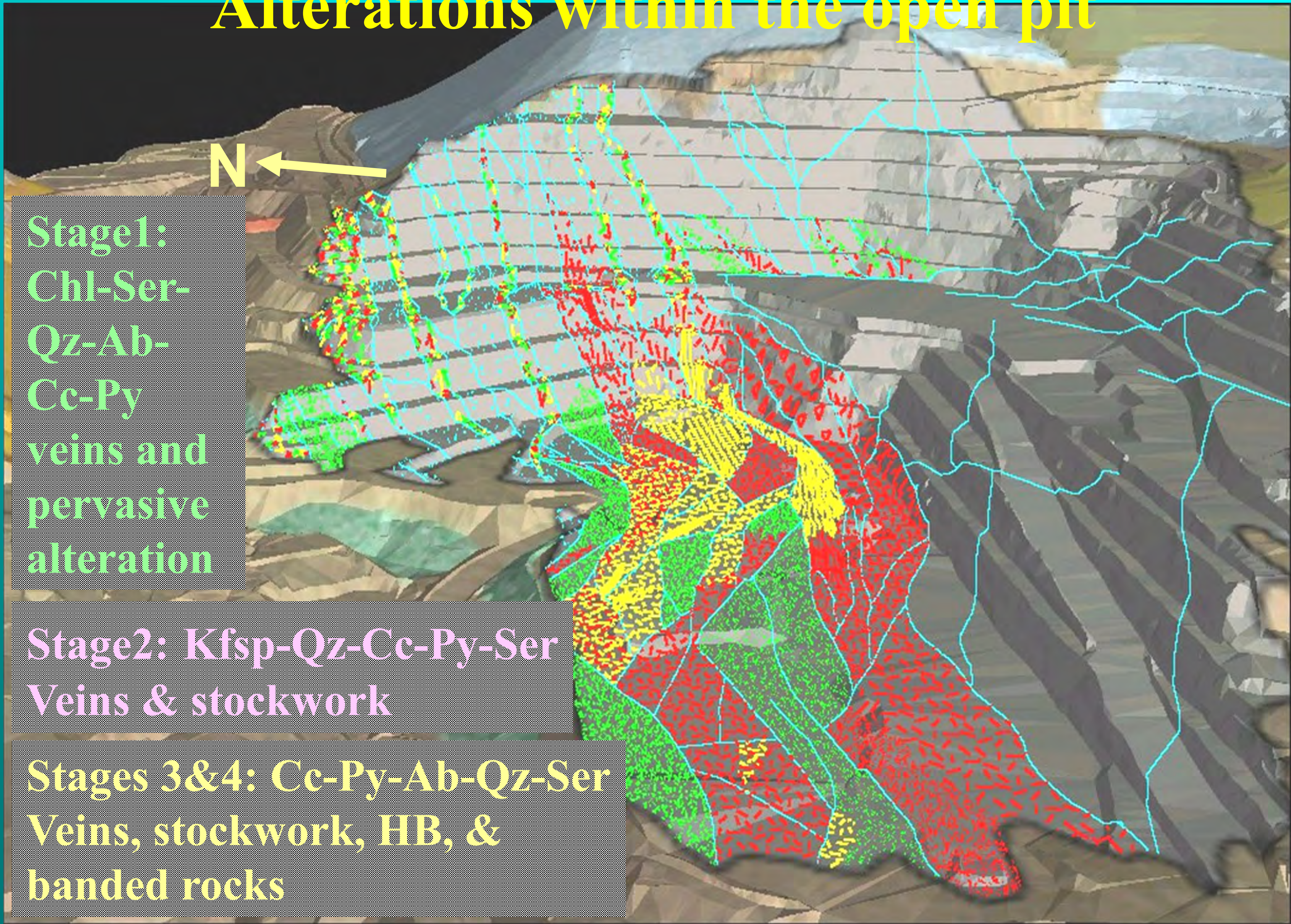
- Hosted in a Vendian carbonaceous phyllite
- The orebody is oriented subparallel to the Kumtor Fault Zone (KFZ)
- Mineralization occurs in multistage stockwork and hydrothermal brecciation of Late Paleozoic ? age

Lithological units in the open pit area



Courtesy of A. Ivanov and K. Ansdell

Alterations within the open pit

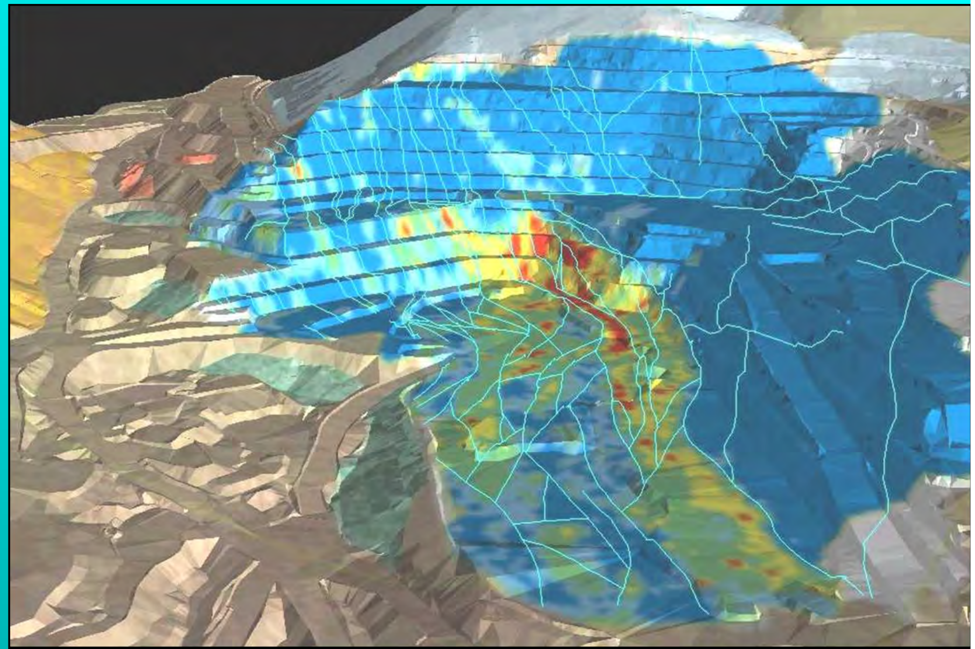


Courtesy of A. Ivanov and K. Ansdell

Kumtor Deposit

NE looking view of the Kumtor open pit in August 2001. SE dipping Kumtor fault is shown in red. In contrast to its traditional interpretation as a reverse fault, some kinematic indicators suggest it has a sinistral strike-slip component. The mineralised gold ore bodies occur in its hanging wall near tracks (also see next slide).

Photo A. Yakubchuk



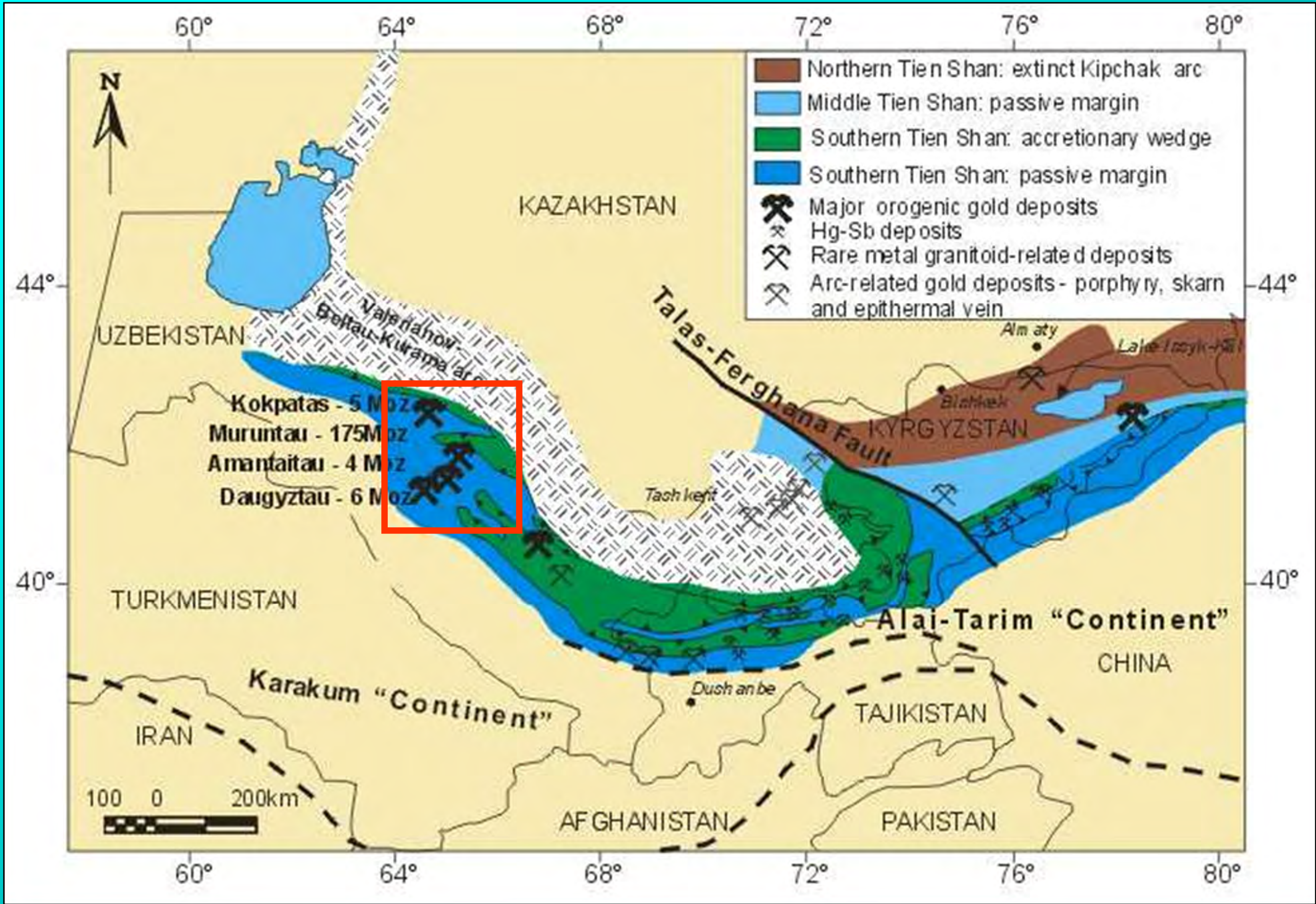
Au g/t

7.0 3.0 0.8 0.3 0.0

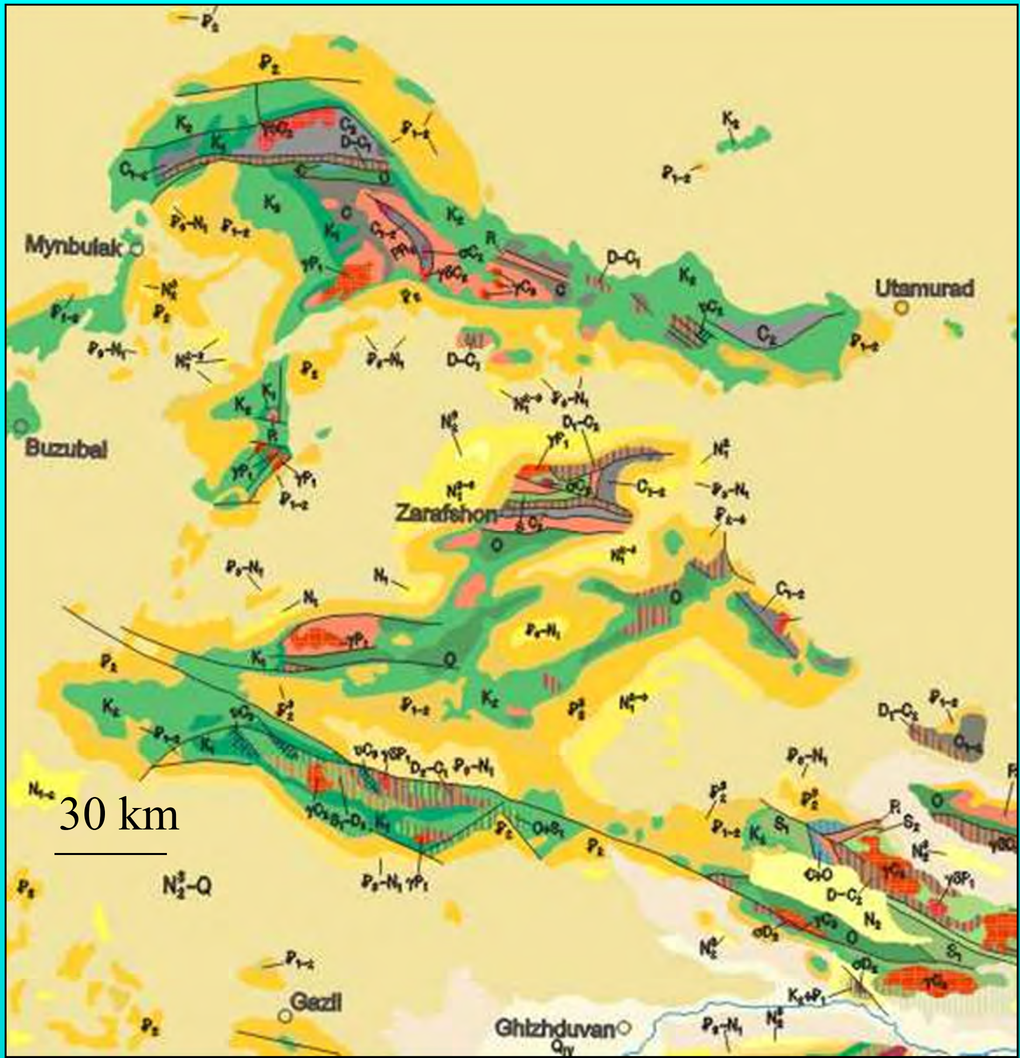
A computer stimulation of the Kumtor open pit with gold grades shown.

Courtesy of A. Ivanov and K. Ansdell

Case Studies: Kyzylkum District



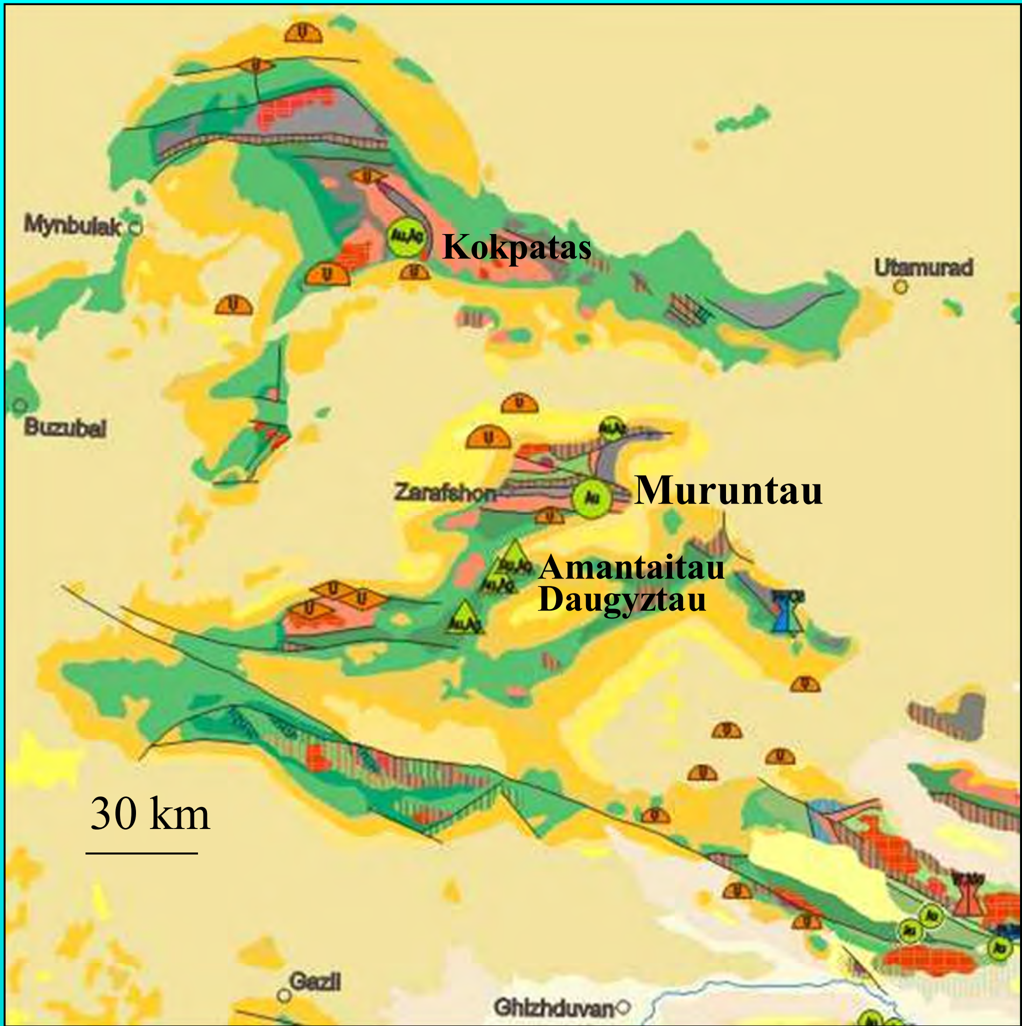
Case Studies: Kyzylkum District



- Extensive Mesozoic-Cenozoic sedimentary basins
- Isolated outcrops of Late Proterozoic to Late Paleozoic rocks
- domination of metamorphosed clastic sediments with black shales
- presence of Carboniferous-Permian I-type granite intrusions

Mineral Deposits Map of Central Asia, Seltmann, Shatov and Yakubchuk (eds), 2001

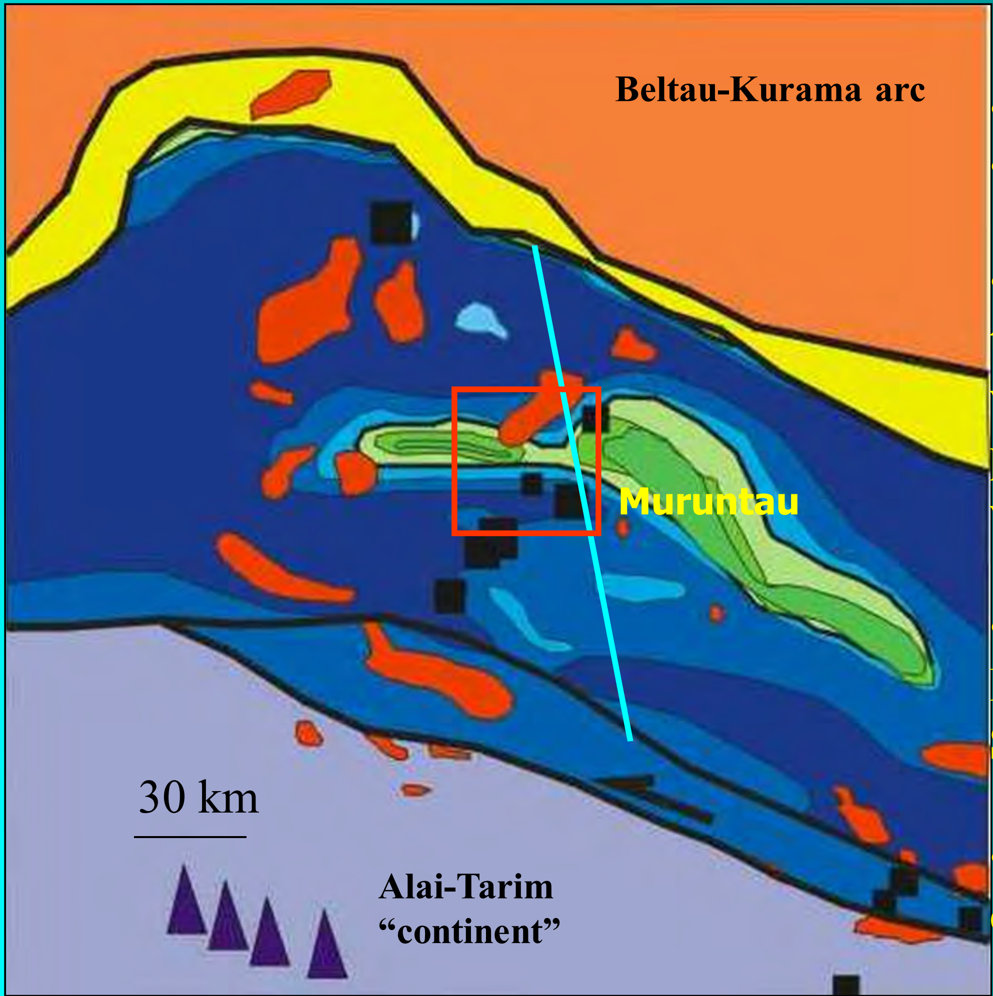
Case Studies: Kyzylkum District

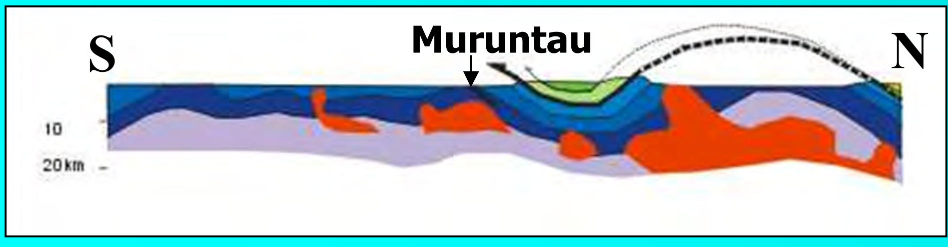


- Largest gold deposits occur in the Lower Paleozoic Besopan Formation
- Disseminated and vein stockwork mineralization style
- Some deposits associate with granitoid intrusions
- Understanding of the linkage between isolated outcrops is important

Mineral Deposits Map of Central Asia, Seltmann, Shatov and Yakubchuk (eds), 2001

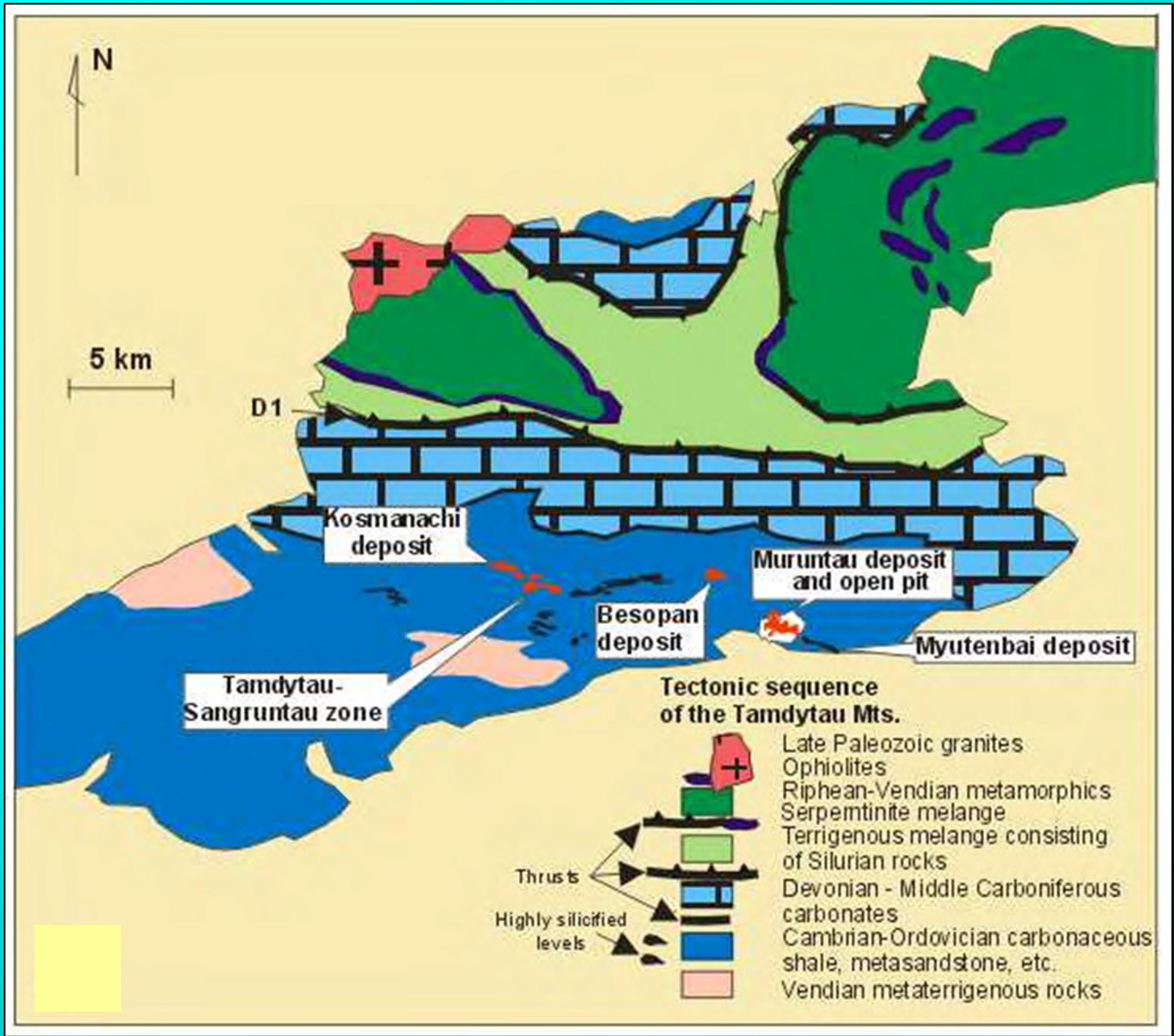
Case Studies: Kyzylkum District





- Collisional zone between the Beltau-Kurama arc and Alai-Tarim "continent"
- Passive margin(?) rock sequence with tectonically superimposed accretionary wedge or alternatively all this tectonic package may constitute an accretionary wedge (e.g., Savchuk et al., 1991, 1993)
- Largest gold deposits occur below in the Lower Paleozoic passive margin Sedimentary sequence
- Granitoid intrusions display significant extent especially at the depth

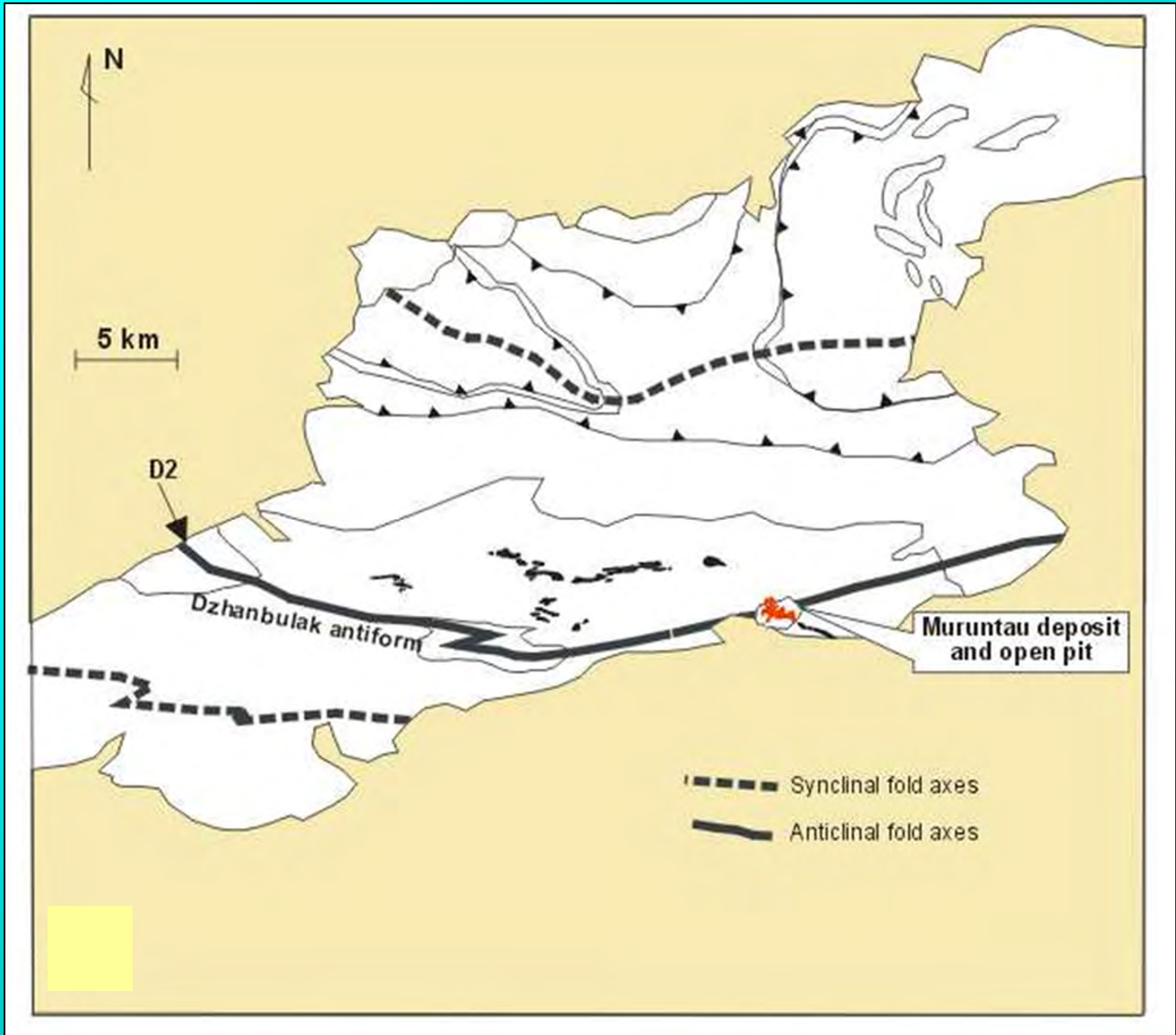
Kyzylkum District: Tamdy Mountains



- Imbricated thrust structure with accretionary wedge rocks being superimposed on top of passive margin sedimentary rock sequences
- Multi-phase deformations
- Post-collisional granitoids
- Economic gold mineralization in the apparent autochthonous rocks

Compiled using Savchuk et al., 1991; Drew, 1993

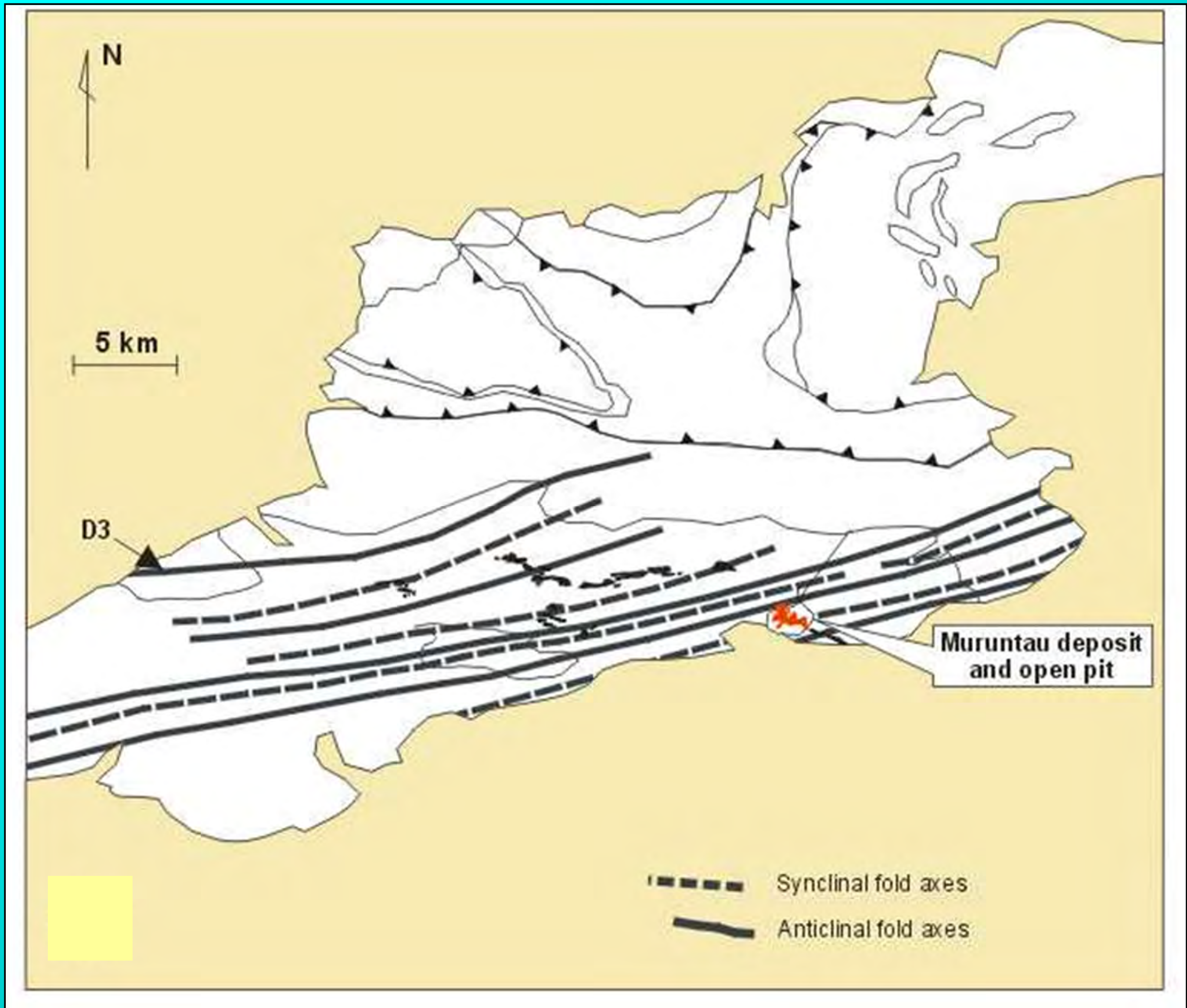
Kyzylkum District: Tamdy Mountains



- A silicified sulfide-rich folded Tamdytau-Sangruntau thrust? zone can be traced within the passive margin sequence for more than 20 km following the tectonic stratification

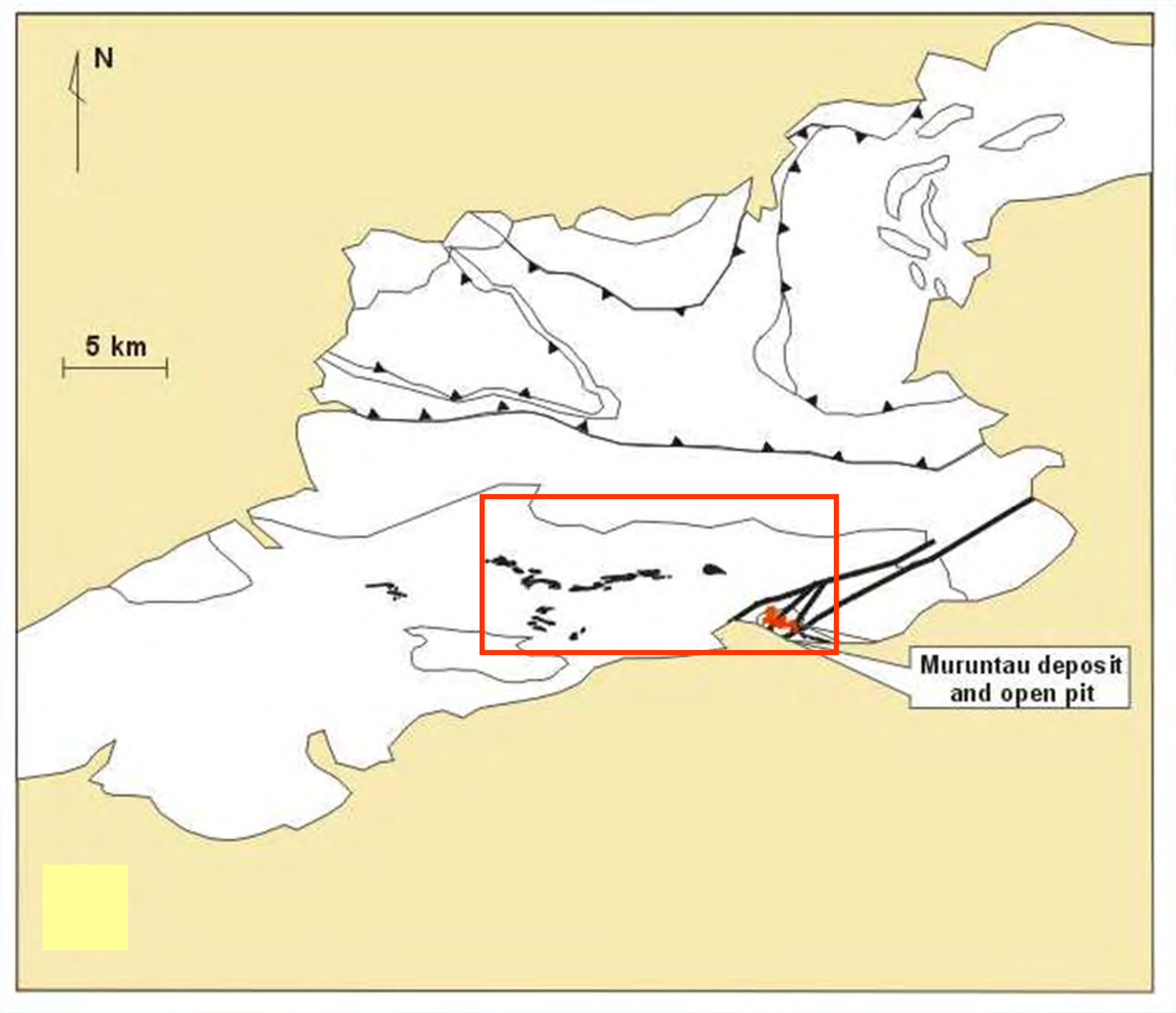
- Muruntau deposit occurs at the closure of the D2 Dzhanbulak anticline

Kyzylkum District: Tamdy Mountains



- Muruntau deposits coincides with the most tightly-spaced part of en echelon system of D3 folds, controlling Q3 high-Au veins

Kyzylkum District: Tamdy Mountains

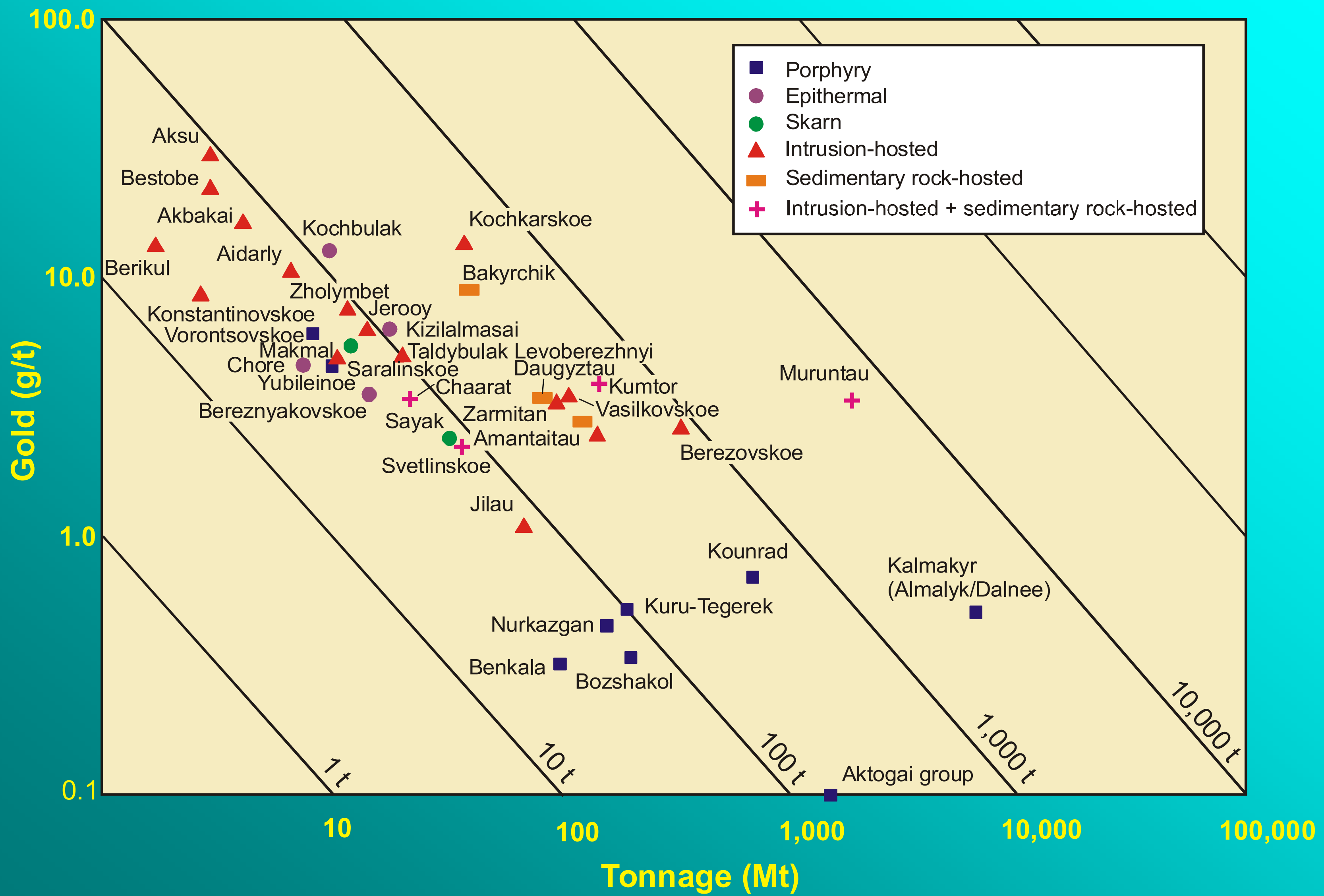


- Muruntau deposits coincides with the youngest system of NE-trending subvertical strike-slip? faults which control positioning of the late Ag veins

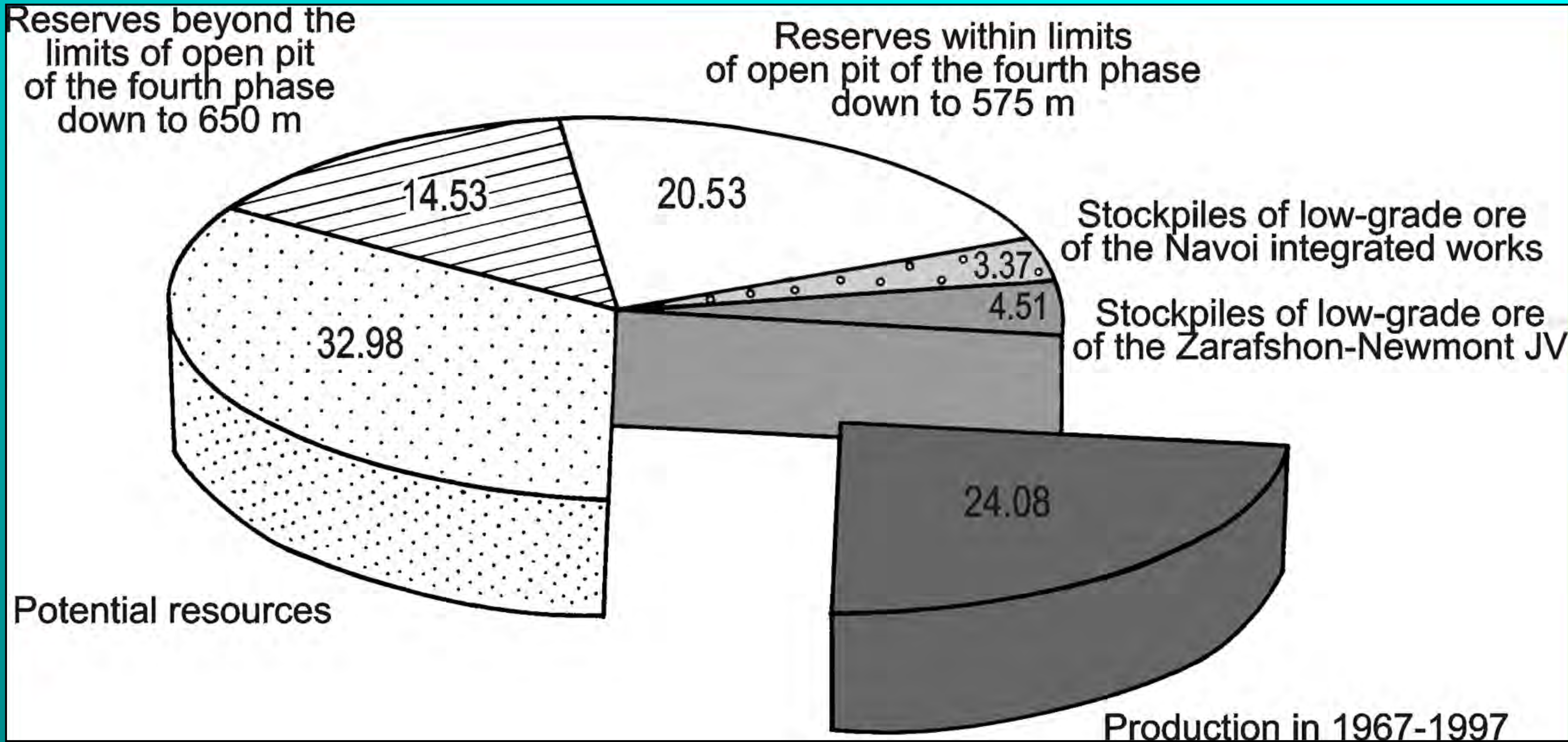
Muruntau Deposit

- Discovered in the 1950s following old workings and geochemical anomalies
- First exploration works focussed on high-grade quartz veins and showed no economic potential of the deposit
- Drill testing of low-grade disseminated mineralization showed presence of huge resource of 175 Moz Au @ 2.5-3 g/t
- Operated by state-owned Navoi Mining and Metallurgical Combine, plus tailings processing by Zerafshon-Newmont JV
- Annual production ~2 Moz Au (since 1967)

Muruntau deposit



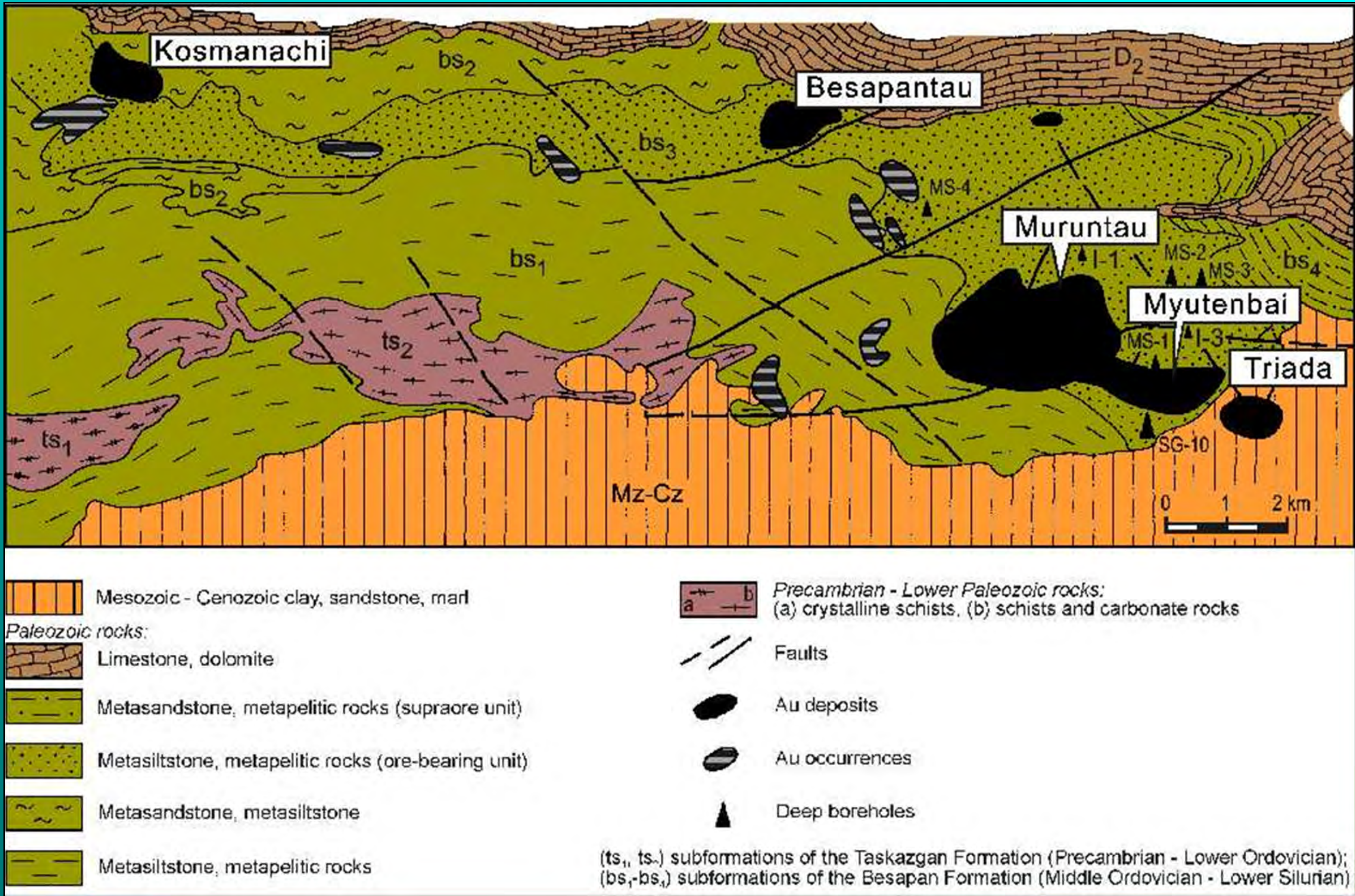
Muruntau Deposit: Reserves



Reserves, potential resources, and production of gold at the Muruntau deposit, %.
24.8% ~ 40 Moz

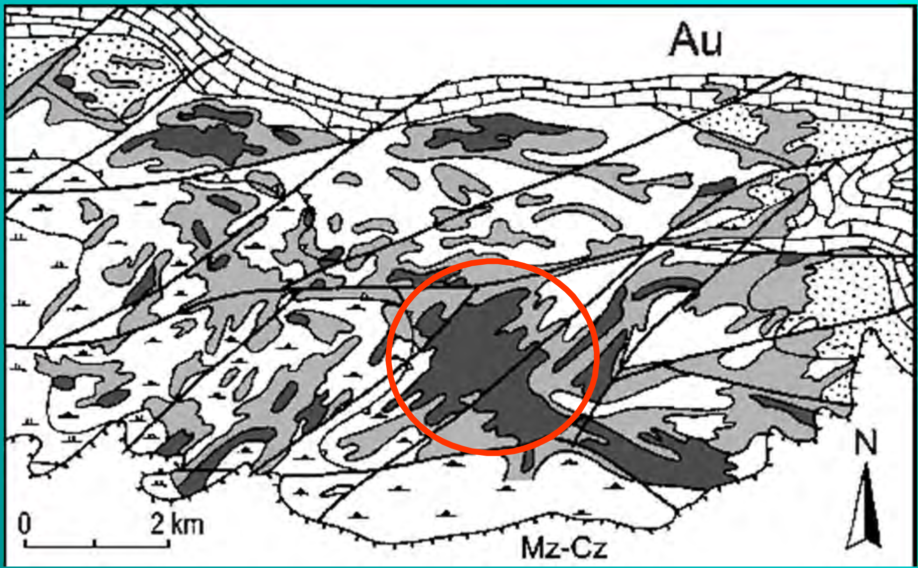
Data of the State Committee for Geology, Republic of Uzbekistan;
Shayakubov et al., 1999

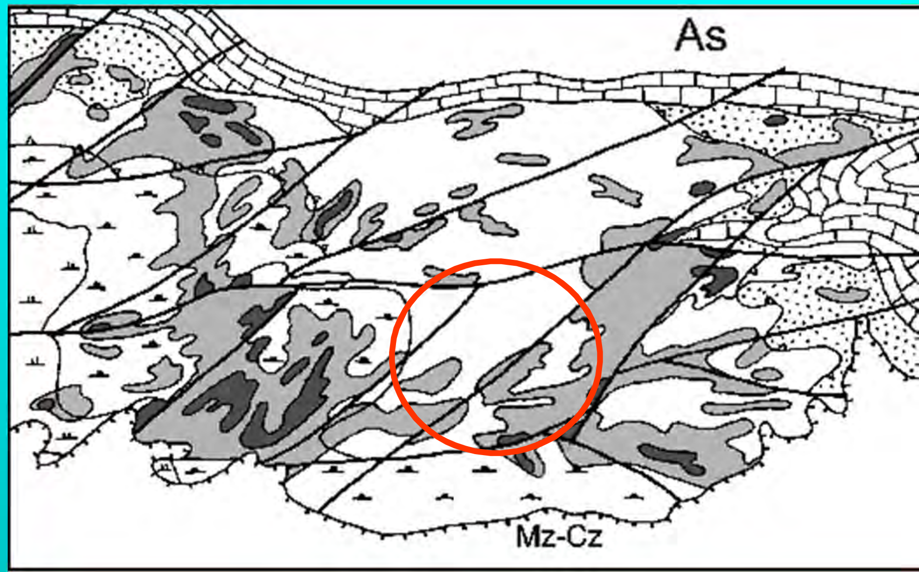
Muruntau Deposit: Local Geology

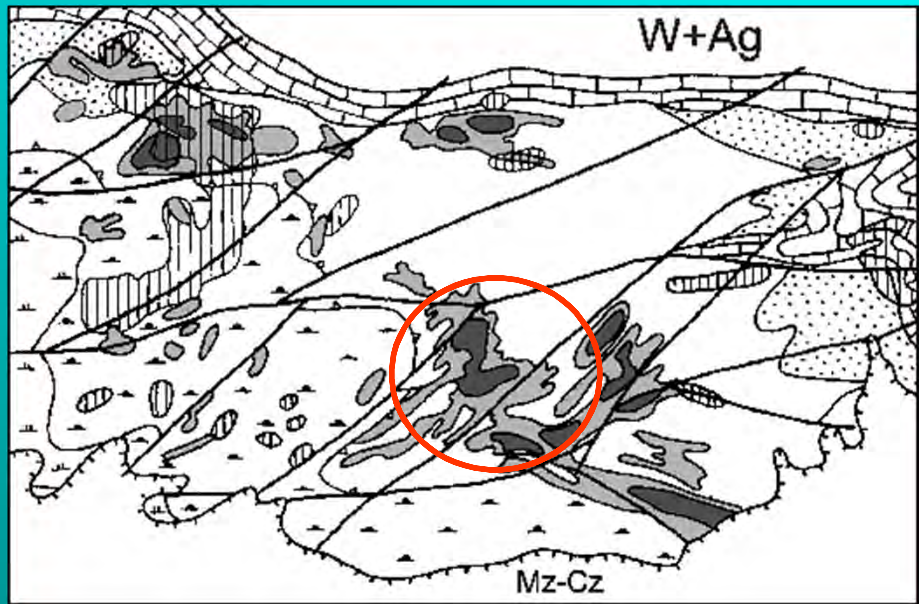


Kremenetsky et al., 1995

Muruntau Deposit: soil anomalies

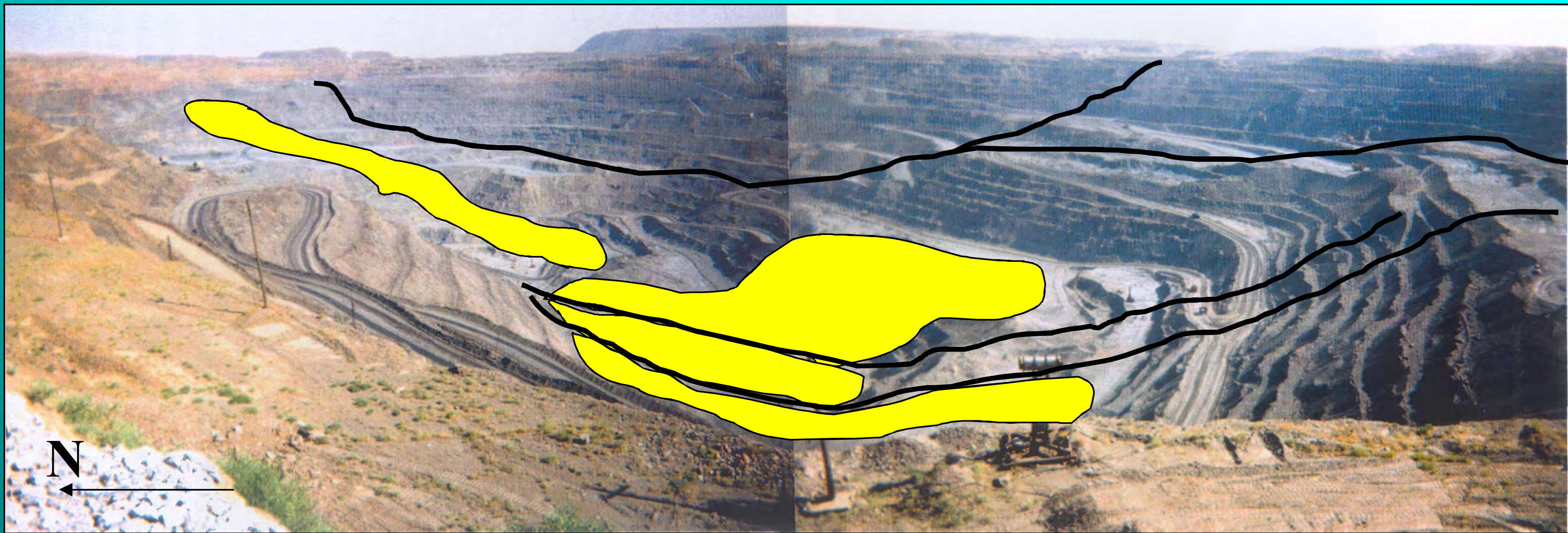






Shayakubov et al., 1999

Muruntau Deposit: ore bodies

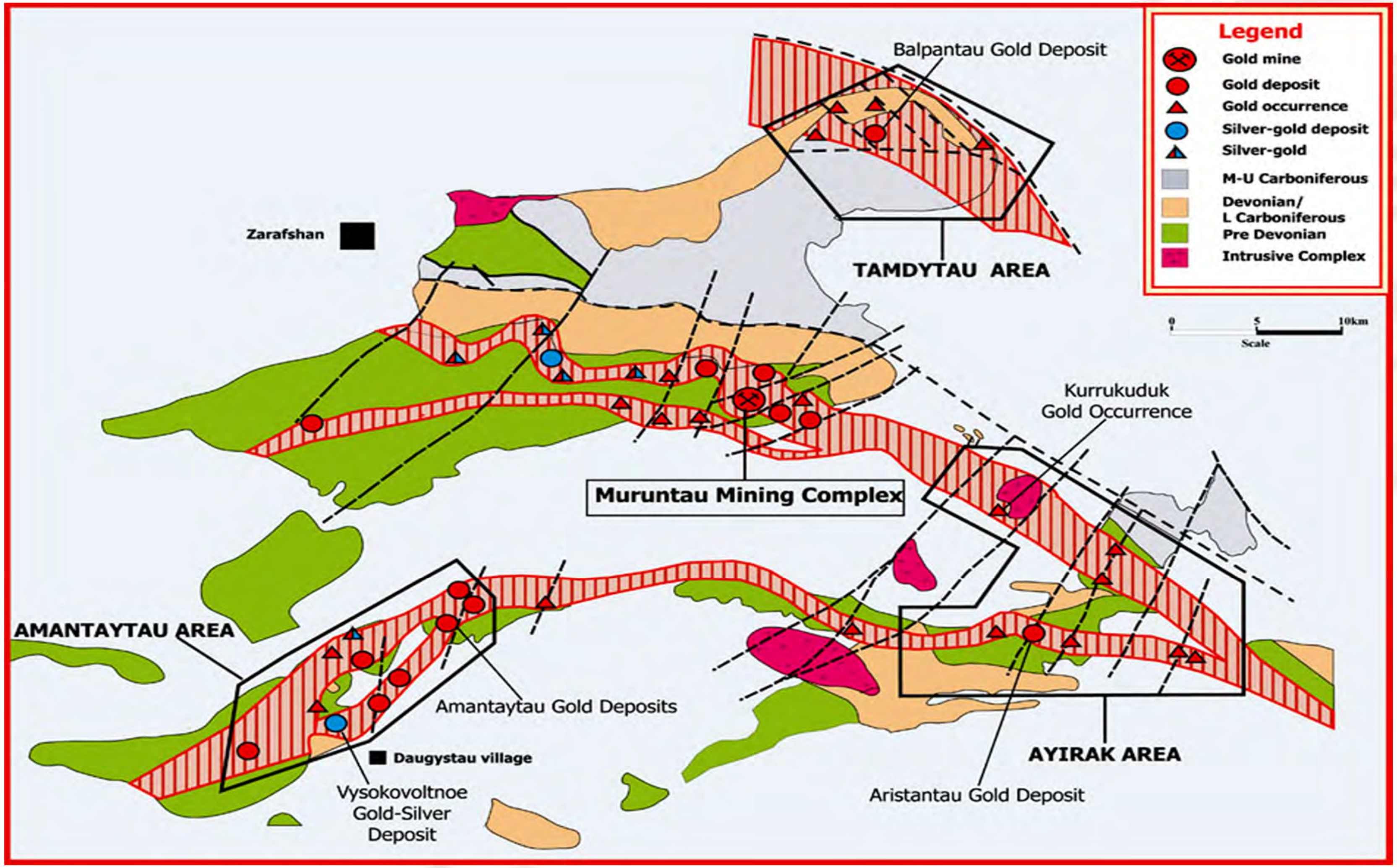


Panoramic view looking southeast across the Muruntau open pit (Uzbekistan) in September 1999. This is the world's largest gold open pit whose approximate size is 3x2 km. The depth is 330 m. In the foreground is the first ore body. The second and third ore bodies are in the centre of the pit. Muruntau dumps can be seen in the background.

4 types of quartz veins: Q1 – flat low-grade veins, Q2 – stockwork veins of 3-5 g/t Au, Q3 – steep "Central veins", Q4 – low-Au, high-Ag veins

Photo T.Graupner

What happens around Muruntau?
Amantaytau Licence Areas by Oxus Mining Plc



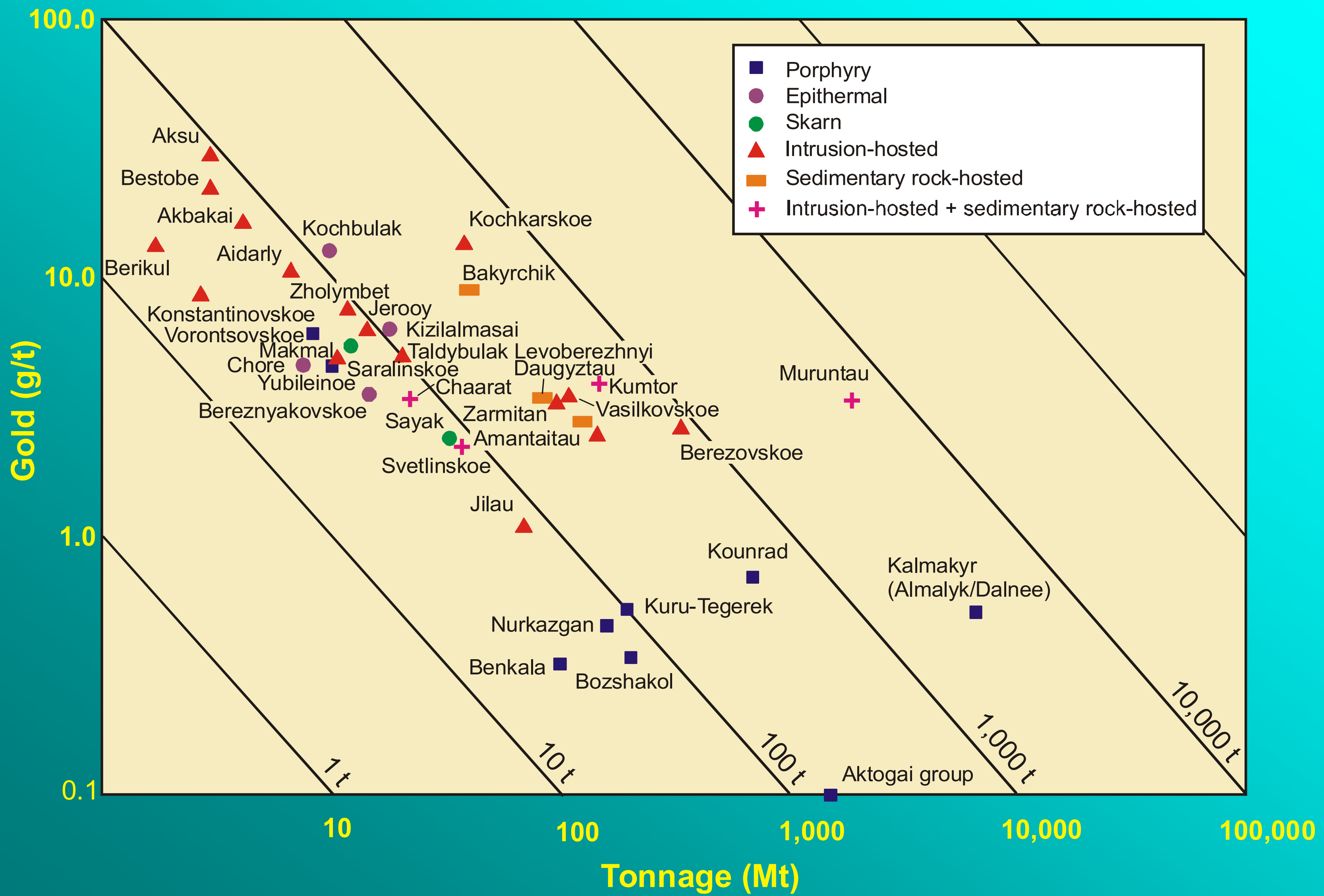
Oxus Mining plc

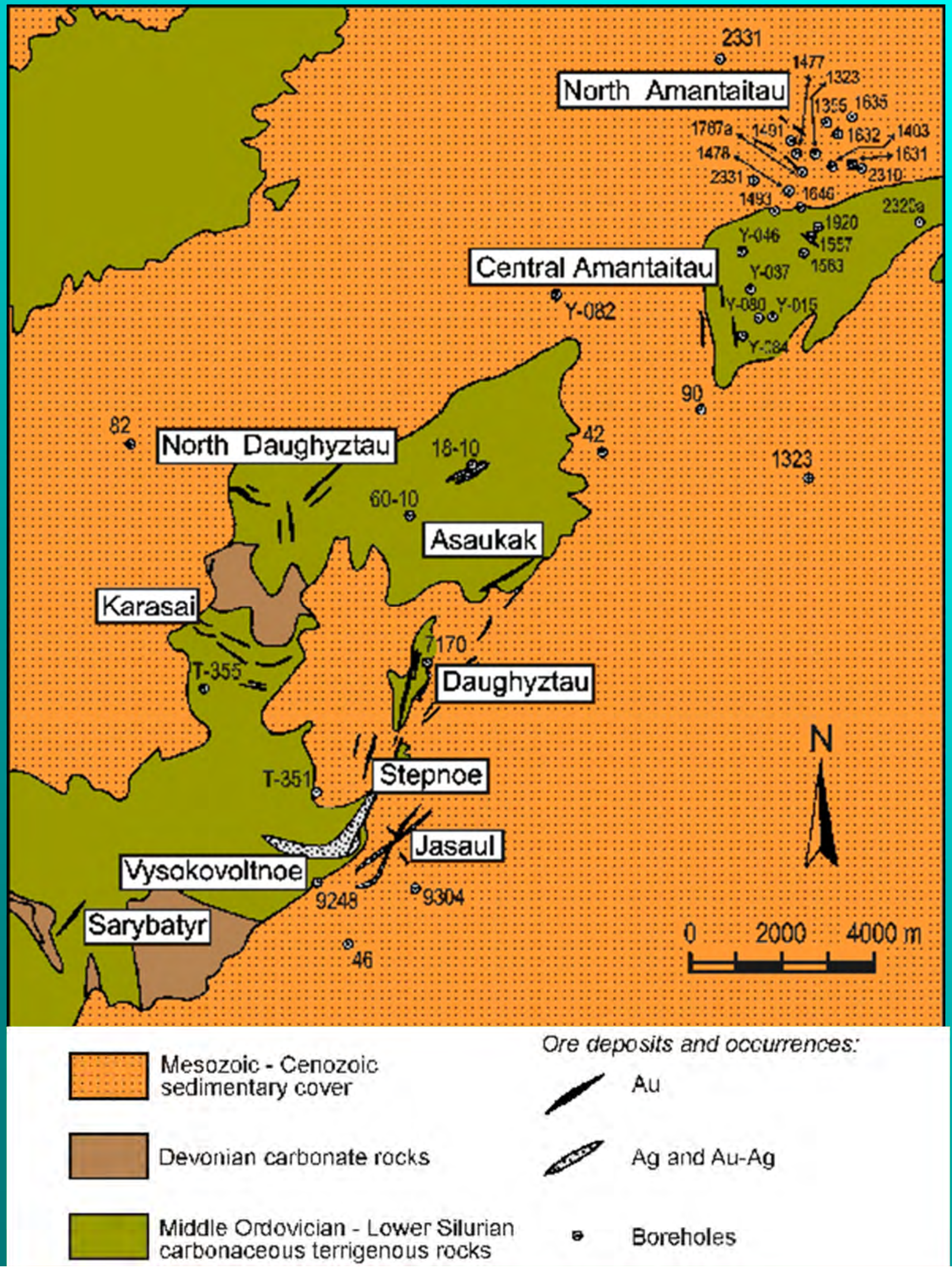
Amantaitau and Daugyztau Deposits

- **50-50 JV between Oxus Mining Plc and Navoi Mining and Metallurgical Combine**

<u>Daugyztau</u> resource 6 Moz Au and 3.3 Moz Ag in 46.2 Mt ore

Amantaitau and Daugyztau deposits



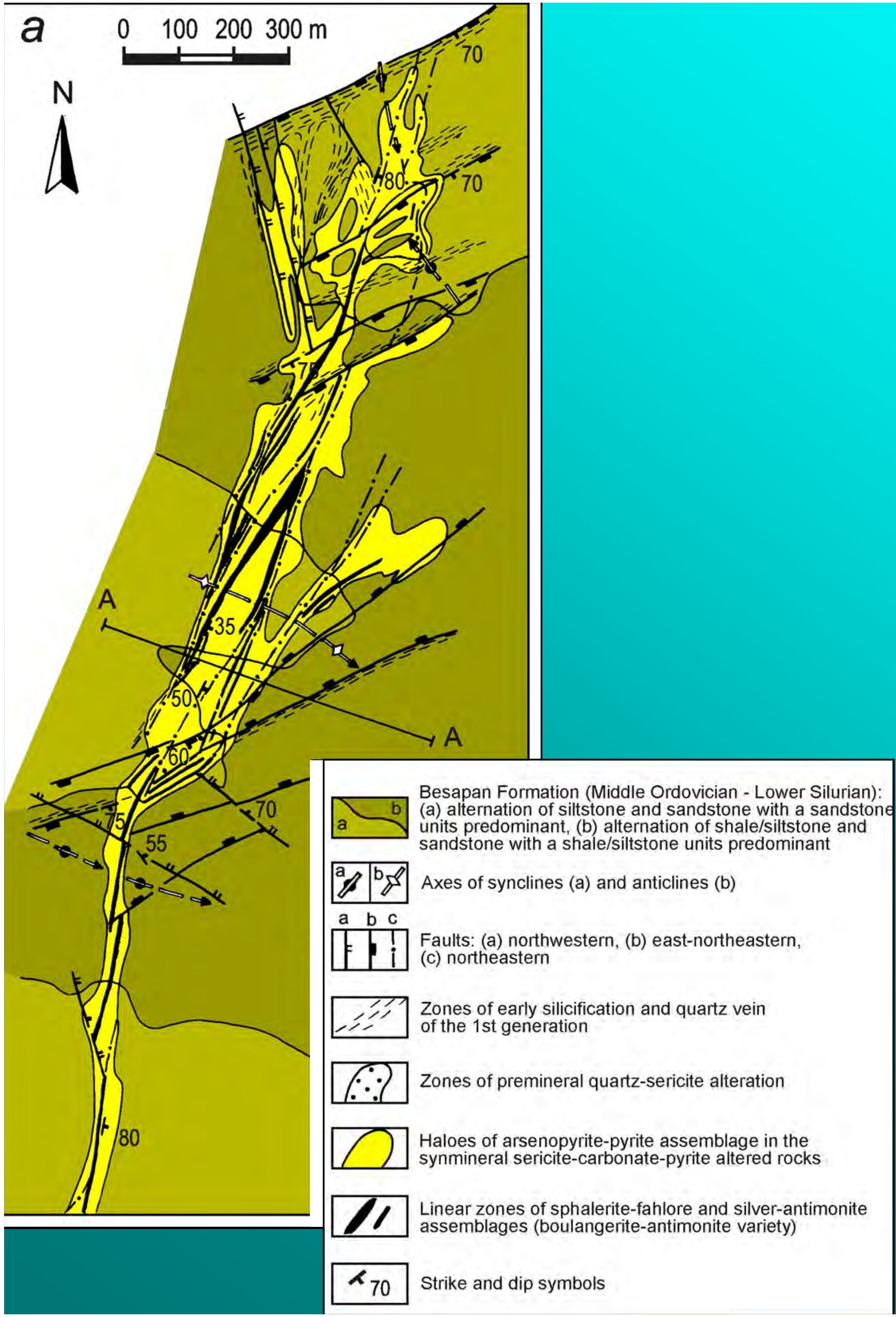


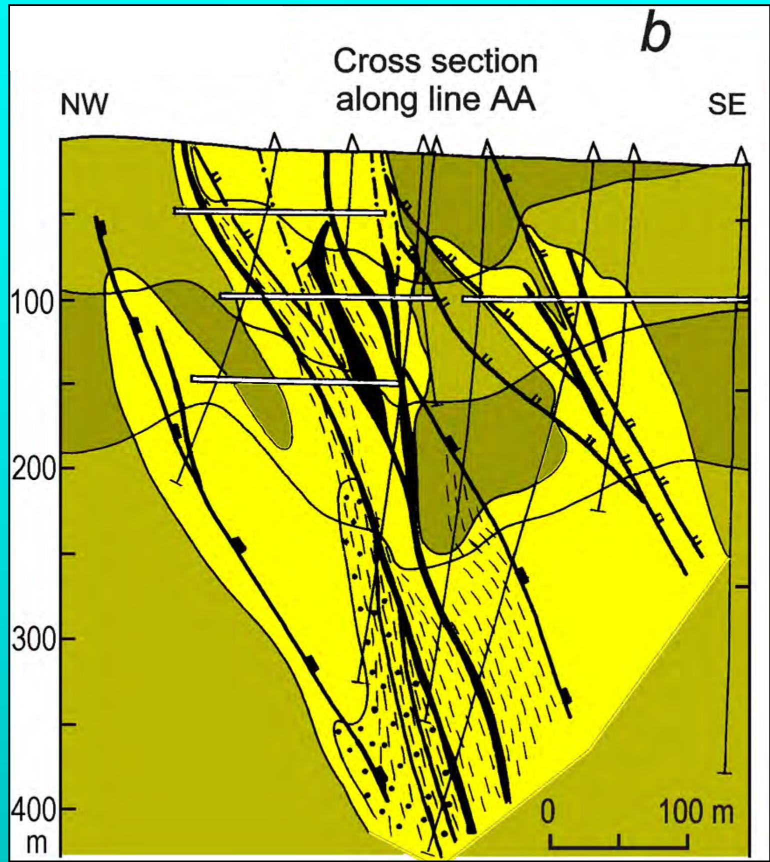
Amantaitau and Daugyztau Deposits

- All deposits occur in Besopan Formation in similar lithologies to Muruntau, but veins are dominant
- They basically constitute a single deposit

Shayakubov et al., 1999

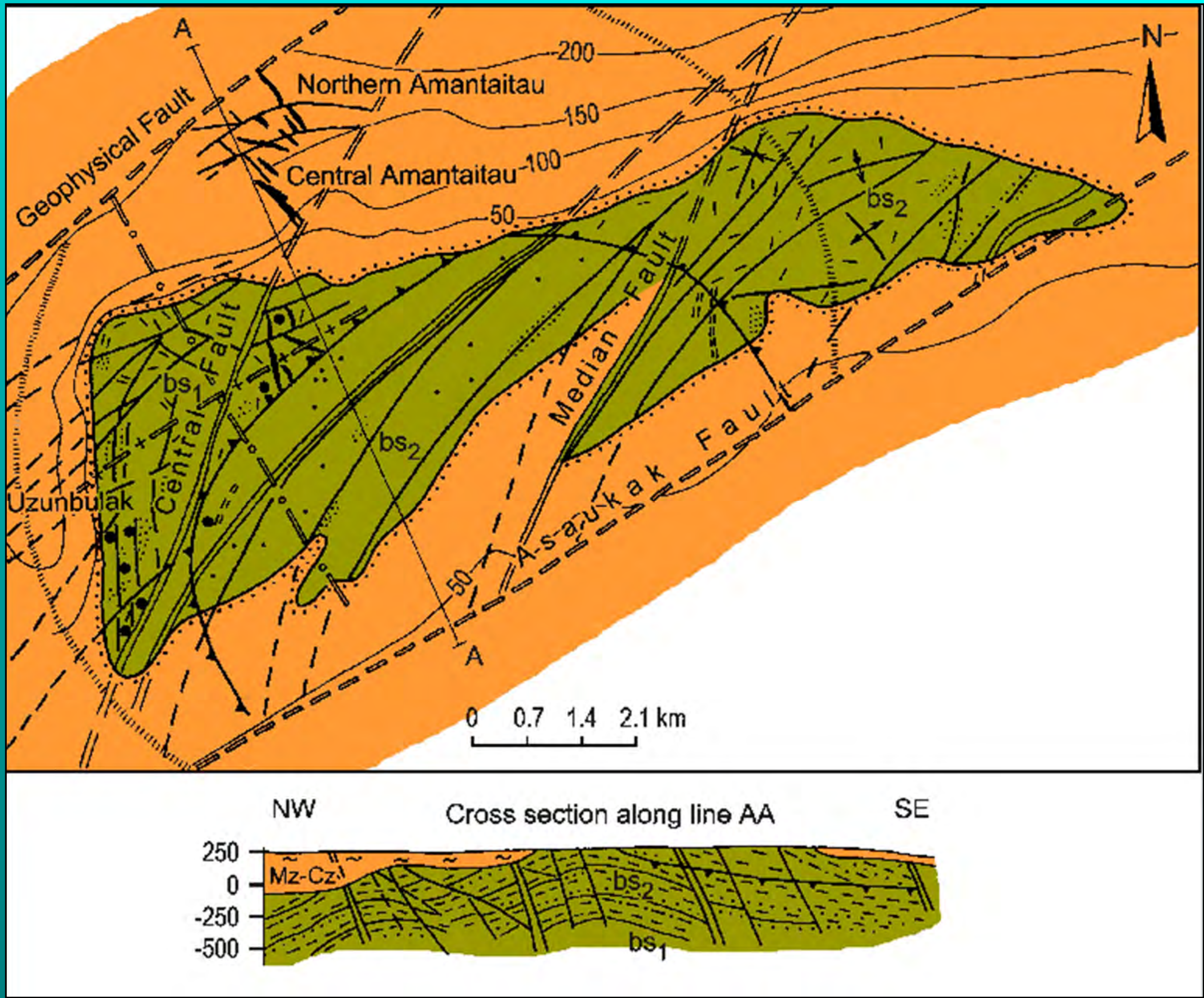
Daugyztau Deposit





Shayakubov et al., 1999

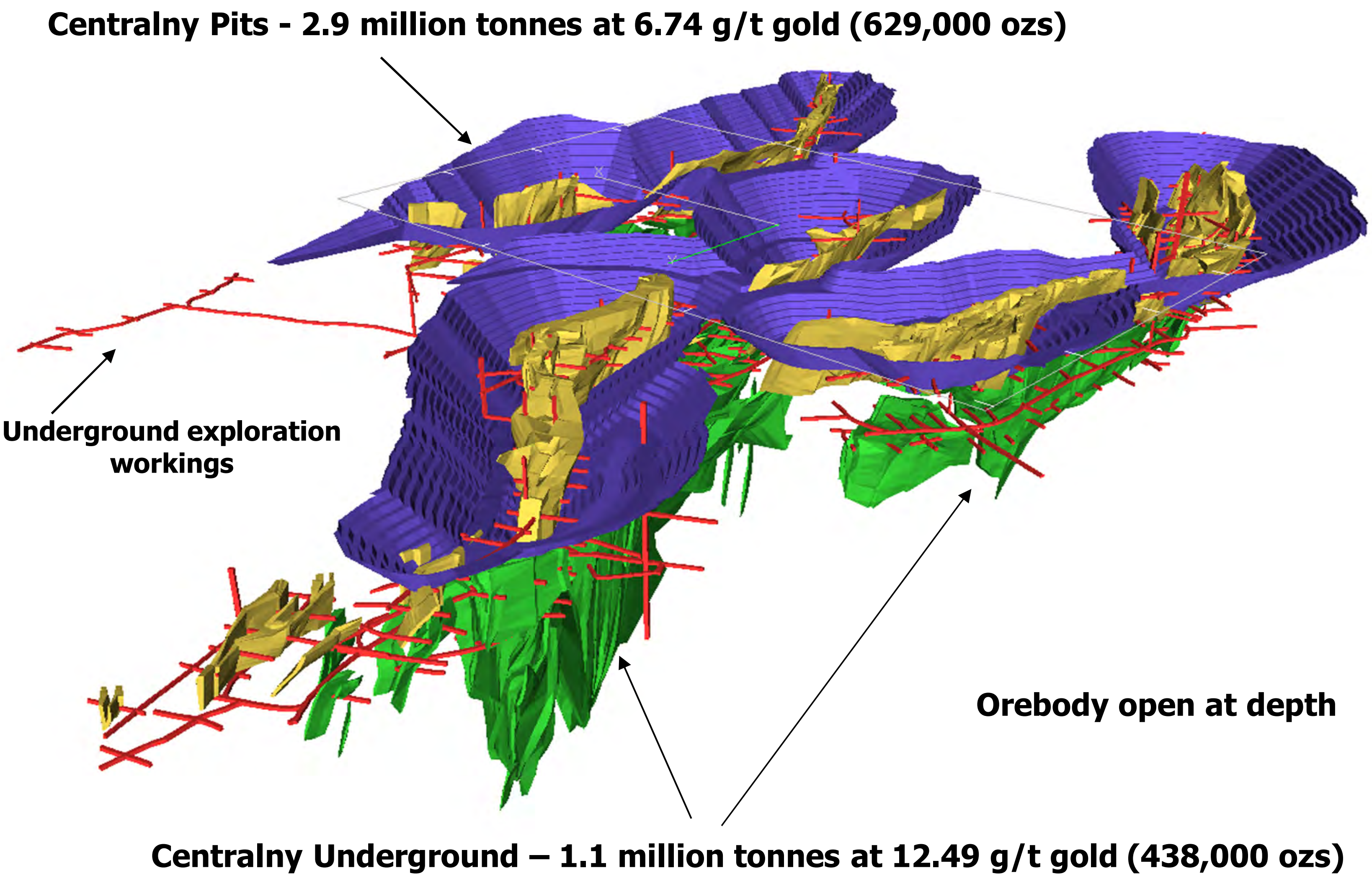
Amantaitau Deposit



Part of the deposit is hidden under Mesozoic Cenozoic sediments

Shayakubov et al., 1999

Amantaytau Centralny Open Pit & Underground



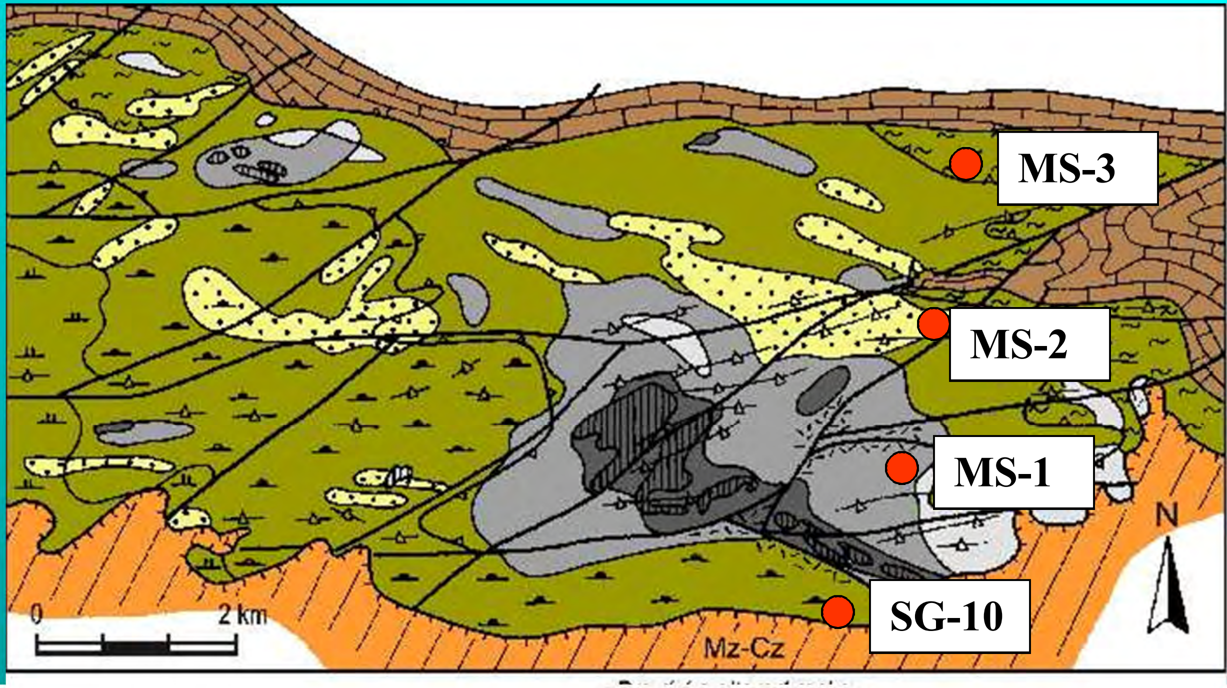
Amantaytau - Open Pit Gold Mine

- Reserve of 8.3 million tonnes at 3.75 g/t (1Moz gold*)
- Initial 8 year life based on 1 million tonne p.a. plant
- Initial annual production of 170,000 ozs gold
- Additional resources of 6.4 Moz gold equivalent
- Pre-production capital cost $40 million
- Total (taxed) cost of production - $200 per oz
- Project Internal Rate of Return 46.9% (ungeared)

Amantaytau - Underground Gold Project

- Pre-feasibility study completed for a 13 g/t underground mine
- Current underground resource of 2.38 million ozs
- Production rate 190,000 ozs per year for 10 years
- Production start-up in 2005

Muruntau Deposit: alteration



Deep drillholes

- Carbonate rocks
- *Besapan Formation:*
  - Green Besapan
  - Variegated Besapan
  - Gray Besapan
  - Lower Besapan
- Dykes
- Faults

Pre-dyke altered rocks:

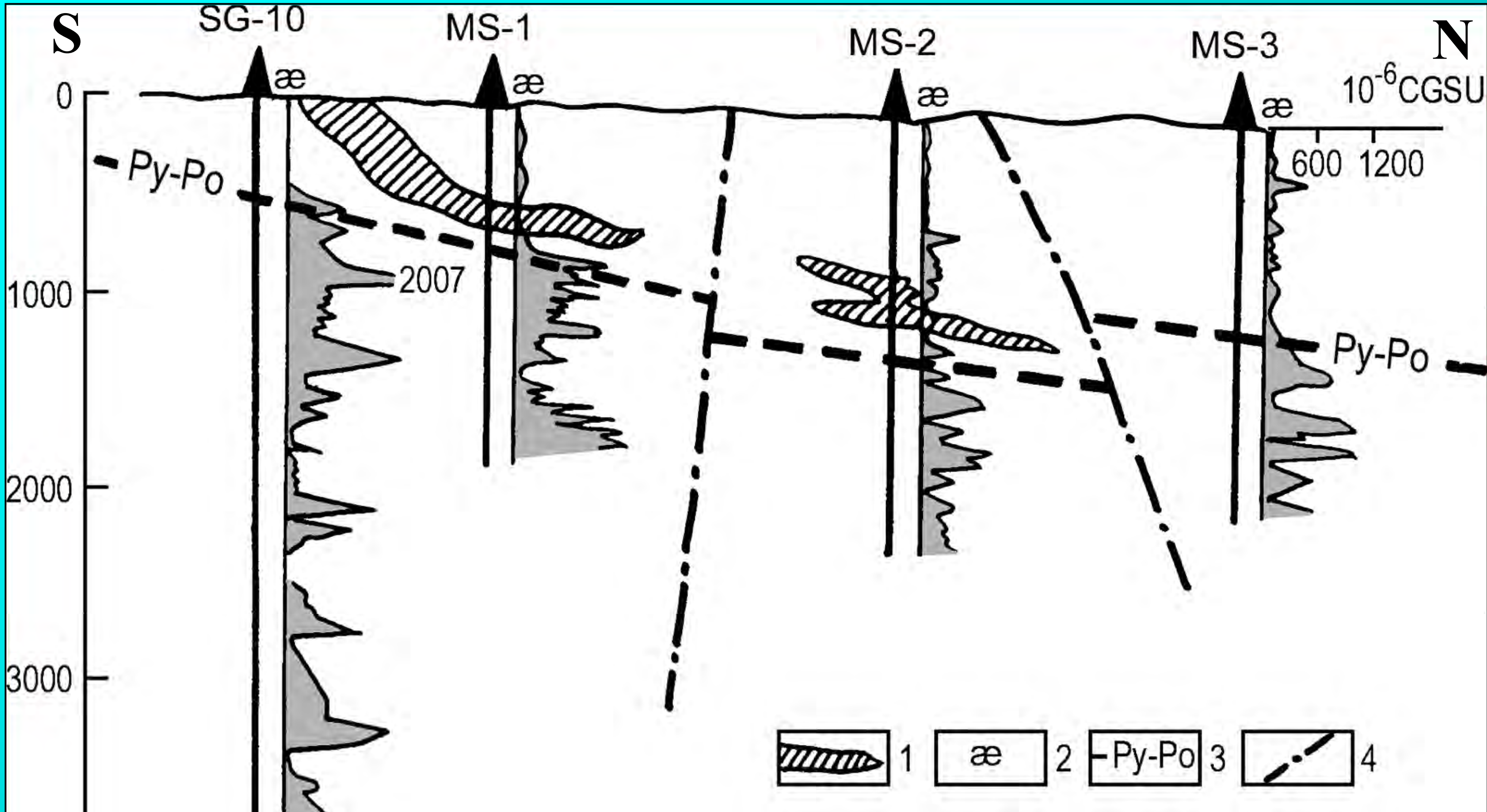
- Biotitized rocks of the outer zone
- Biotite-feldspar-quartz rocks of the transitional zone
- Quartz-potassic feldspar rocks of the inner zone

Post-dyke altered rocks:

- Quartz-albite lenses and irregular spots
- Quartz-albite veins with tourmaline
- Sericitic rocks
- Au ore lodes
- Contour of exposed Paleozoic rocks

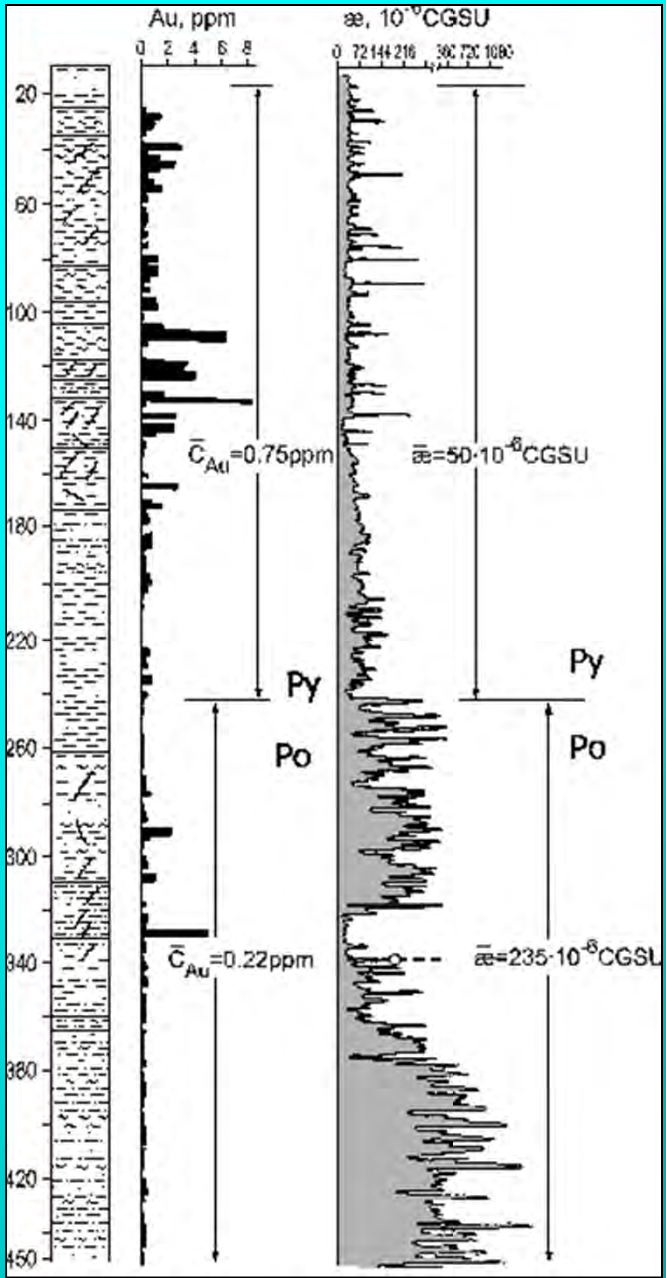
Shayakubov et al., 1999

Muruntau: deep structure
(on the basis of deep drilling)



1 - ore bodies, 2 – magnetic susceptibility,
3 – pyrite-pyrrhotite transition, 4 – faults

after Shvetsov et al. (from Shayakubov et al., 1999)

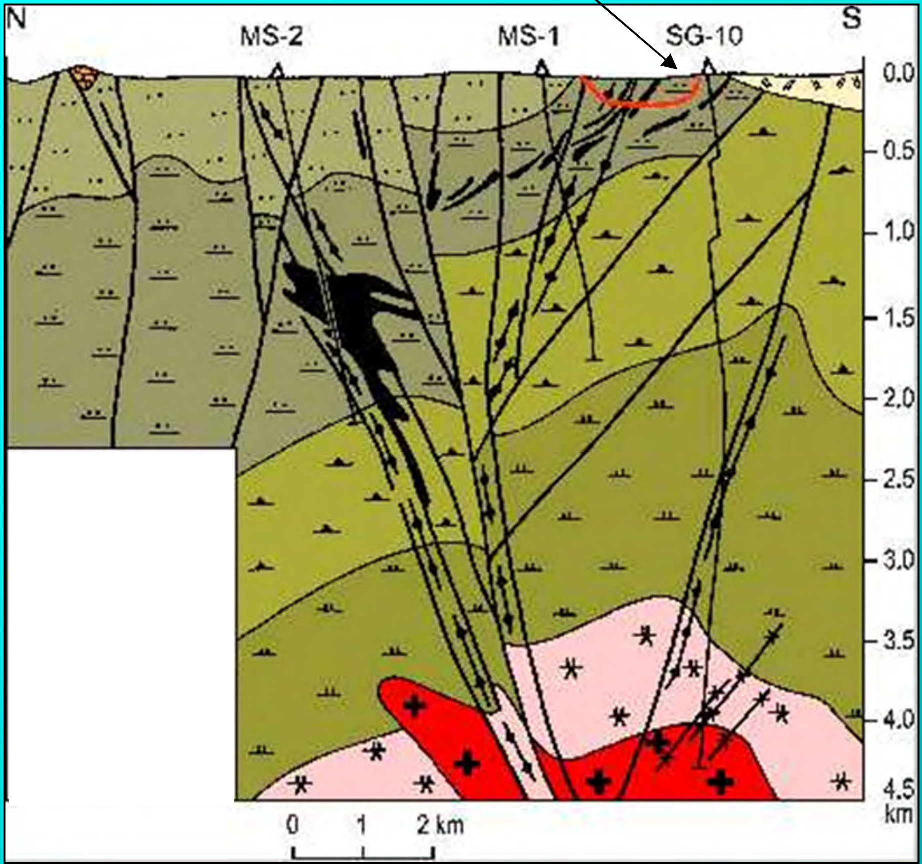


Muruntau: deep structure (on the basis of deep drilling)

after Shvetsov et al. (from Shayakubov et al., 1999)

Muruntau: deep structure (on the basis of deep drilling)

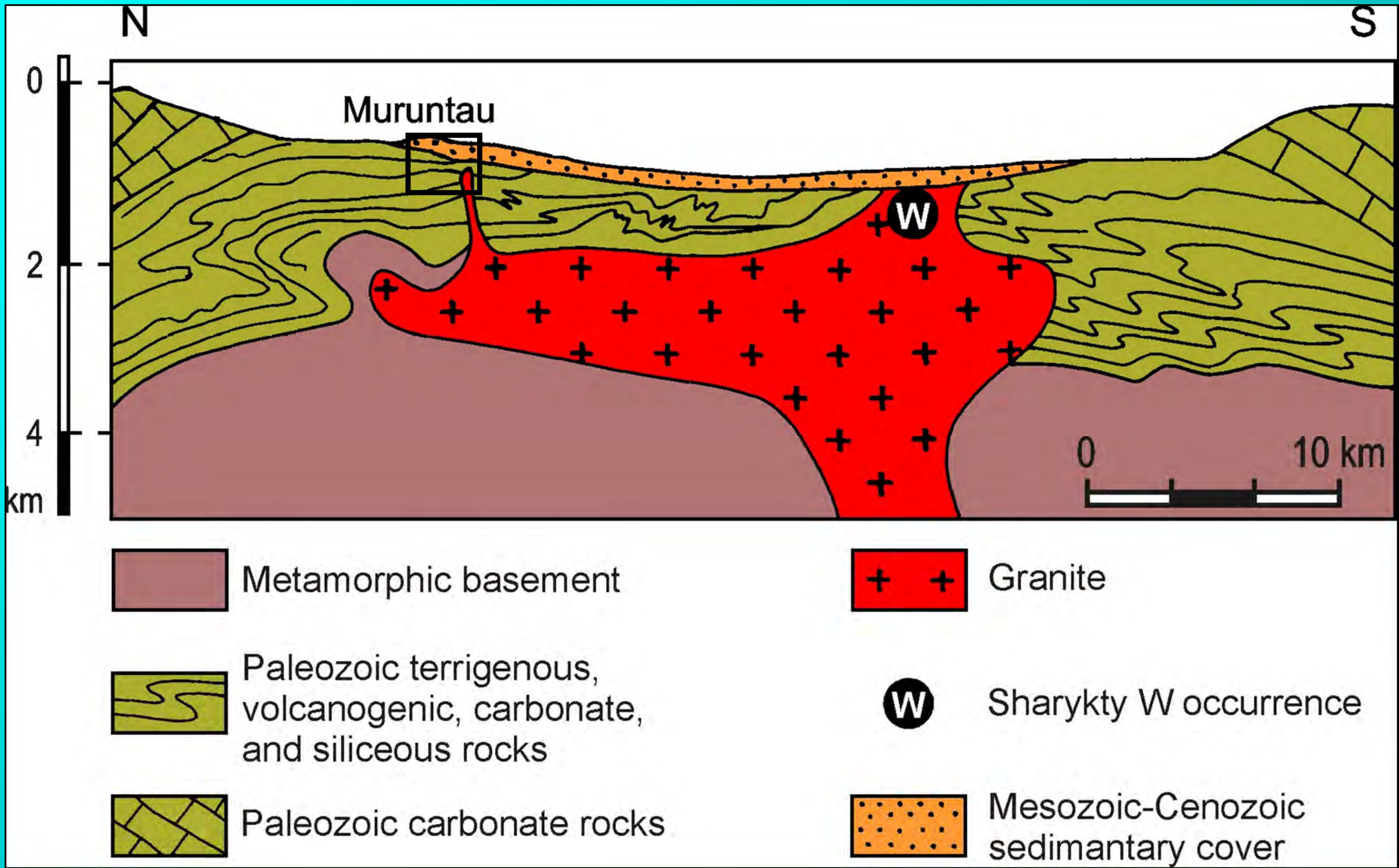
Muruntau pit



Cenozoic
Carbonate rocks
Upper Variegated Besapan
Middle and Lower
Varigated Besapan
Gray Besapan
Lower Besapan
Upper Taskazgan
PZ3? leucogranite
Dykes
Steep faults
Ore bodies

after Shvetsov et al. (from Shayakubov et al., 1999)

Kyzylkum District: Tamdy Mountains



Rakhmatulaev, 1999

Muruntau: Granite rocks

Chemical composition (wt %) of leucogranite and related dykes from the SG-10 borehole (after V. Donskoi, I. Khamrabaev & V. Yakovlev)

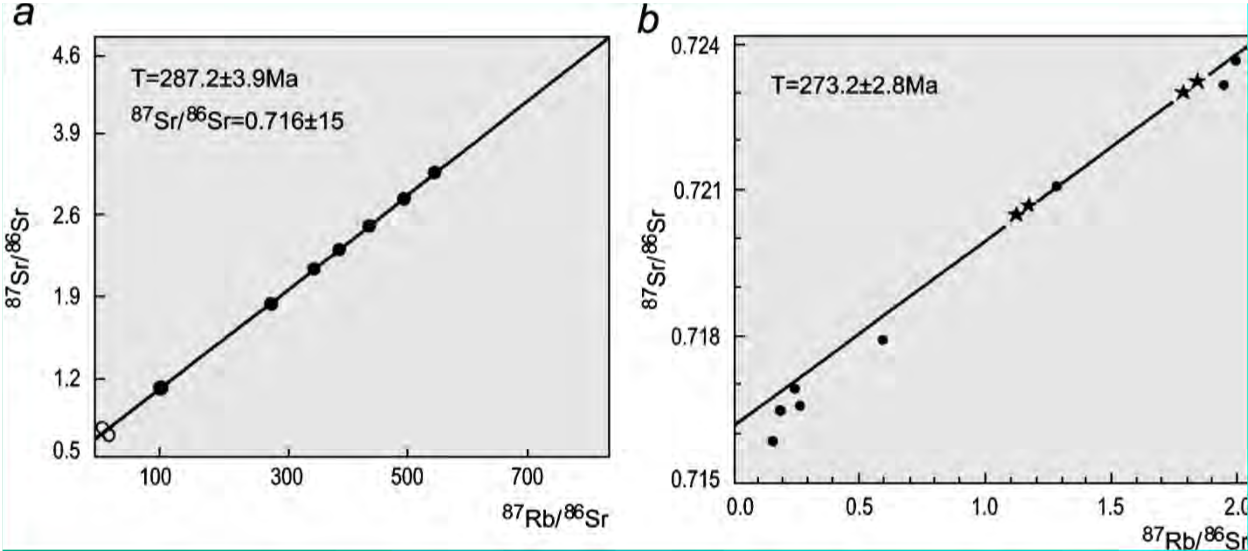
Rock	Depth, m	n	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	FeO	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	LOI	H_2O	CO_2	SO_3	Total
1	4060–4160	6	75.61	0.03	12.70	0.42	1.17	0.02	0.10	0.50	4.02	4.56	0.03	0.55	0.10	0.20	0.12	100.13
2	4060–4160	3	75.10	0.04	12.83	0.67	1.02	0.02	0.25	0.50	4.06	4.56	0.03	0.59	0.10	0.20	0.12	100.09
3	4005–4258	8	75.45	0.03	12.51	0.35	1.07	0.02	0.18	0.58	4.13	4.39	0.02	0.76	0.10	0.31	0.24	100.14
4	4060–4160	2	75.35	0.05	13.26	0.32	1.11	0.01	0.09	0.56	4.11	4.56	0.03	0.45	0.10	0.20	0.10	100.30
5	4060–4160	7	75.50	0.03	13.18	0.26	0.90	0.03	0.28	0.48	4.13	4.00	0.04	0.68	0.10	0.22	0.19	100.02
6	4259	1	75.84	0.02	12.49	0.62	1.07	0.02	0.36	0.45	3.77	4.57	0.02	0.46	0.10	0.25	0.10	100.14
7	3490–3931	6	74.75	0.03	13.77	0.43	1.01	0.02	0.20	0.65	3.70	3.74	0.04	0.90	0.11	0.20	0.67	100.22
8	3770–3778	2	75.22	0.04	13.39	0.37	0.80	0.04	0.30	0.42	4.13	4.28	0.03	0.54	0.10	0.20	0.51	100.37
9	3882–3886	5	76.06	0.03	12.70	0.62	1.18	0.04	0.19	0.66	3.66	4.14	0.04	0.51	0.10	0.20	0.11	100.24

Note: *Leucogranites:* (1, 2) fine- and medium-grained, (3) pegmatoid, (4) mylonitized, (5) equigranular, (6) near the borehole bottom; *dykes:* (7) pegmatite, (8) aplite-like leucogranite with garnet and tourmaline, (9) porphyritic leucogranite and granite porphyry; n — number of samples.

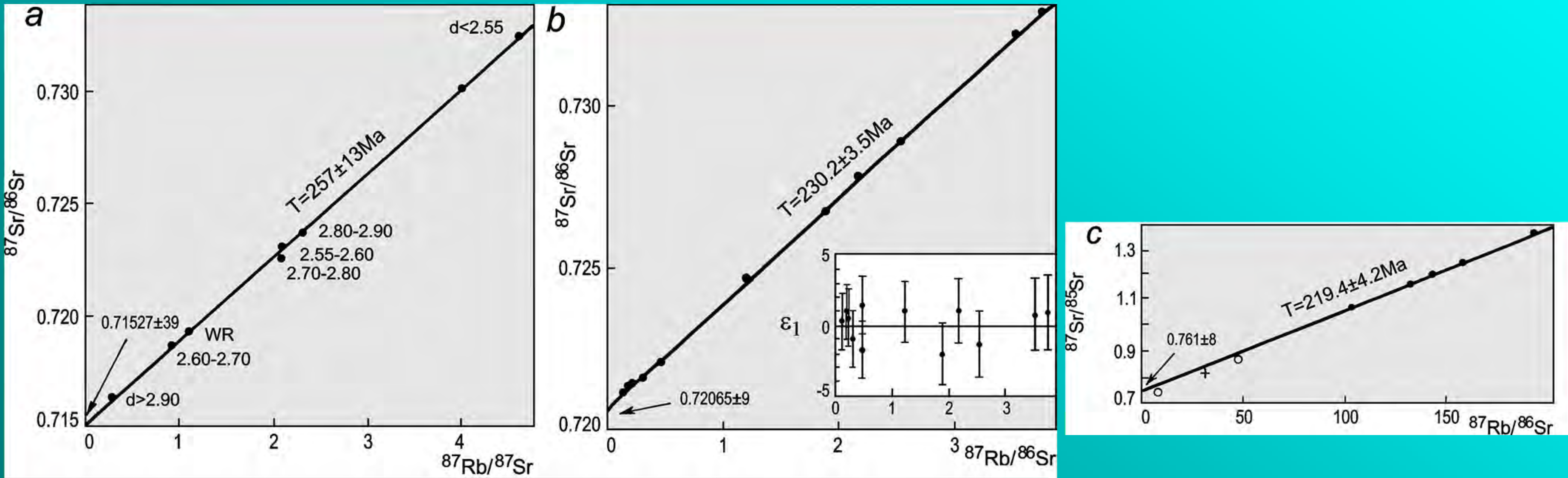
Muruntau Deposit: age data

Rock	Age, Ma
Rb-Sr age of igneous rocks from the Muruntau ore field (Kostitsyn, 1994, 1996)	
Monzodiorite porphyry (dykes) Granite porphyry (dykes) Leucogranite, SG-10 borehole Adamellite of the Sardara pluton	284.4±1.9–285.4±5.1 274.2±5.7 287.2±3.9 286.2±1.8
Ar-Ar age from the Muruntau ore field (Wilde et al., 2001)	
Sericite	245 and 220 Ma

Muruntau age

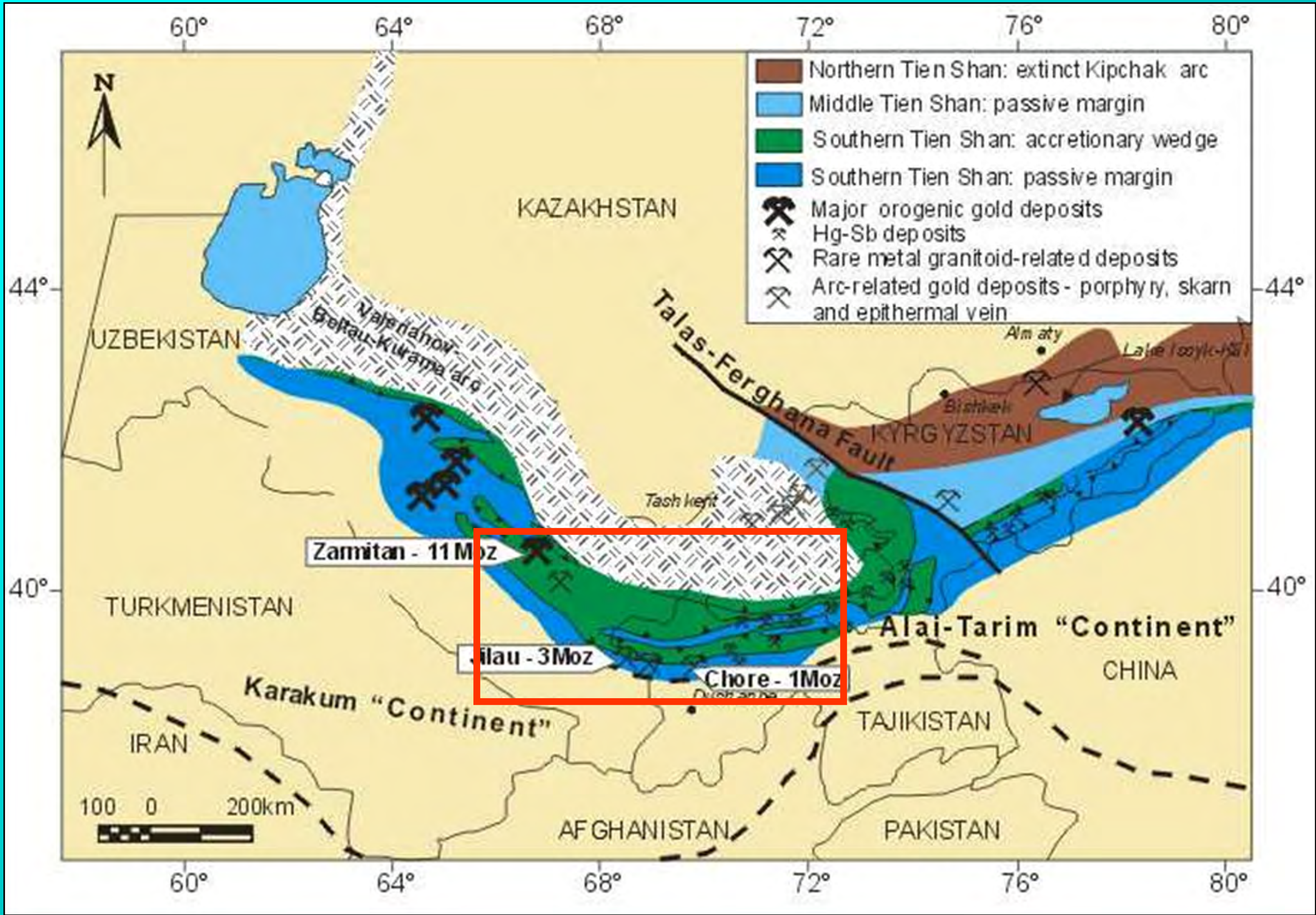


Rb-Sr isochrons for the leucogranite from the SG-10 borehole (a) and biotite-feldspar-quartz altered rocks (b) from the Muruntau deposit (after Kostitsyn, 1993, 1994).

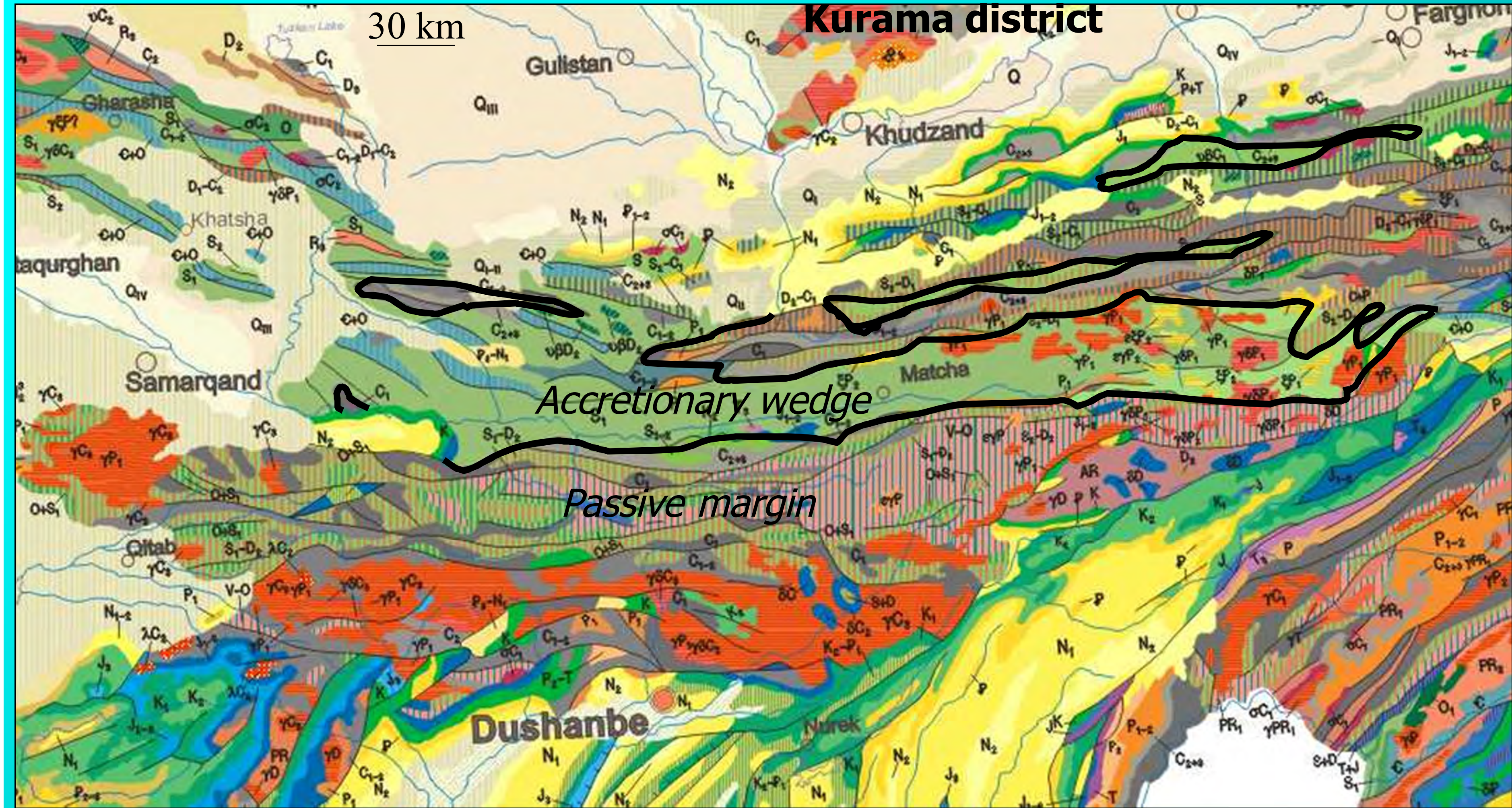


Rb-Sr isochrons for quartz-tourmaline (a), quartz-arsenopyrite (b), and quartz-adularia (c) veins at the Muruntau deposit (after Kostitsyn, 1996).

Zerafshan District



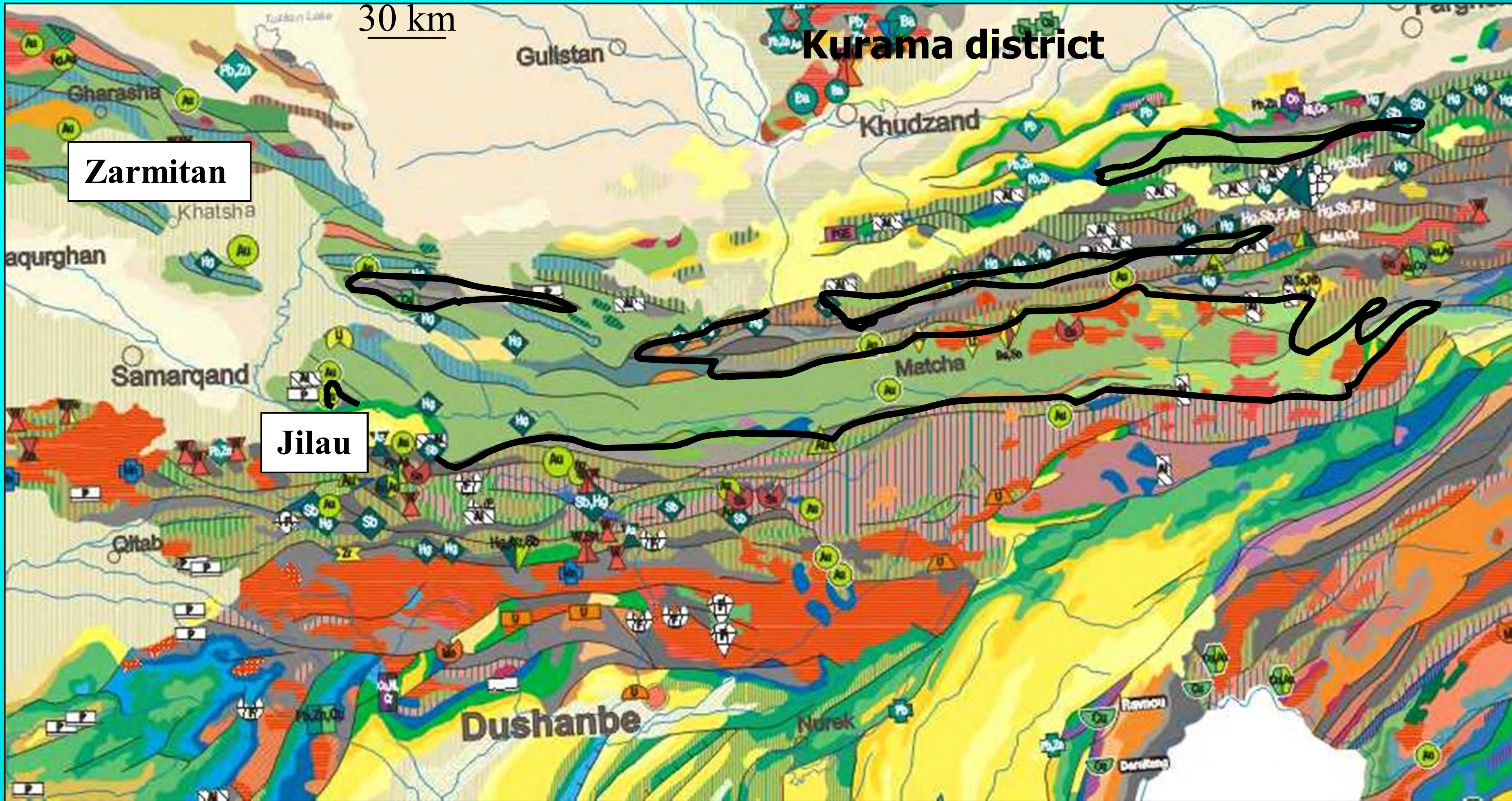
Zerafshan District



Very long and narrow deformed allochthones of Early Paleozoic accretionary wedge thrust on Early-Middle Paleozoic passive margin

Base map: Mineral Deposits Map of Central Asia, Seltmann, Shatov and Yakubchuk (eds), 2001

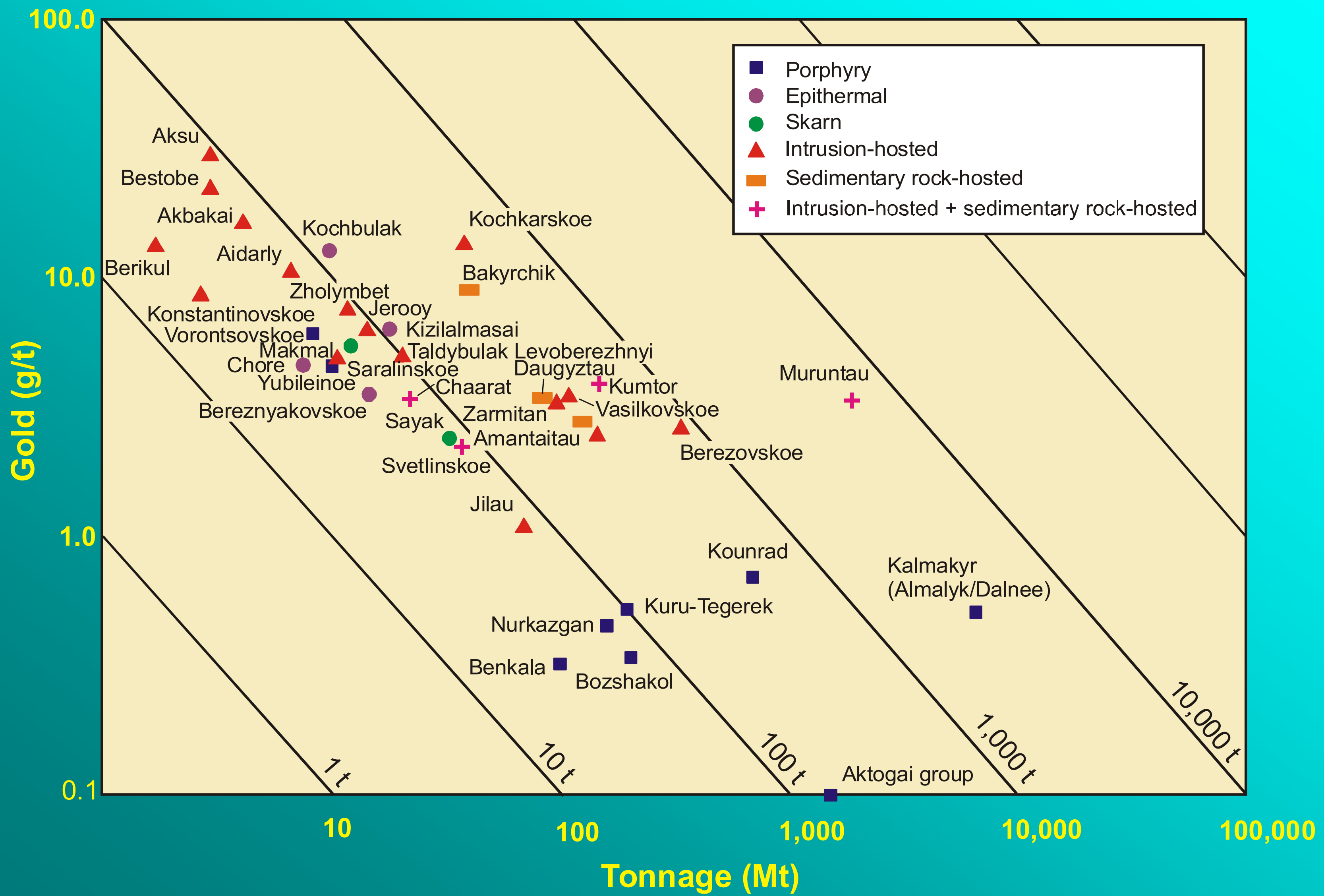
Zerafshan District



The majority of gold and all mercury deposits occur in the passive margin sedimentary rock sequences

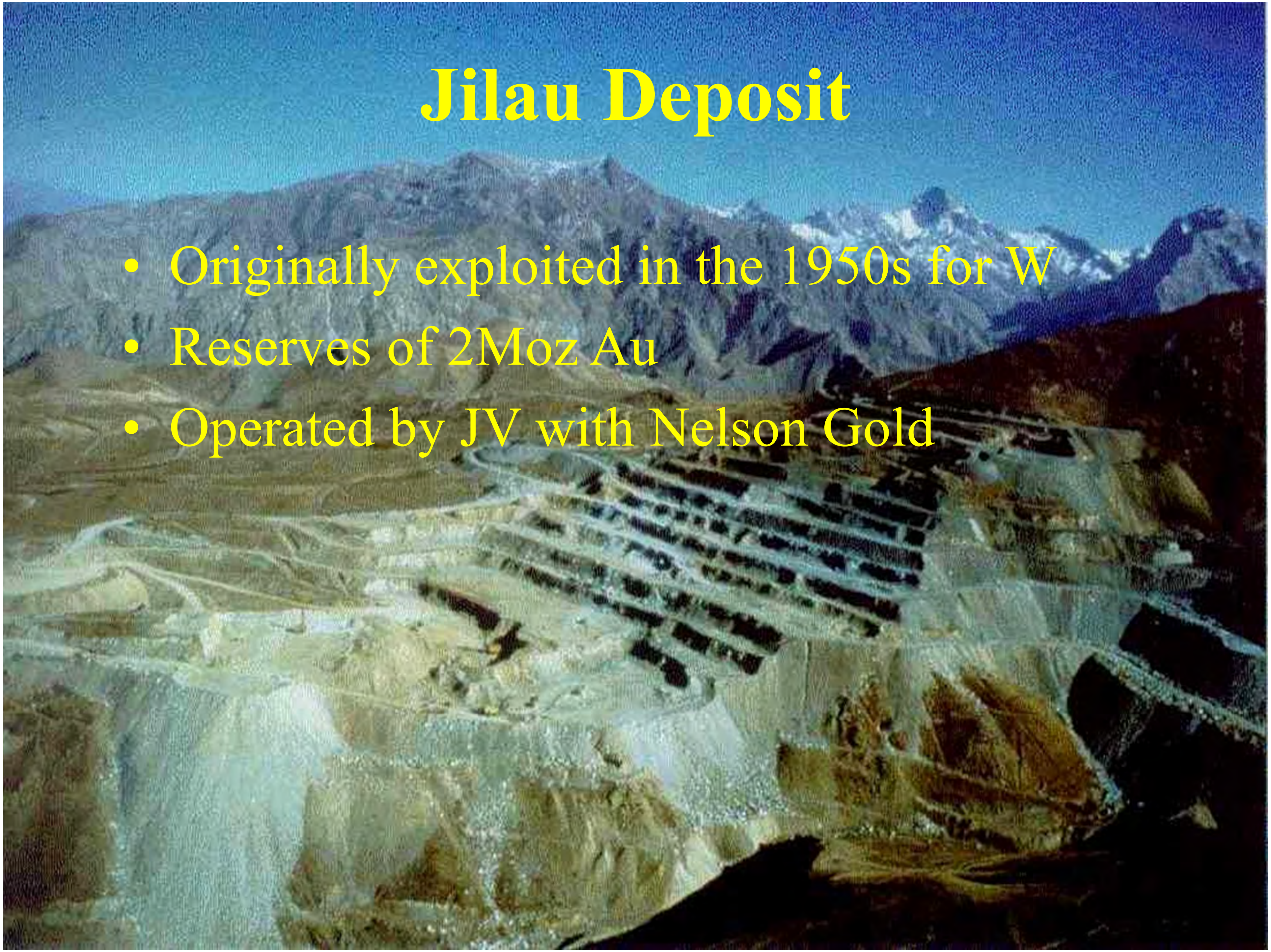
Base map: Mineral Deposits Map of Central Asia, Seltmann, Shatov and Yakubchuk (eds), 2001

Jilau deposit

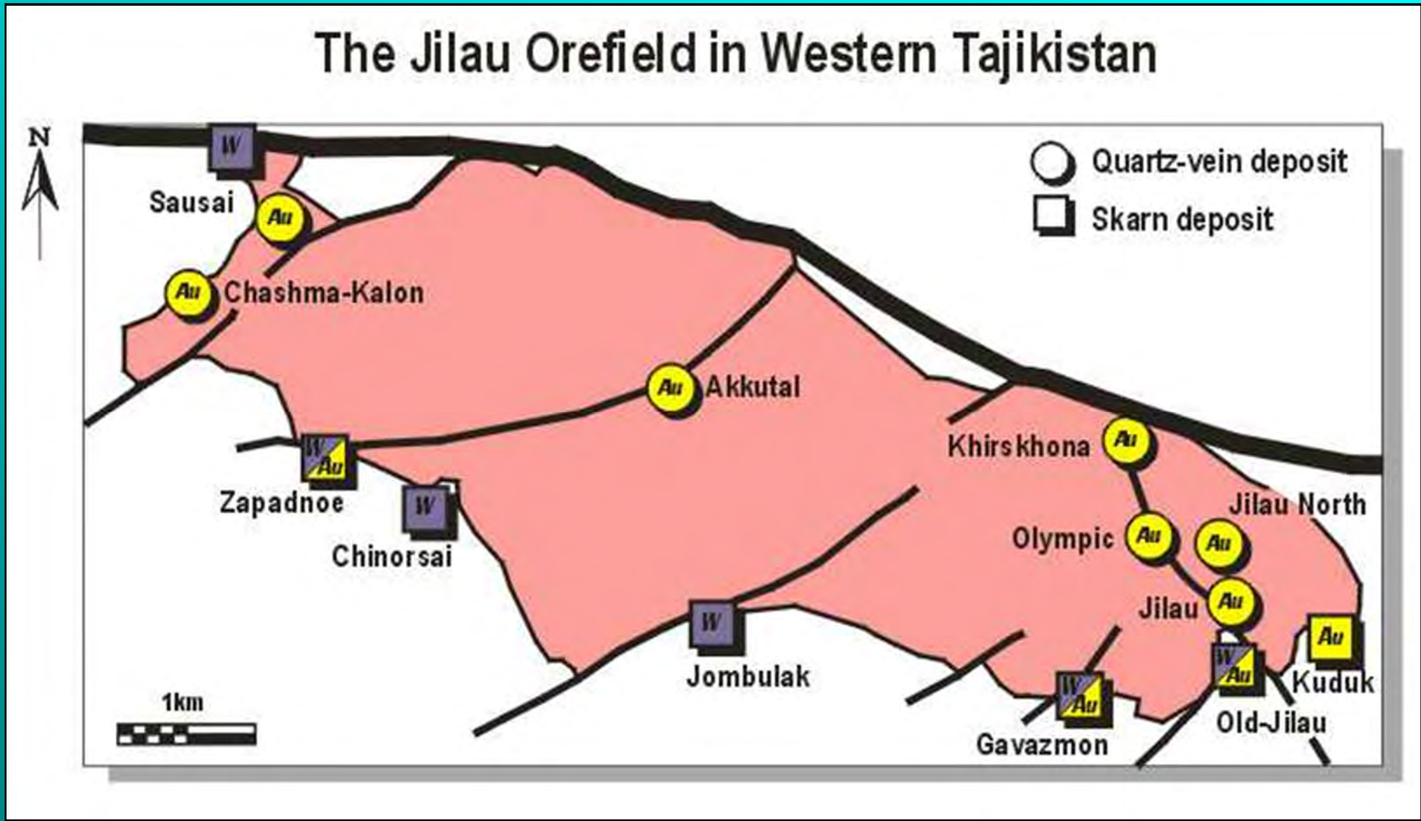


Jilau Deposit

- Originally exploited in the 1950s for W
- Reserves of 2Moz Au
- Operated by JV with Nelson Gold



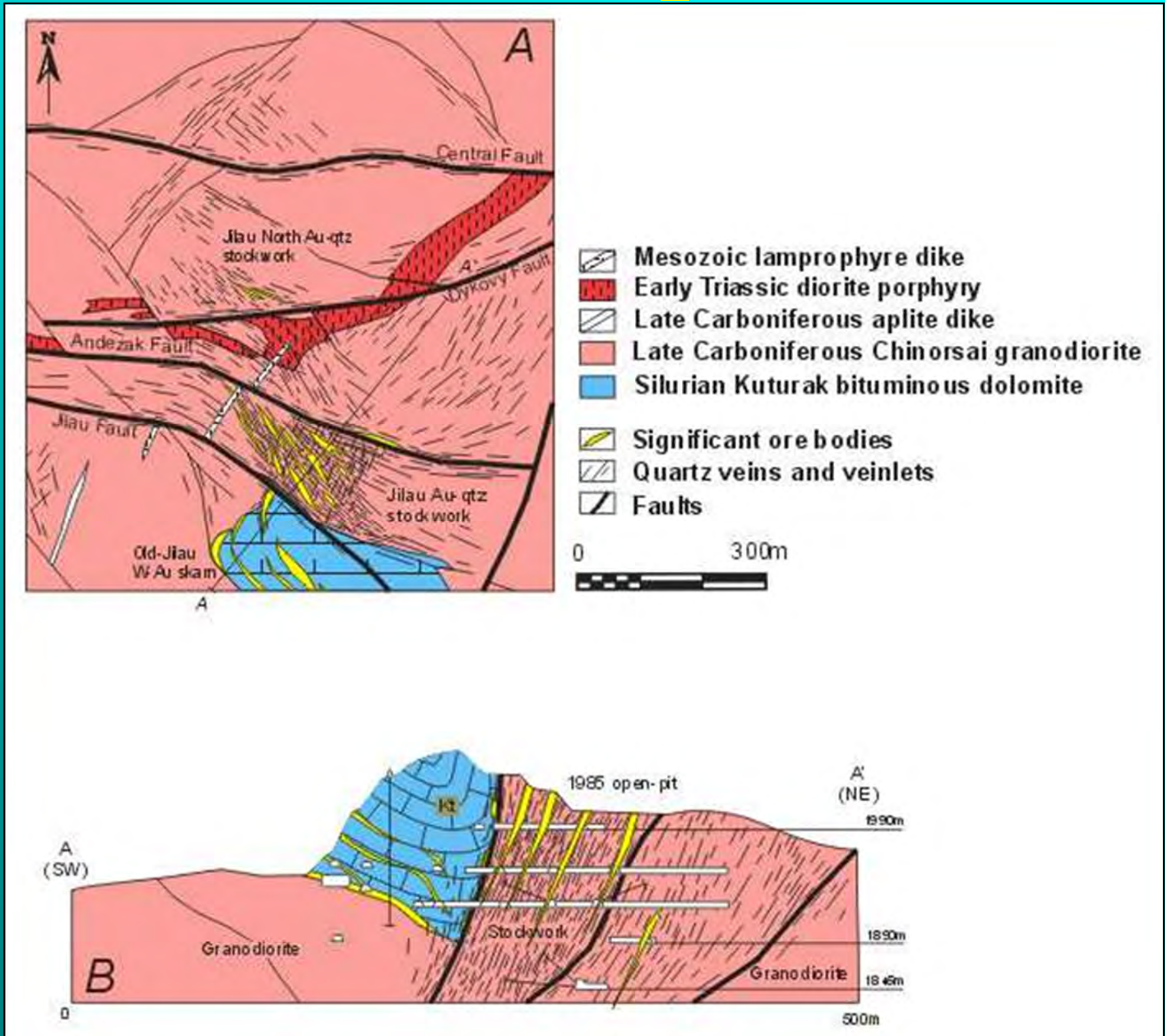
Jilau Deposit



Many vein and skarn deposits occur around 299 Ma I-type granitoid intrusive complex

Cole, 2000

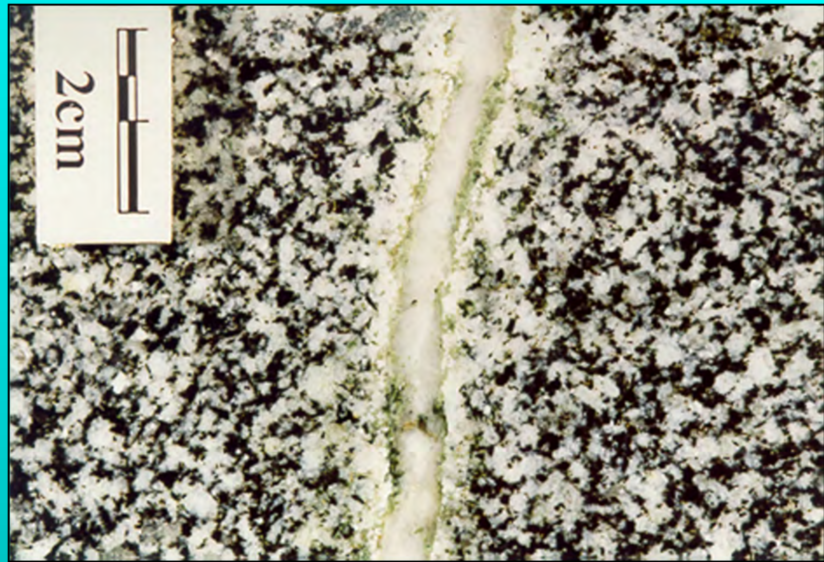
Jilau Deposit



• There are two discrete orebodies: Au-bearing stockwork and scheelite skarn
• Both orebodies contain Au-W-As-Bi metal suite

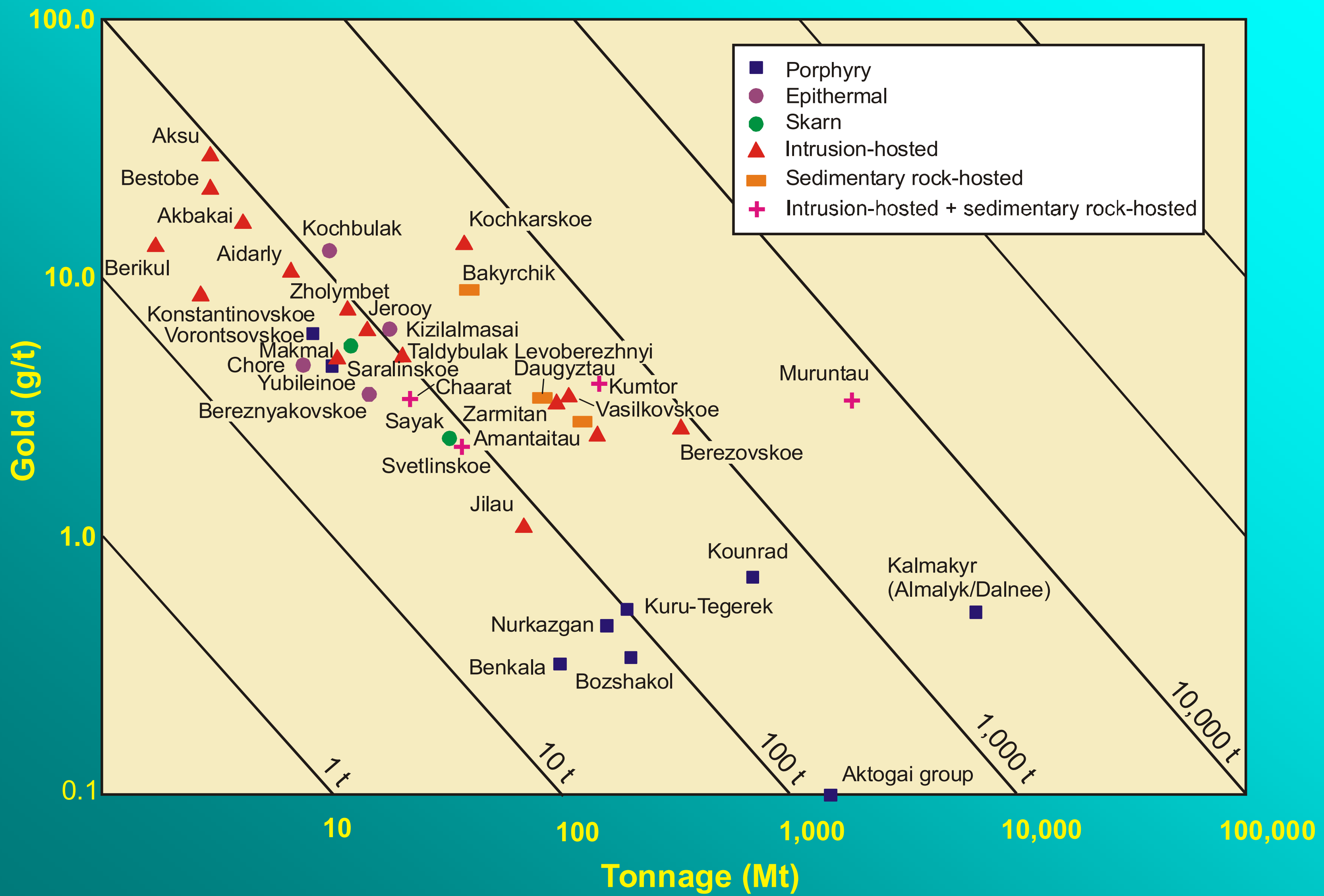
Cole, 2000

Jilau Deposit



Cole, 2000

Zarmitan deposit



Zarmitan: Regional geology

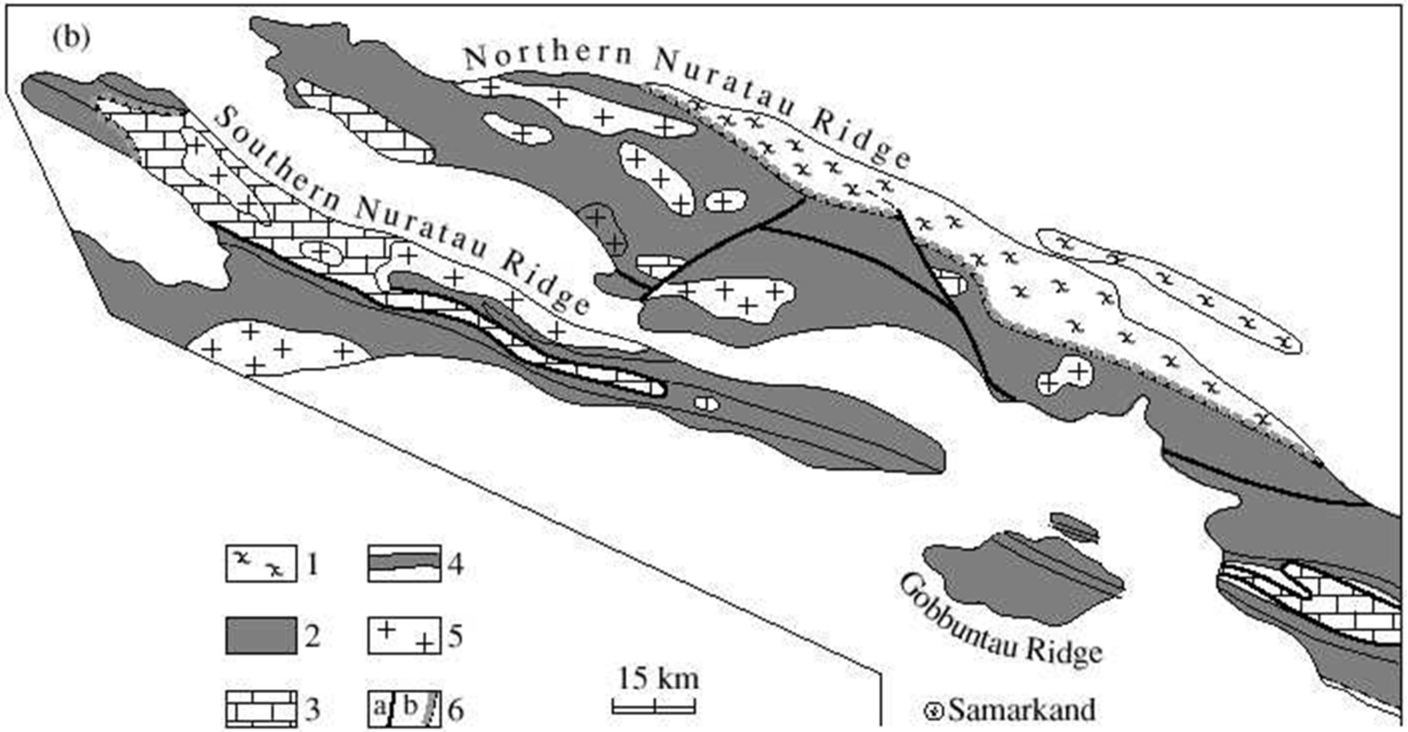


Fig. 1. Location of the Charmitan deposit (a) and tectonic scheme of Nuratau Mountains (Ruzhentsev and Sokolov, 1983) (b).
1, 2—Tectonostratigraphic terrains: 1—Turkestan–Alai, 2—Turkestan–Zeravshan; 3—Middle and Upper Paleozoic carbonate rocks and flysch; 4—Southern Nuratau shear zone; 5—granitoid; 6a—subvertical faults, 6b—thrusts.

GEOLOGY OF ORE DEPOSITS Vol. 38 No. 3 1996

Zarmitan: Regional geology

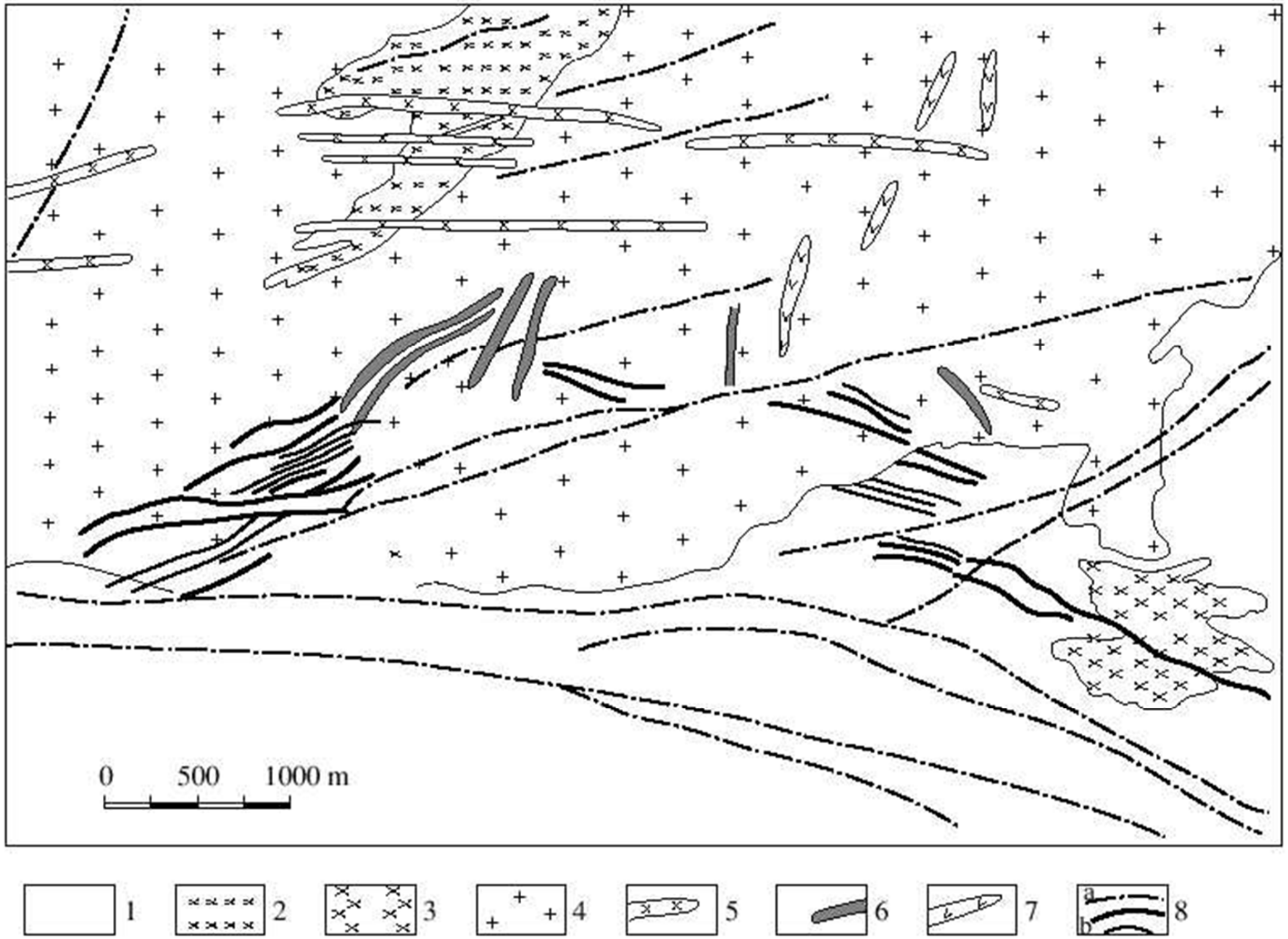
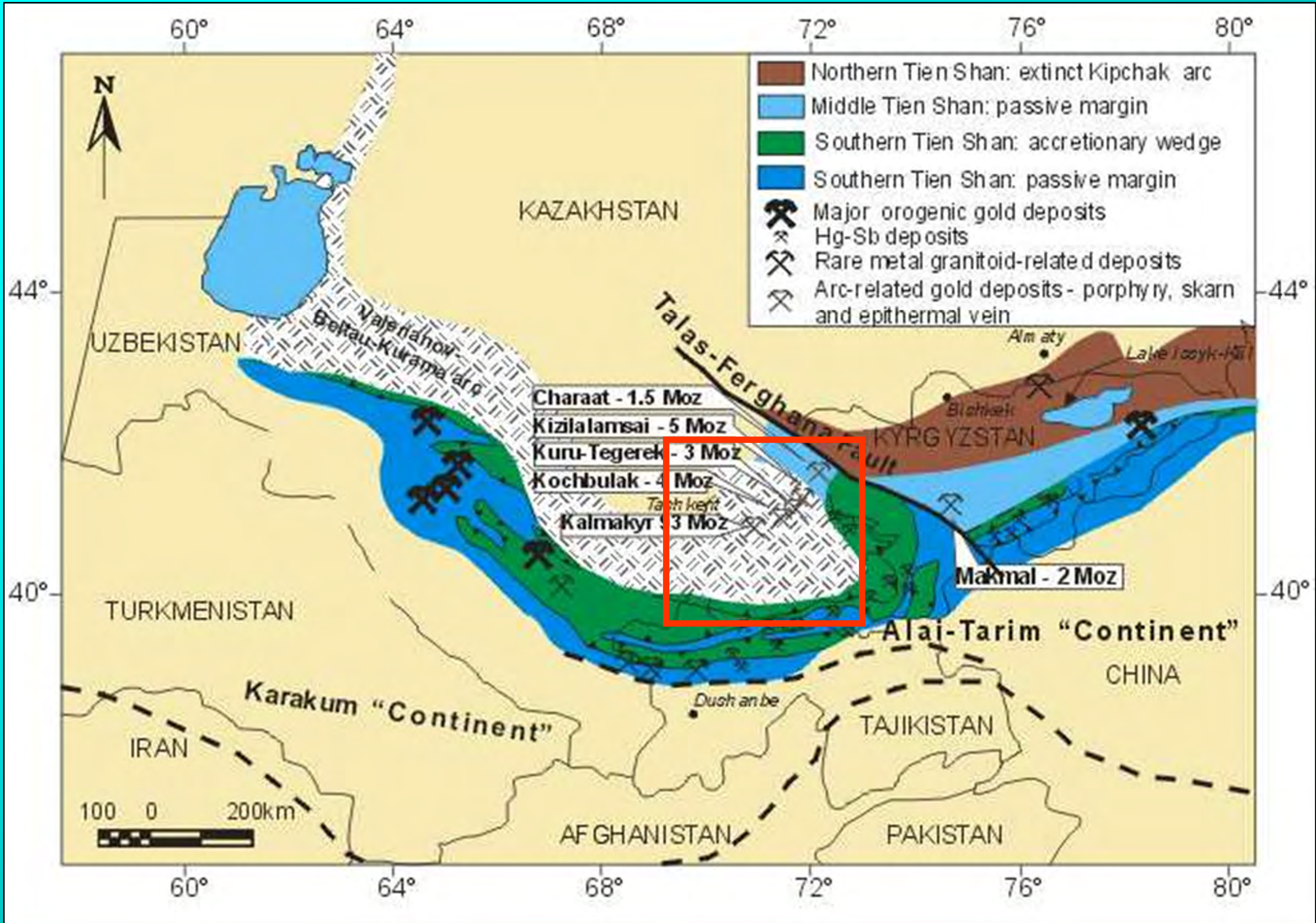
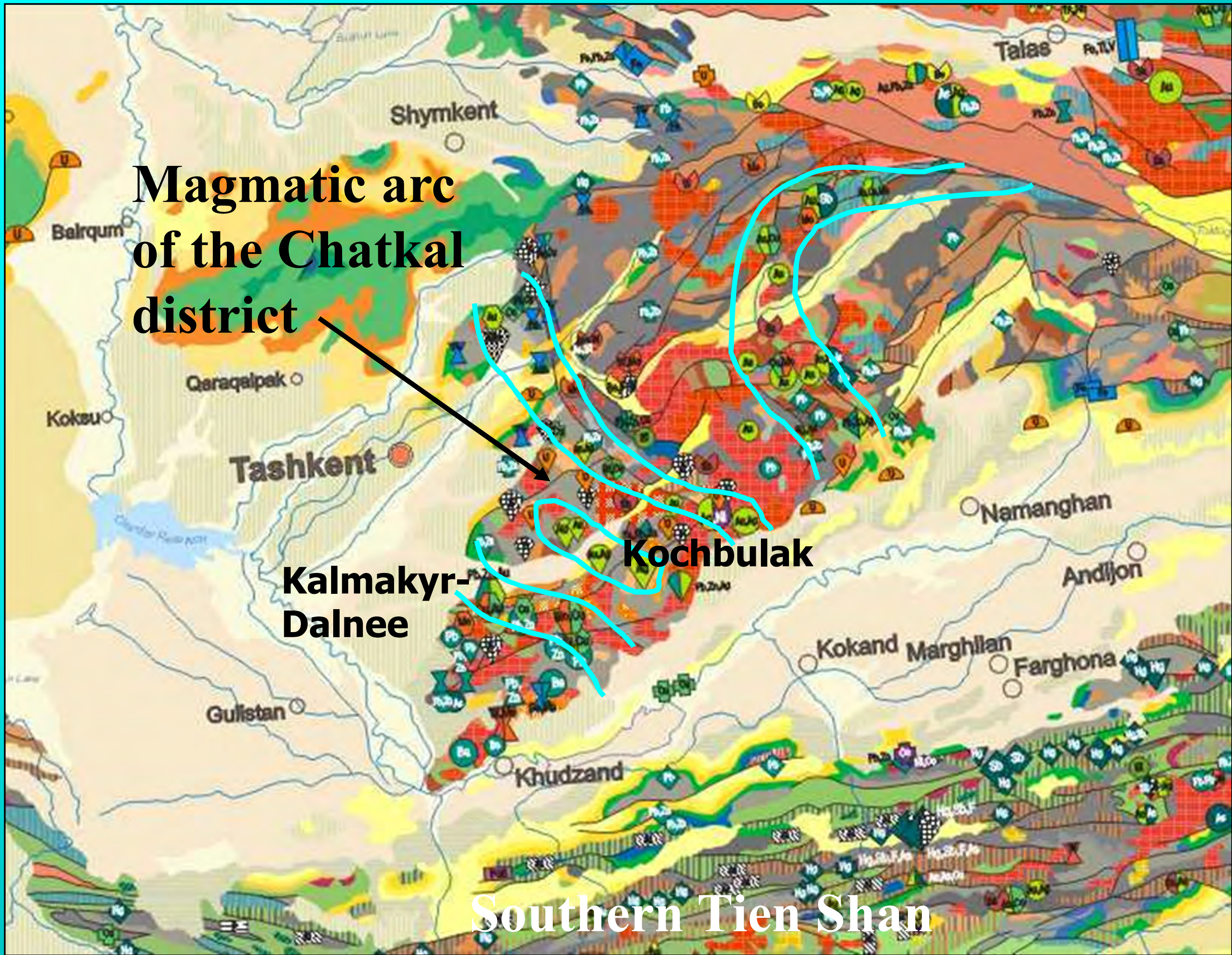


Fig. 2. Geological scheme of the Charmitan deposit (after the Charmitan Geological Exploration Expedition, 1989).
1—Metamorphozed sandstone and shale; 2—syenite; 3—quartz syenite; 4—granosyenite; 5—granite and adamellite dikes; 6—granosyenite dike; 7—essexite and lamprophyre dikes; 8—faults (a) and ore bodies (b).

Case Studies: Chatkal District

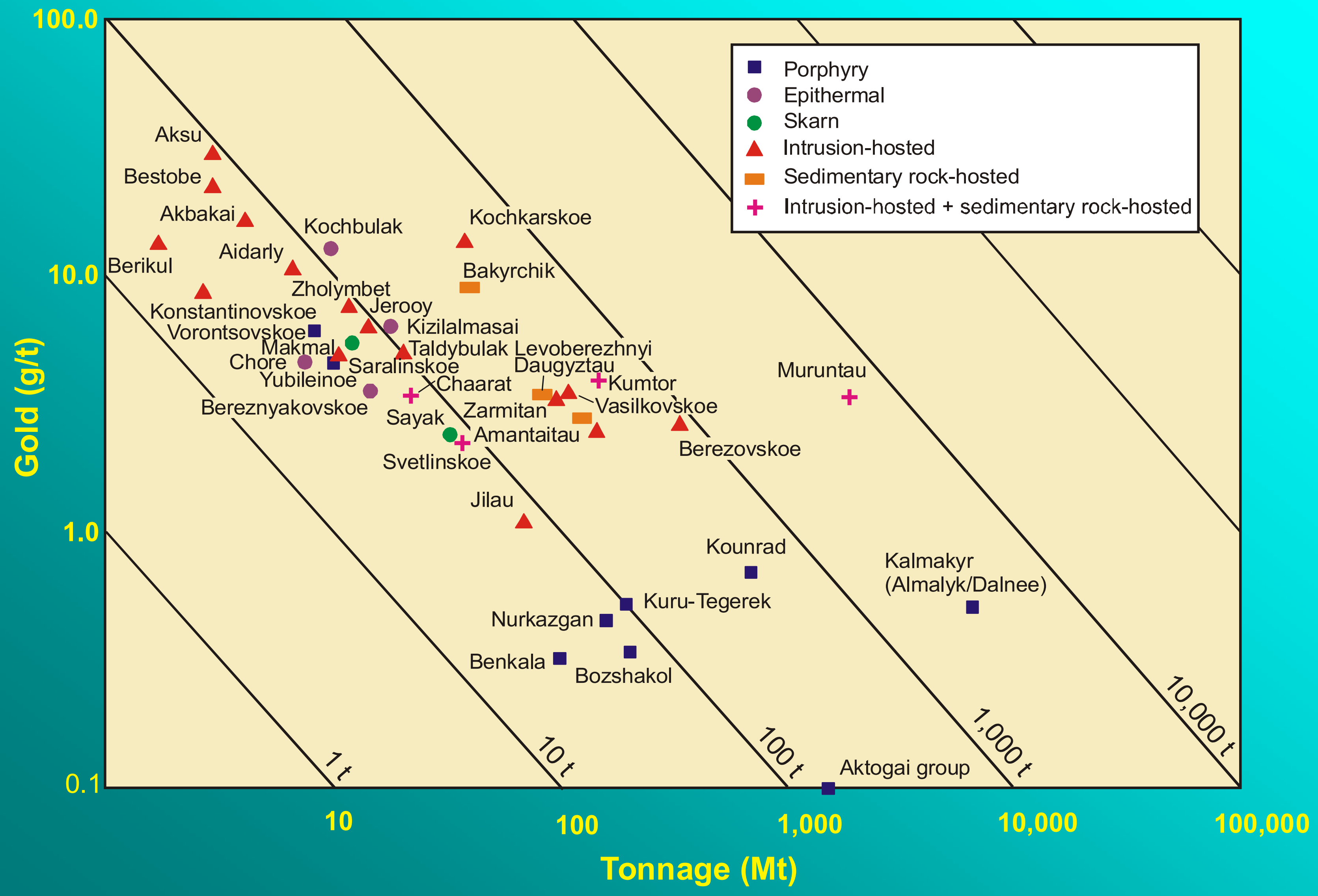


Chatkal District and Its Mineral Trends



Mineral Deposits Map of Central Asia, Seltmann, Shatov and Yakubchuk (eds), 2001

Kalmakyr-Dalnee deposits



Kalmakyr and Dalnee Cu-(Au)-porphyries

- Discovered in the 1925, but production started in 1949
- Since 1954 until 1998 produced 4 Mt of Cu
- Resource of 8,000 Mt @ 0.58% Cu, 0.05% Mo, 0.5 g/t Au, 3 g/t Ag, Te, Se, Re, Pd
- Operated by State-owned Almalyk Mining and Metallurgical Integrated Works
- One of the world's largest open pit operations - 4x2 km and 660 m deep

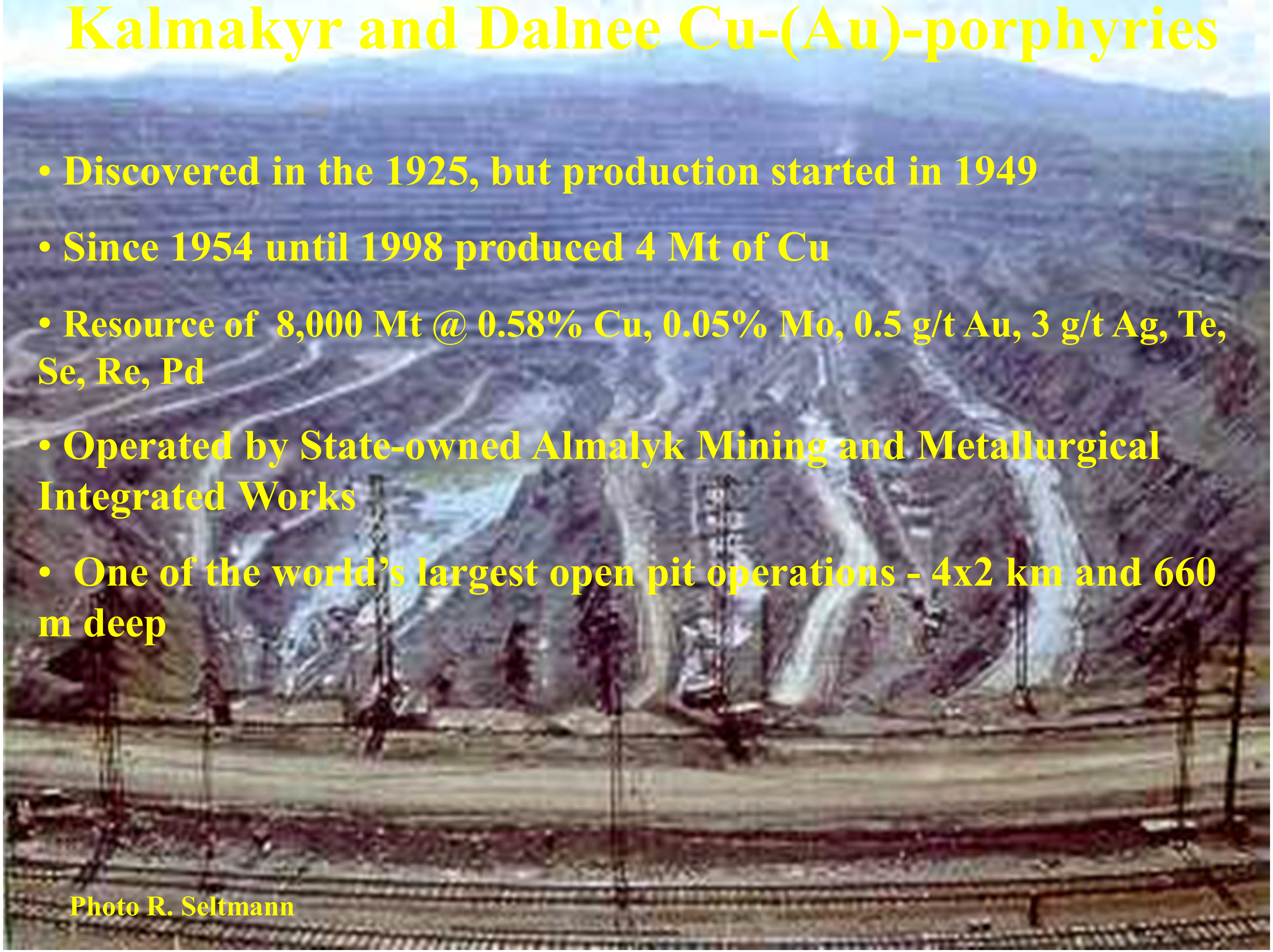
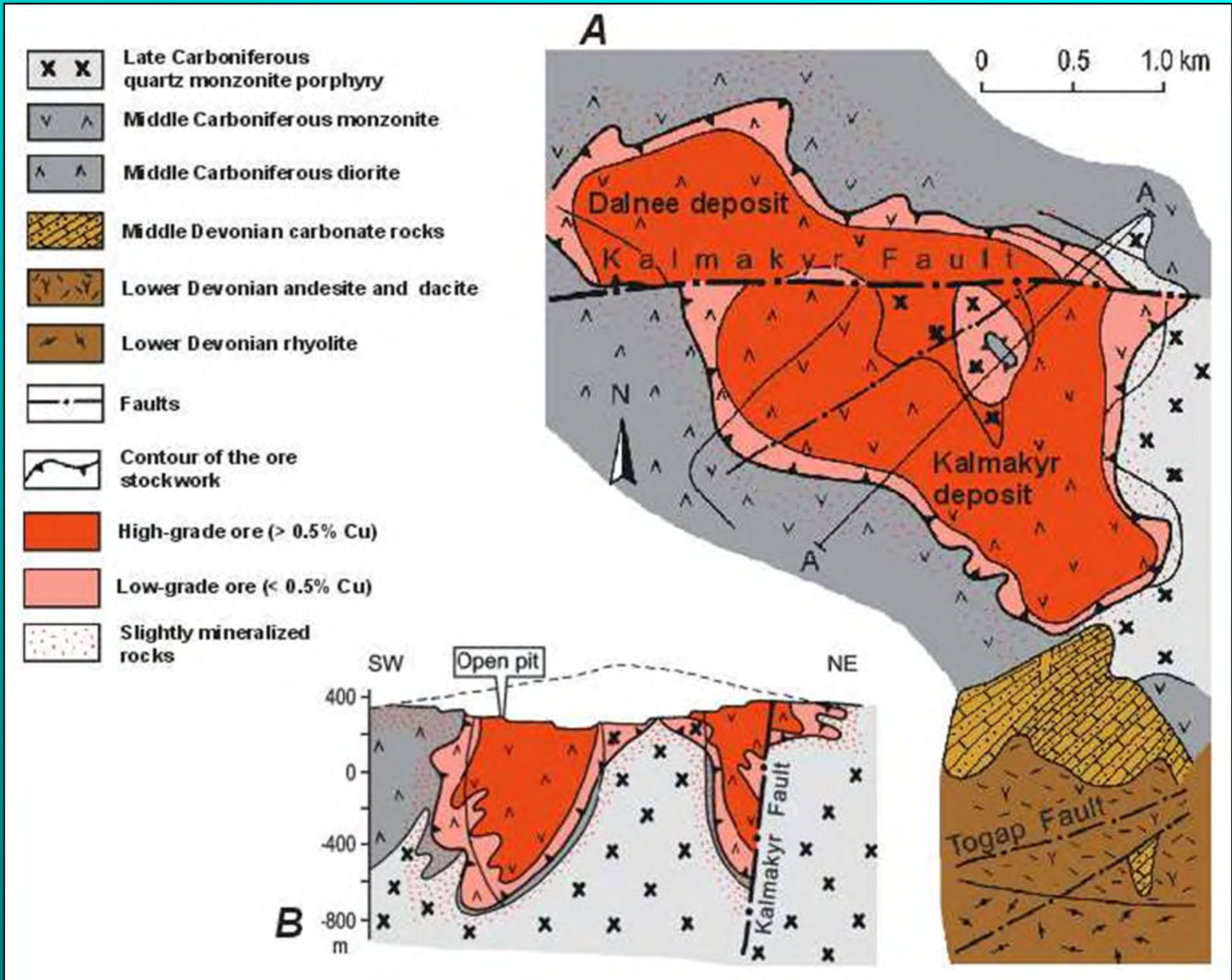


Photo R. Seltmann

Kalmakyr and Dalnee Cu-(Au)-porphyries

450 Mt flotation tailings of the Almalyk plant
with Cu, Mo, Re, Zn, Pb, In, Cd, Se, Te, Au, Ag, and Ir contents
occupy 4x2 km of which 165 Mt have grades greater than 0.2% Cu.
Background shows the Almalyk Cu ore dressing and metallurgy plant.

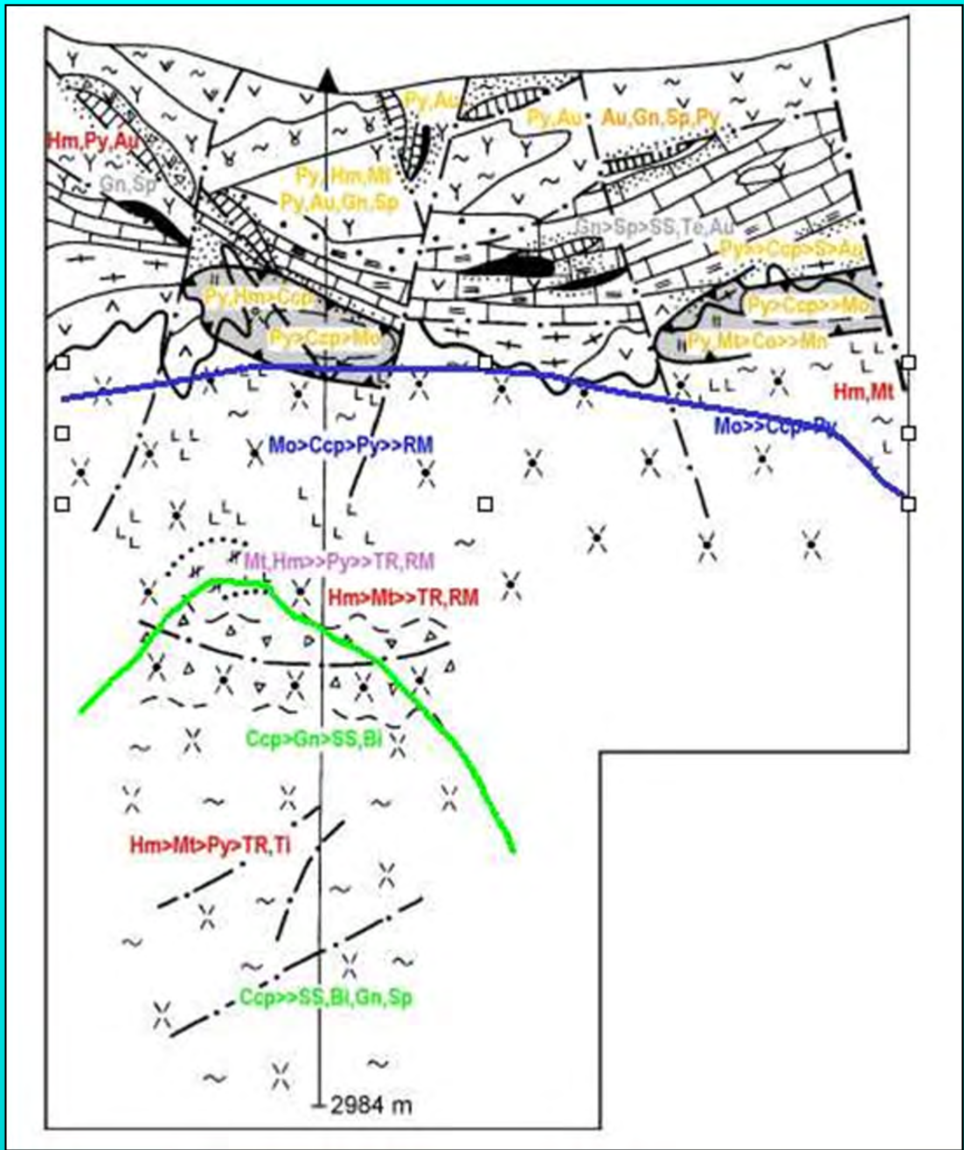


Kalmakyr and Dalnee Cu-(Au)-porphyries

- Middle-Late Carboniferous age
- Mineralized stockwork is found at the exocontact of quartz monzonite porphyry intrusion
- Hypogene ore, supergene blanket eroded?
- Low grade, but large system extending to a depth of more than 3km

Shayakubov et al., 1999

Structure of the Lower Kauldy porphyry on the basis of deep drilling to 2984 m



Nikolaeva et al., 1991 (from Shayakubov et al., 1999)

Vertical ore zonation

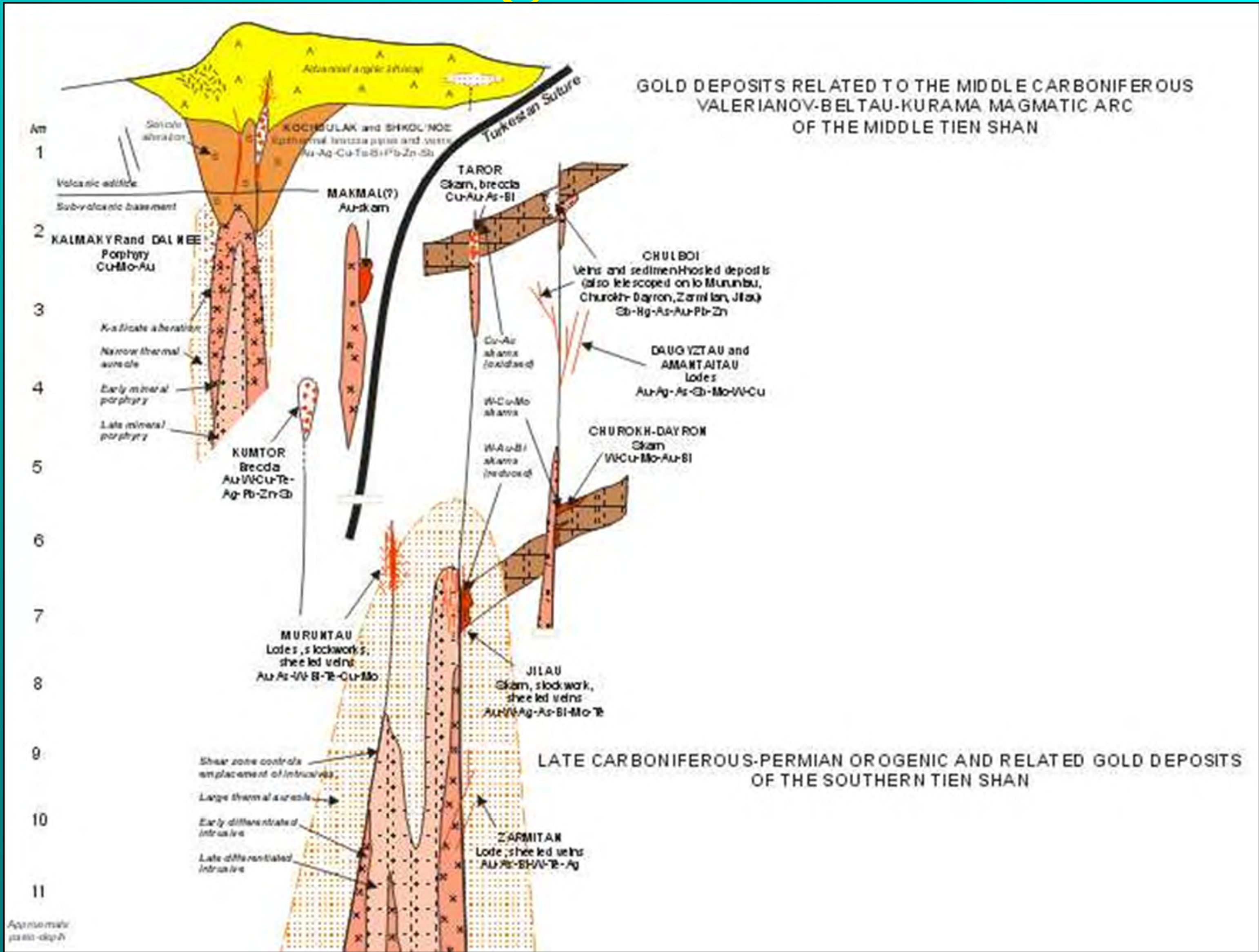
Pyrite, hematite, magnetite, gold, galena, sphalerite

Molybdenite, chalcopyrite, pyrite, rare metals

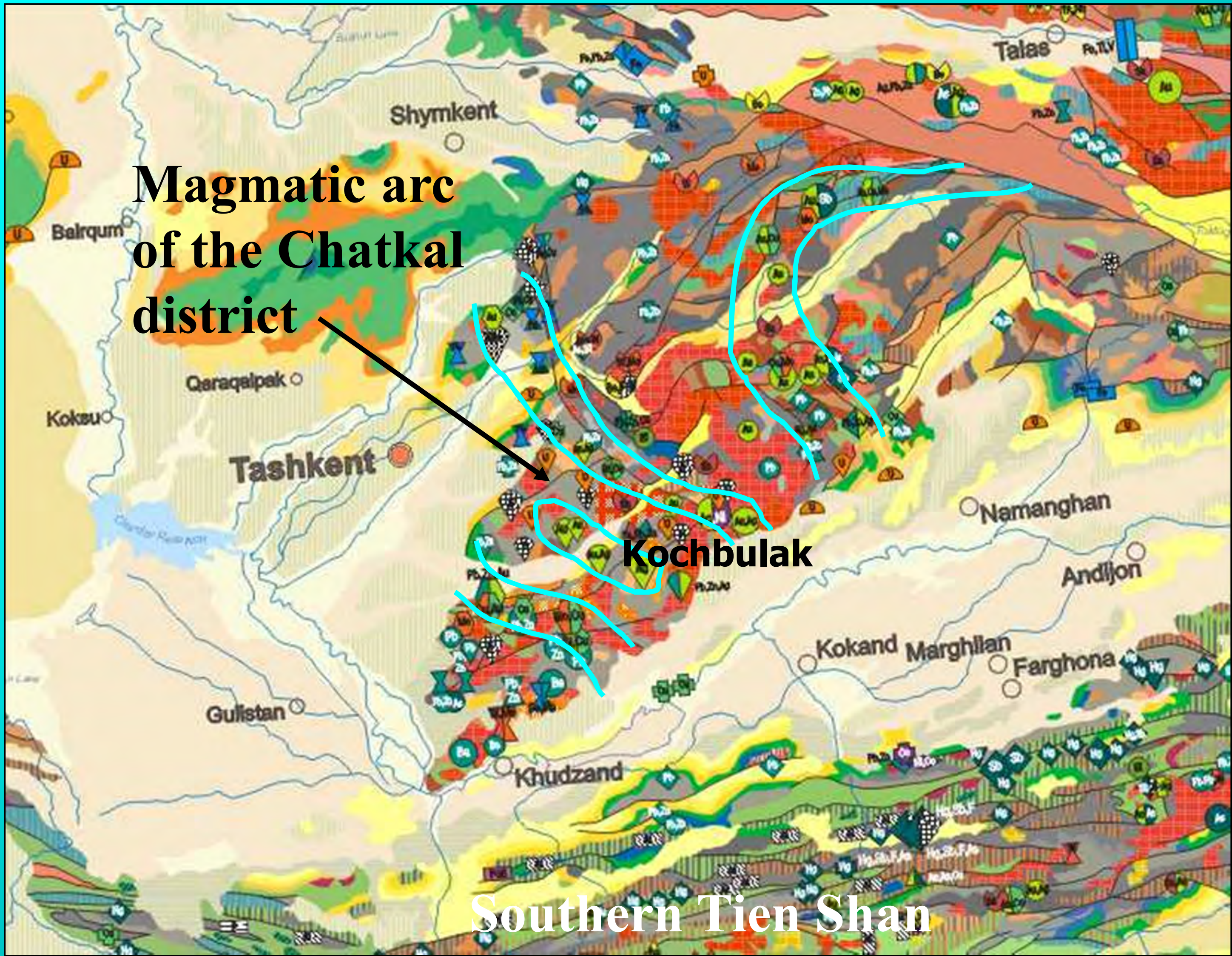
Chalcopyrite, galena, sulphosalts, Bi minerals

Chalcopyrite, sulphosalts, Bi minerals, galena, sphalerite

Source, transport, deposition controls and role of granitoid intrusions

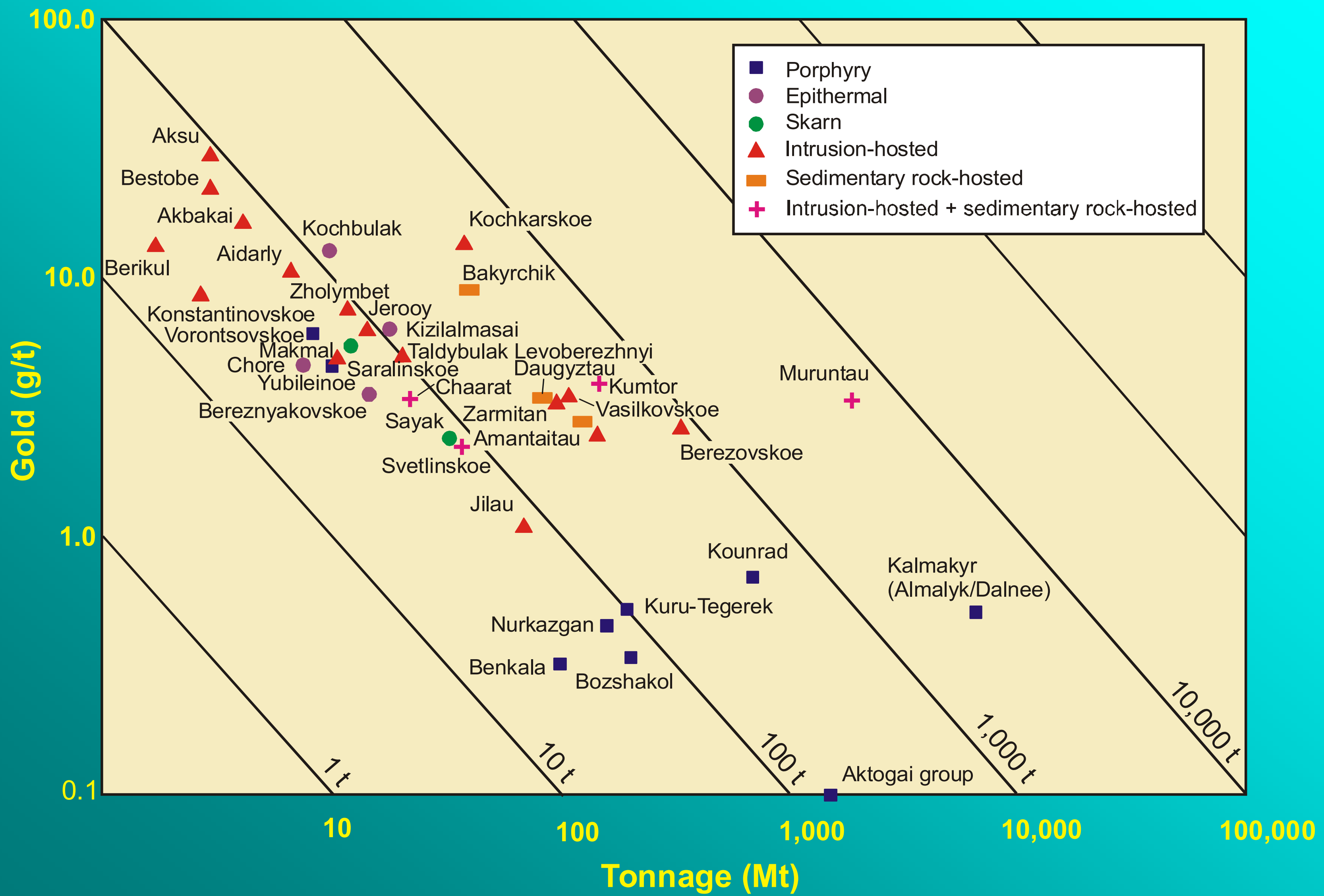


Chatkal District and Its Mineral Trends

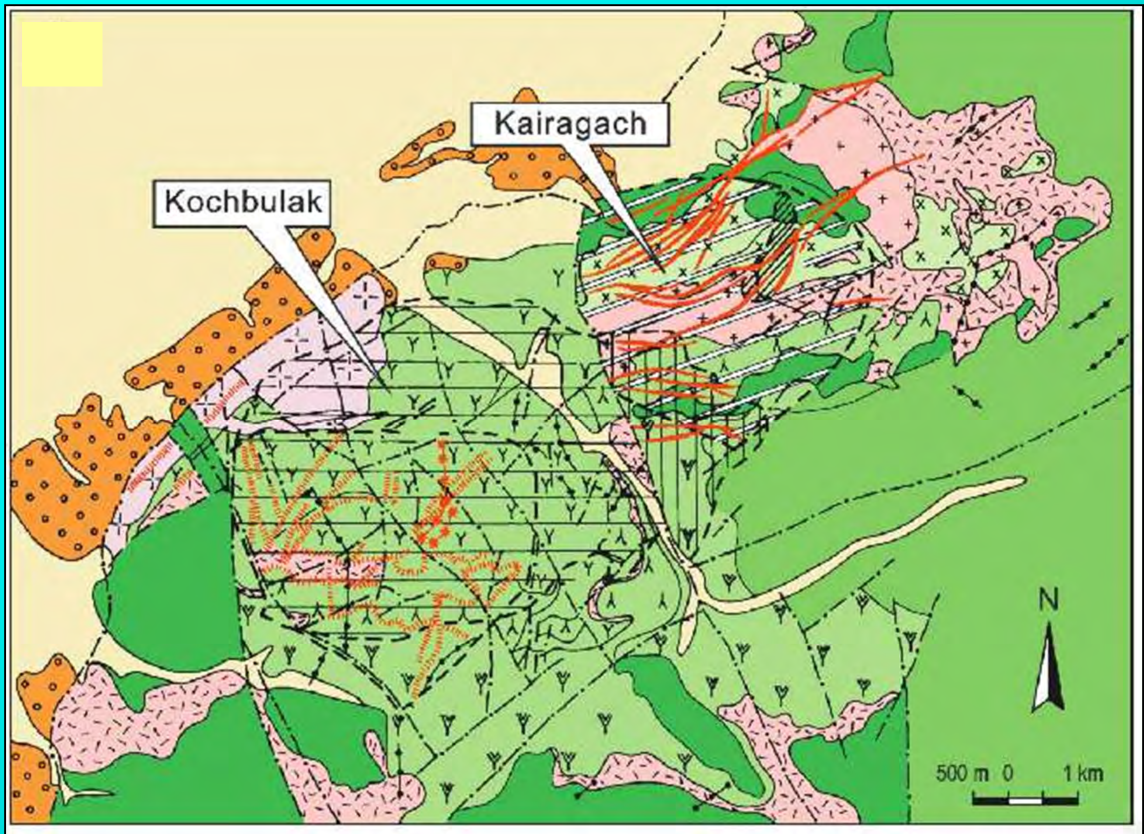


Mineral Deposits Map of Central Asia, Seltmann, Shatov and Yakubchuk (eds), 2001

Kochbulak deposit



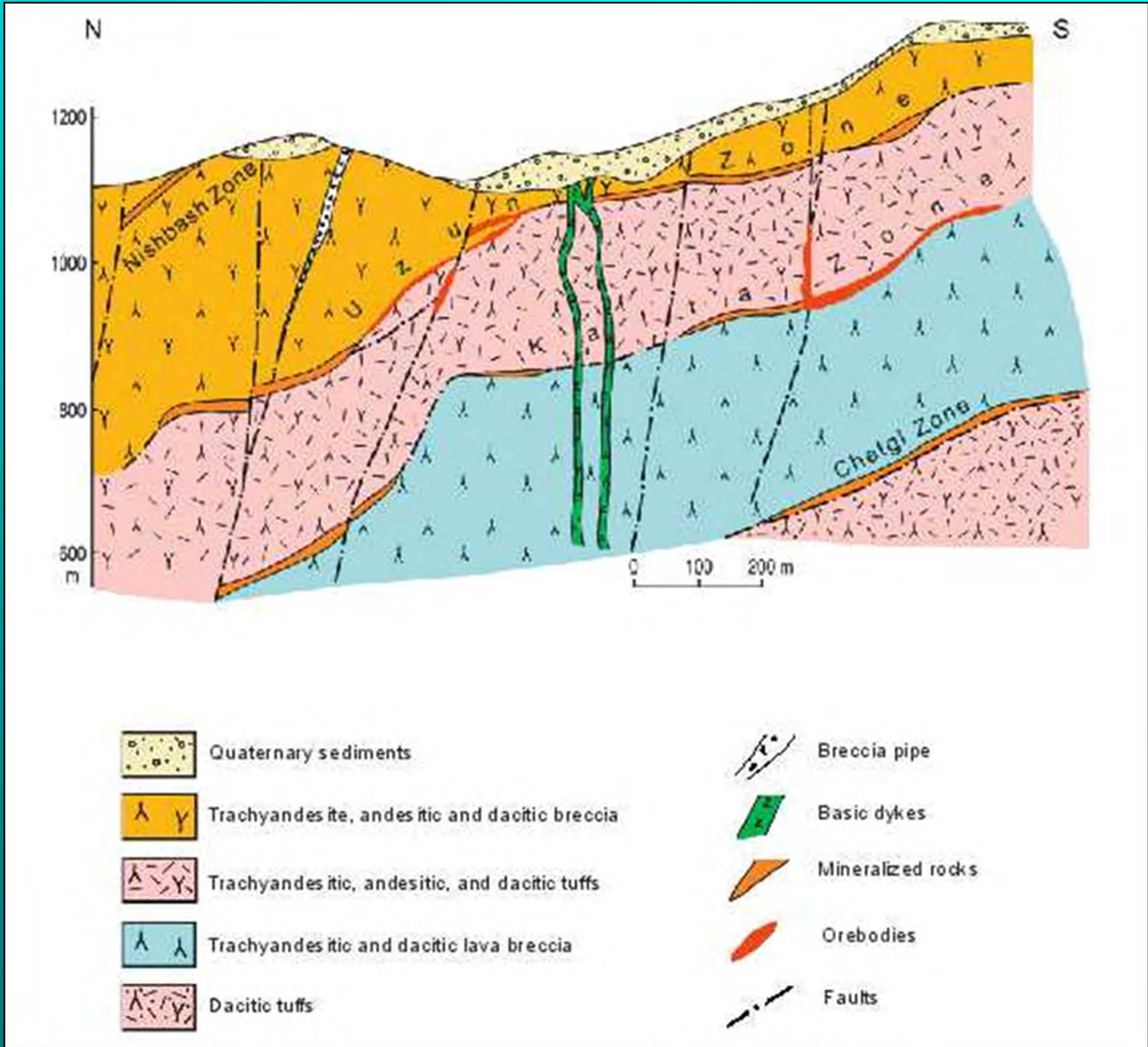
Kochbulak Au-Ag epithermal deposit



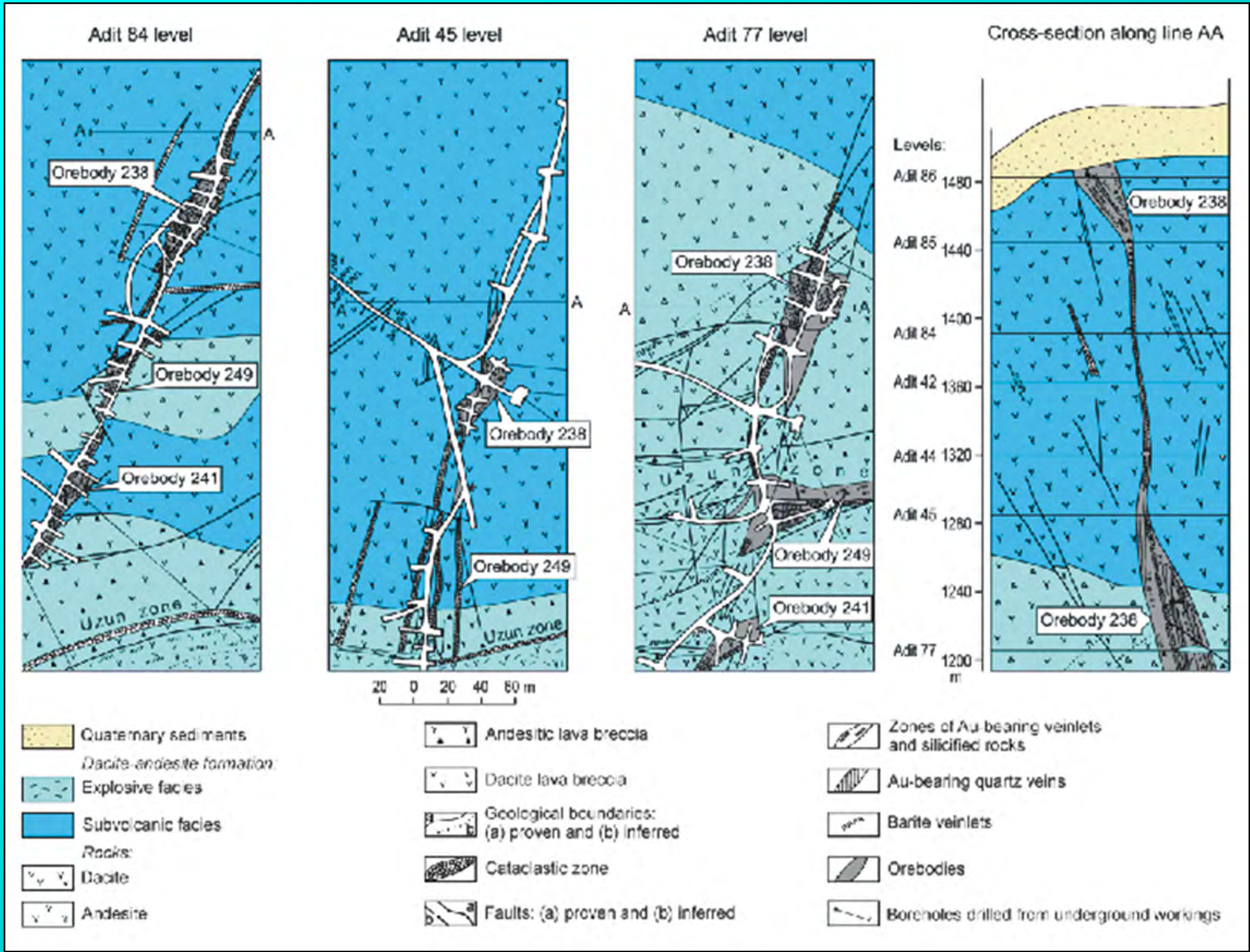
- Middle to Upper Carboniferous
- Caldera setting with latites to monzodiorite porphyries
- fluid channelling related to explosive breccia pipes at top and steep dipping mesothermal veins at depth
- Mineralization extends to a depth of 2,000 m with transition into mesothermal style
- 5.6 Mt @ 13.4 g/t Au, 120 g/t Ag, 0.2% Cu reserves
- 120 t Au, 400 t Ag resources with Te

Kovalenker, 1995

Kochbulak Au-Ag epithermal deposit

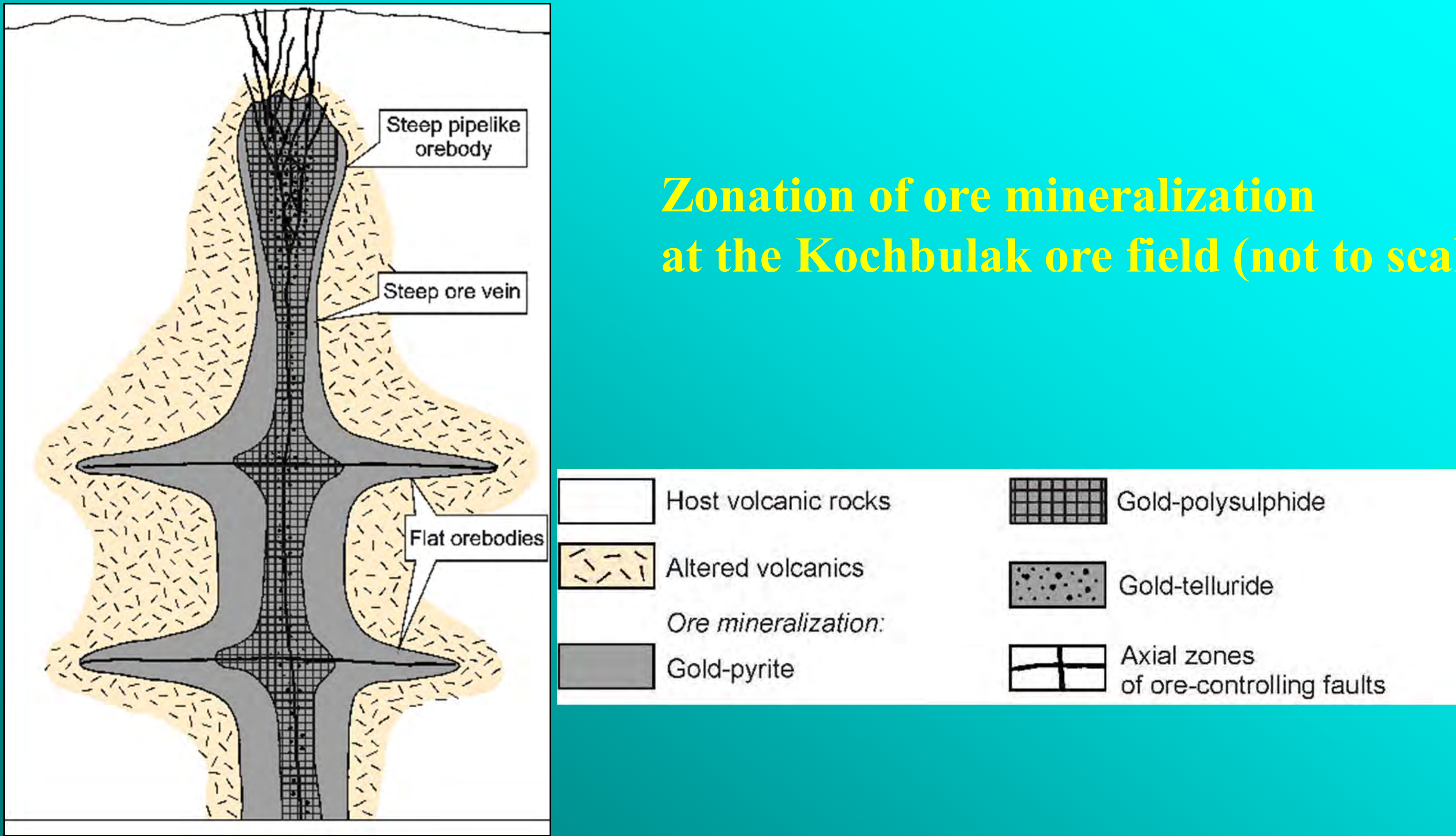


Kochbulak Au-Ag epithermal deposit



Ore zones of the Kochbulak deposit

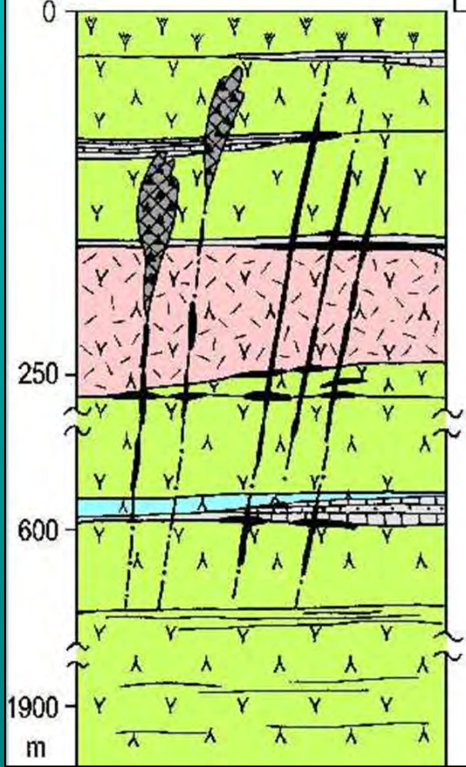
Kochbulak Au-Ag epithermal deposit: ore zonation



Zonation of ore mineralization at the Kochbulak ore field (not to scale

Shayakubov et al., 1999

Kochbulak Au-Ag epithermal deposit: ore zonation

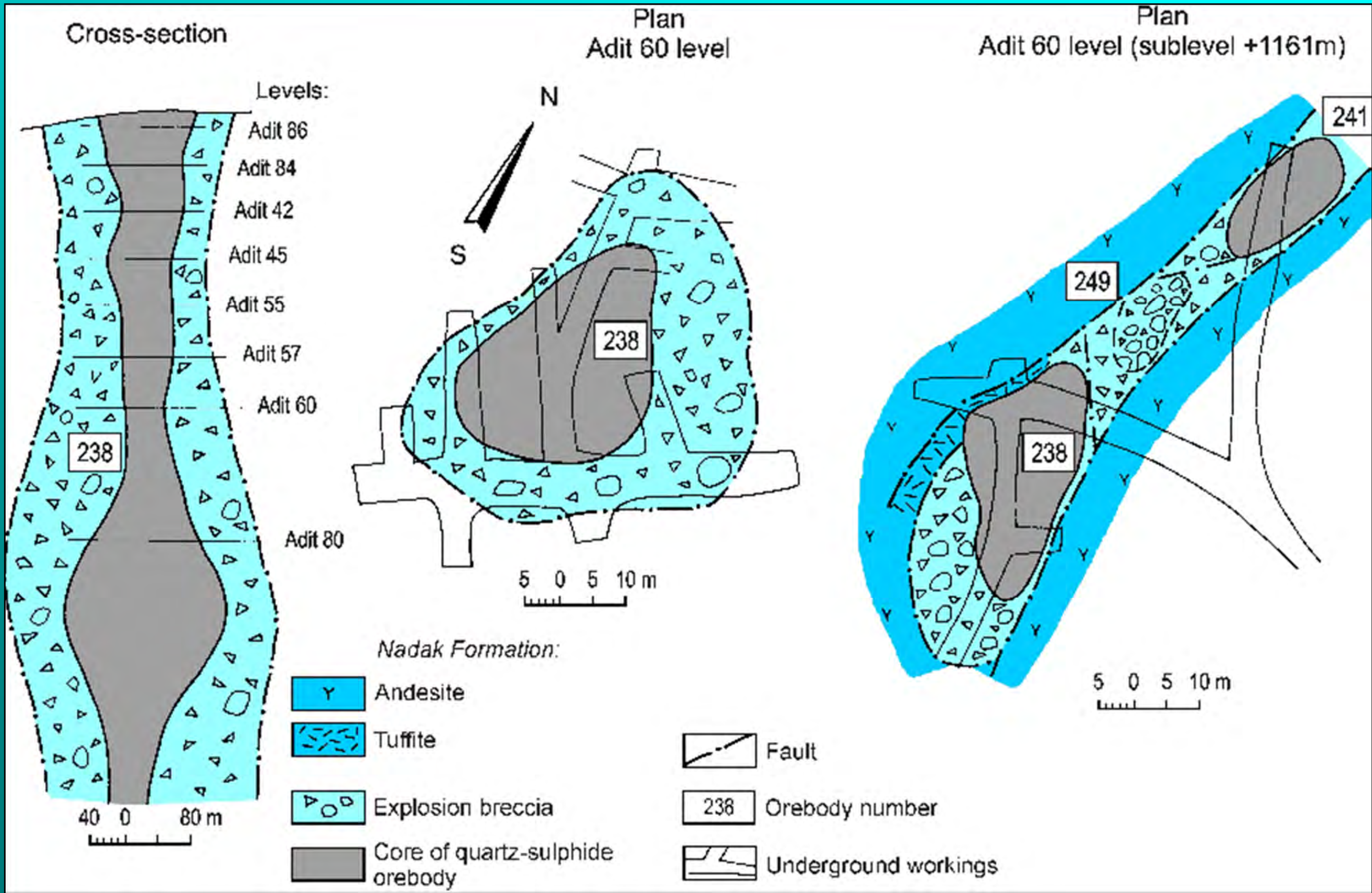


Ore zone		Mineral type	Au reserves, %	
Nishbash, Uzun, Kalta	I	Gold-telluride	35	62%
		Gold-polysulphide	25	
		Gold-pyrite	2	
Chetgi	II	Gold-telluride	5	18%
		Gold-polysulphide	10	
		Gold-pyrite	3	
Paski, New, Deep	III	Gold-telluride	1	20%
		Gold-polysulphide	4	
		Gold-pyrite	15	

Distribution of mineral types and gold reserves in vertical section

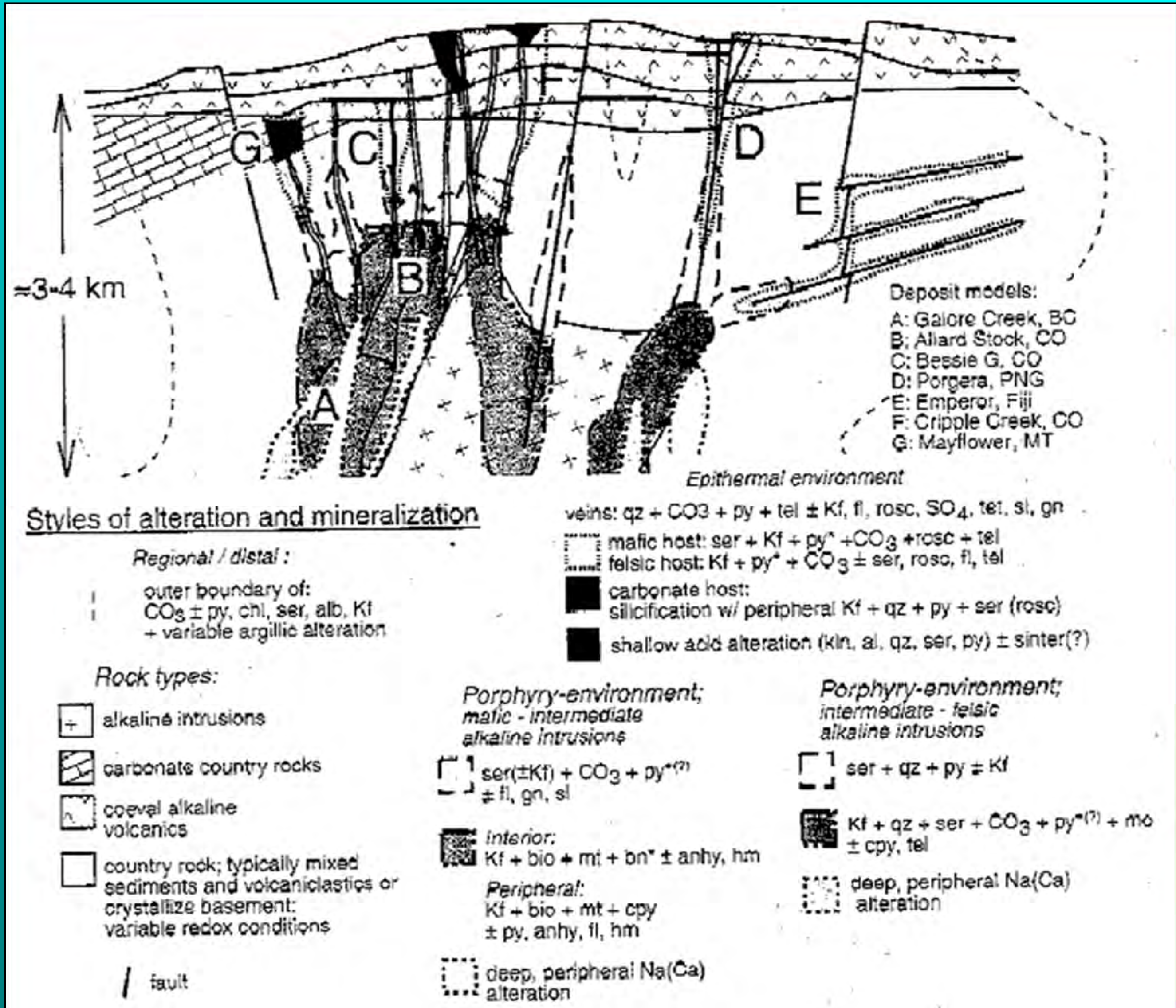
Shayakubov et al., 1999

Kochbulak Au-Ag epithermal deposit

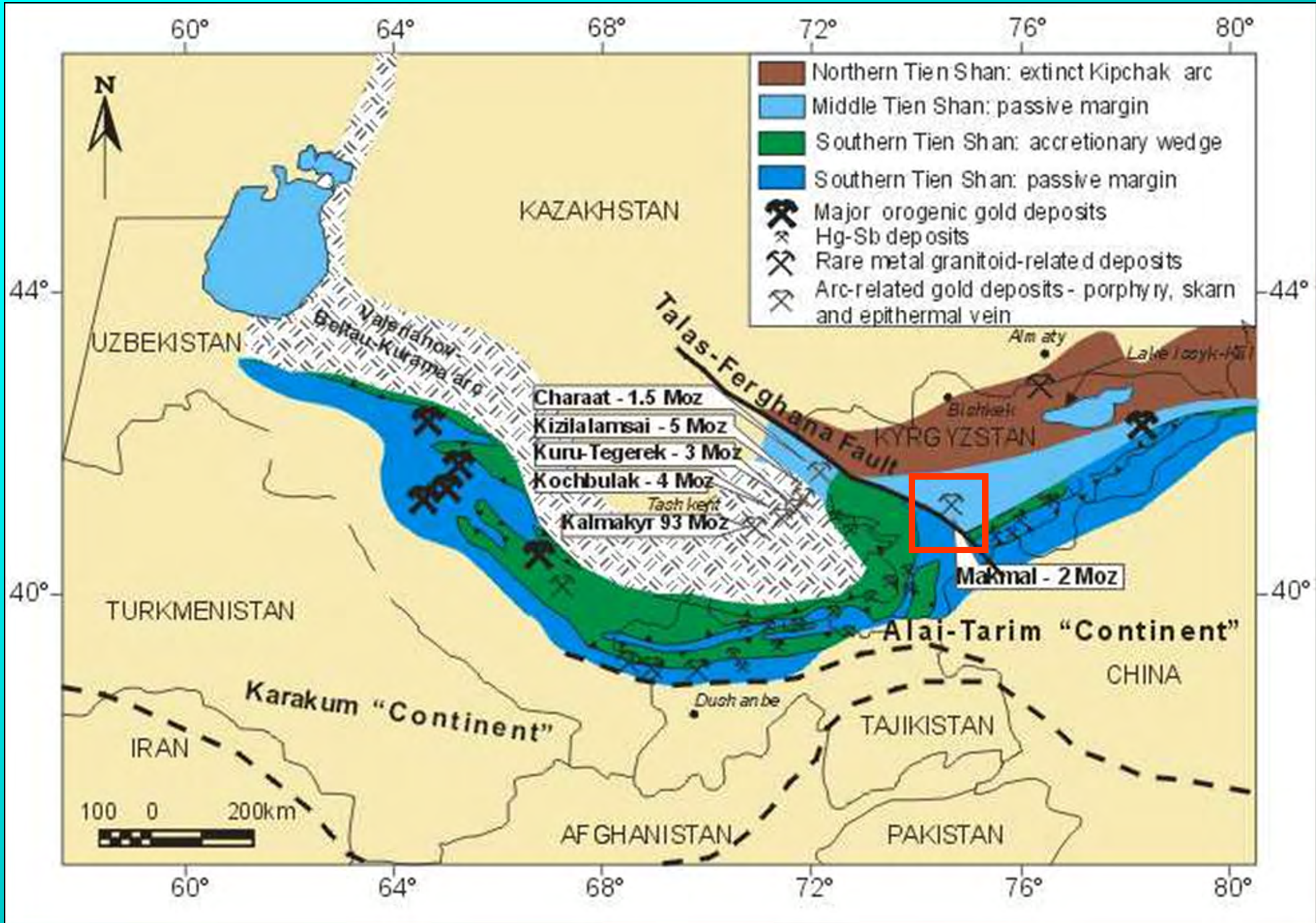


Shayakubov et al., 1999

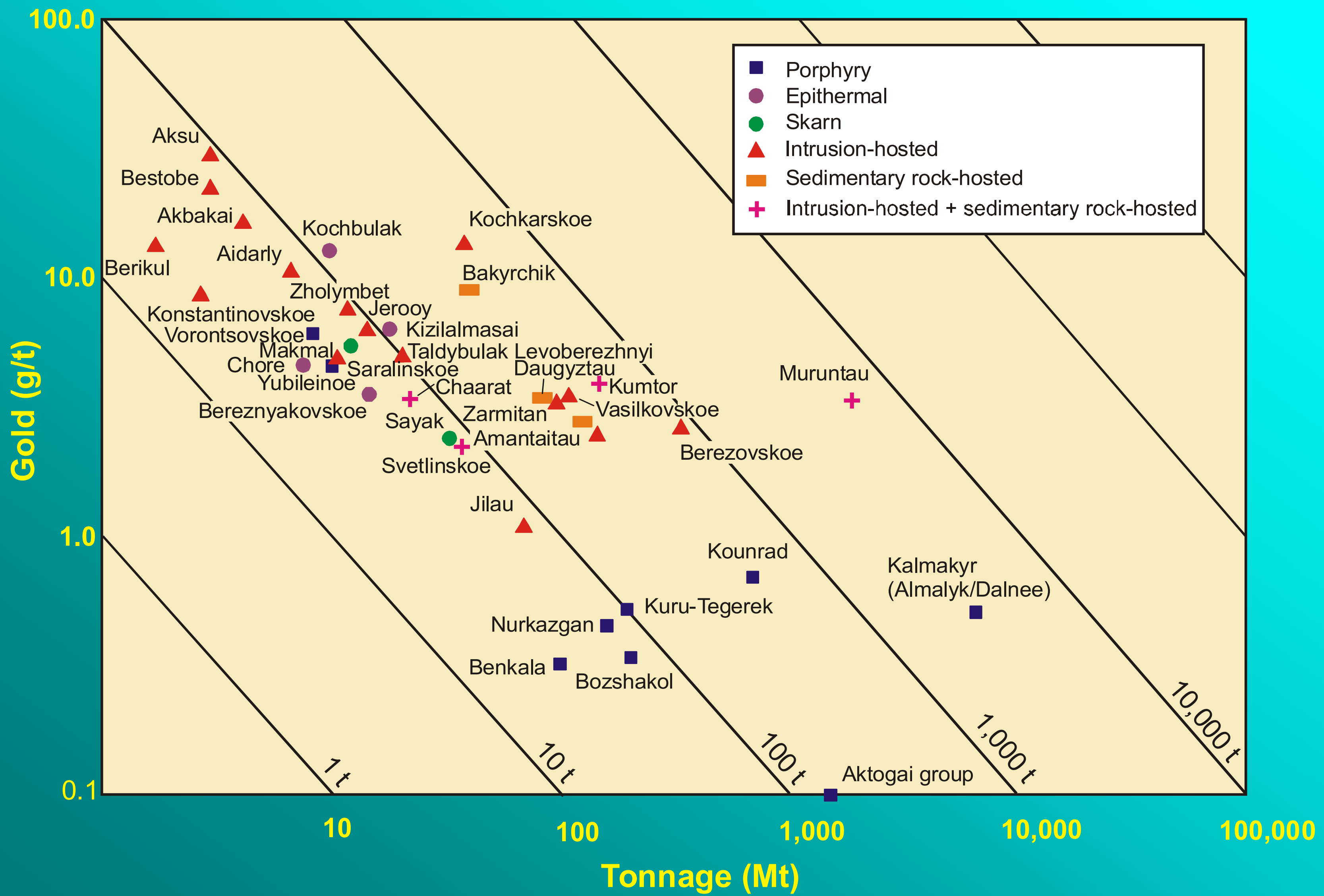
Possible structure beneath Kochbulak



Case Studies



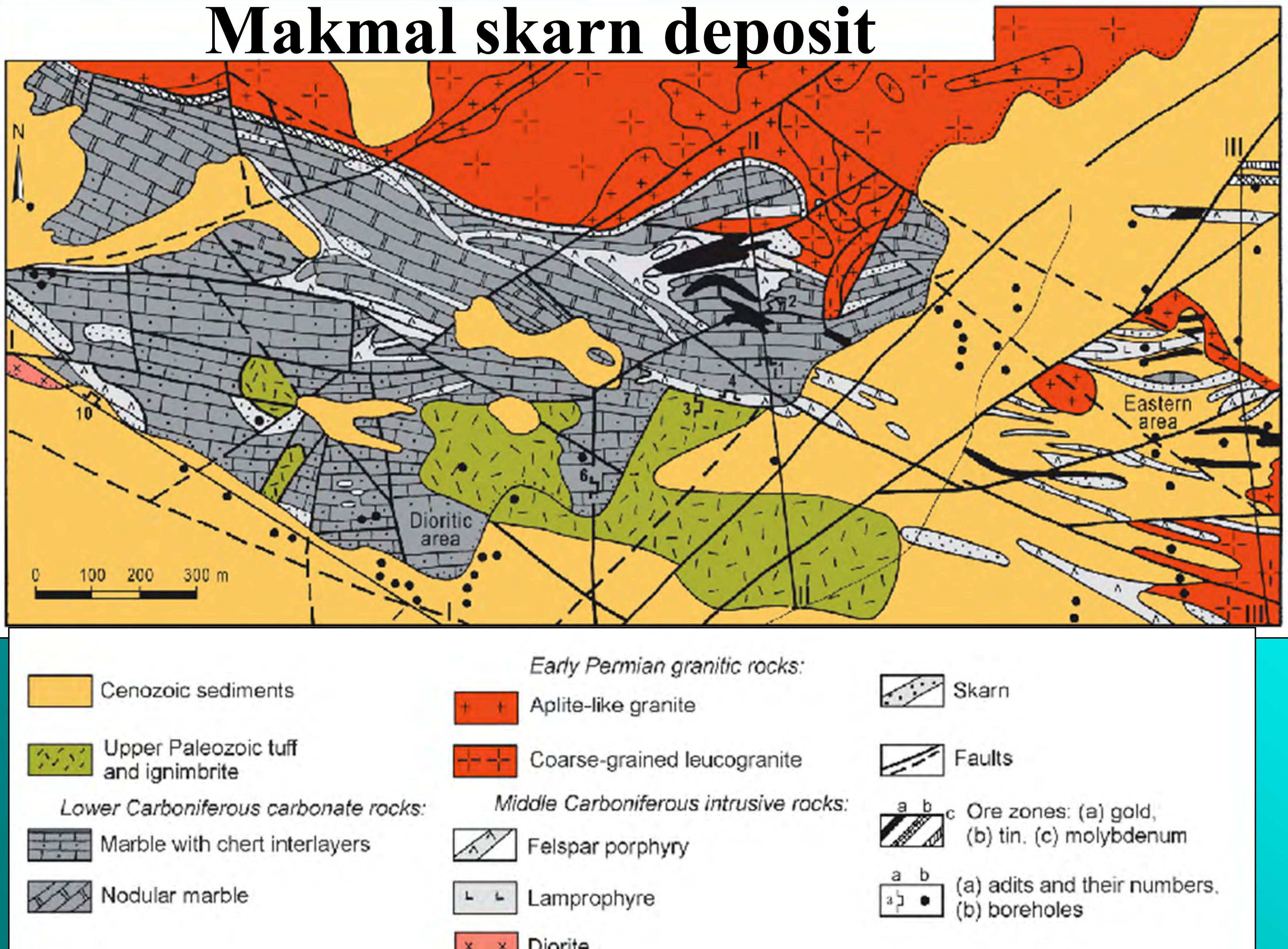
Makmal skarn deposit



Makmal skarn deposit

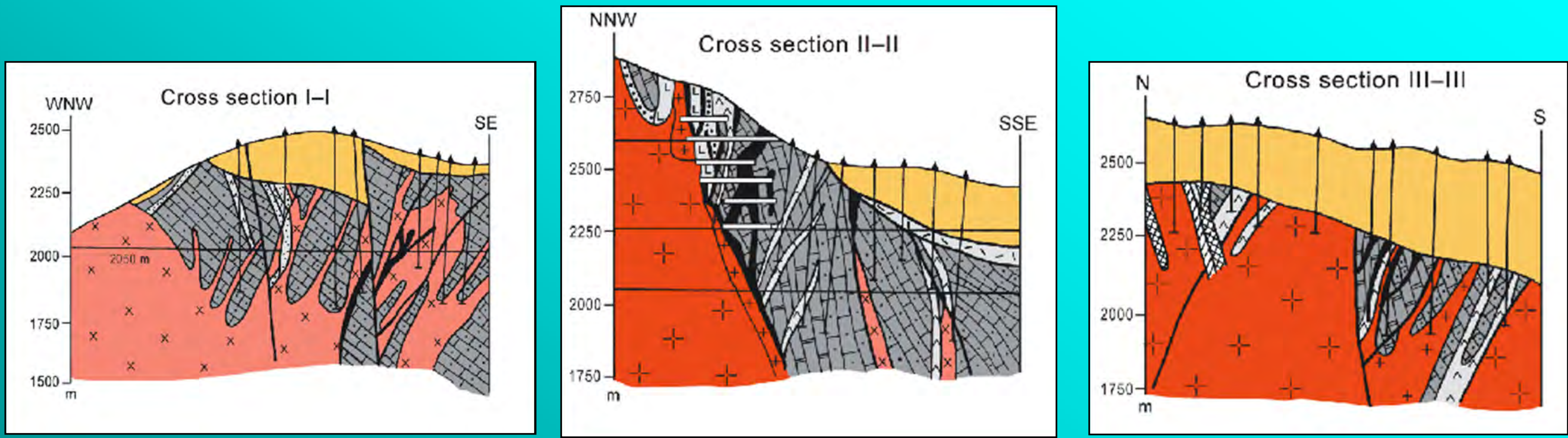
Makmal open pit is a small-scale operation. Greyish rocks are Carboniferous limestones. The top of the hill in the background is the Early Permian granite. The steep-dipping skarn ore body is clearly visible near the shovels.

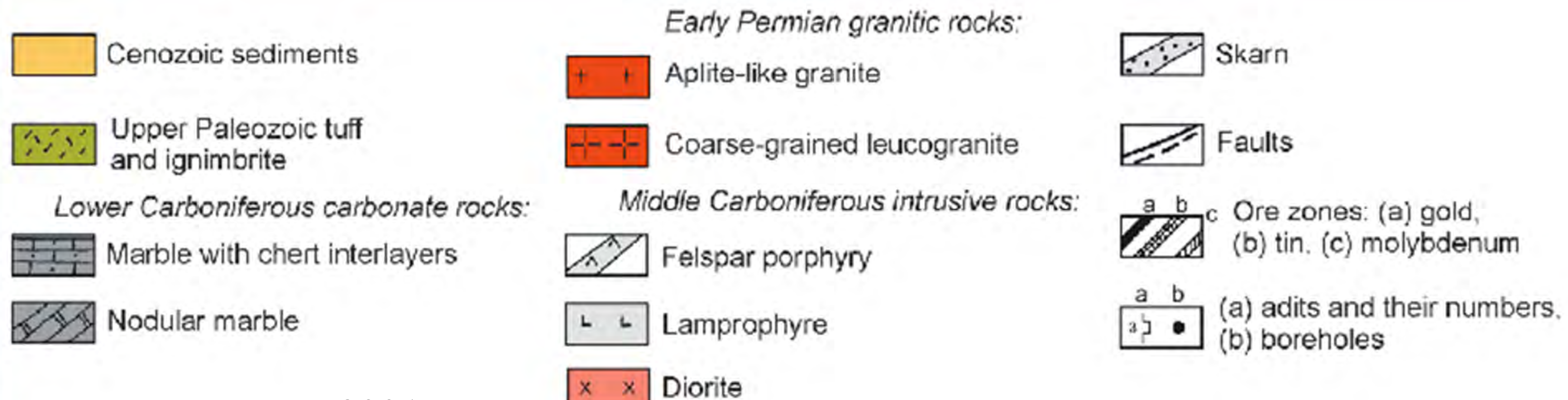
Makmal skarn deposit



Jenchuraeva et al., 2001

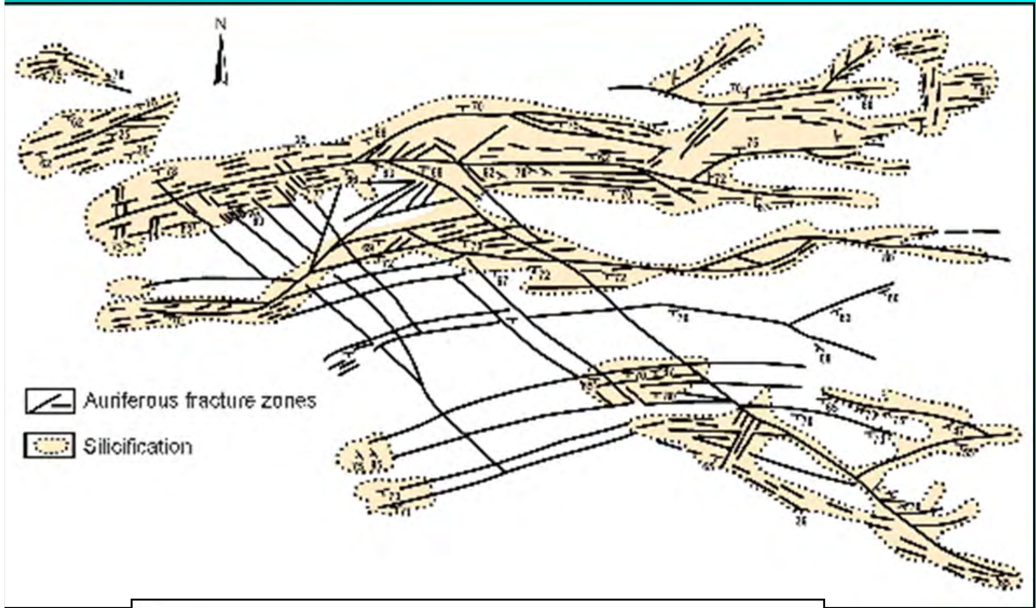
Makmal skarn deposit

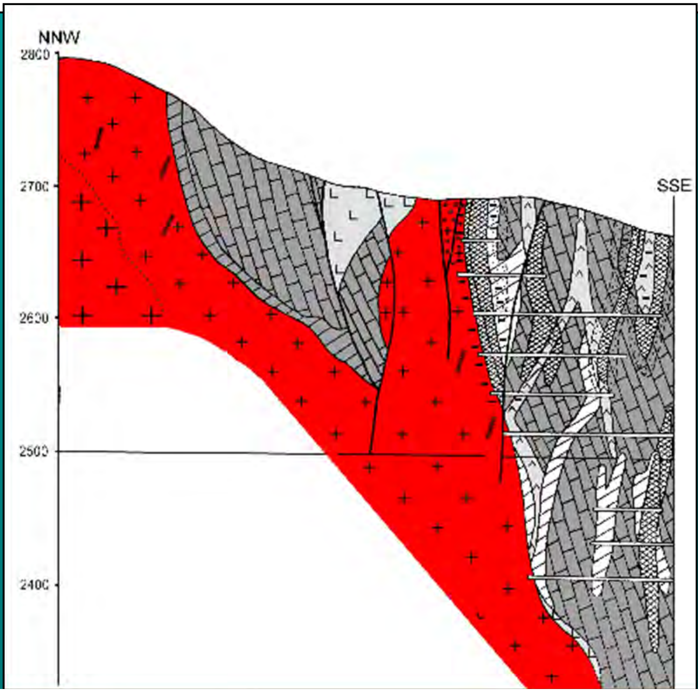




Jenchuraeva et al., 2001

Makmal skarn deposit



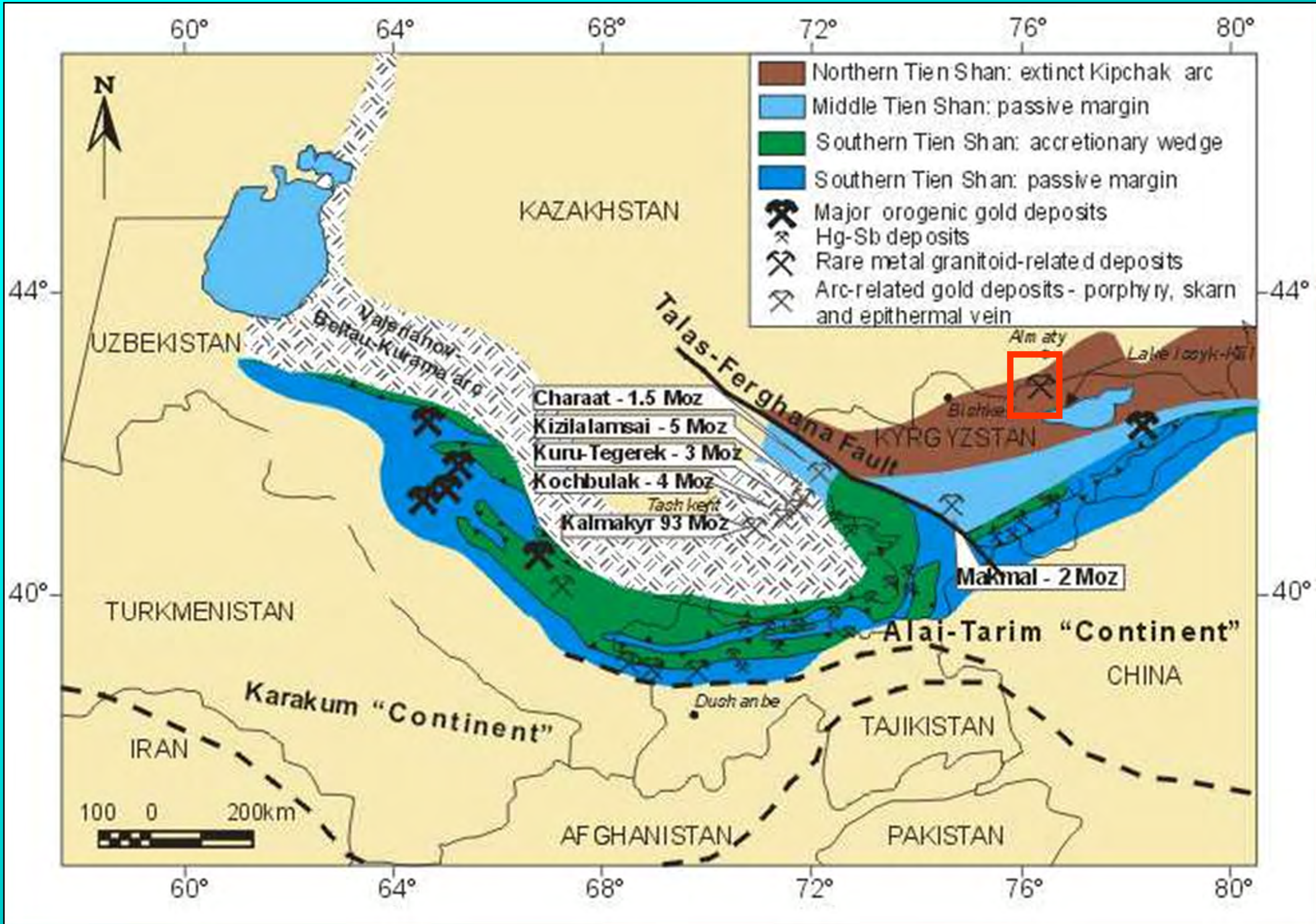


Types of ore mineralization at the Makmal deposit

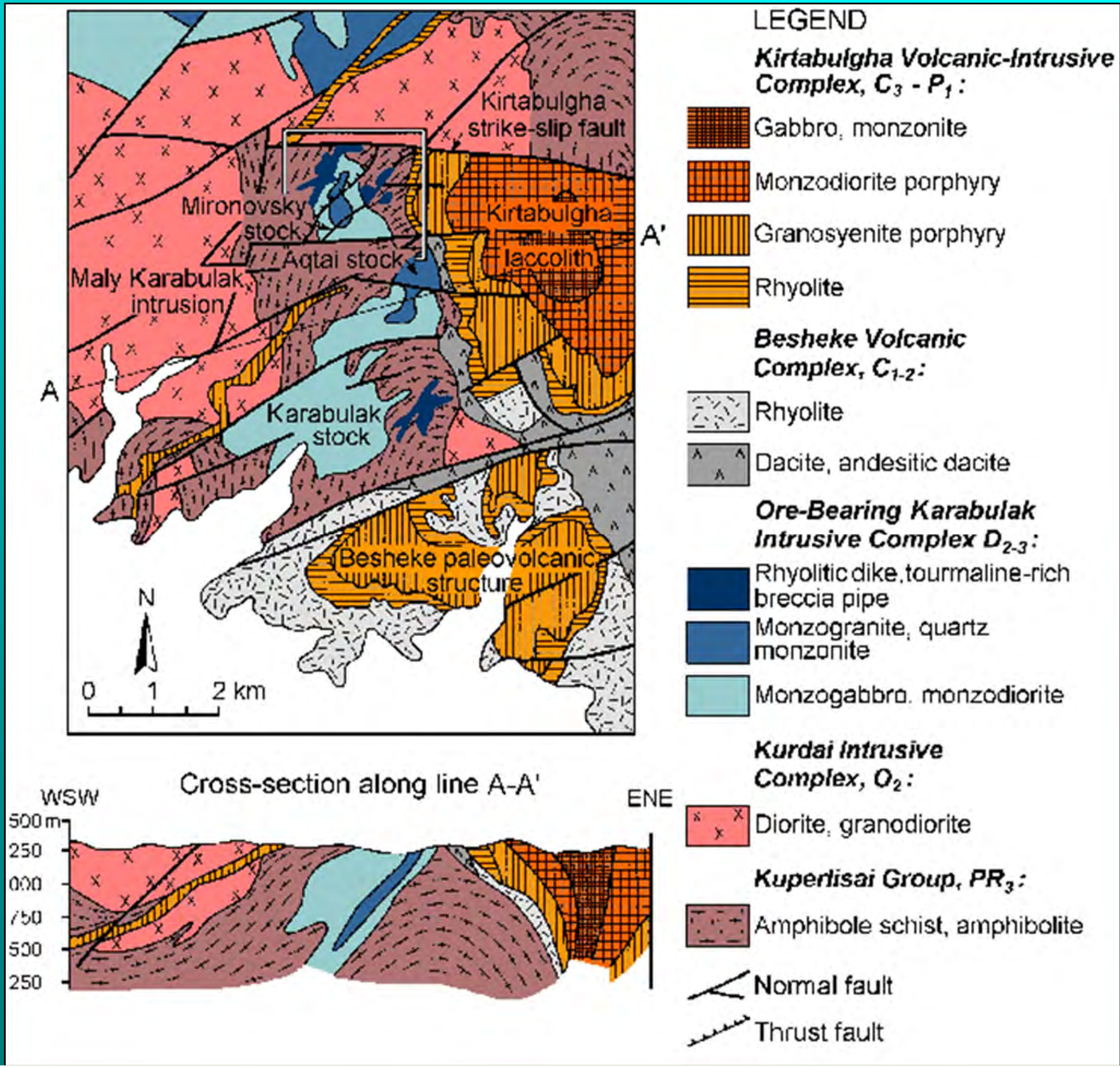
Type	Ore mineral	Gangue mineral
Magnetite skarn	Magnetite Hematite Pyrite Chalcopyrite Galena Sphalerite	Garnet Pyroxene Serpentine
Massive sulphide	Sphalerite Galenobismutite Pyrite Chalcopyrite Native gold Native silver Hematite Tetrahedrite Freibergite Arsenopyrite Bismuthine Native bismuth Boulangerite	Quartz Garnet Epidote Actinolite Tremolite Barite
Sn-bearing greisen	Cassiterite Topaz Beryl Magnetite Wolframite Molybdenite	Quartz Muscovite
Gold–sulphide	Native gold Pyrrhotite Chalcopyrite Galena Sulphosalts Bismuthine Native bismuth	Quartz

Jenchuraeva et al., 2001

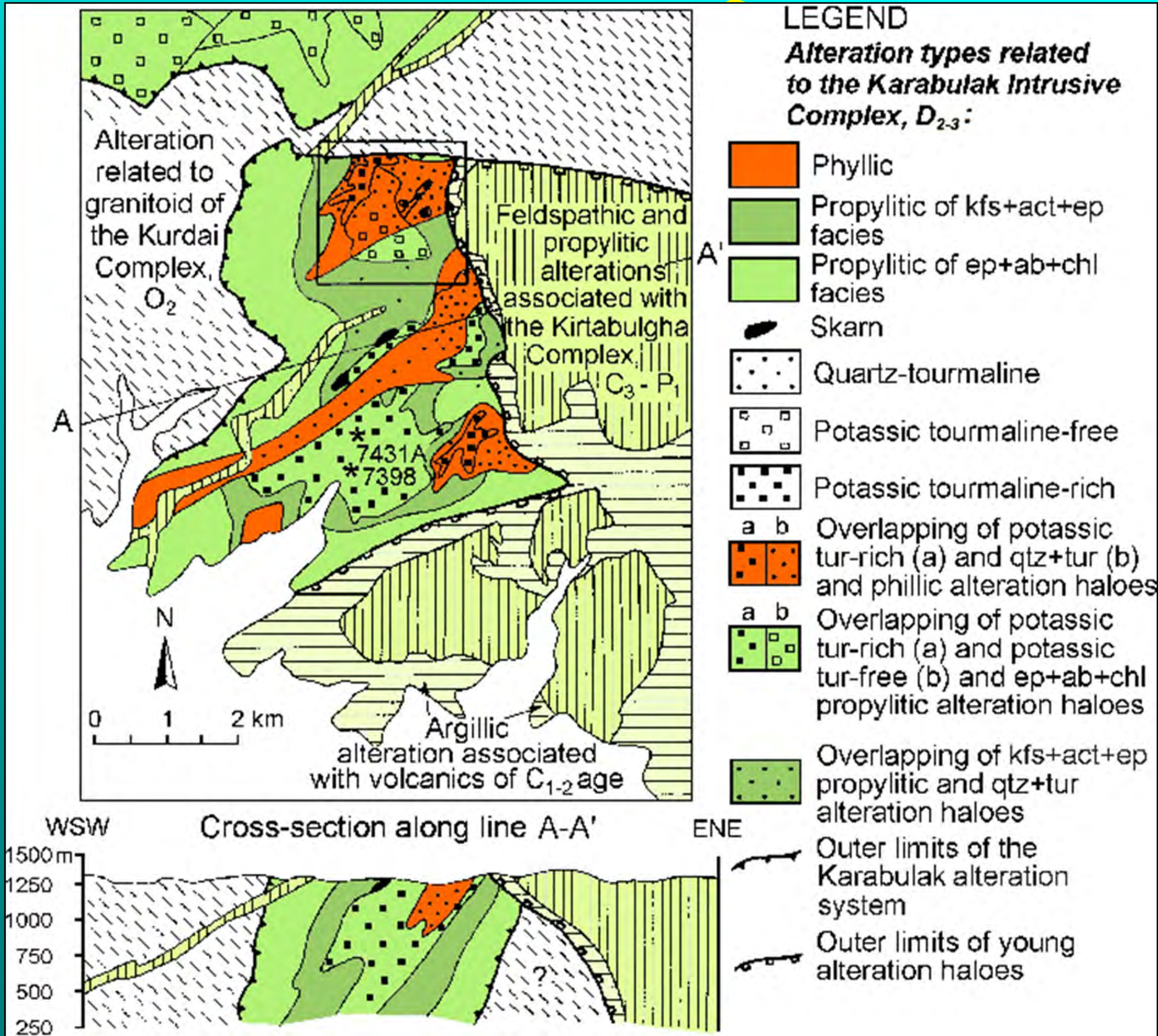
Mironovskoe deposit



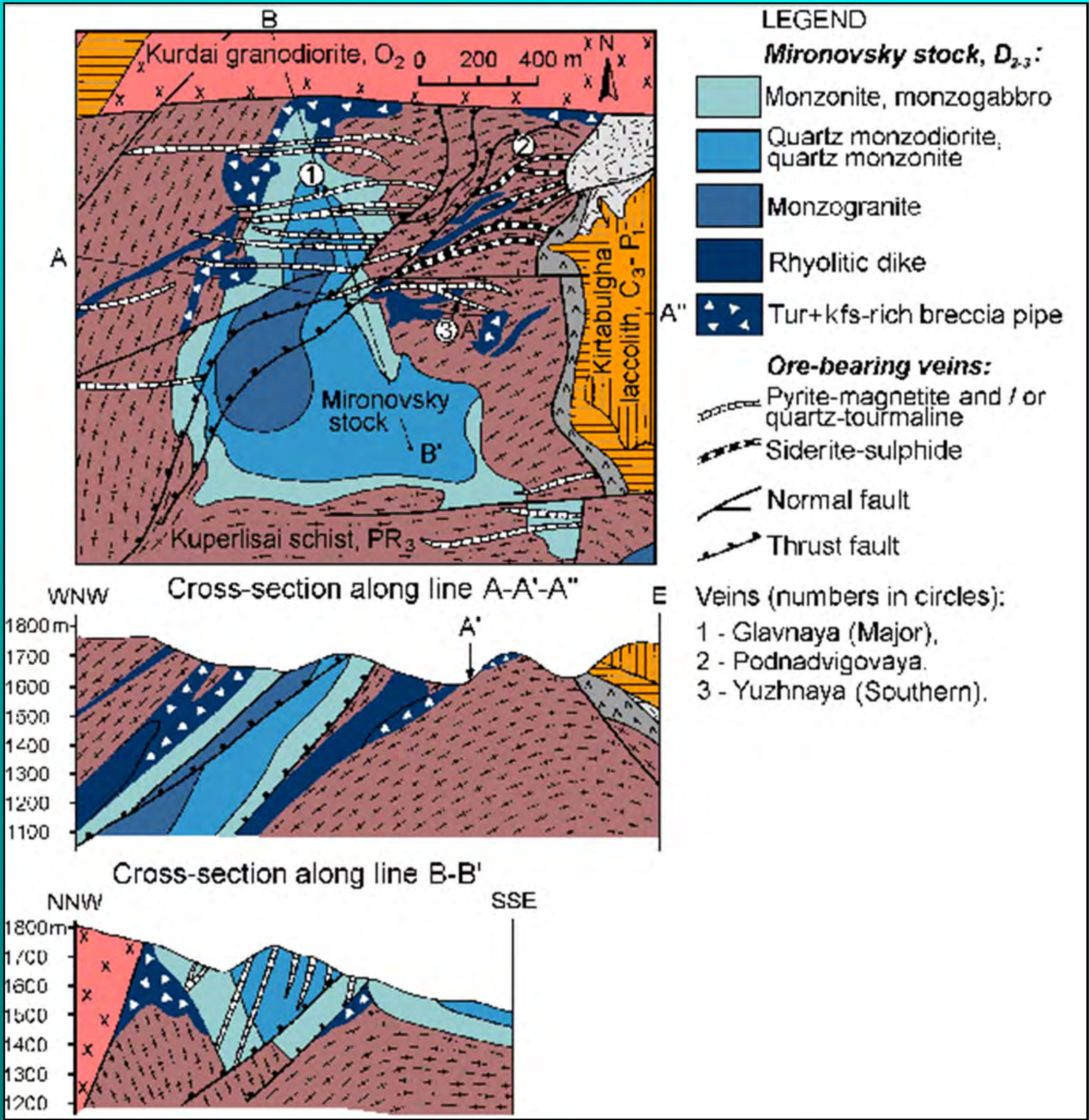
Mironovskoe Cu-Bi-Au deposit: Regional Geology



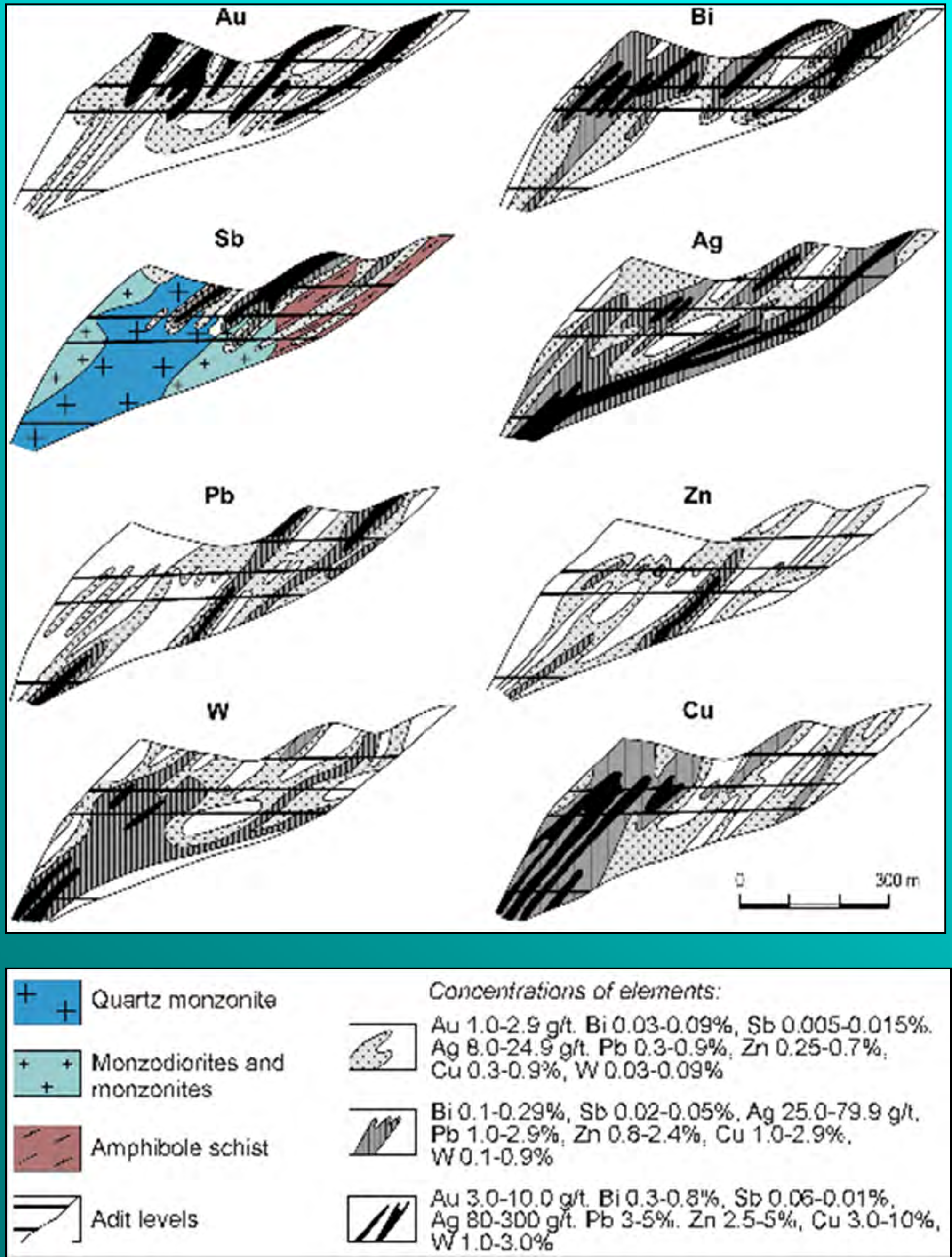
Mironovskoe Cu-Bi-Au deposit: Alteration



Mironovskoe Cu-Bi-Au deposit: Local Geology

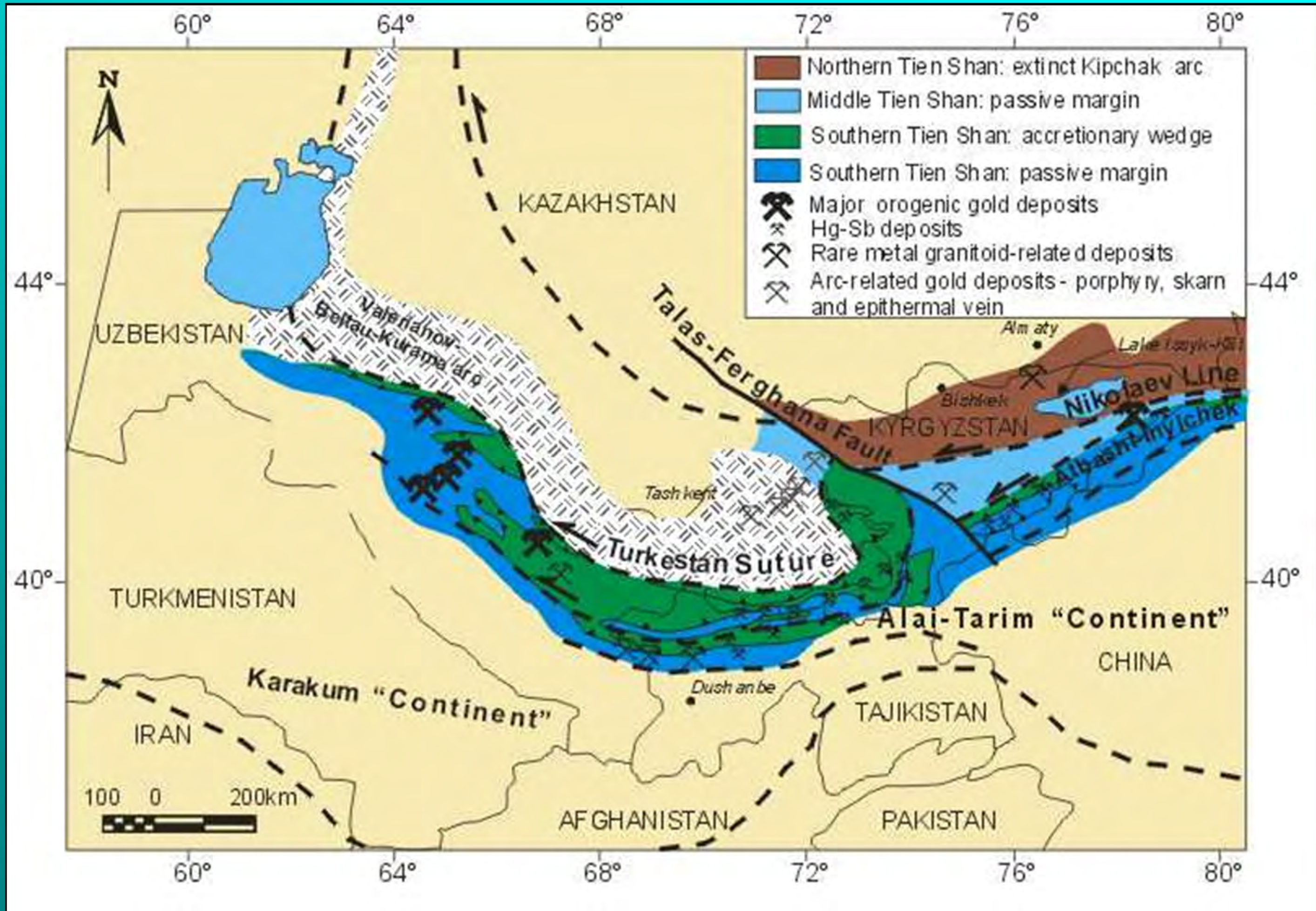


Mironovskoe Cu-Bi-Au deposit: Ore Distribution

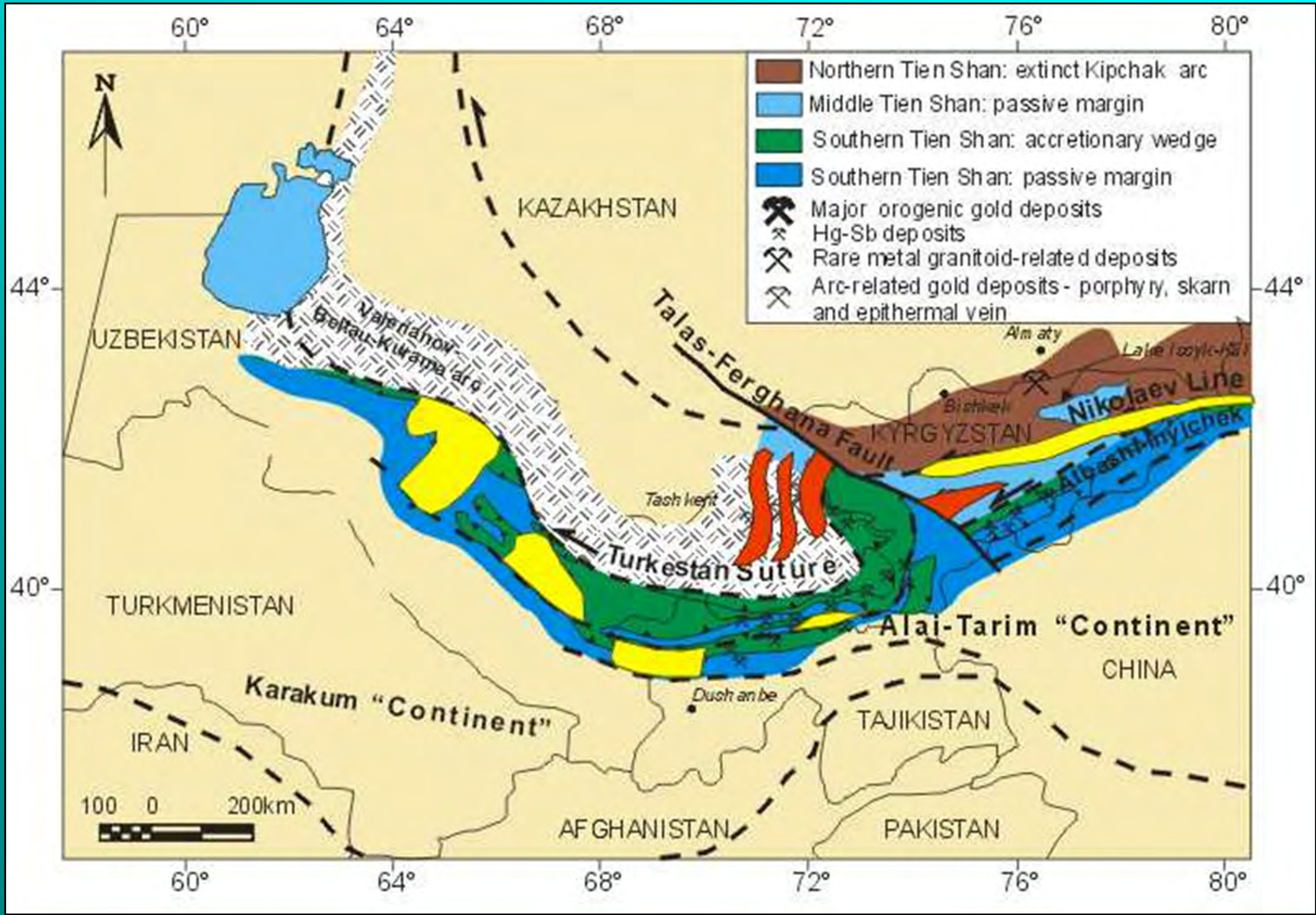


4. Structural and lithological control of the auriferous and related deposits of the Tien Shan gold province

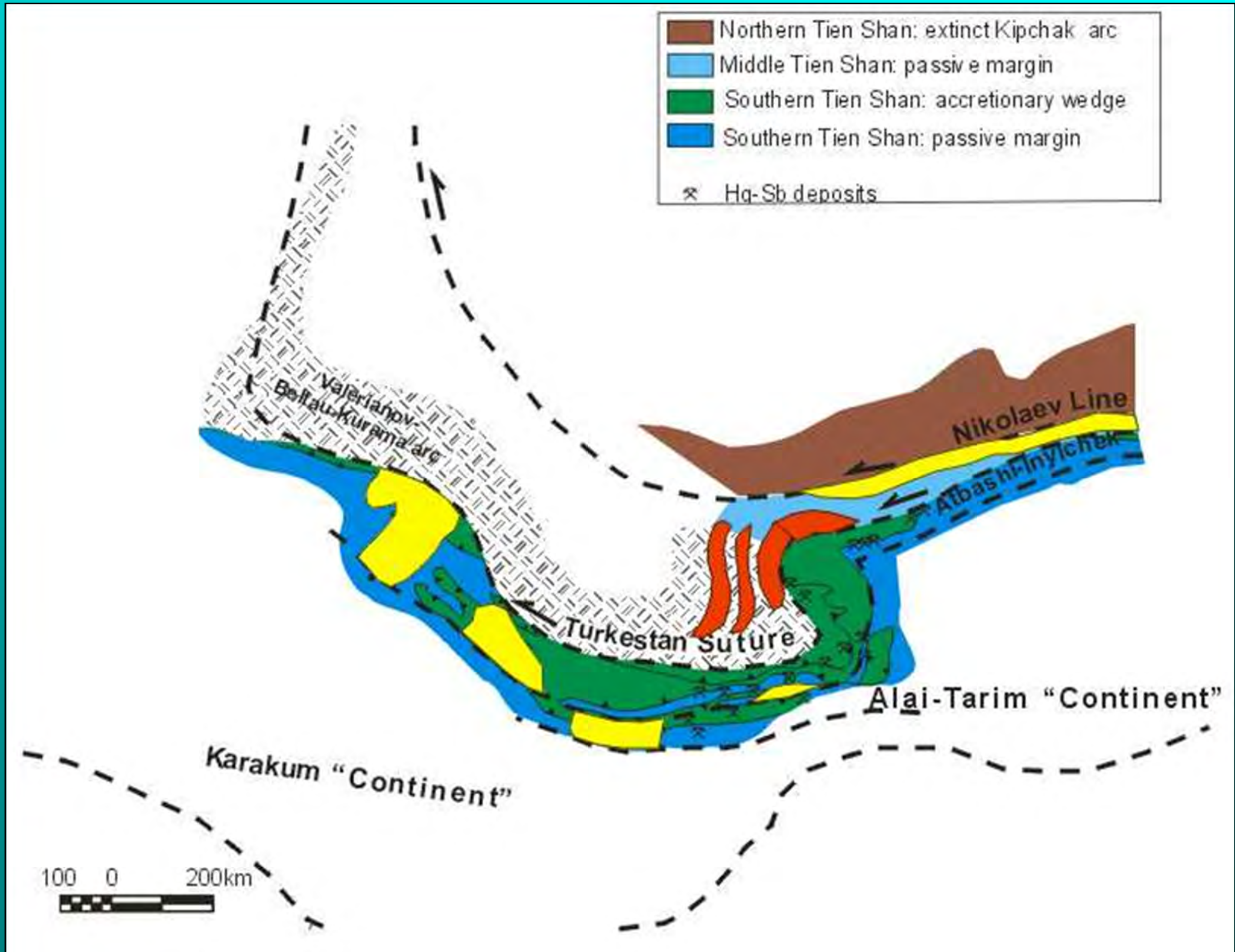
Role of Cenozoic and Mesozoic deformations



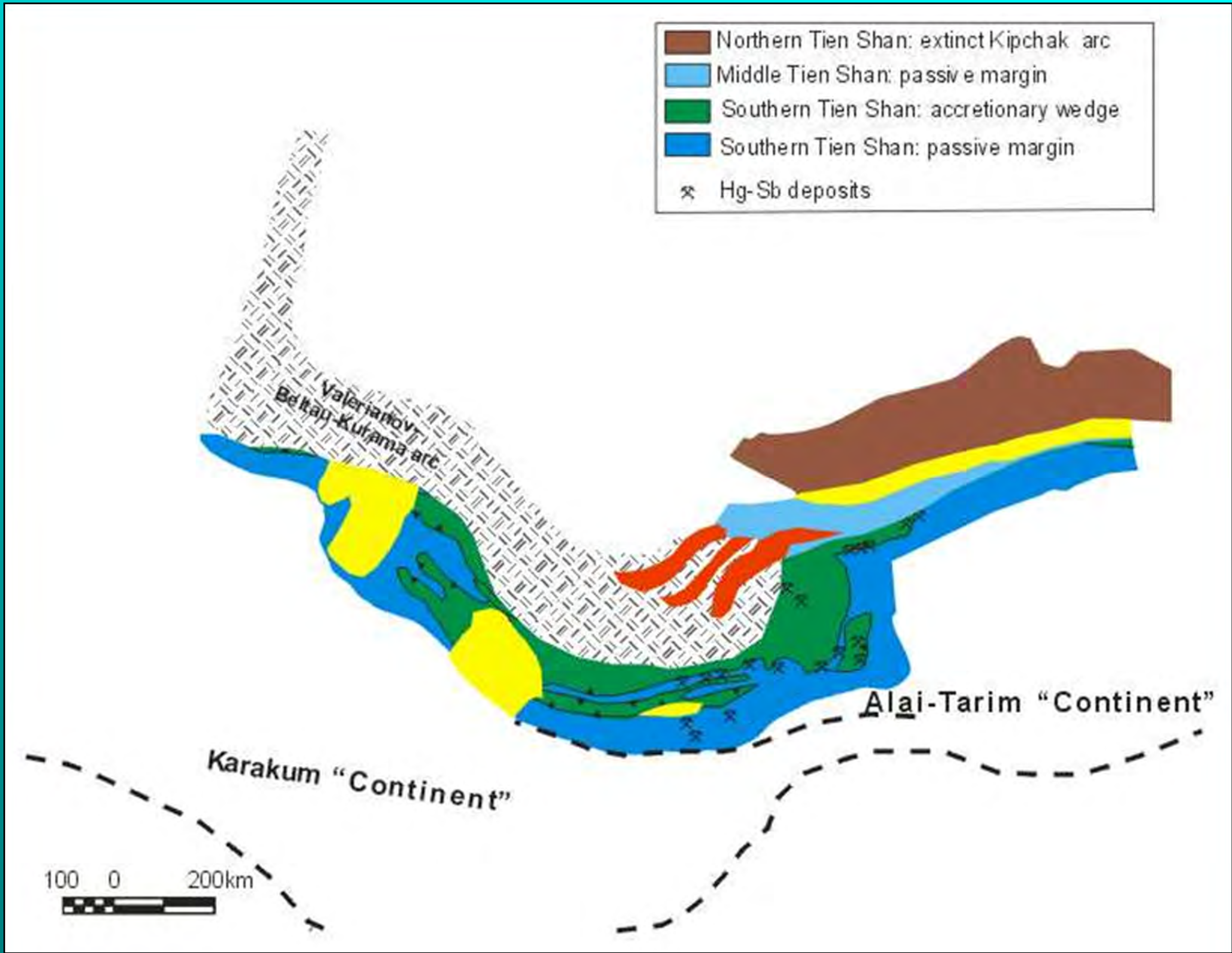
Role of Cenozoic and Mesozoic deformations



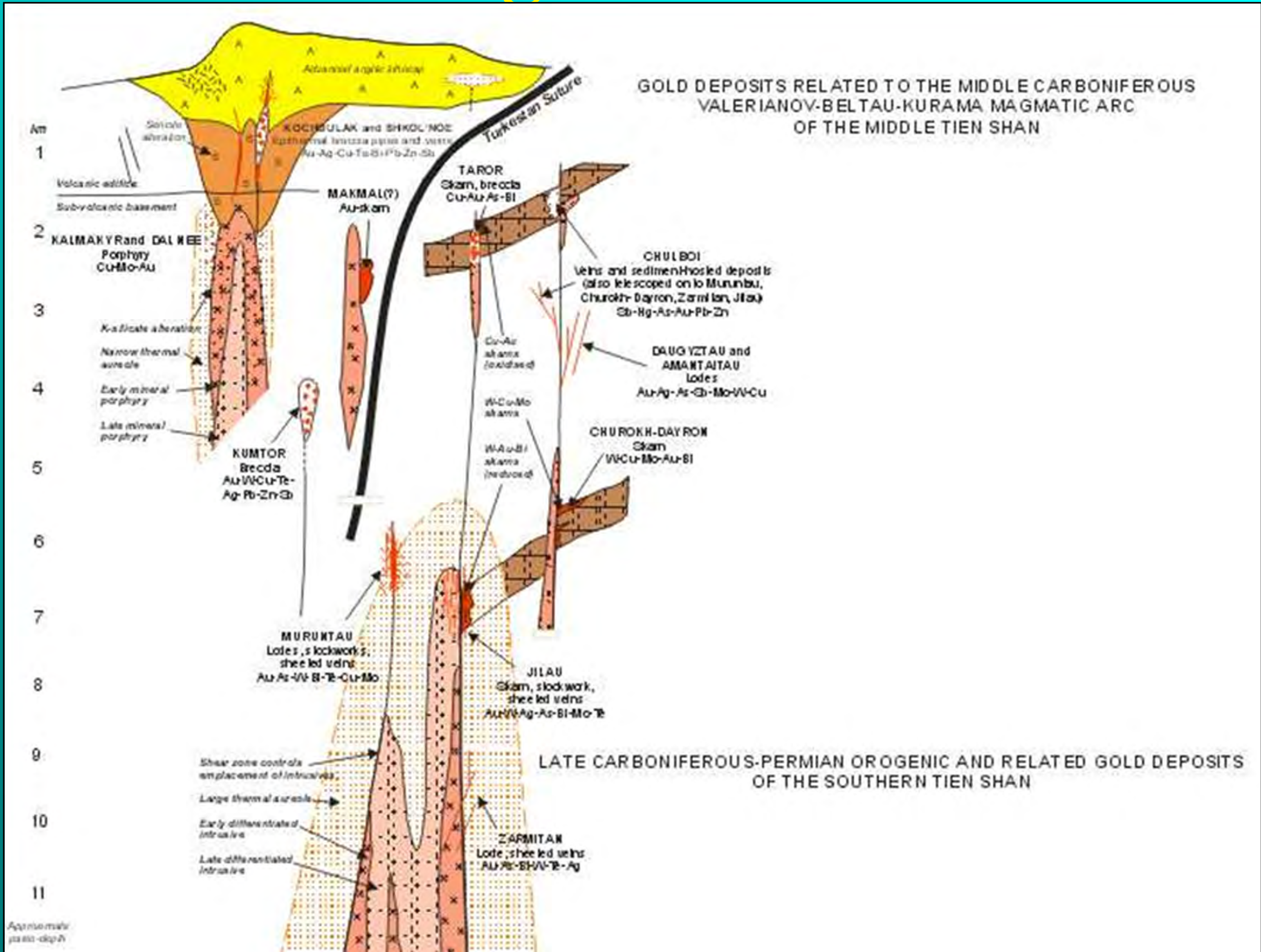
Role of Late Paleozoic deformations



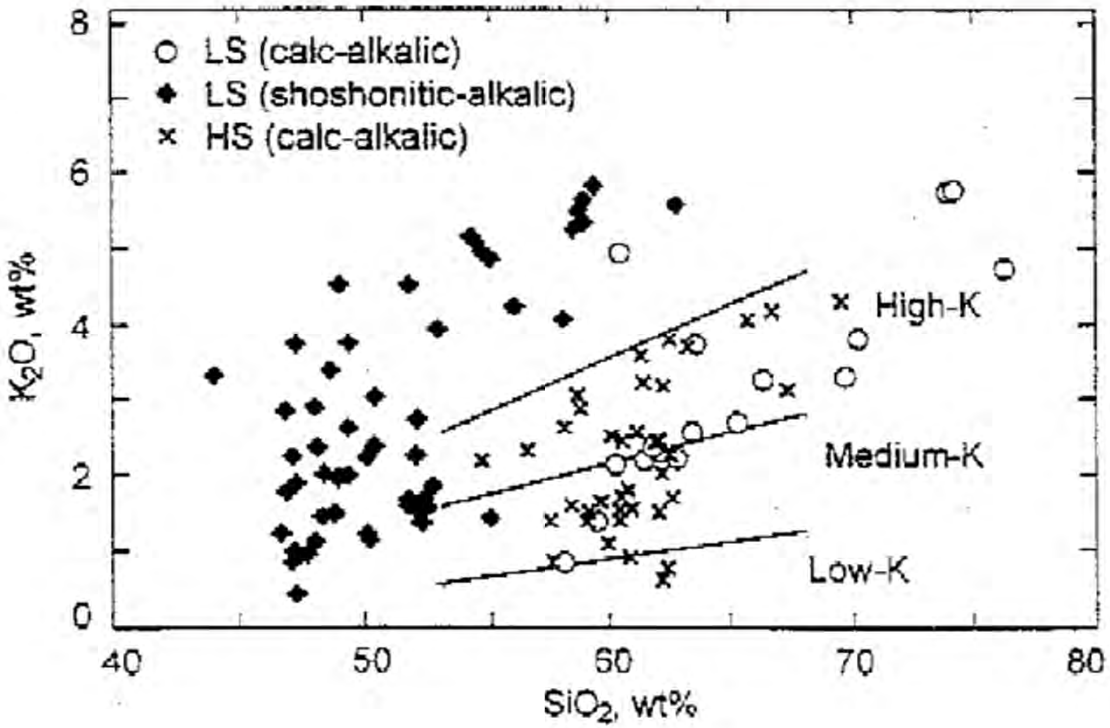
Role of Late Paleozoic deformations



Source, transport, deposition controls and role of granitoid intrusions



Source, transport, deposition controls and role of granitoid intrusions



The composition of magmas deduced to be related to LS and HS mineralization (Arribas, 1995; Hedenquist et al., 1996). LS deposits form in settings with a large range of magma composition, whereas HS deposits appear to be restricted to a narrower range of andesite to dacite composition.

Source, transport, deposition controls and role of granitoid intrusions

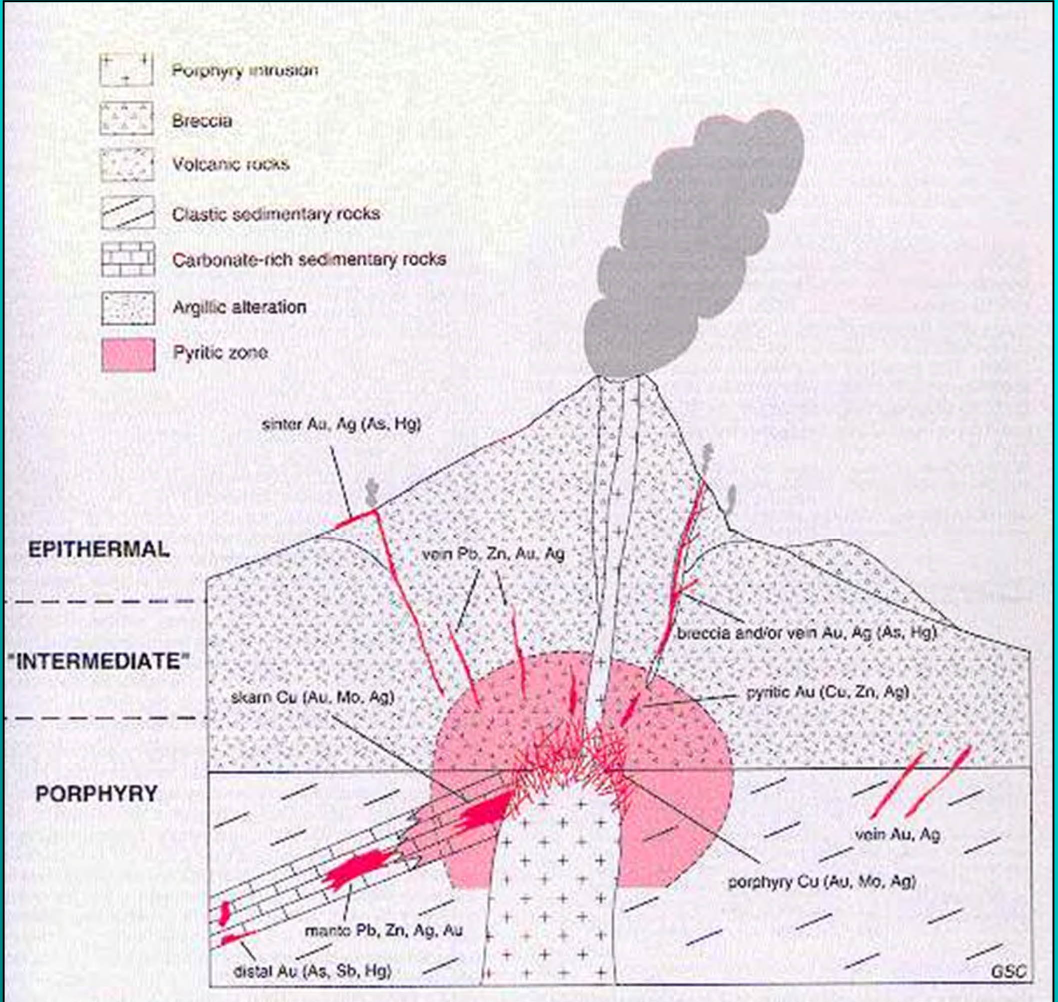
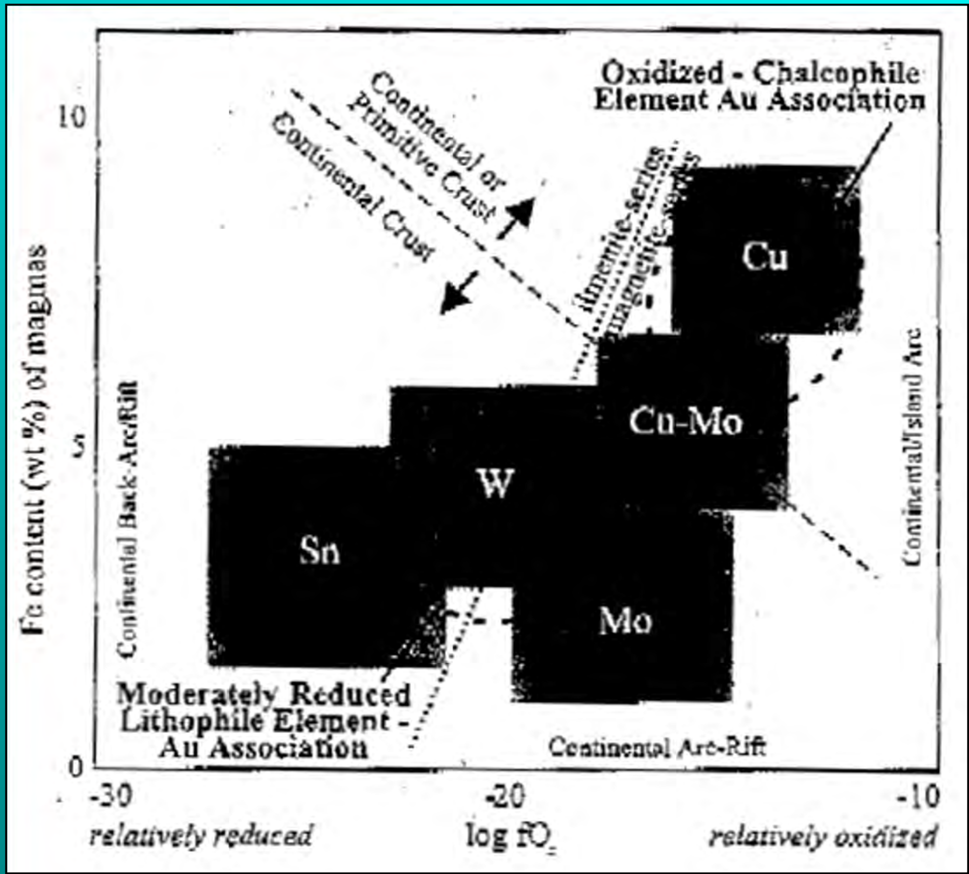


Figure 19-10. Schematic diagram of a porphyry copper system in the root zone of an andesitic stratovolcano showing mineral zonation and possible relationship to skarn, manto, "mesothermal" or "intermediate" precious metal and base metal vein and replacement, and epithermal precious-metal deposits.

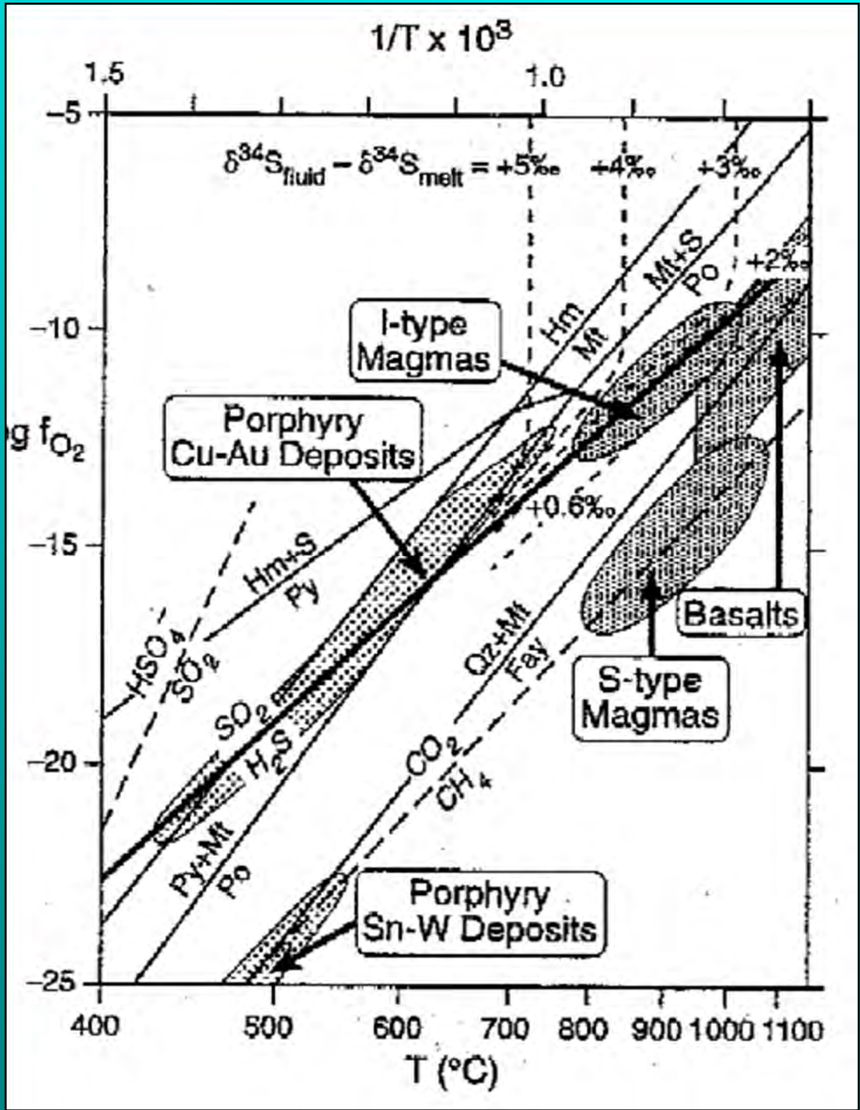
Kirkham and Sinclair, 1988

Source, transport, deposition controls and role of granitoid intrusions



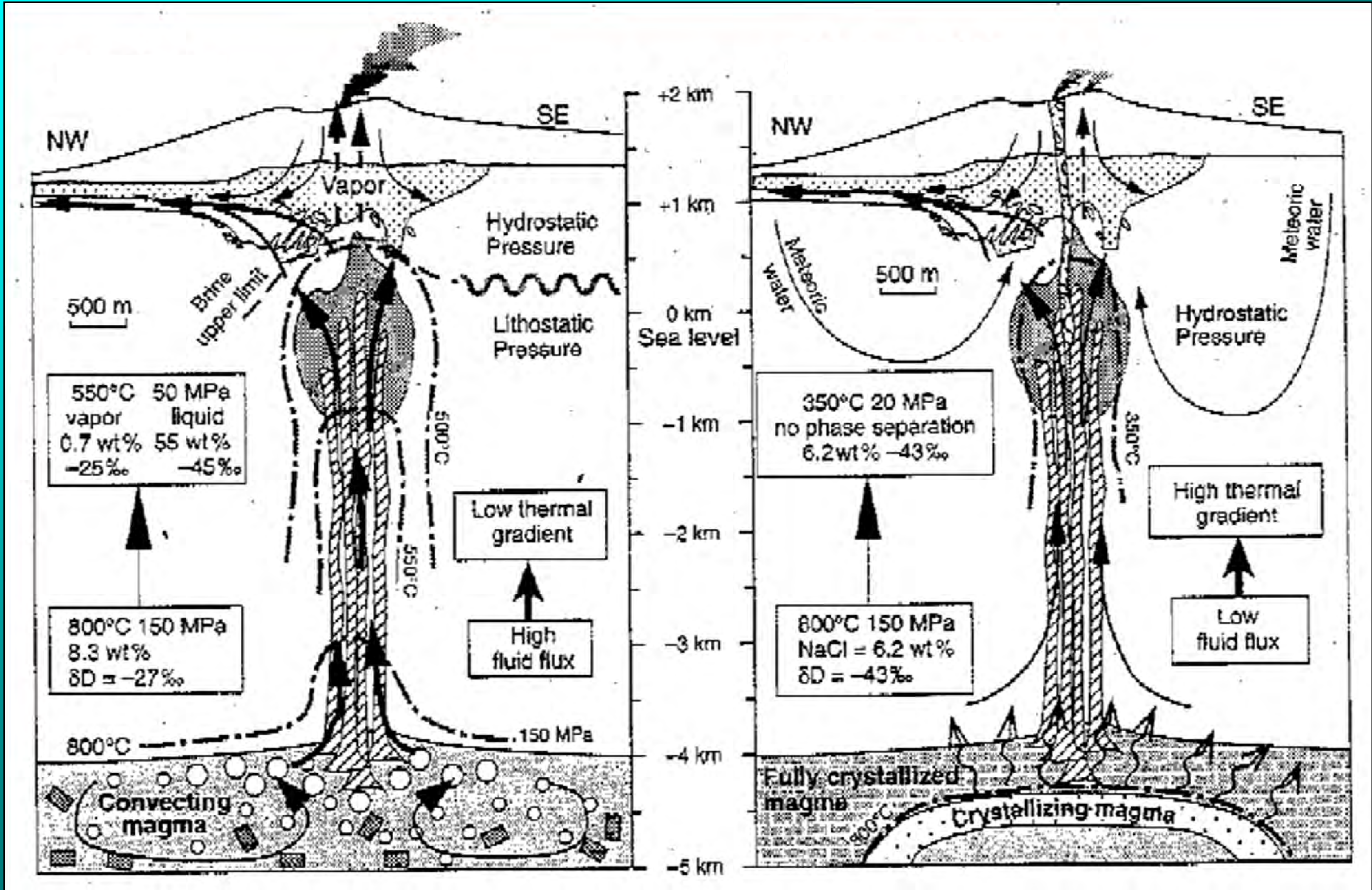
Lang et al., 2000

Source, transport, deposition controls and role of granitoid intrusions



Ohmoto and Rye, 1979

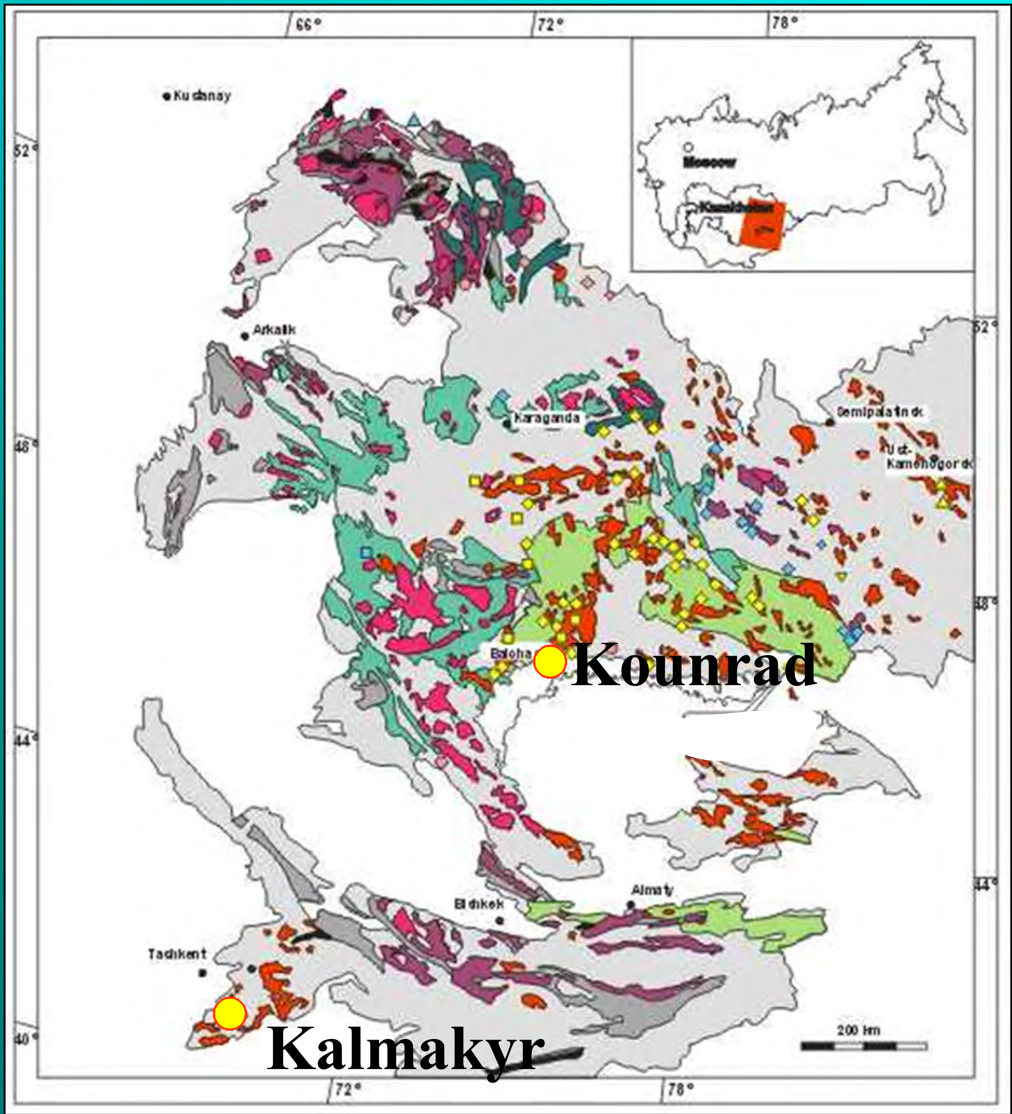
Source, transport, deposition controls and role of granitoid intrusions



Shinohara and Hedenquist

5. Possible analogues

Cu-(Mo)-porphyry deposits of Central Asia



Paleozoic
Proterozoic
Archean

Folded sediments and metamorphic rocks

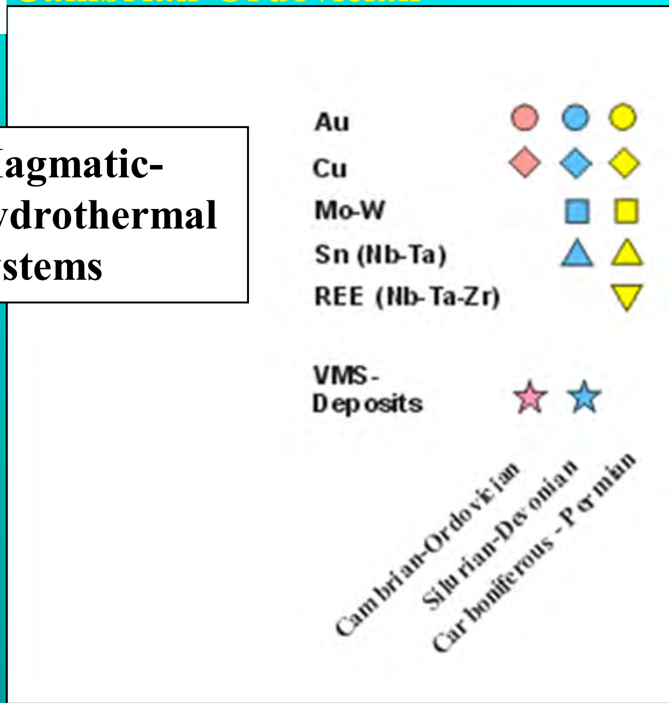
Permo-Carboniferous
Silurian-Devonian
Cambrian-Ordovician

Intrusive rocks

Permo-Carboniferous
Silurian-Devonian
Cambrian-Ordovician

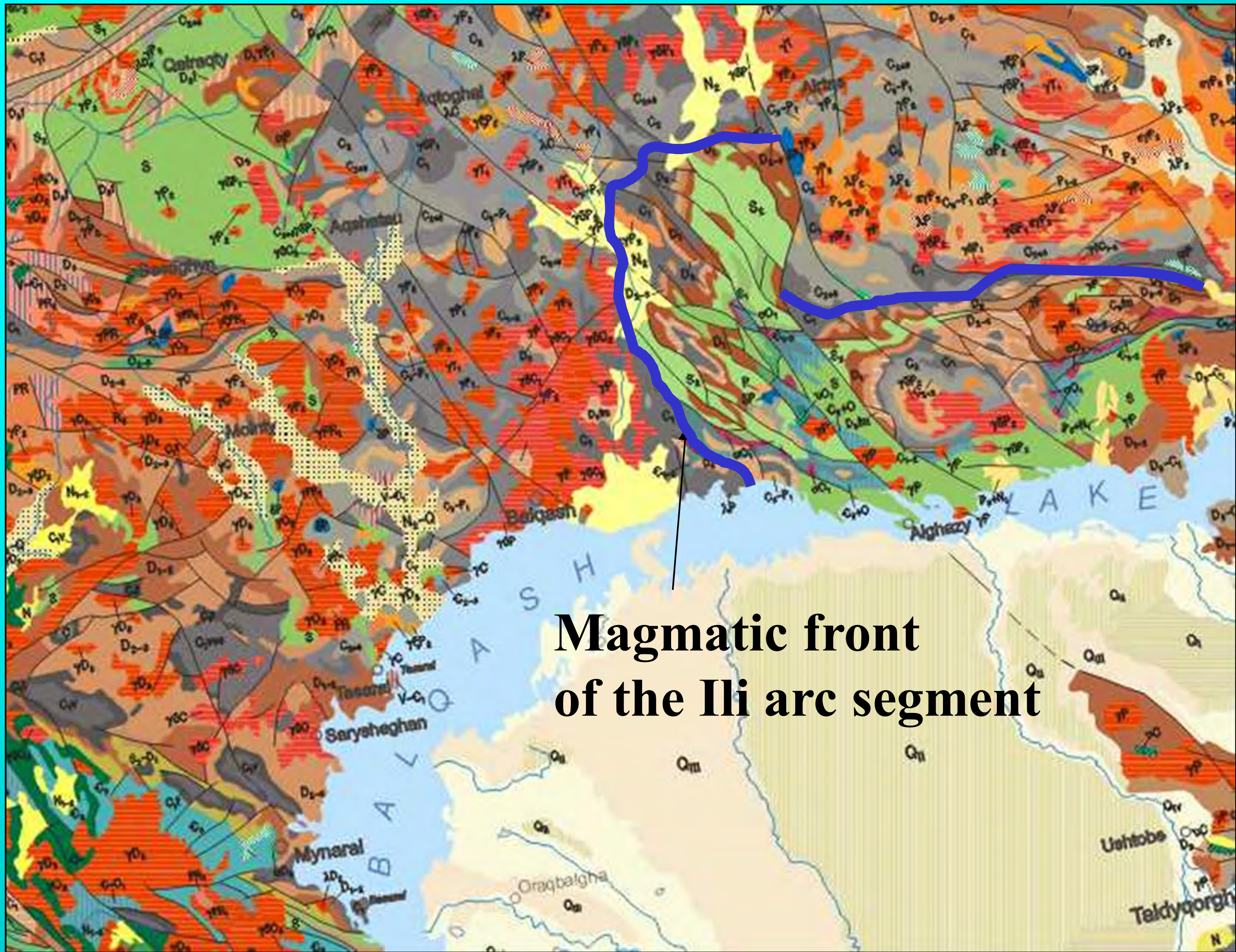
Volcanic rocks

Magmatic-hydrothermal systems



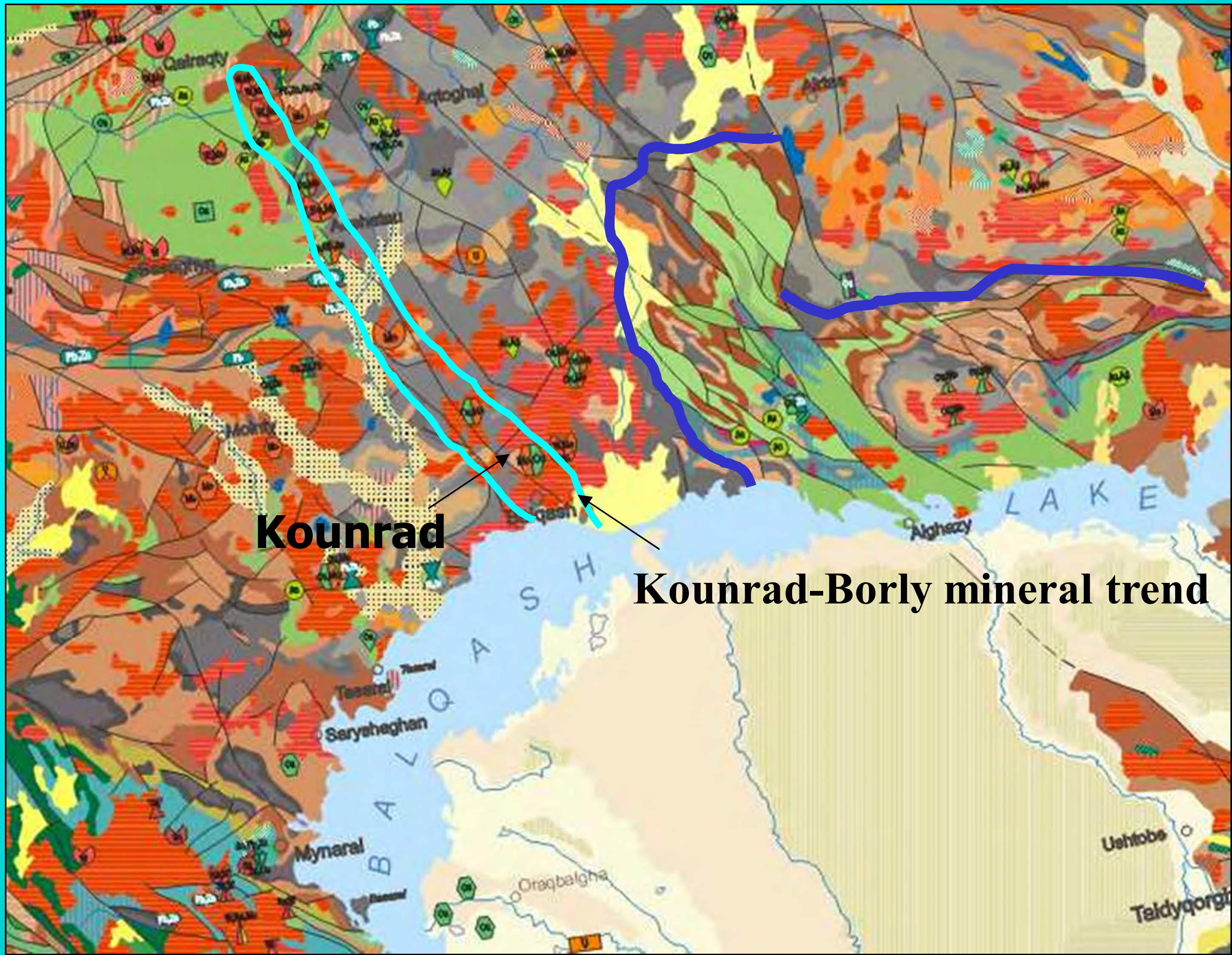
magmatic belts after Heinhorst et al., 1999

Kazakh-Mongol arc in Kazakhstan



Base map: Mineral Deposits Map of Central Asia, Seltmann, Shatov and Yakubchuk (eds), 2001

Kazakh-Mongol arc in Kazakhstan



Base map: Mineral Deposits Map of Central Asia, Seltmann, Shatov and Yakubchuk (eds), 2001

Kounrad porphyry deposit, Kazakhstan

- Early Carboniferous in age
- >800 Mt @ ~1.0% Cu, 0.7g/t Au of initial reserves and grades
- mined out supergene enrichment blanket
- Mo, Ag, Re, Se, Te, palladium credit
- remaining reserve of hypogene ore is 220 Mt @ 0.34% Cu, 0.017 g/t Au

The Kounrad porphyry Cu-Mo(Au) deposits

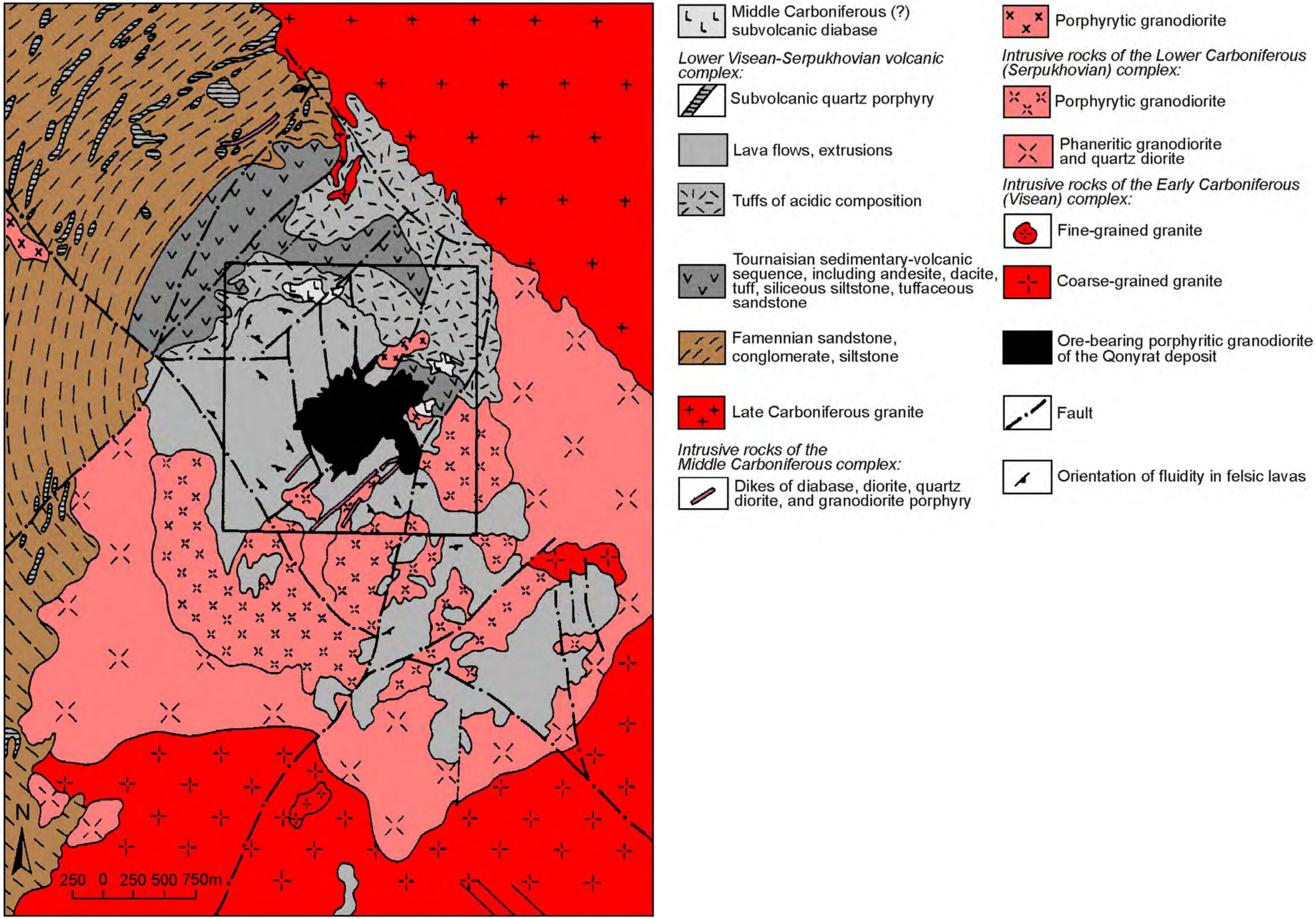
The Kounrad (Konyrat) Cu porphyry deposit is related to the Carboniferous-Permian volcano-plutonic foldbelt of the Balkhash crustal segment of southern Central Kazakhstan. It belongs with respect to its formation geotectonically to the extensional period of an accretional arc setting.

The host-rocks consist of several thousand metres thick volcanic and volcano-sedimentary units of Devonian to middle Carboniferous age. Related to a prolonged period of crustal growth by subduction and accretion, connected with uplift, doming, and extensional rifting, longlasting volcano-plutonic activities were succeeded by **cauldron subsidence**. Evidence for the caldera formation are fault-controlled circular volcano-tectonic depressions, existence of quartz porphyry ring dykes in the surrounding of the tonalite-granodiorite stocks and geophysical anomalies that are contouring the distribution of volcano-sedimentary units with increasing thickness to the centre.

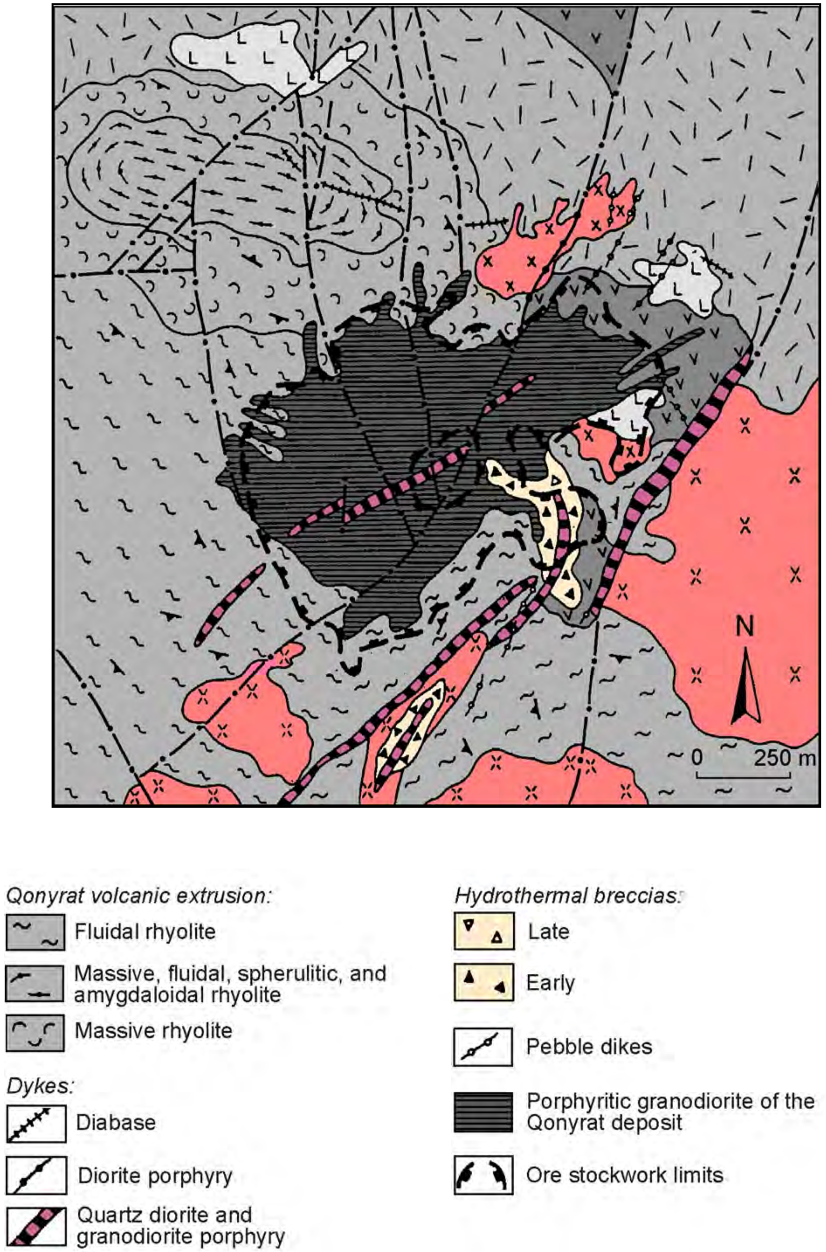
I-type calc-alkaline intermediate to felsic arc magmatism of Ordovician to Carboniferous (tonalite-granodiorite suite) contributed in its final stages to form the ***Kounrad Cu (Mo, Au) porphyry***. The mineralization is in quartz-serizite altered granodiorite and associated volcanics (stocks and dykes) of Lower Carboniferous. The flat dip of the intruded host rock units towards the magmatic centre in the depression obviously supports directed flow of meteoric waters and its circulation within the cupola parts of the intrusion thus catalyzing element redistribution and mineralization in the stocks and their host rocks.

Internal collision in Late Carboniferous and Permian locally produced extensional regimes which control the most highly evolved ***W-Mo leucogranites at Eastern Kounrad***.

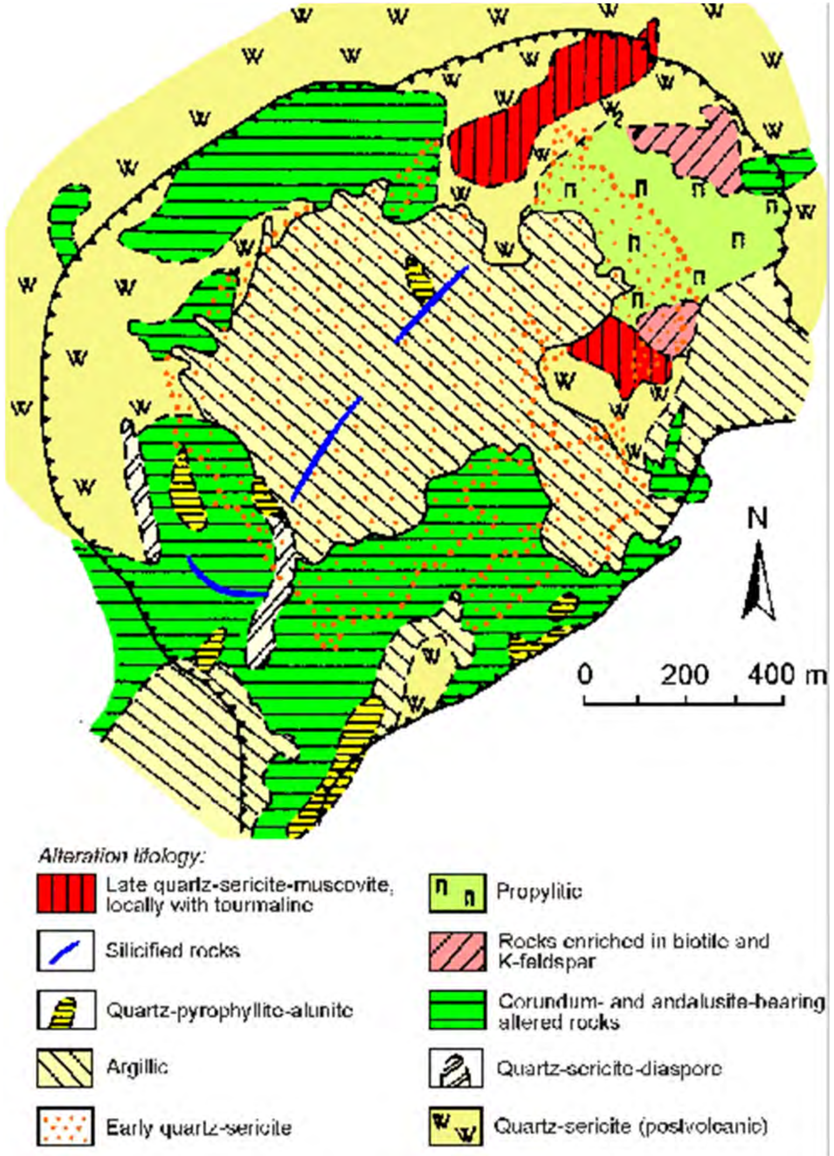
Kounrad: a caldera setting?



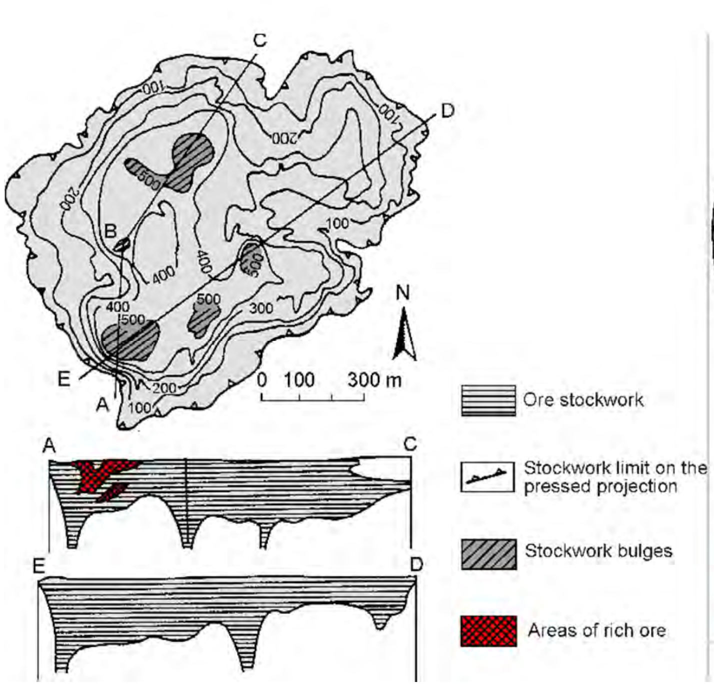
Kounrad: Geology



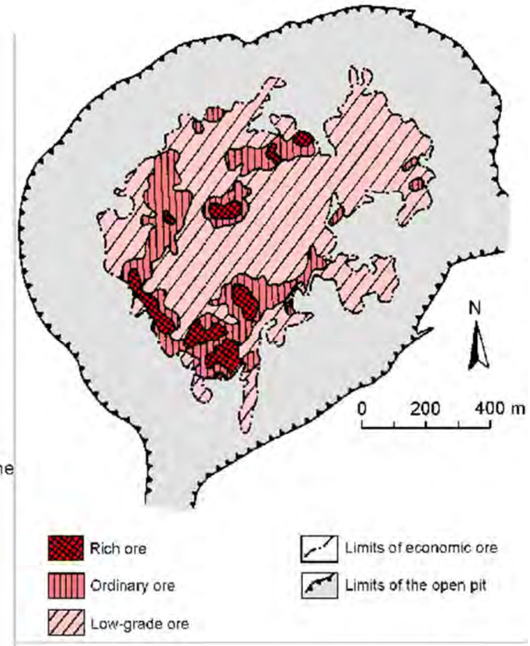
Alteration patterns



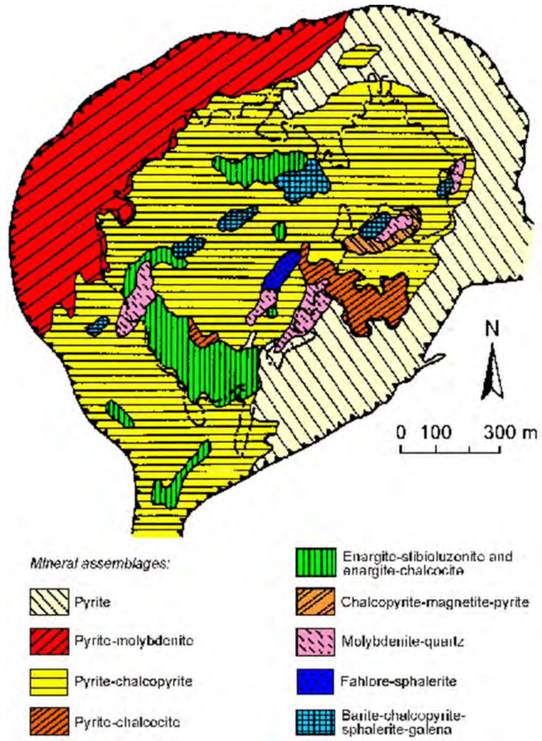
Kounrad porphyry deposit



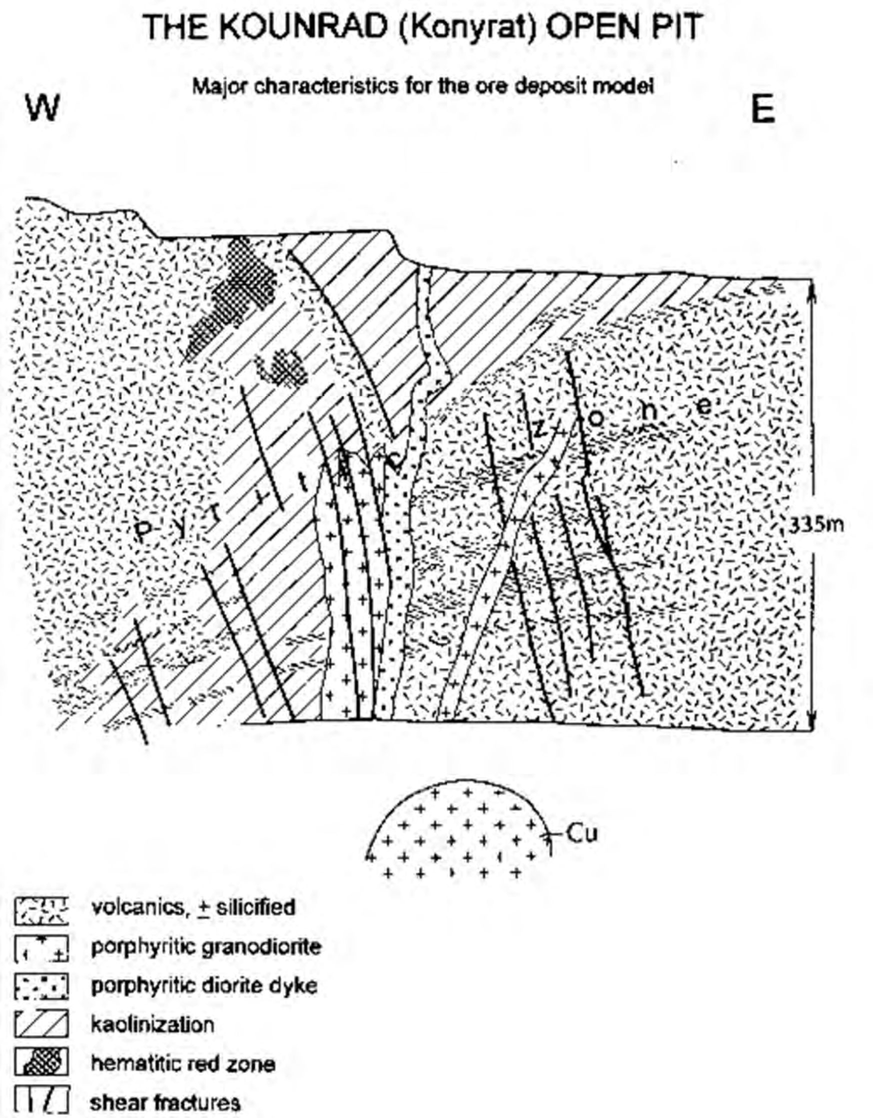
Morphology of ore stockwork



Ore distribution in the mineralized stockwork



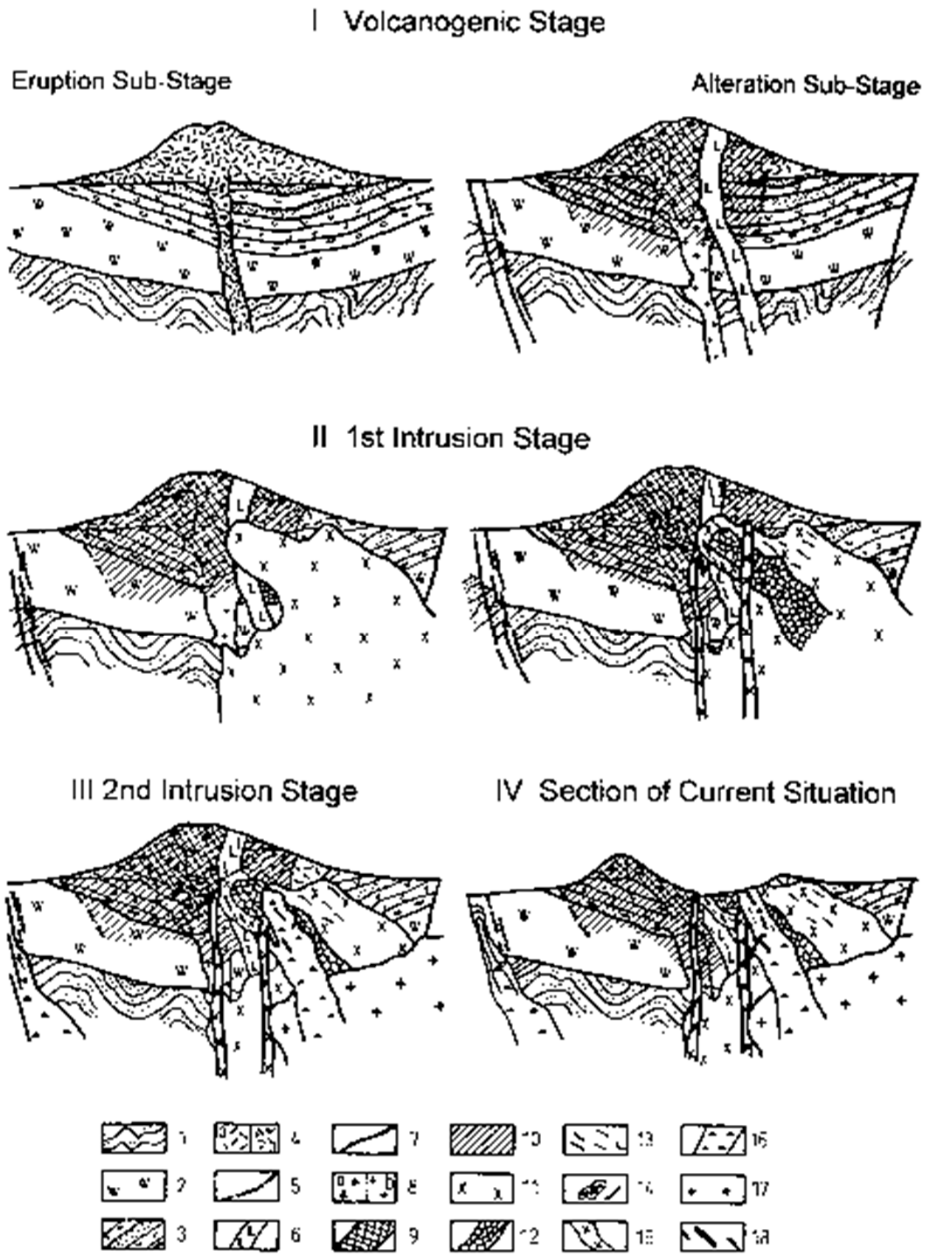
Hypogene mineral zoning



Kounrad (Konyrat) Cu porphyry displays mostly all characteristics that are typical for mineralized Cu porphyry systems. It belongs to the quartz-muscovite-pyrite type and the ores are related to disseminations and stockworks most of which were mined in the open pit. Copper mineralization with >0.2% Cu continues down to 700m depth. The dimensions of the present day open pit are 2,200 x 1,800 m with a depth of 330m, which is projected to increase to 550m. The metal content of ca. 700,000 t Cu in ores with 0.34 % Cu (cut-off at 0.2 %) classifies the deposit in international scale as low grade. Abundances of Mo (50 ppm), Au (0.01 ppm), Ag (1ppm) and Re (0.3 ppm) are valuable by-products. There are remaining reserves of about 120 Mt ore with average Cu content of 0.385%.

Products of intensive fracturing (major faults controlling fluid flow and ore distribution, stockwork-forming hydraulic fracturing joints, hydrothermal breccias and breccia pipe bodies) and of primary and secondary fluid-rock reactions (high-temperature to low-temperature alteration zones) characterize multistage formation processes visible in the open pit. The well developped alteration zones range from mostly barren, often silicified diorite-granodiorite porphyry stocks and dykes in the open pit centre to the depths. Those unmineralized rocks are surrounded upwards by the potassic alteration zone (outcropped at the open pit base levels) and followed by the pyrite shell, the phyllic (sericitic) and propylitic zones. The top parts are characterized by kaolinization (argillization) and silicification of host rocks, mostly volcanics. The near-surface parts of the stockwork were oxidized and enriched in ores secondarily.

Petrogenetically of interest are **Cu-Ni mineralized mafic dykes** and stocks of diabase and diorite that crosscut and postdate the alteration zones and indicate less restites or umulates but mixing contribution of a mafic (mantle?) component to the magmatic system.

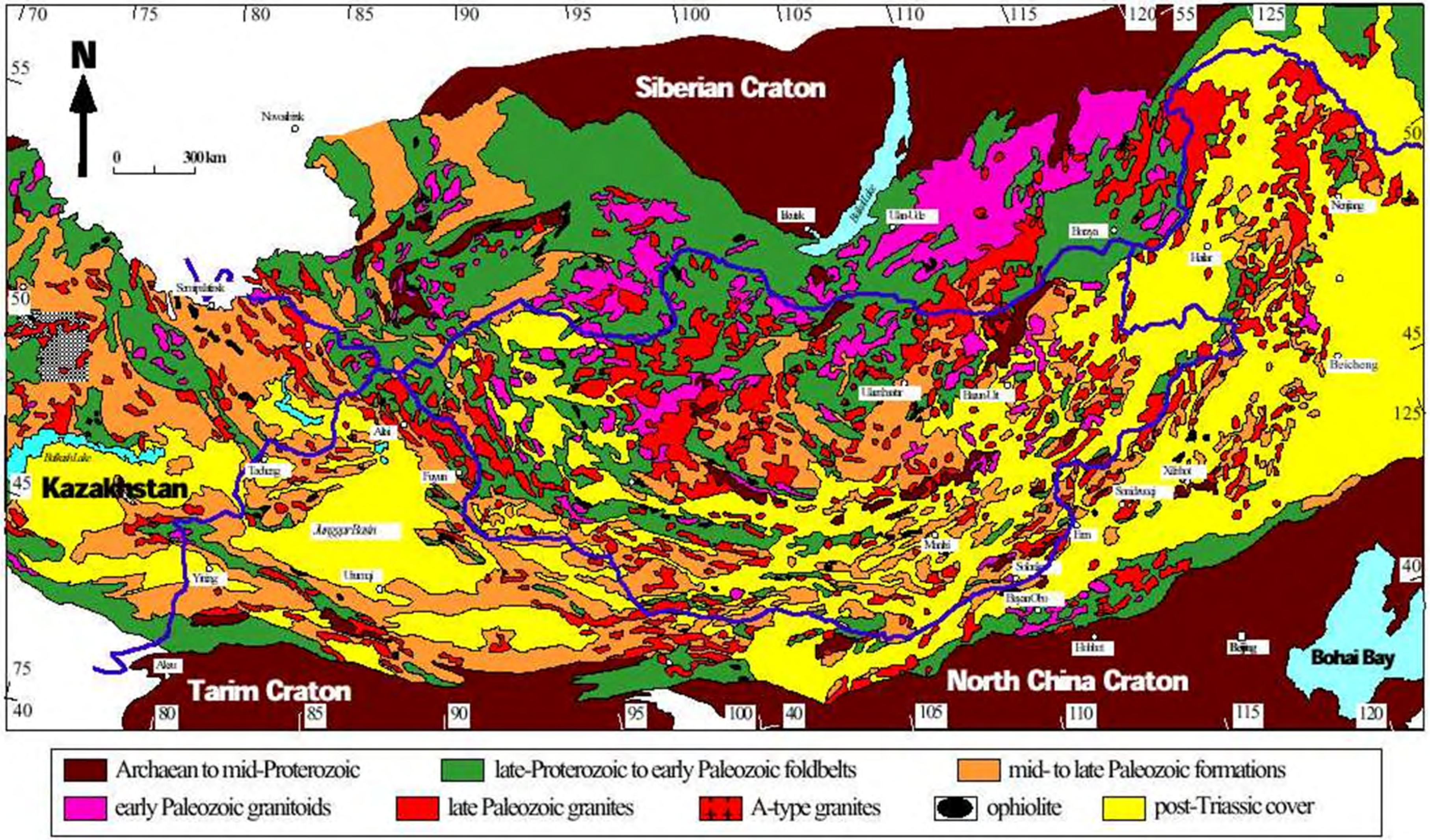


Kounrad: Evolution scheme of magmatism and mineralization

1 - Famennian terrigenic sequence;
2 - sequence of andesitic porphyries;
3 - effusive-sedimentary sequence;
4 - volcanogenic sequence:
  a - effusive facies, b - extrusive facies;
5 - ring faults;
6 - subvolcanic bodies of diabase;
7 - subvolcanic dykes and stocks of rhyolite;
8 - porphyry extrusions:
  a - quartz porphyry, b - granite porphyry;
9 - silicification („secondary quartzites“);
10 - propylitization;
11 - granodiorite and granodiorite porphyry;
12 - breccias of 1st stage;
13 - stockwork of silicification, argillization;
14 - vein-impregnative copper mineralization;
15 - stocks and dykes of quartz diorites and diorite porphyrites;
16 - breccias of 2nd stage;
17 - leucocratic granites of E Kounrad pluton;
18 - molybdenite, baryte, base metal veins m

/Modified after A.I. Poletaev/

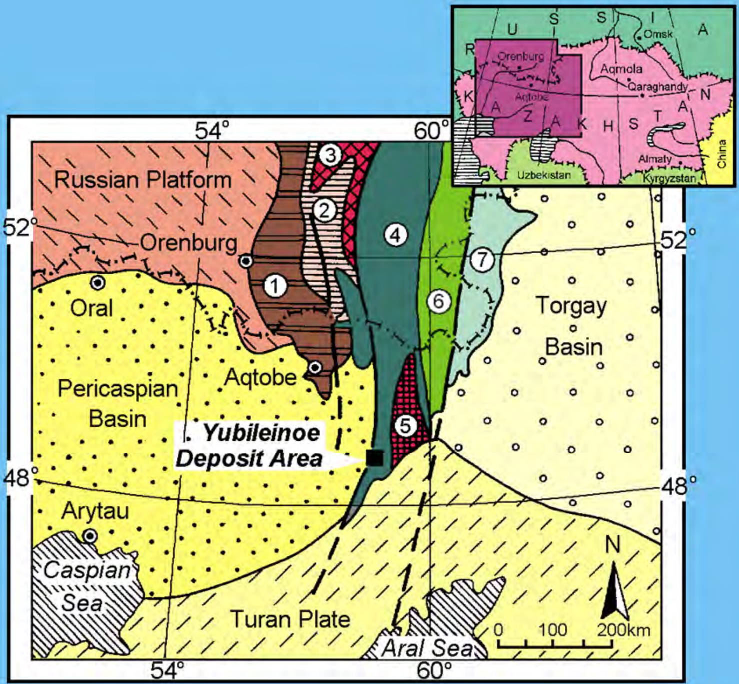
Extension of Kazakh porphyry belts to NW China and Mongolia



after Bor-Ming Jahn, unpubl.

Yubileinoe deposit, South Urals

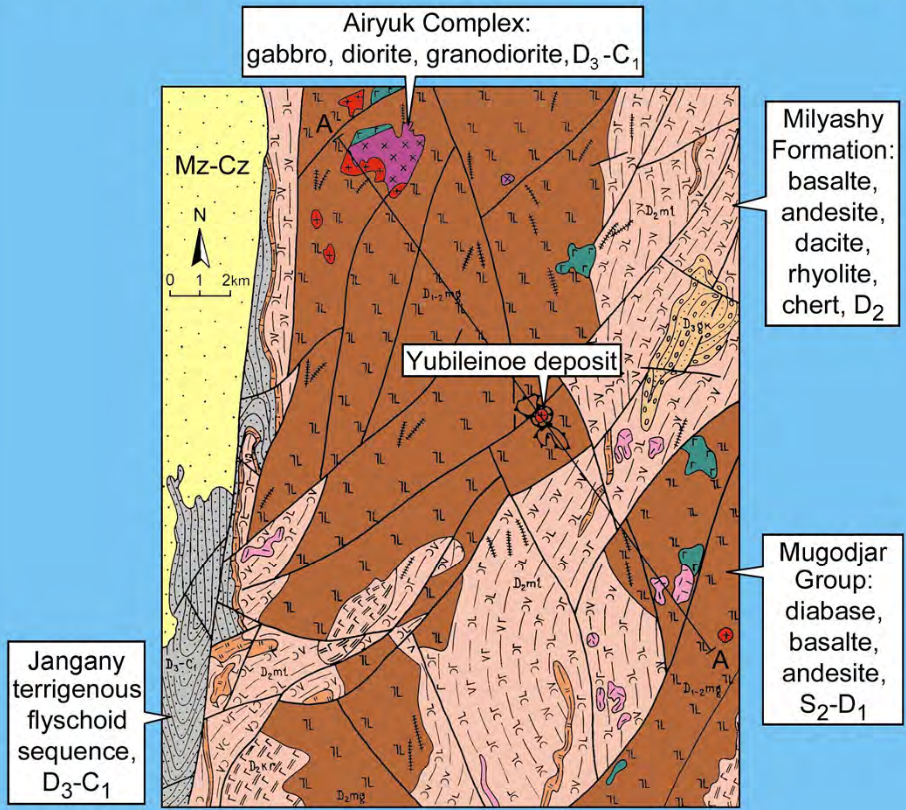
Location Map of the Yubileinoe Deposit Area



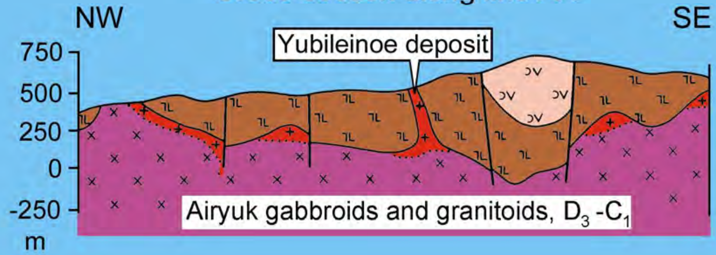
Tectonic zones of the Southern Uralides:

(1) Pre-Uralian Foredeep, (2) West-Uralian Zone,
(3) Central-Uralian Zone, (4) Magnitogorsk-Mugodjar Zone,
(5) West-Mugodjar Zone, (6) East-Uralian Zone,
(7) Trans-Uralian Zone

Geology of the Yubileinoe Deposit Area

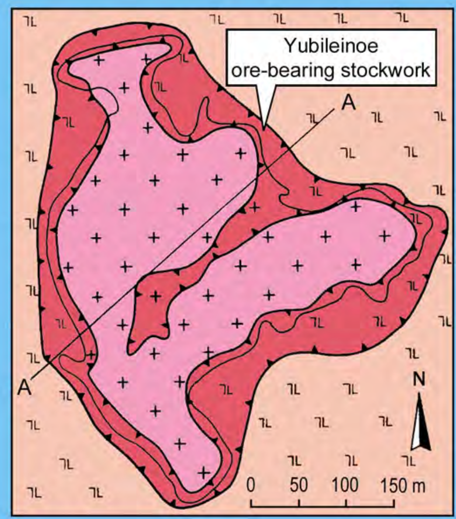


Cross-section along line AA

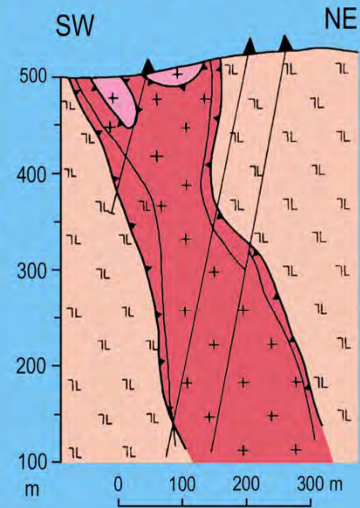


Geology of the Yubileinoe Cu-Au Porphyry Deposit

Plan

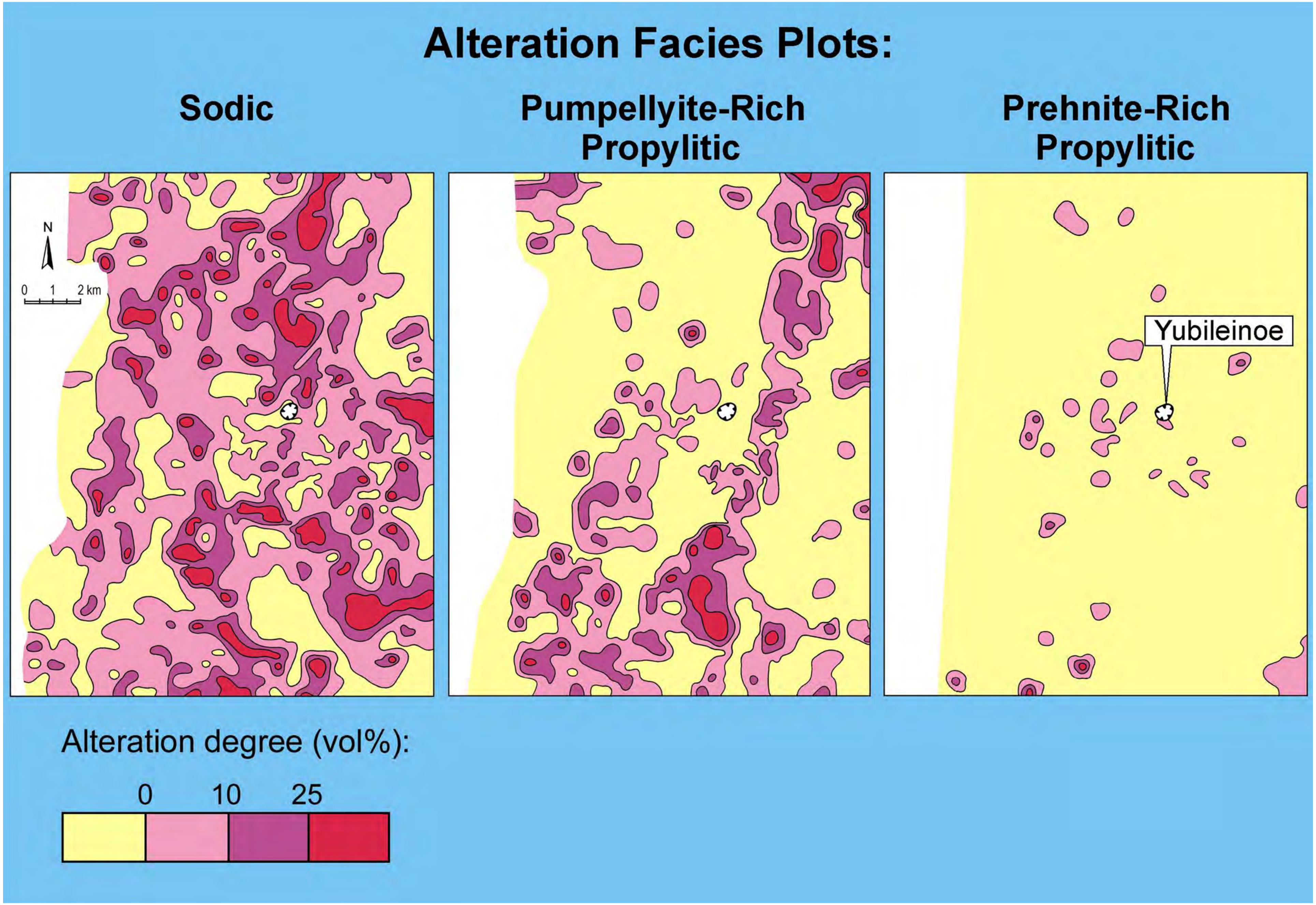


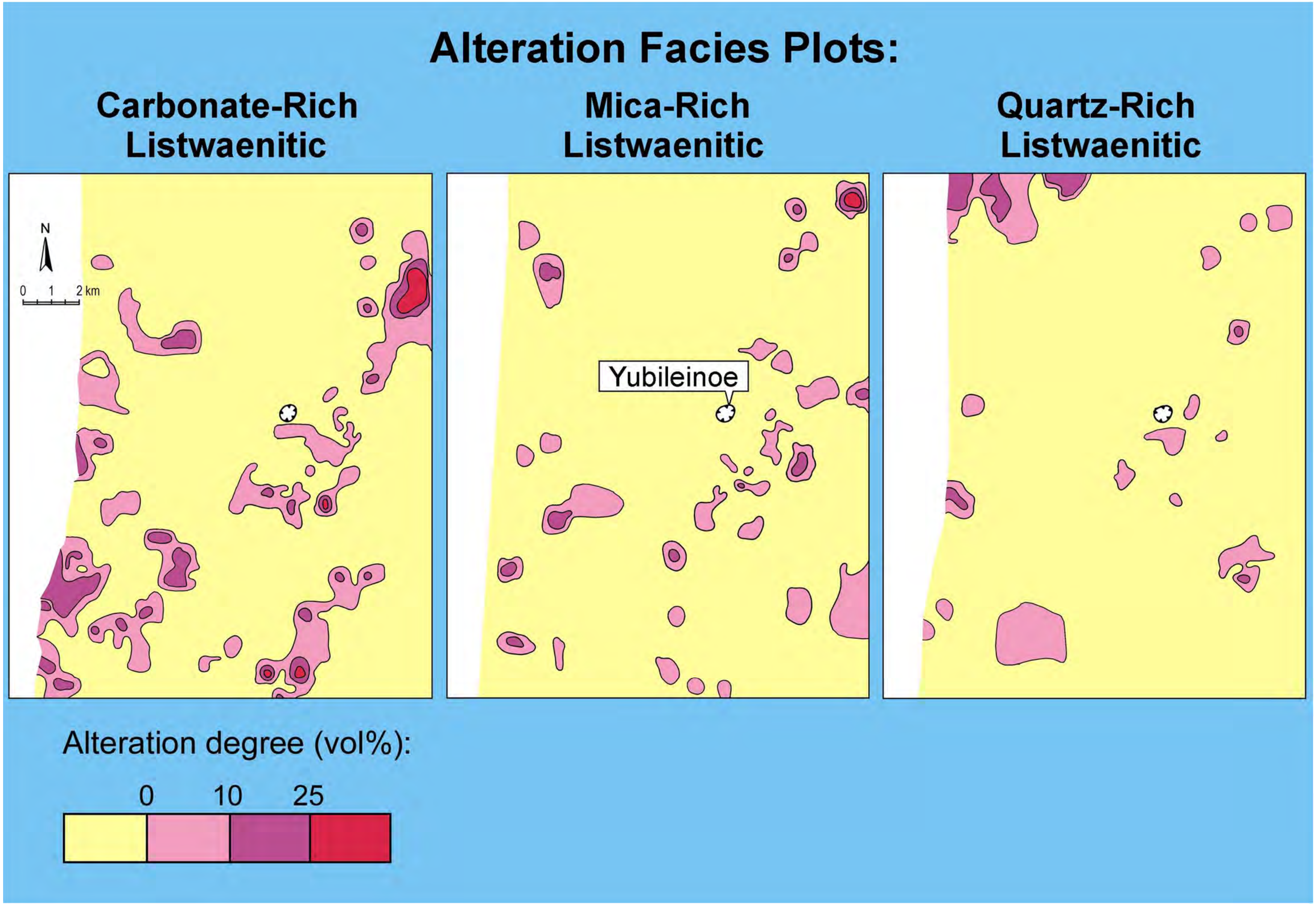
Cross-section along line AA

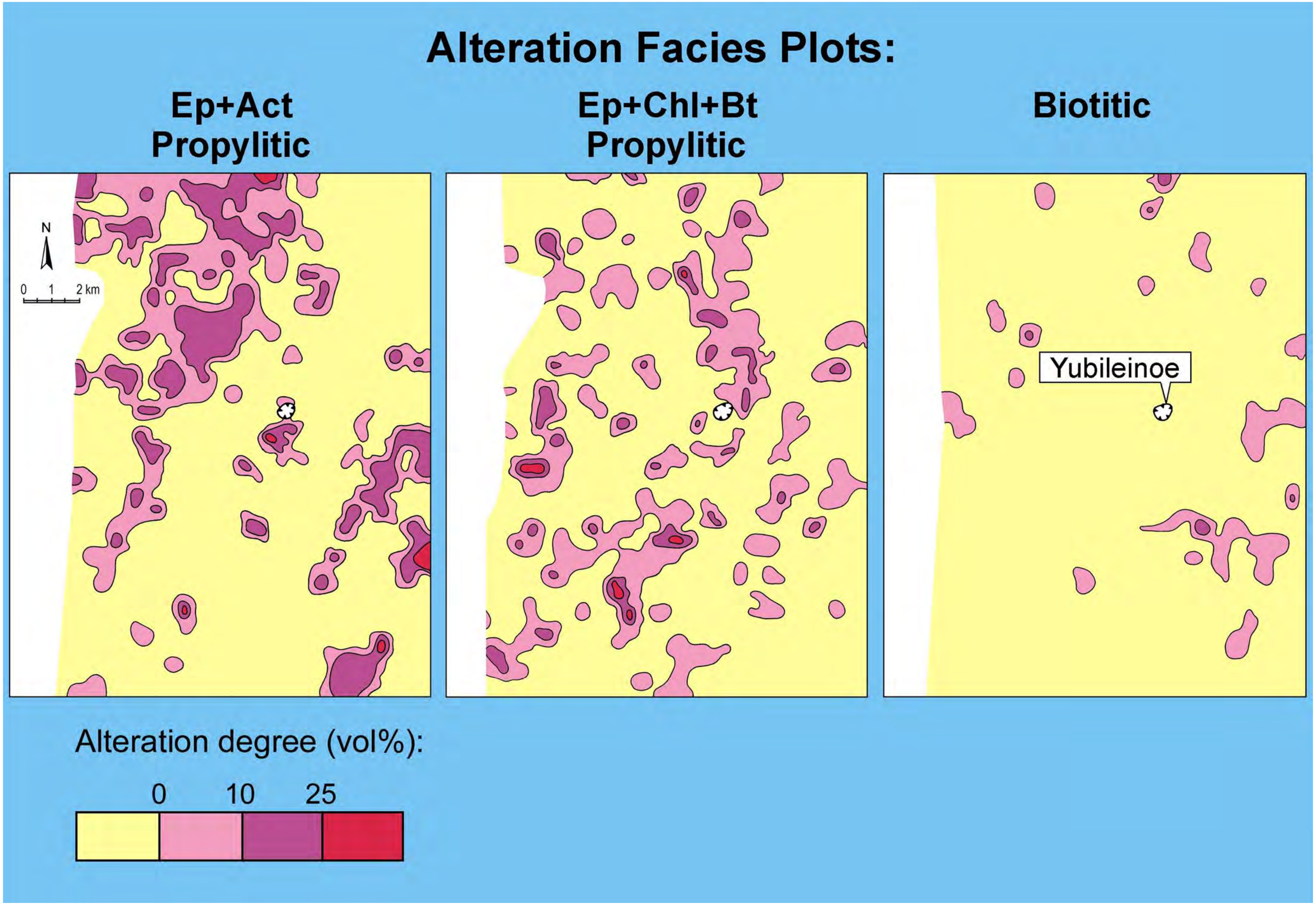


Yubileinoe granodiorite- and plagiogranite-porphyry, D_3-C_1

Mugodjar Group: diabase, basalt and andesite, S_2-D_1


Alteration Facies Plots:
Sodic
Pumpellyite-Rich Propylitic
Prehnite-Rich Propylitic
N
0 1 2 km
Yubileinoe
Alteration degree (vol%):
0 10 25


Alteration Facies Plots:
Carbonate-Rich Listwaenitic
Mica-Rich Listwaenitic
Quartz-Rich Listwaenitic
N
0 1 2 km
Yubileinoe
Alteration degree (vol%):
0
10
25


Alteration Facies Plots:
Ep+Act Propylitic
Ep+Chl+Bt Propylitic
Biotitic
N
0 1 2 km
Yubileinoe
Alteration degree (vol%):
0
10
25

Sequence of Alteration Types in the Yubileinoe Deposit Area

Stage (Substage)		Alteration Type	Facies	Mineral Assemblage
Granitoid-related (D_3–C_1)	Retrograde	Phyllic	qtz+ser/ms+ank qtz+chl+ank	qtz+ser/ms+ank+py qtz+chl+ank+py
		Propylitic	ep+chl+bt ep+act/hb	ep+chl+bt+kfs ep+act/hb+qtz+kfs
	Prograde	Skarn		grt+cpx+ep+qtz
		Hornfels		qtz+bt+fs+hb
		Feldspathic		qtz+kfs+ab+bt
Volcanic-associated (S_2–D_2)		Listwaenitic	quartz-rich mica-rich carbonate-rich	qtz+(hser, py) qtz+hser/fuchsite dol+chl+qtz+mica
		Propylitic	pumpellyite-rich prehnite-rich	pmp+chl±prh, cc, qtz prh+chl±pmp, cc, qtz
		Sodic		qtz+ab+chl

Lena gold province, Russia
Sukhoi Log deposit

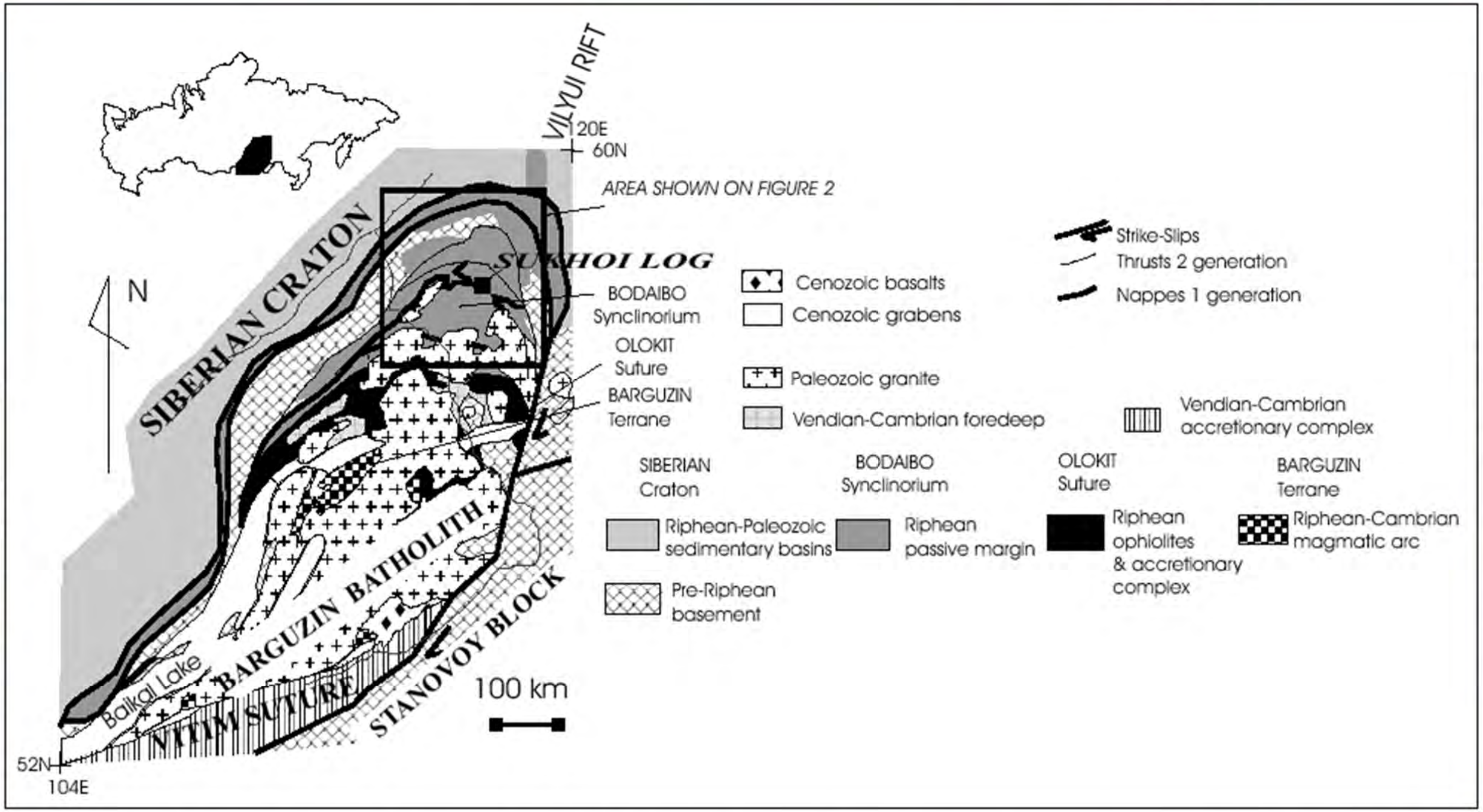
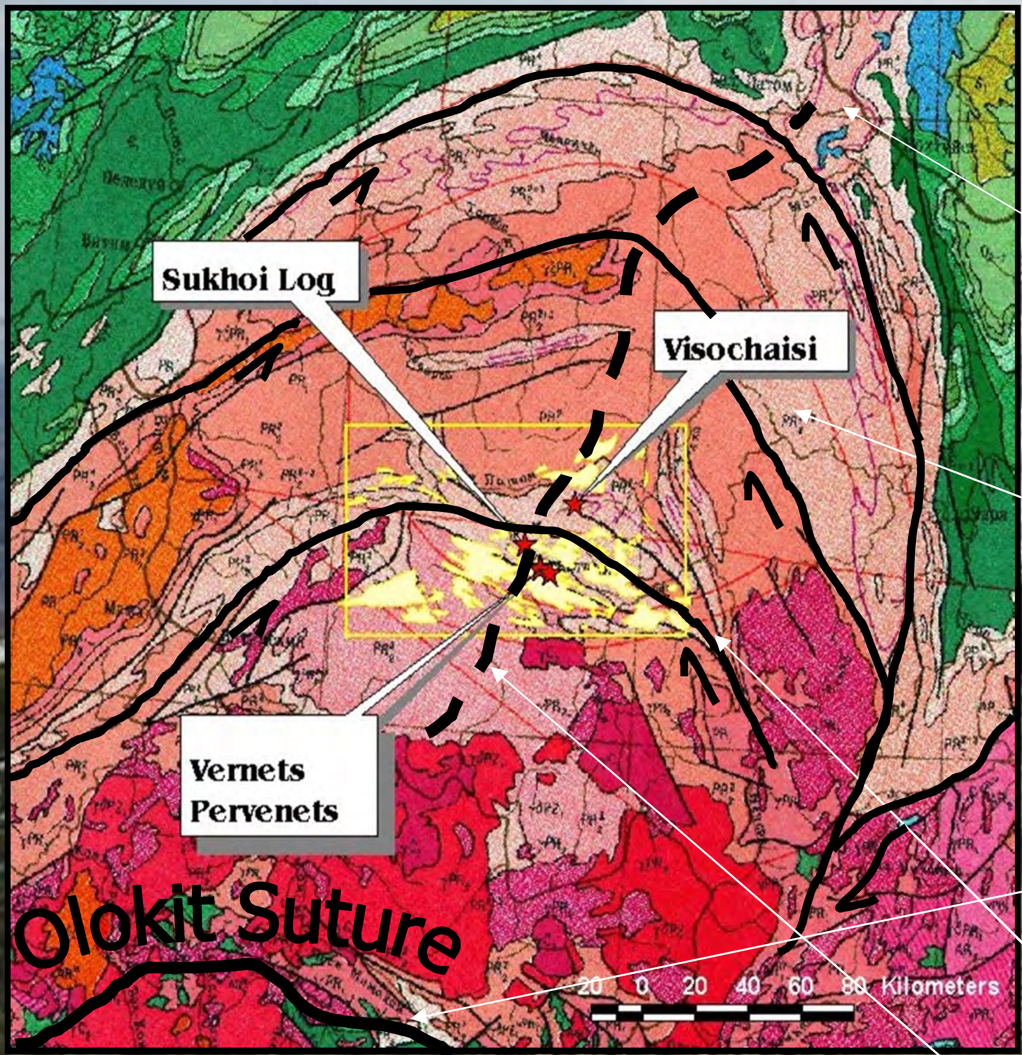


FIGURE 1. Tectonic elements of the Baikalide Orogen. The Bodaibo Synclinorium was deformed between the Barguzin island arc terrane and Siberian Craton. The Olokit suture forms a boundary between the oroclinally bent Bodaibo Synclinorium and Barguzin terrane.

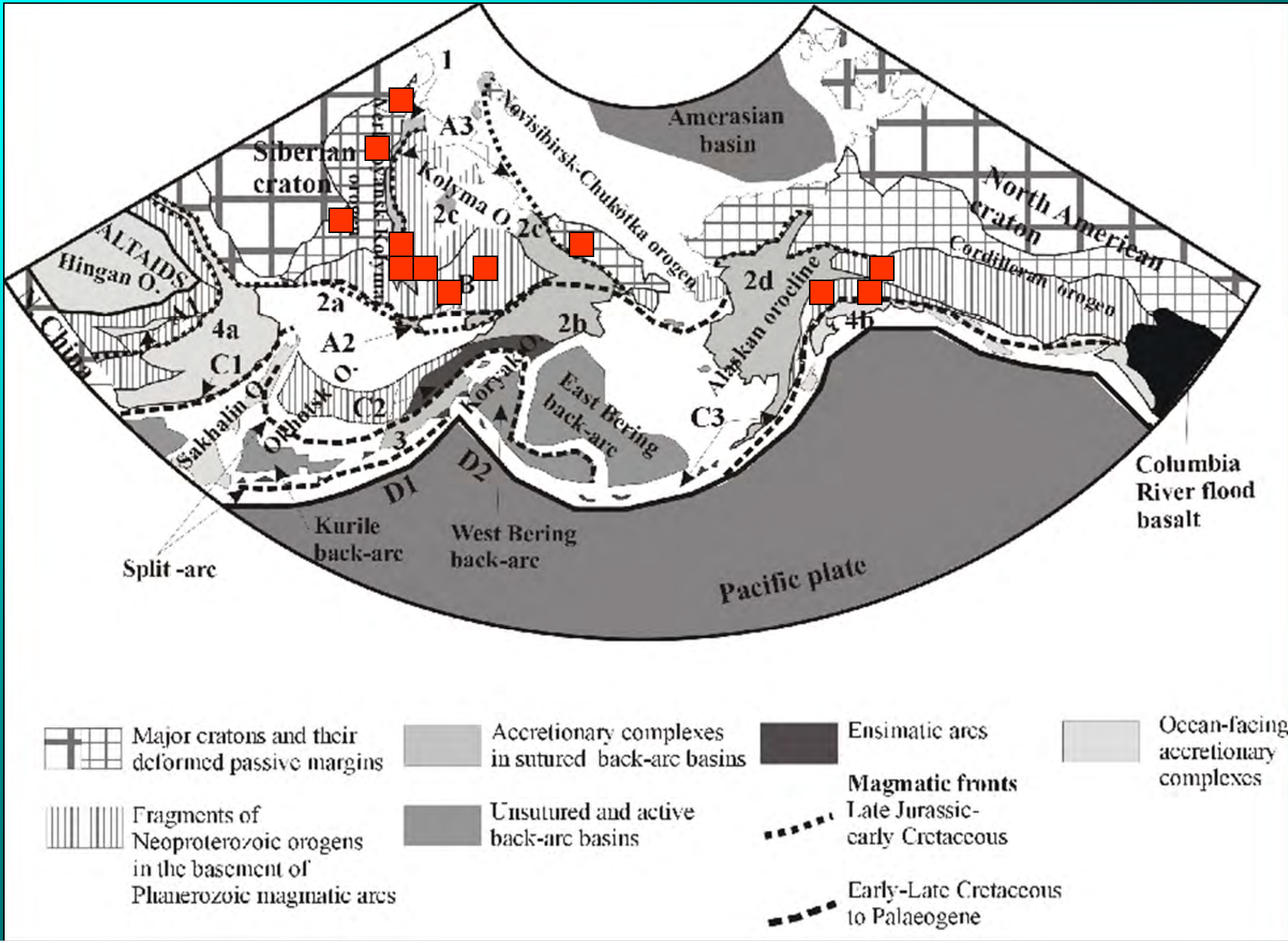
Lena gold province, Russia



Geology of the Patom Highlands

- Archean basement
- Proterozoic passive margin and rift
  - 12 - 20 km sediments
- Baikalide Orogen
  - Neoproterozoic
  - Continent-arc collision
  - Major fold/thrust event
- Late strike-slip faults and thrusts
- Major orocline
  - NE axis

Kolyma province, NE Russia



Great Basin, Nevada, USA

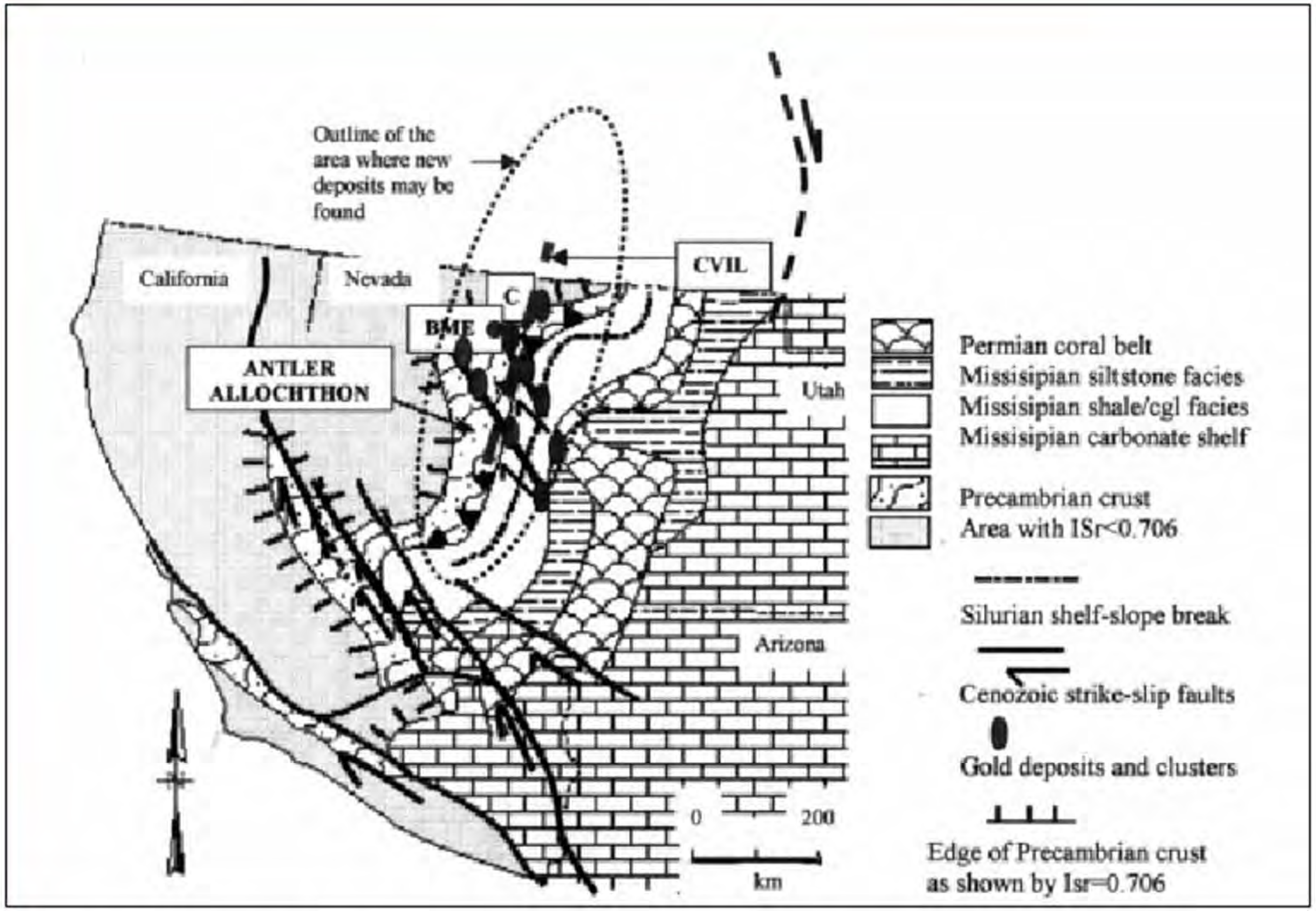


FIGURE 4. Outline map showing pre-Mesozoic units, Cenozoic strike-slip pattern and gold trends of the Great Basin (adopted and modified from Wooden et al., 1998). Traditionally defined Battle Mountain-Eureka (BME) and Carlin (C) trends represent possible strike-slip lineaments, along which the gold deposits occur in en-echelon position. On the other hand, the regional pattern suggests that the Carlin-type gold deposits occur in the geometrical center of an extensional dextral strike-slip megaduplex forming negative flower megastructure of the Great Basin, whose axis is traced by the Crescent Valley-Independence lineament (CVIL) by Peters (1998). This model infers that new deposits may be found in favorable lithologies within the oval-shaped area shown.

Great Basin, Nevada, USA

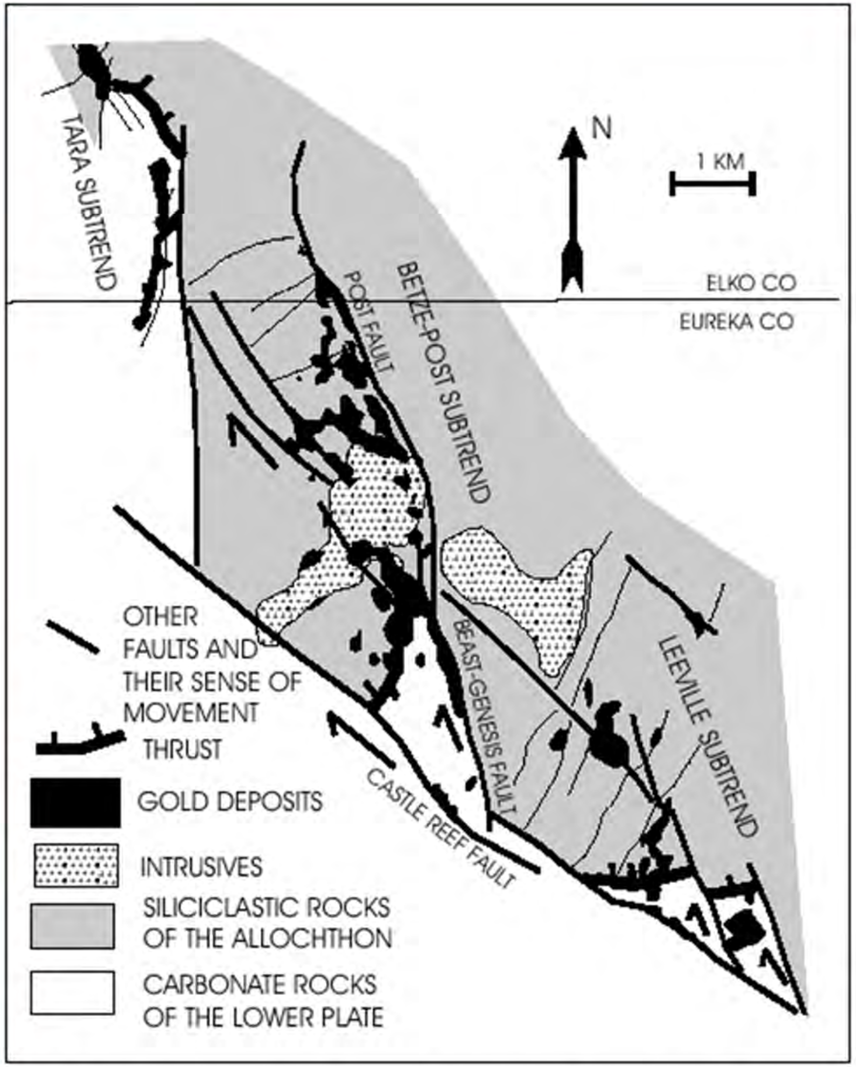


FIGURE 5. Location of the major known deposits in the Carlin trend (modified after Teal and Jackson, 1997) shows three NNW-striking subtrends having an oblique position with respect to the bounding Castle Reef fault. The structural pattern suggests en echelon structure controlled by a dextral strike-slip fault. There is probably more than one generation of strike-slip faulting. All major deposits occur in the central Betze-Post subtrend.

6. Conclusions, practice and discussions