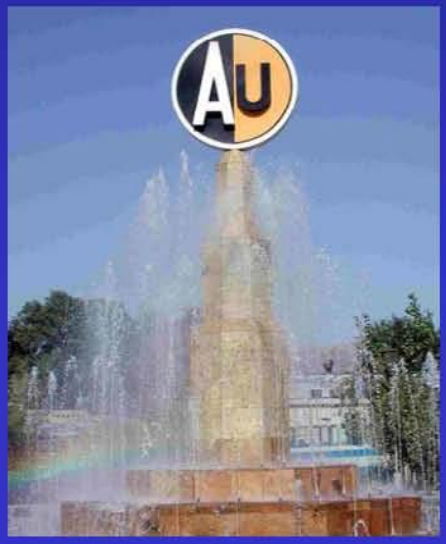
The Muruntau auriferous system



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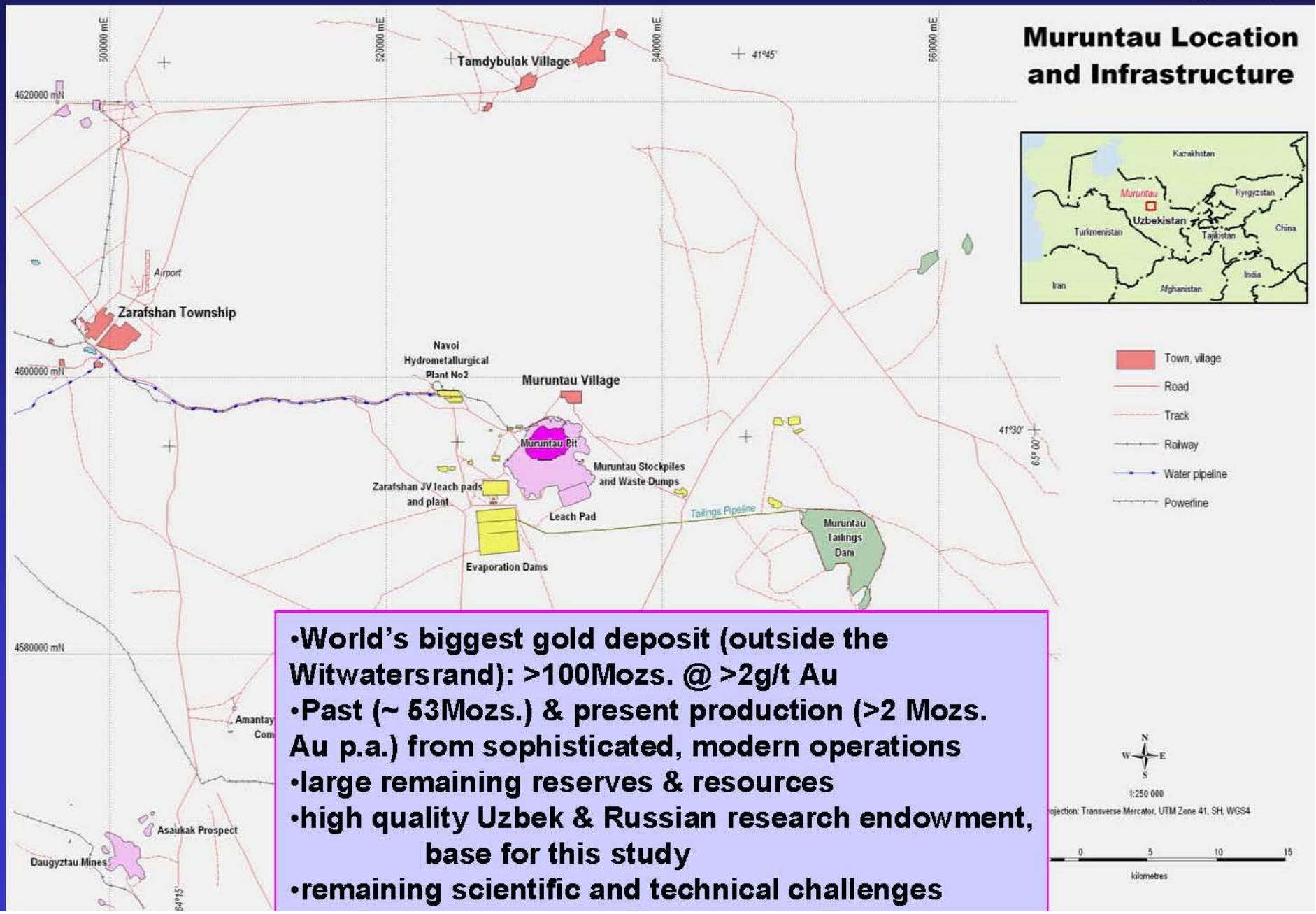
We thank…

- NGMK: N.I. Kuchersky and C.B. Inosemzev
  - Muruntau technical staff, especially V. 'Hobbit' Yantsen
- State Committee on Geology & Mineral Resources and IMR: N.A. Akhmedov, B.A. Isakhodjaev, I.M. Golovanov
- Kyzylkum Geological Expedition: T. Shaymuratov
- CERCAMS project sponsors: Placer Dome
- S. Westhead (OXUS); Resource & Exploration Mapping

….for facilitating and contributing to this study

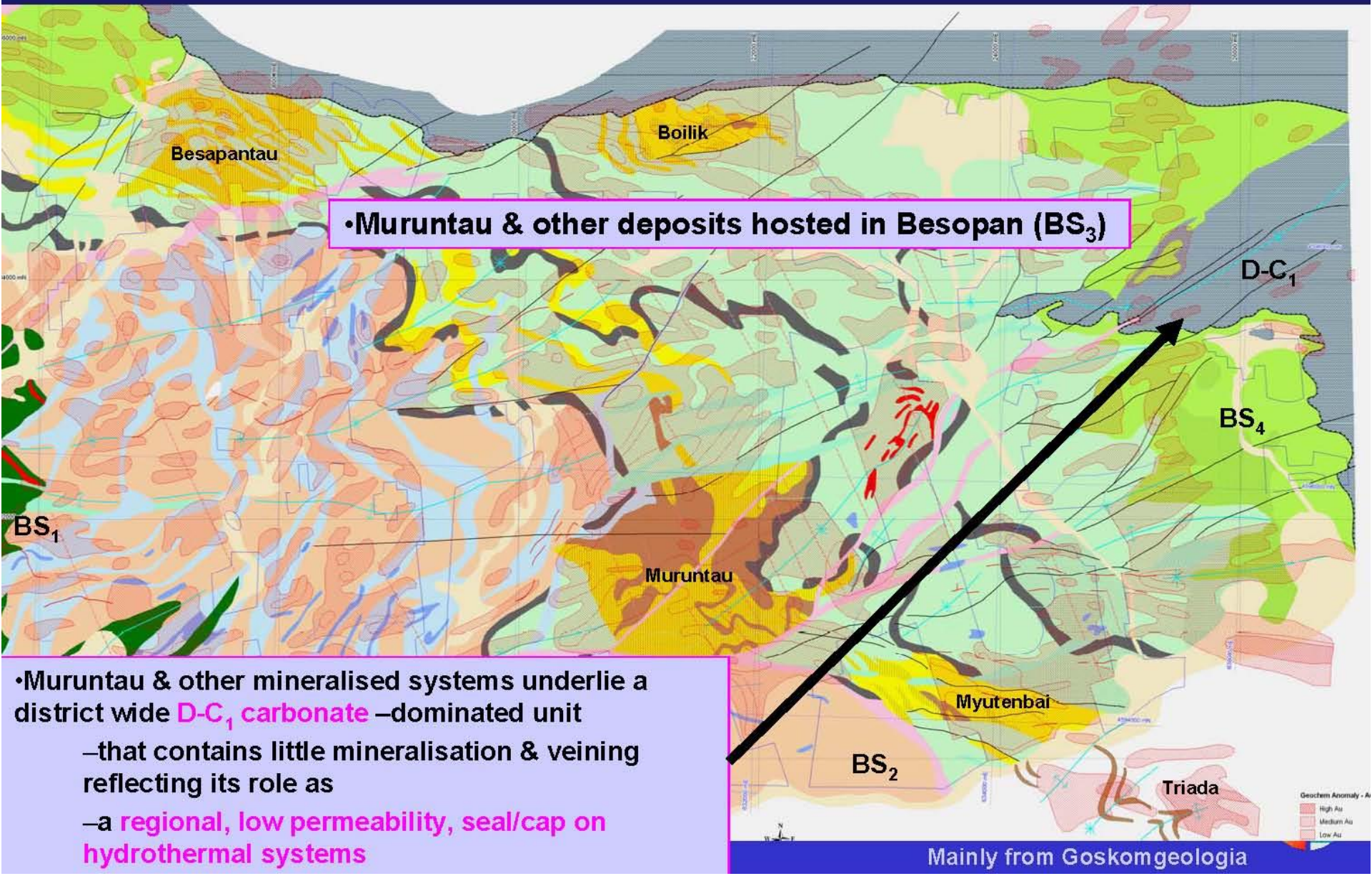
'olga oltin marchamat'

Muruntau



- World's biggest gold deposit (outside the Witwatersrand): >100Mozs. @ >2g/t Au
- Past (~ 53Mozs.) & present production (>2 Mozs. Au p.a.) from sophisticated, modern operations
- large remaining reserves & resources
- high quality Uzbek & Russian research endowment, base for this study
- remaining scientific and technical challenges

Muruntau: near surface gold anomalies and regional seal



•Muruntau & other mineralised systems underlie a district wide $D\text{-}C_1$ carbonate –dominated unit

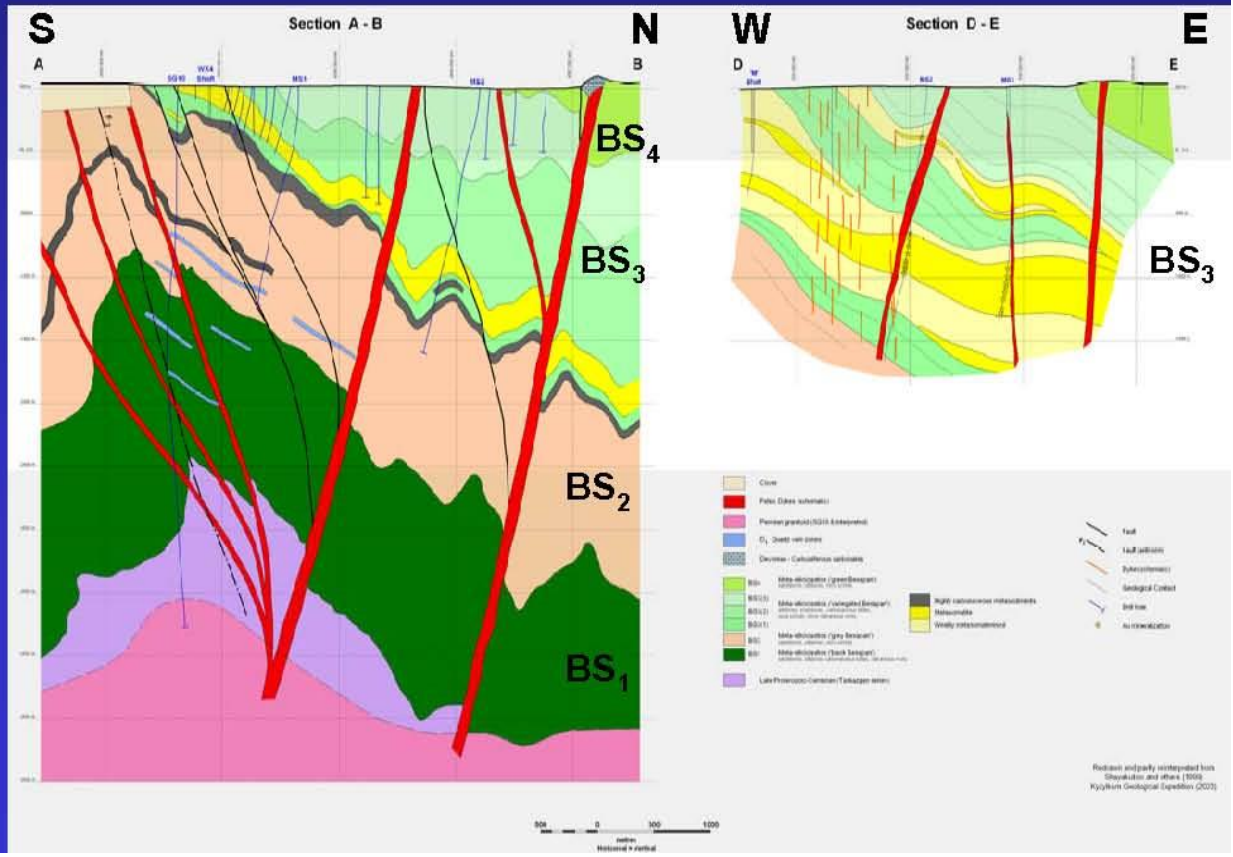
–that contains little mineralisation & veining reflecting its role as

–a regional, low permeability, seal/cap on hydrothermal systems

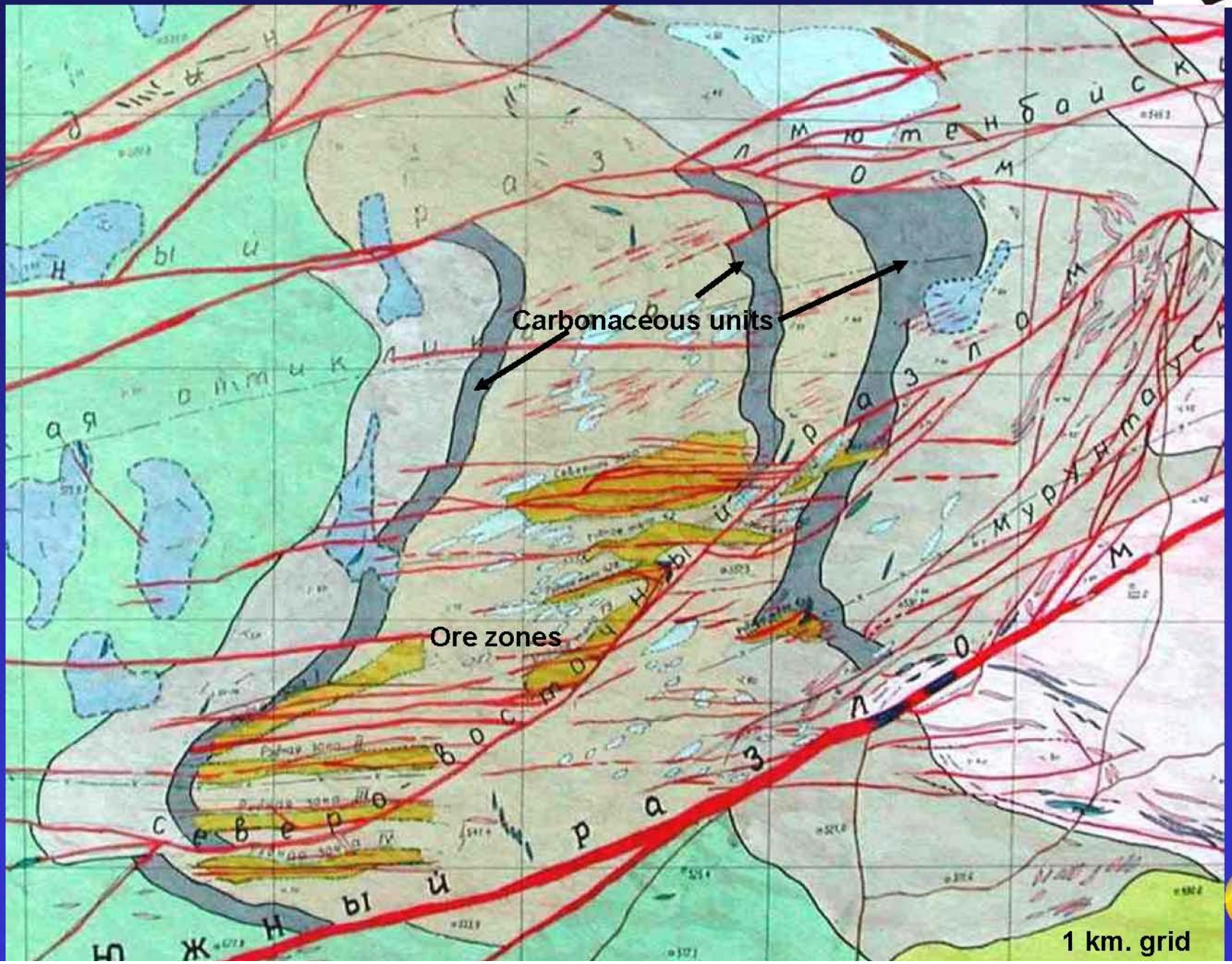
Muruntau district: lithostratigraphy

- BS_3: key lithological, layering & compositional features:
  - –thin layered psammopelites dominate, interbedded with psammites and also highly carbonaceous pelites
  - –veining, mineralisation & potassic alteration is broadly stratabound/ focused in three main BS_3 psammopelitic packages
    - •higher fracture/vein abundances in these units reflecting their rheology & somewhat feldspathic composition
  - –separated by highly carbonaceous pelites
    - •partition strain & fracturing, acting as local 'screens' due to higher ductility
    - •sources of reductant (CH_4-bearing fluids)

- BS_3 or similar packages, key exploration targets



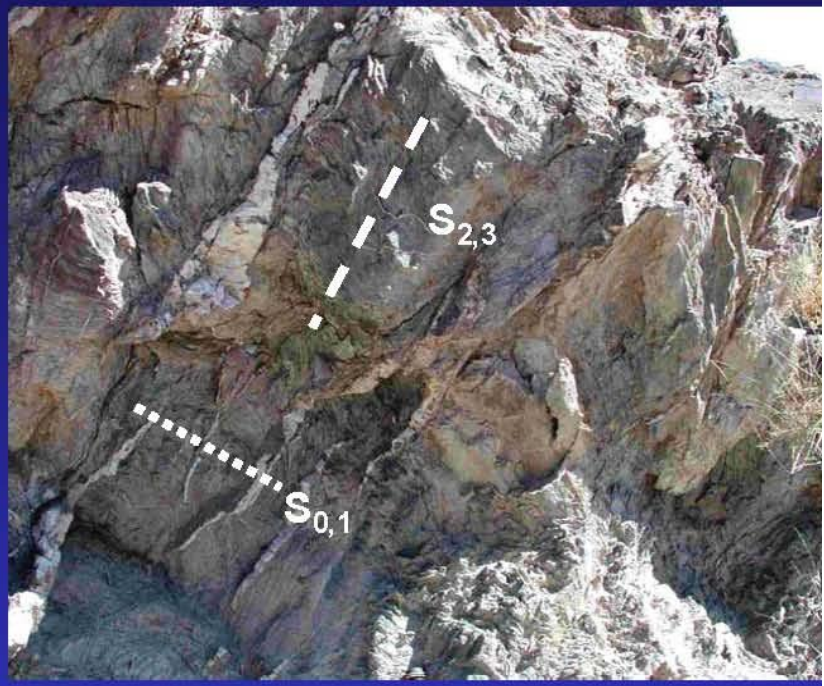
Muruntau: surface geology (1963)



Muruntau district: structural elements & history

D_1: major regional NNE-SSW (fold-thrust) shortening

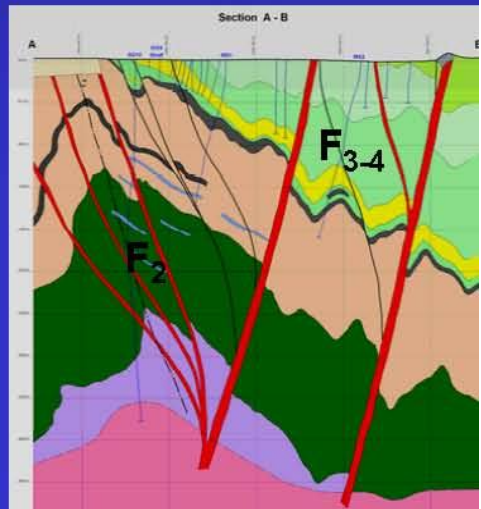
- S_1: strong layer-subparallel foliation, associated recrystallised quartz veinlets
- S_1 in Palaeozoic metasediments & D-C_1 carbonates
  - D_1 is Hercynian age
- minor folds, no large nappes
- small displacement thrusts, no major lithostratigraphic disruptions
- basement-involved, not thin-skinned deformation
- regional lower greenschist facies metamorphic grade



E-W F_2 crenulation folds in S_1 & layering, Kosmaonachi

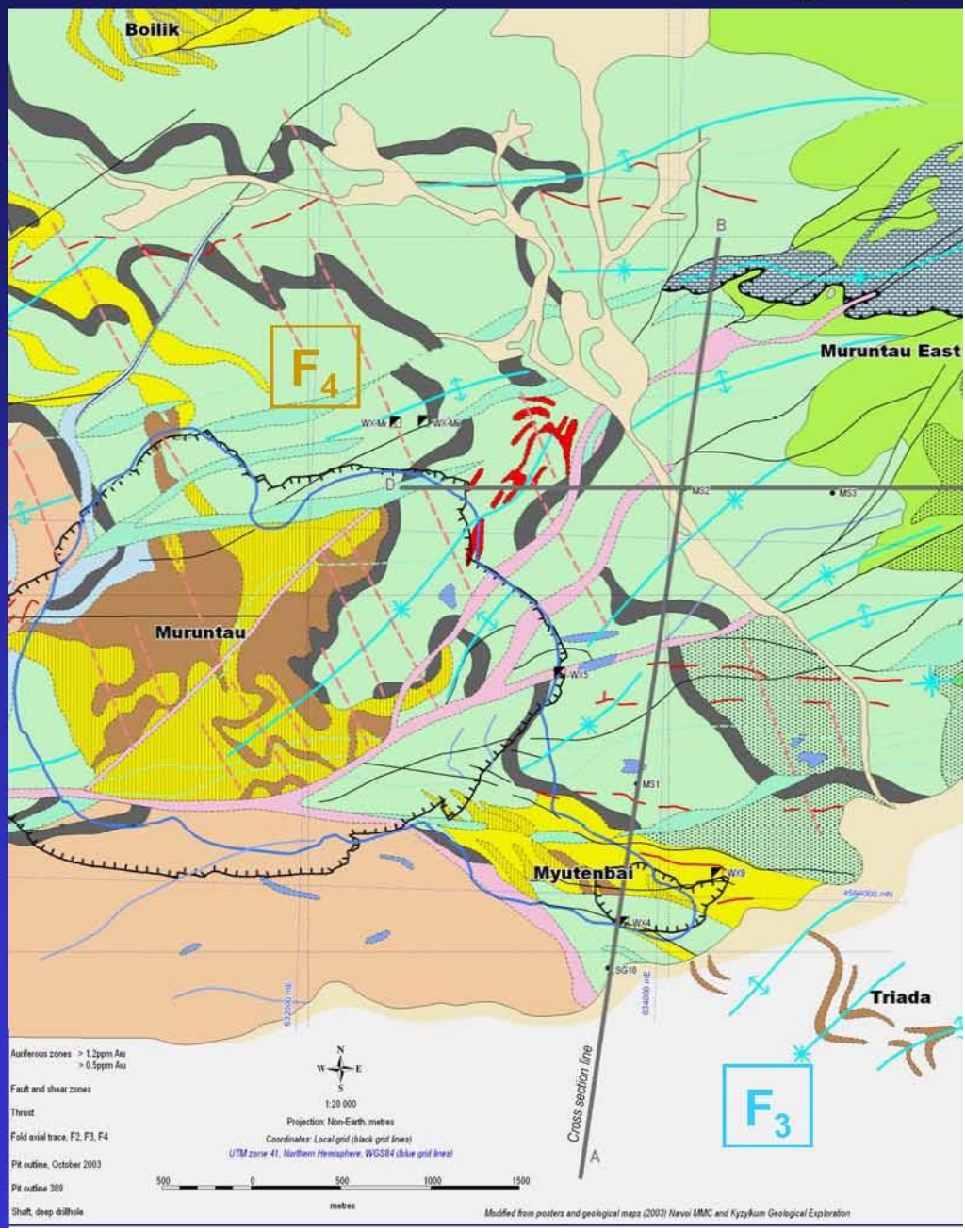
- D_2: N-S shortening
- crenulates S1, steep axial surfaces, E-W fold axes
- mesoscopic to regional folds (eg Dzhanbulak antiform)

F_3 crenulate S_1, D-C_1, Muruntau Nose



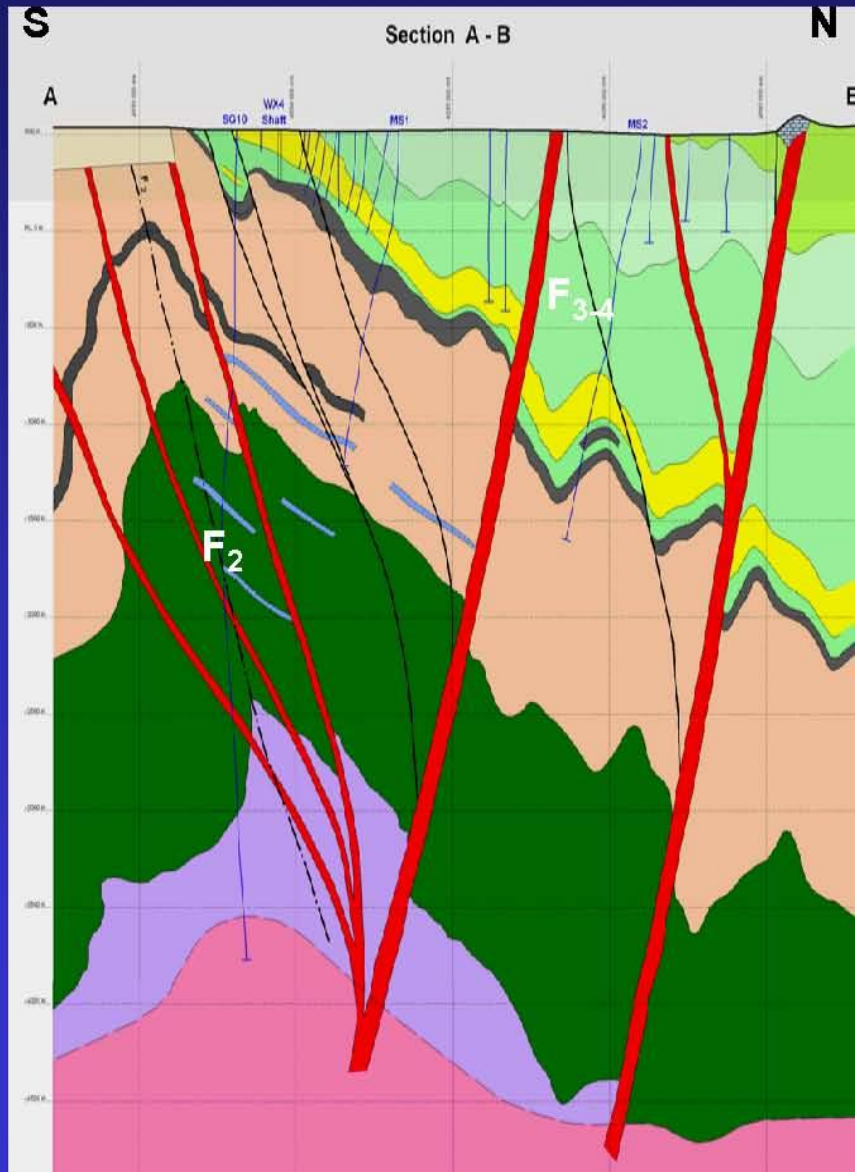
Muruntau district: structural elements & history

- D_3: NNW shortening
  - apparently overprints, but may be synchronous with D_2
    - ENE fold axes, steep axial surfaces
    - common in Daugyztau-Muruntau belt
  - S_3 crenulates S_1, mesoscopic to 100's metre wavelength folds
  - some quartz veining (recrystallised, not mineralised)
  - south dipping reverse faults?
- D_4: weak E-W shortening
  - S_4 crenulates S_1-S_3
  - mesoscopic to tens of metres fold wavelengths
    - minor NNW reverse faults
    - F_4 common in Muruntau area

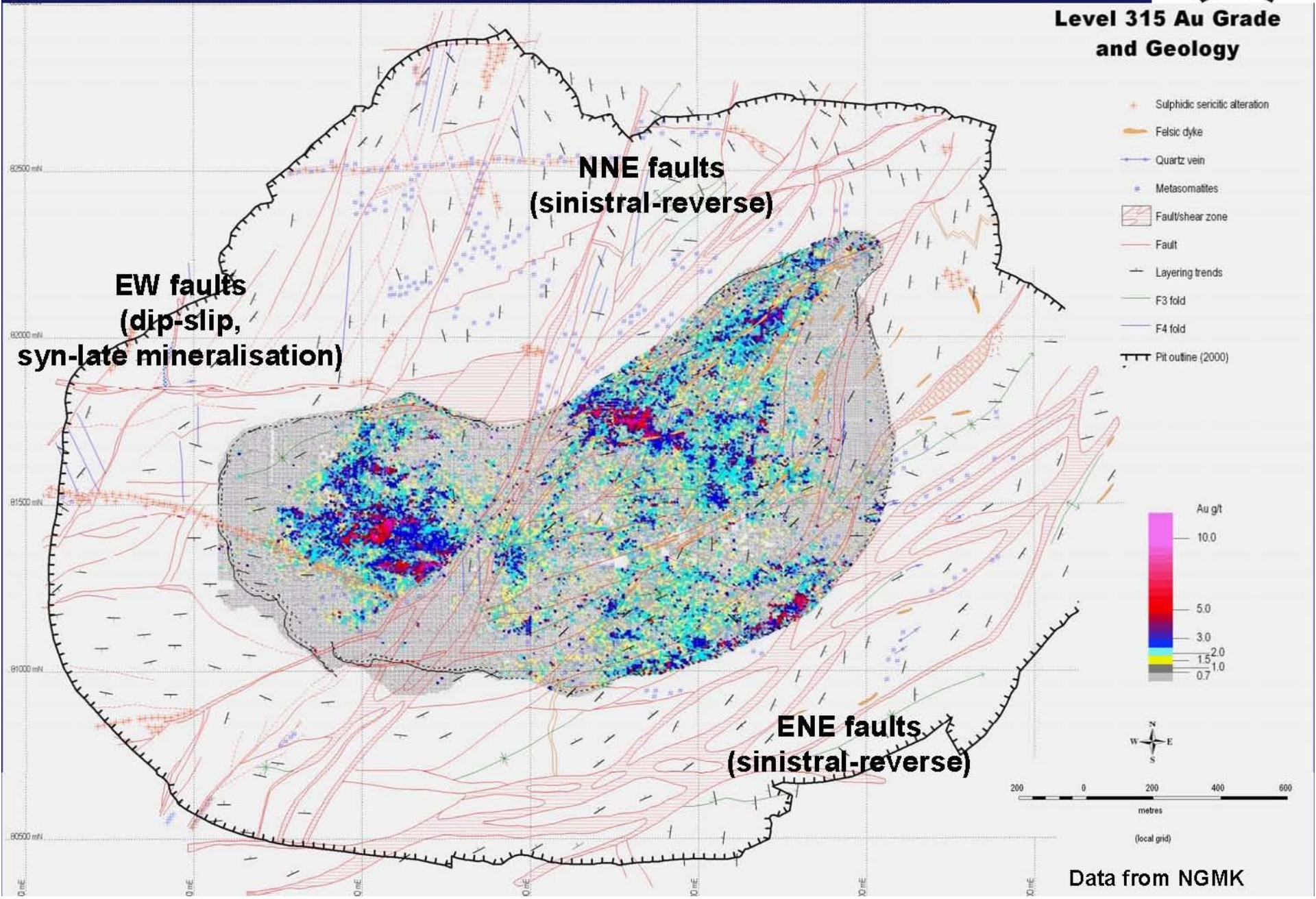


Muruntau ore system: structural setting

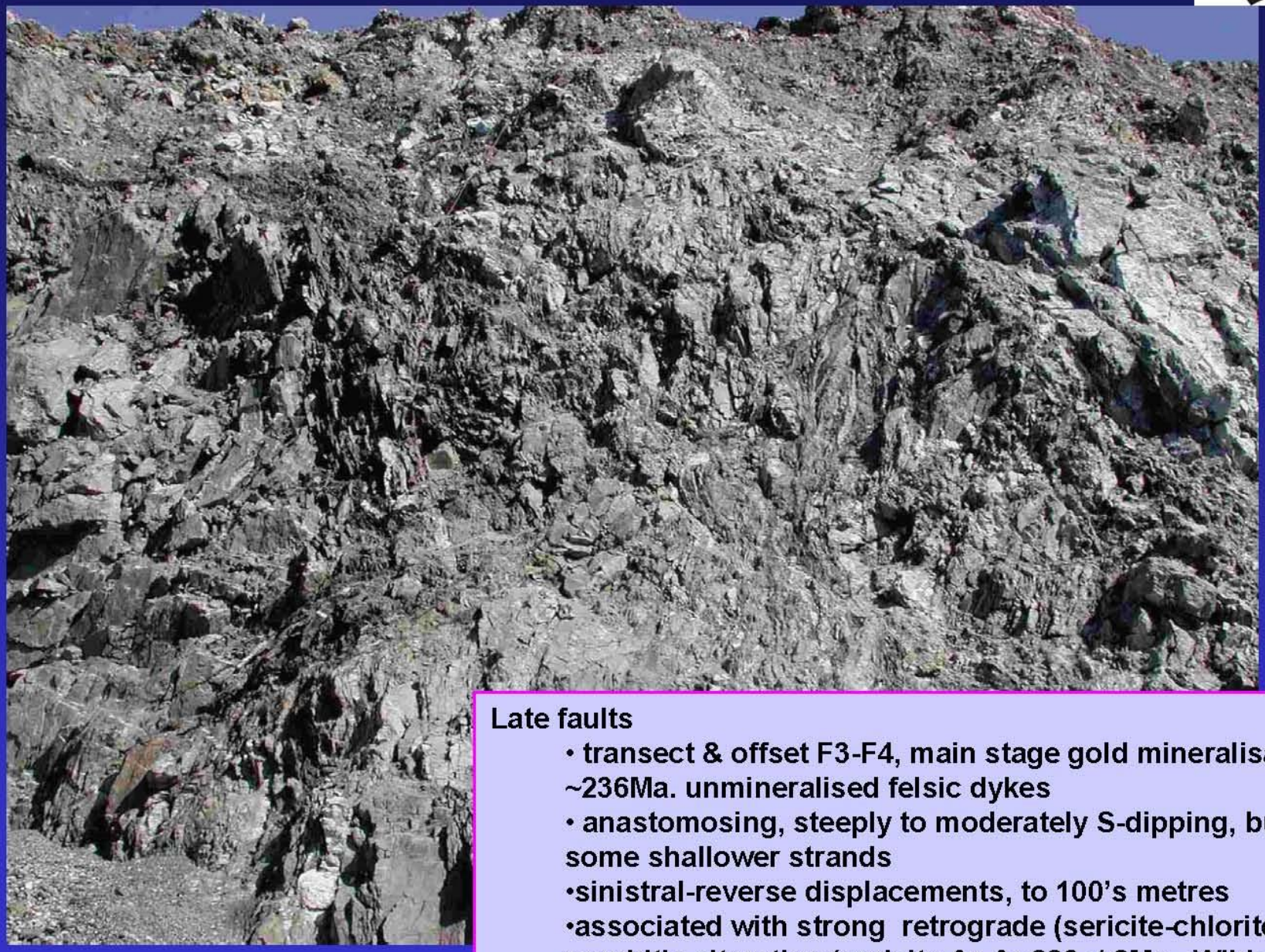
- localised in a structural culmination:
  - product of F_2- $F_{3(4)}$ interference
  - shallowly dipping layering, S_1 and fold axes
- a fold-fault system, not a major shear zone
  - like other giant gold deposits eg. Telfer, Sukhoi Log



Muruntau pit: late fault zones, geology & gold grades



Muruntau: fault zones (looking SE)



Late faults

- transect & offset F3-F4, main stage gold mineralisation, ~236Ma. unmineralised felsic dykes
- anastomosing, steeply to moderately S-dipping, but some shallower strands
- sinistral-reverse displacements, to 100's metres
- associated with strong retrograde (sericite-chlorite) & graphitic alteration (sericite Ar-Ar 226+/-2Ma., Wilde et. al.)

Southern fault, SW open pit, Level 375

Muruntau area: hornfels zones & textures

'Spotted zone' (5mm.across)

'Biotite zone' (Muruntau pit; 3mm. across)

Hornfelsing:

- overprints S_1-S_4
- occurs in a low strain environment lacking penetrative deformation
- produces relatively massive textured rocks at medium- and higher metamorphic grade
- 270-280Ma. Rb-Sr ages (micas) & Nd-Sm (scheelite)

'Cordierite-Kspar zone' (SG-10 drill core, 3900m)

Thermal metamorphic zonation: SG-10

Metamorphic grade, grainsize & textural reconstitution increase with depth to pluton contact (4km)

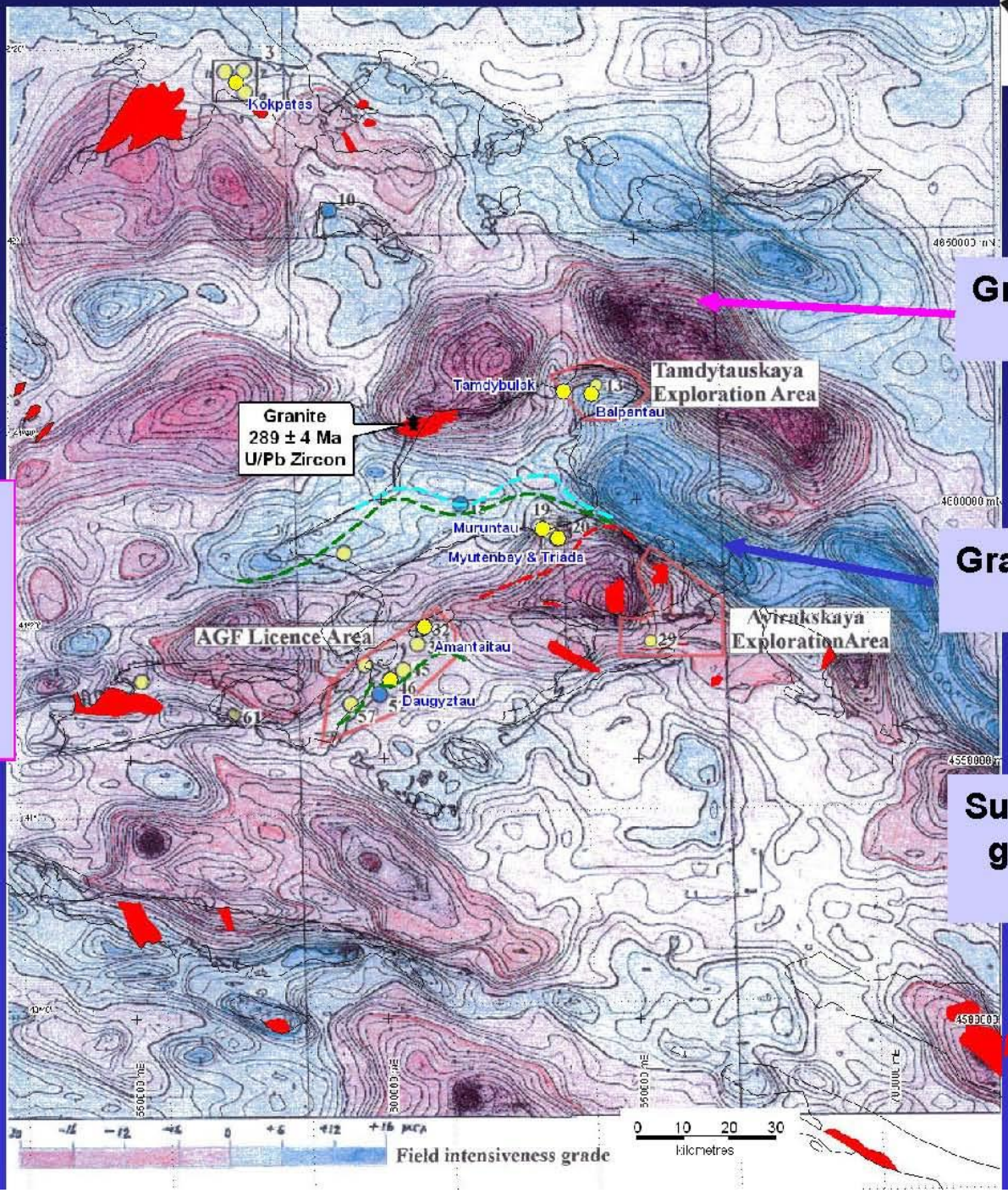
Зональность контактового ореола Мурунтауского рудного поля

Zonation of contact metamorphism of Muruntau ore field

Глубина м Deep m	Тип пород Tipe of rocks / Фации Facies		Метаалевролиты, метапсаммиты, метапелиты Metaaleurolites, metapsammites, metapelites	Известковые породы Calcic rocks
0	Фация полевошпат-кварцевых роговиков Feldspar-quartz hornfees facies	Альбитовые роговики Albite hornfels	Кварц + плагиоклаз + биотит Quartz + plagioclase + biotite	Кальцит + доломит + актинолит + кварц Calcite + dolomite + actinolite + quartz
1743				
3376		Двуполевошпатовые роговики Double-feldspar hor-fels	Кварц + плагиоклаз + калишпат + биотит Quartz + plagioclase + k-feldspar + biotite	
3974	Фация роговообманковых роговиков	Hornblend hornfels facies	Мусковит + биотит + кварц + плагиоклаз + калишпат Muskovite + biotite + quartz + plagioclase + k-feldspar	Кальцит + доломит + диопсид + тремолит + гроссуляр Calcite + dolomite + diopside + tremolite + grossularia
4006	Фация пироксеновых роговиков	Pyroxene hornfees facies	Калишпат + андазулит + биотит + плагиоклаз K-feldspar + andaluzite + biotite + plagioclase	Кальцит + диопсид + волластонит + гроссуляр Calcite + diopside + vollastonite + grossularia
	Гранитный интрузив		Кварц + калишпат + плагиоклаз + биотит + мусковит Quartz + K-feldspar + plagioclase + biotite + muskovite	

Muruntau Geological Museum

Bouger gravity, geology & gold deposits



All significant Au deposits are above the margins of gravity lows (largely concealed felsic plutons)

Gravity lows (pink)

Gravity highs (blue)

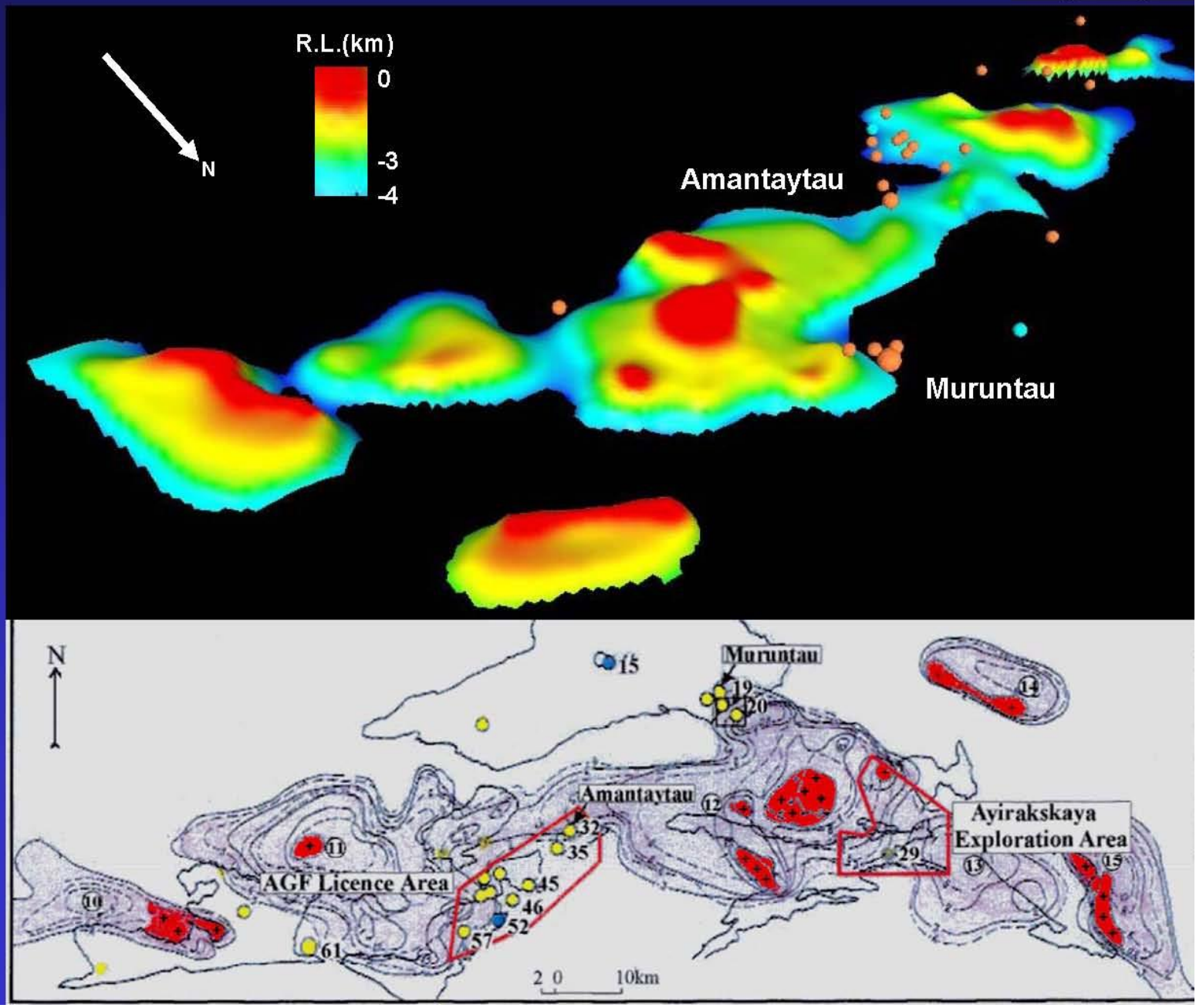
Subcropping granitoids (red)

Spotted zone

Biotite zone

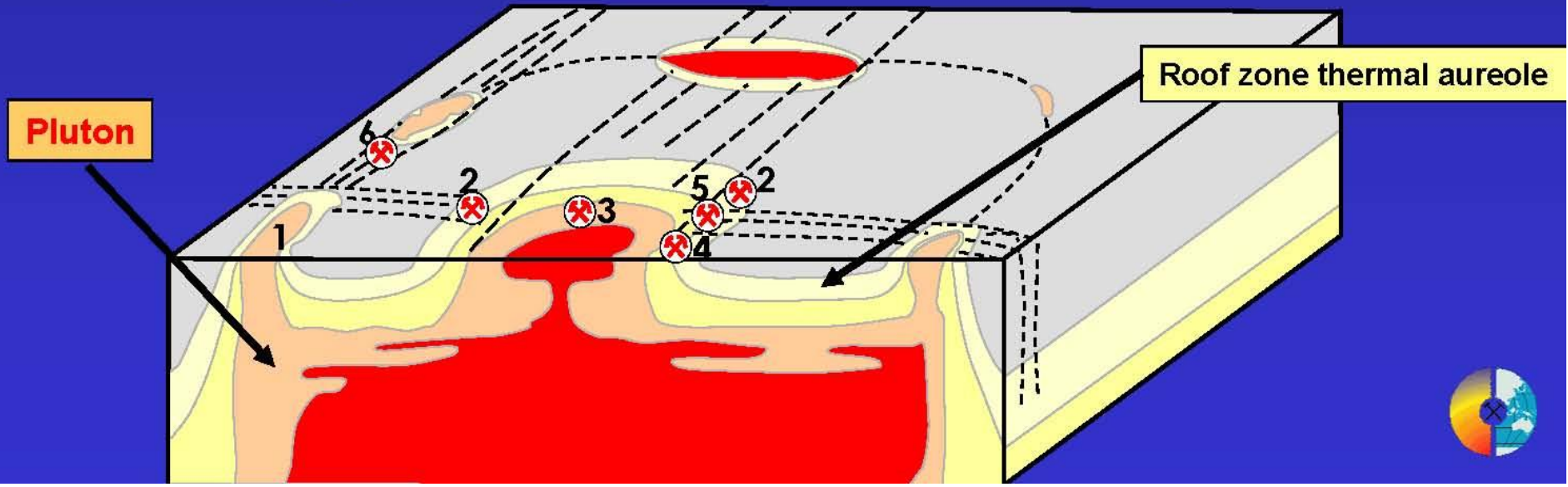
Cord.+/-Kfspar zones

Depths to plutons, Southern Kyzylkum (Revyakin, 1988)

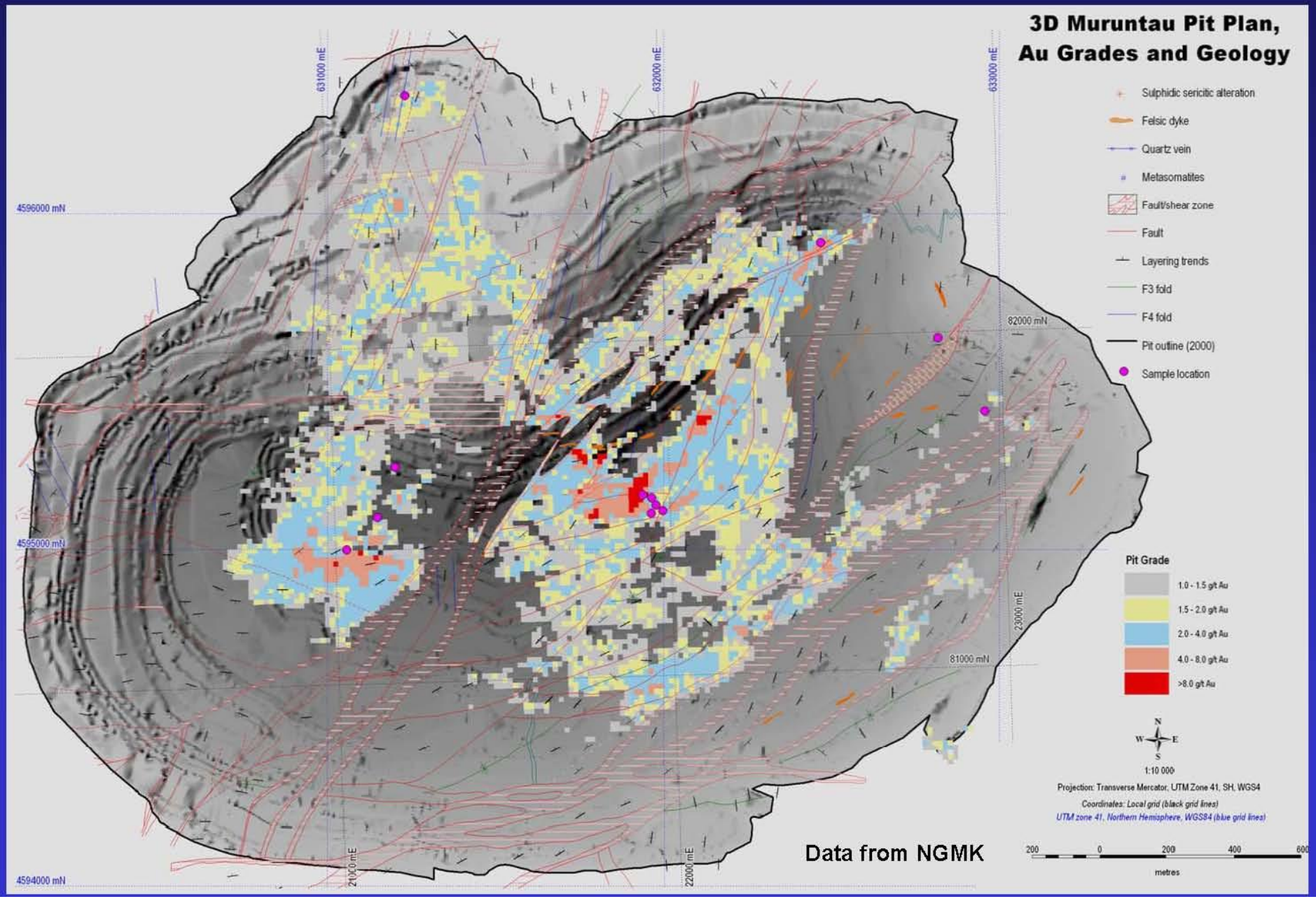


Kyzylkum: thermal metamorphic aureoles

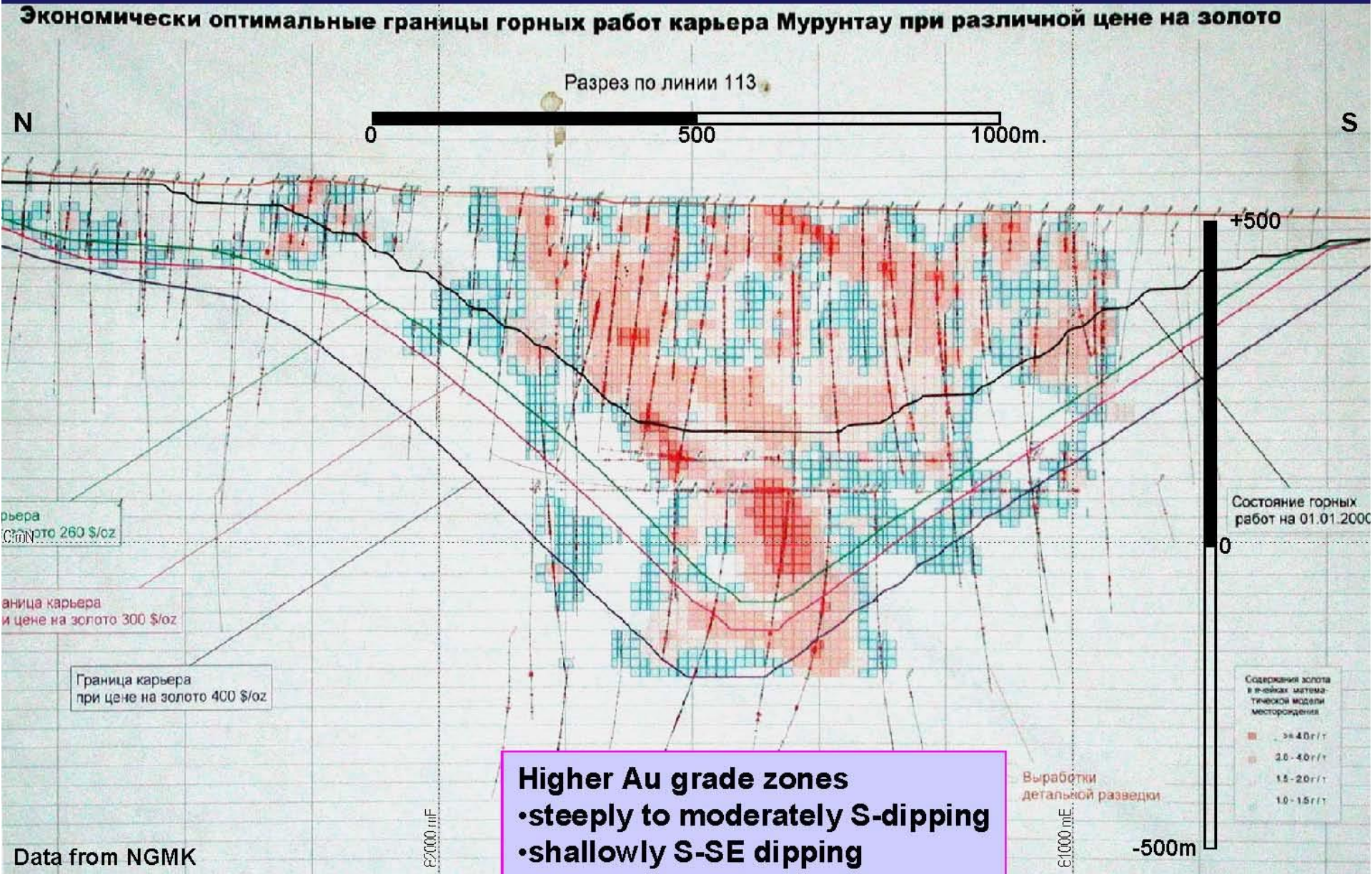
- reflect underlying/concealed (Hercynian, ~285Ma, fractionated, ilmenite-series I-type) plutons
  - intruded late in/postdating penetrative regional deformation
- are broad (up to 6kms wide), resulting from
  - relatively deep seated intrusion (>6-10kms.) into lower greenschist facies rocks
- contain (along with pluton tops) all significant Au deposits in Kyzylkum
  - most such deposits are localised above pluton margins in pluton roof zone thermal aureoles



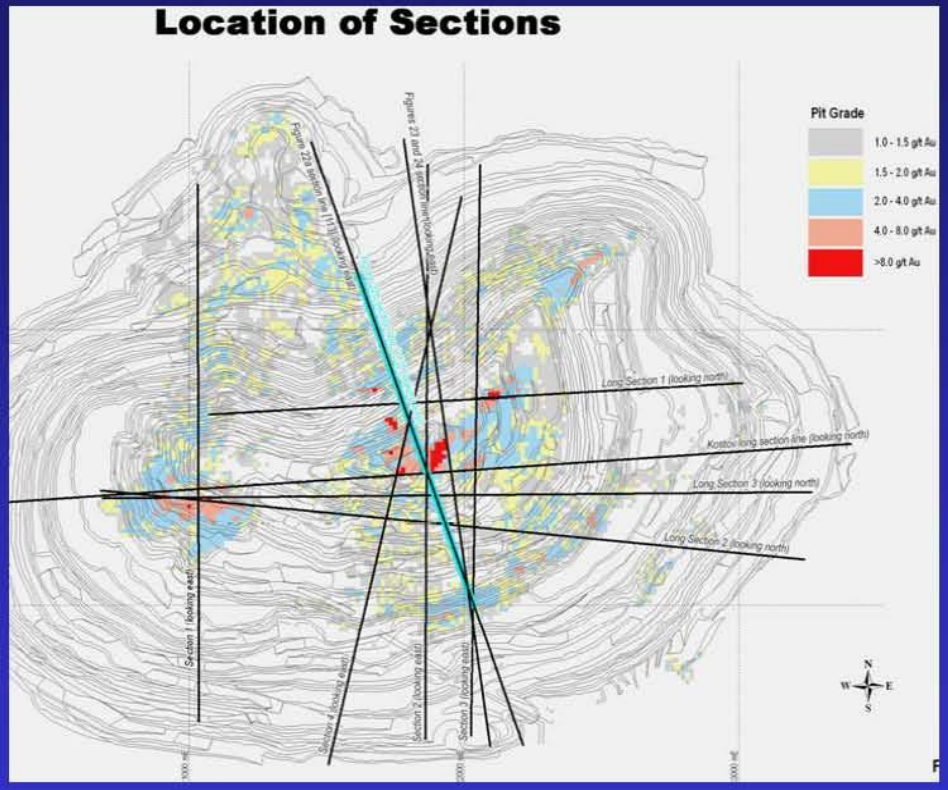
Muruntau pit: ore zones & fault systems



Au grade distribution : Cross section 113, resource & pit models



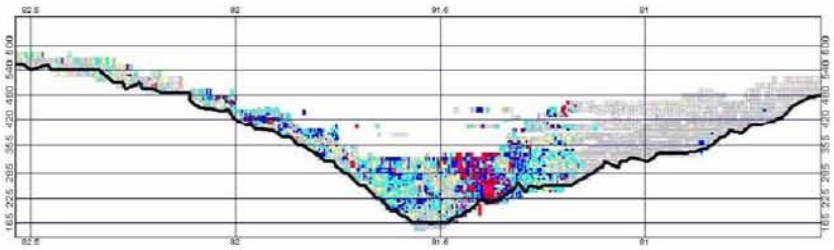
Au grade distribution sections: grade control model



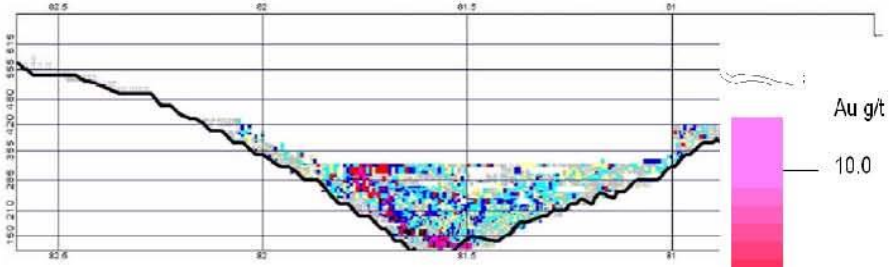
Higher Au grade zones
- **steeply to moderately S-dipping**
- **shallowly S-SE dipping, broadly stratabound**

Data from NGMK

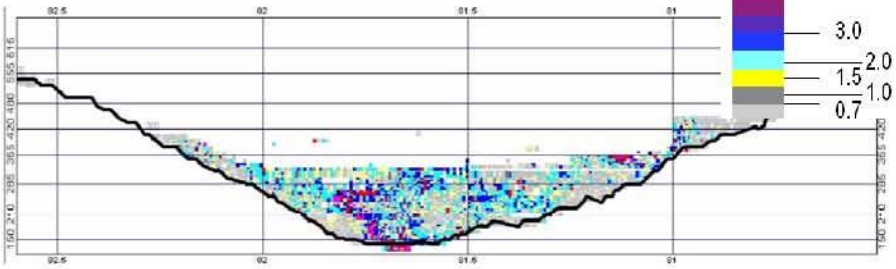
Cross Section 1



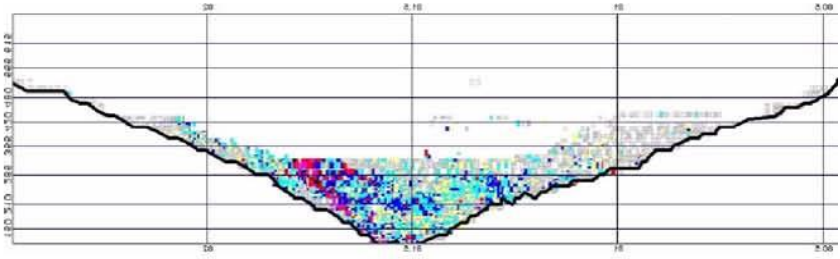
Cross Section 2



Cross Section 3

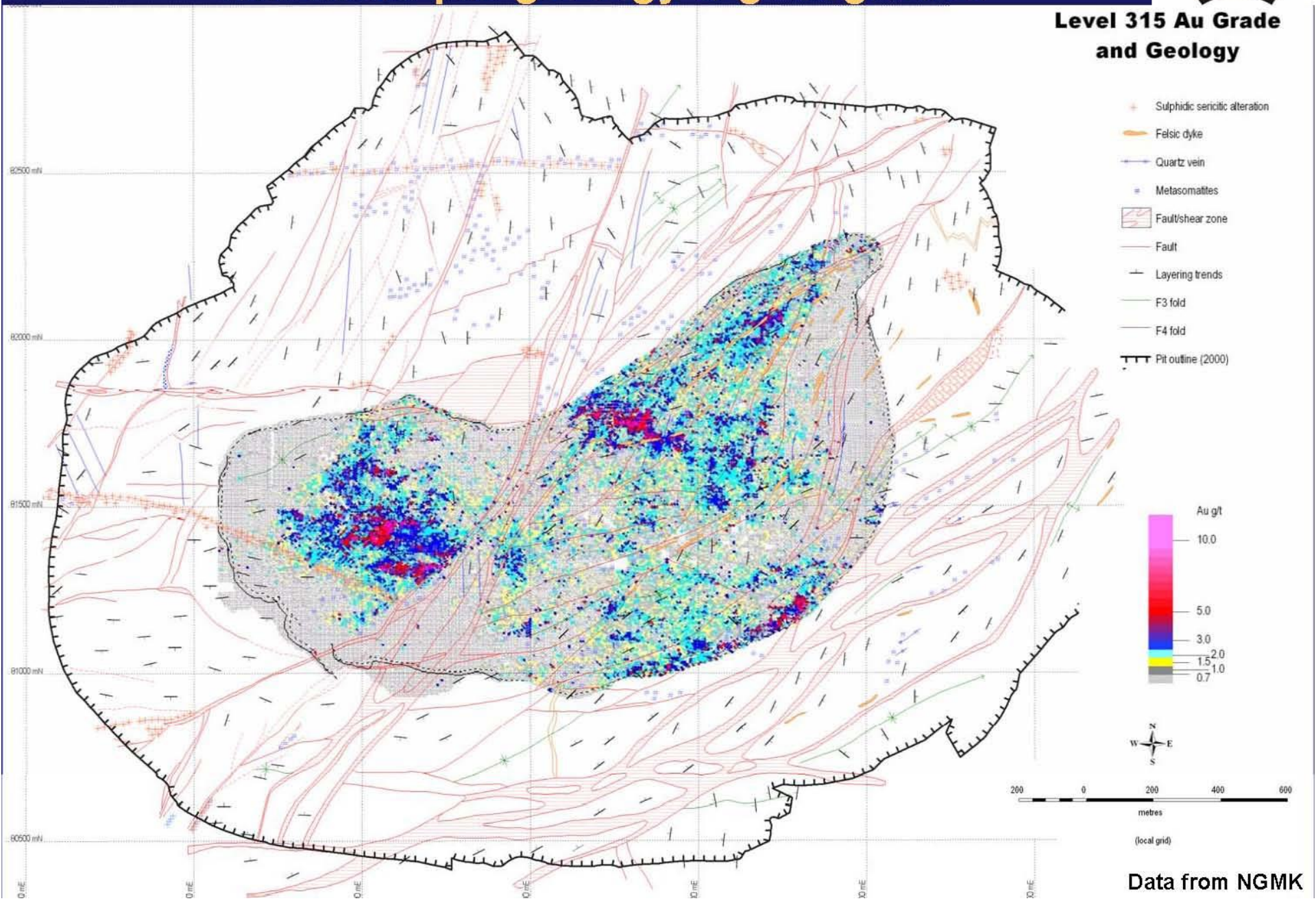


Cross Section 4



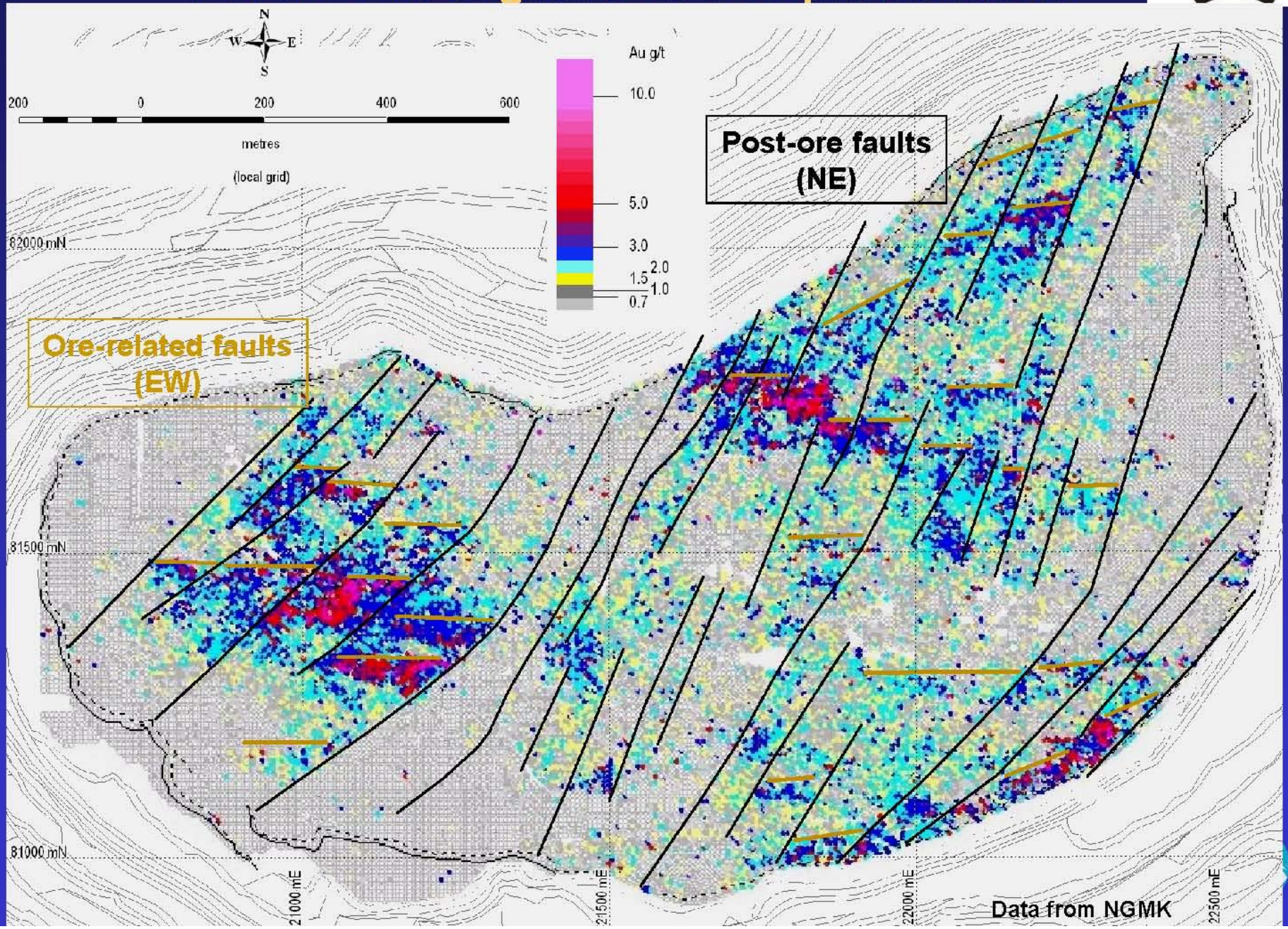
200 0 200 400 600

Muruntau pit: geology & gold grades

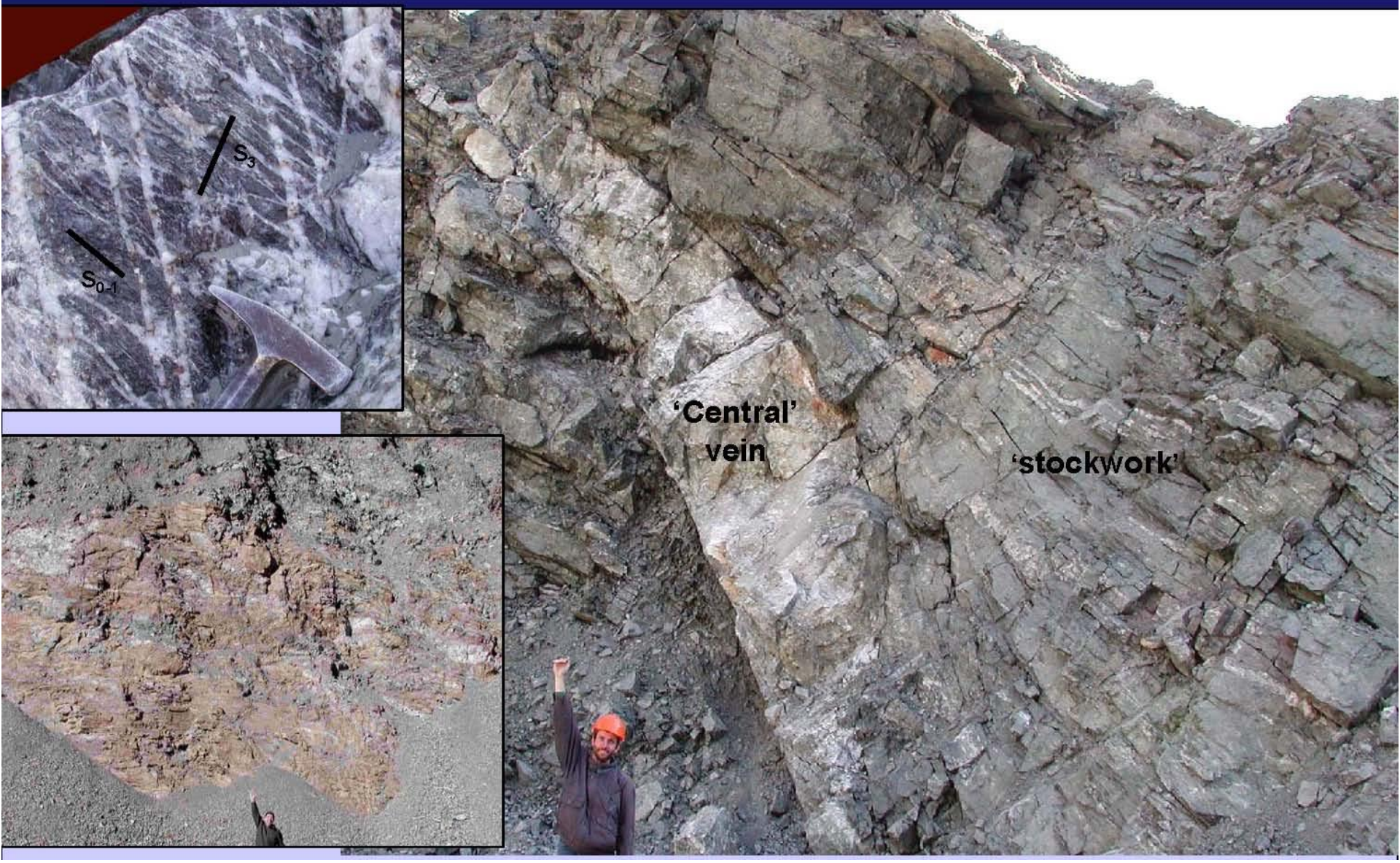


Data from NGMK

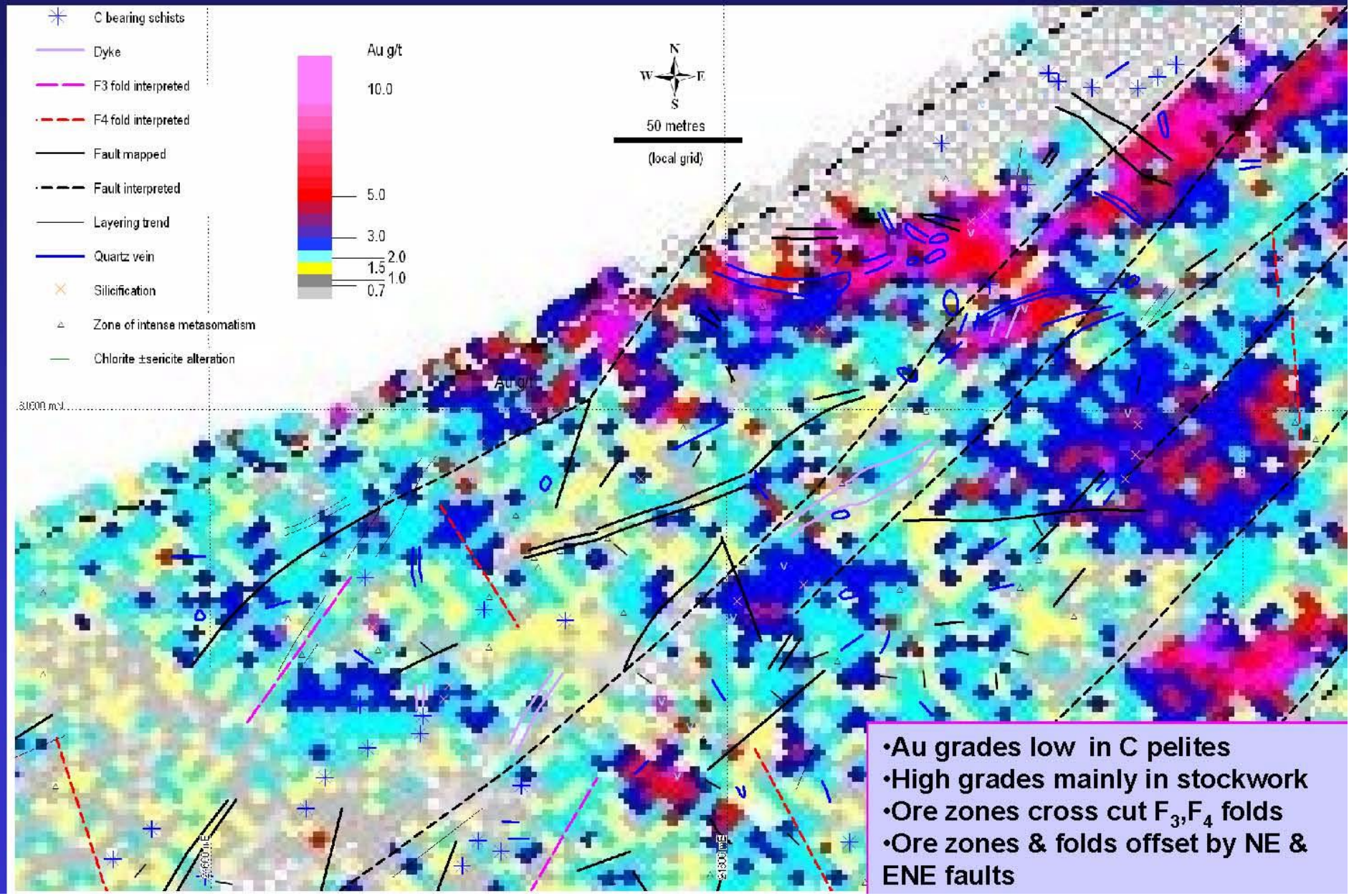
Level 315: Au grades & interpreted faults



Muruntau pit: ore zones

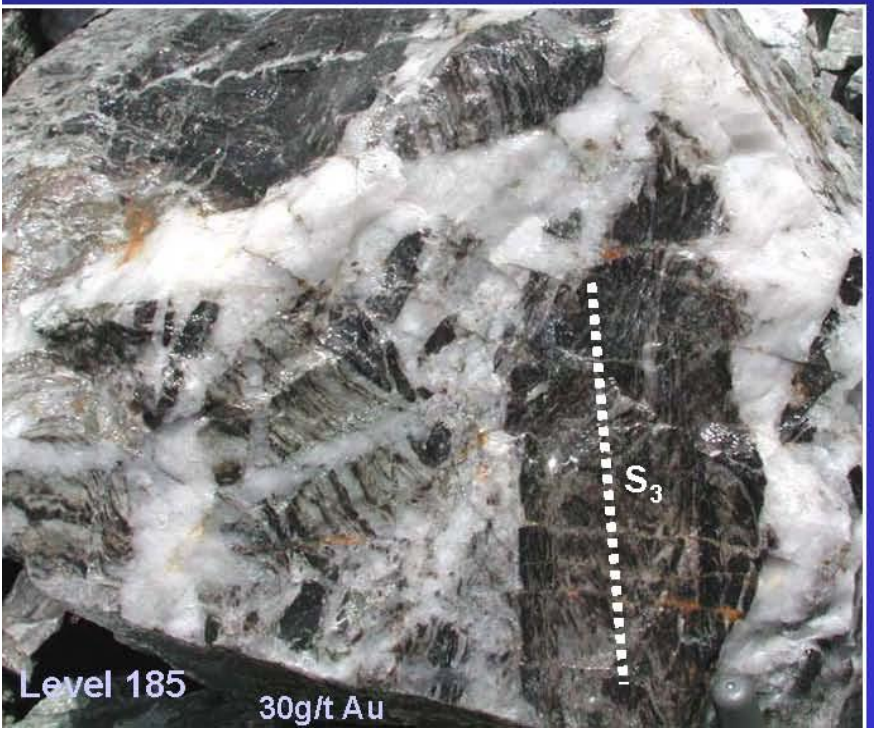


Level 150: Au grades & pit geology



- Au grades low in C pelites
- High grades mainly in stockwork
- Ore zones cross cut F_3,F_4 folds
- Ore zones & folds offset by NE & ENE faults

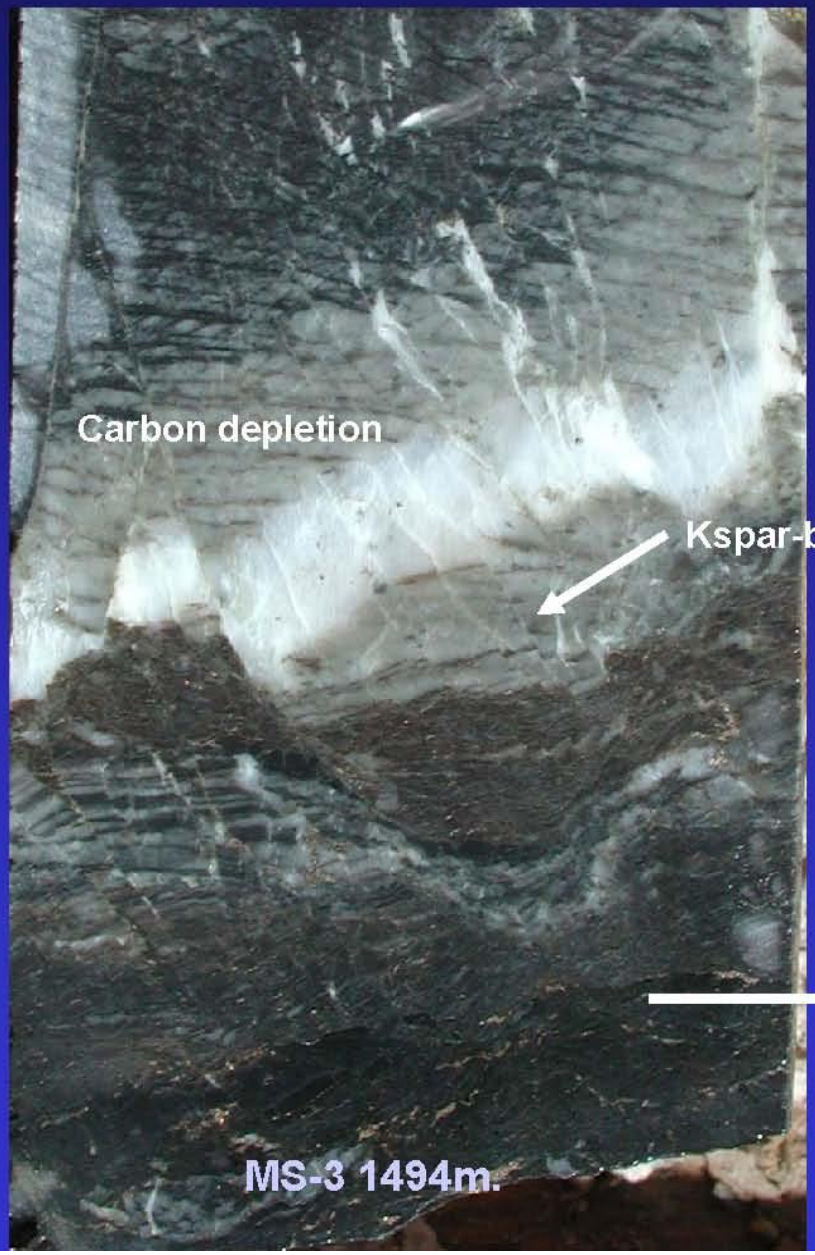
Muruntau: vein geometries, timing & alteration



Muruntau: alteration distribution & timing

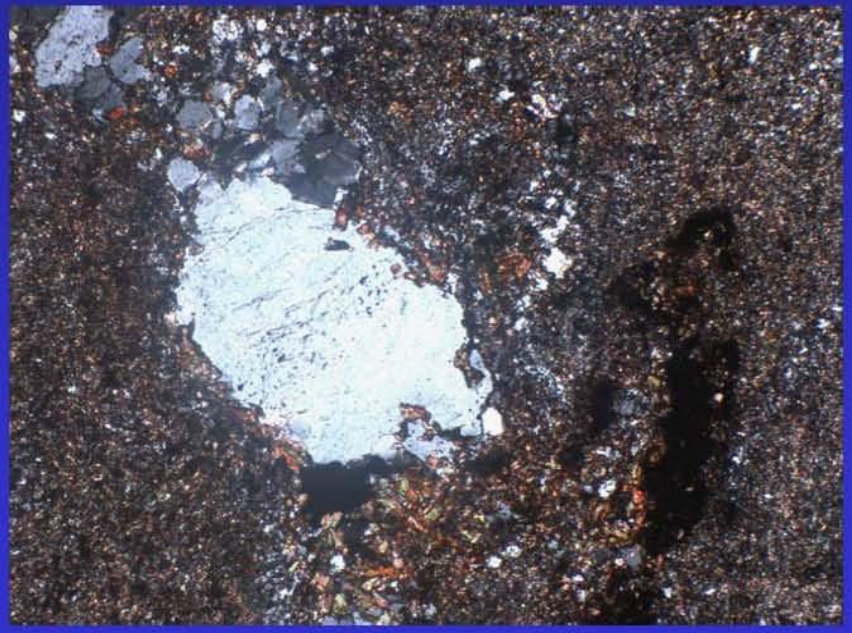
- Veins & related metasomatic envelopes
  - cross cut and overprint D_1-D_4 fabrics
    - and locally associated with reactivation of these structures
  - overlap with hornfels fabrics but are fracture-related
  - developed in low strain, essentially brittle environments
    - attending weak N-S shortening
  - are most strongly developed in psammites & psammopelites of BS_3 reflecting
    - rheology of these relatively feldspathic BS_3 packages
    - interlayered C-rich pelites that partition strain, fracture & fluid flow

Auriferous veins & alteration envelopes



Kspar-Bio alteration & mineralisation

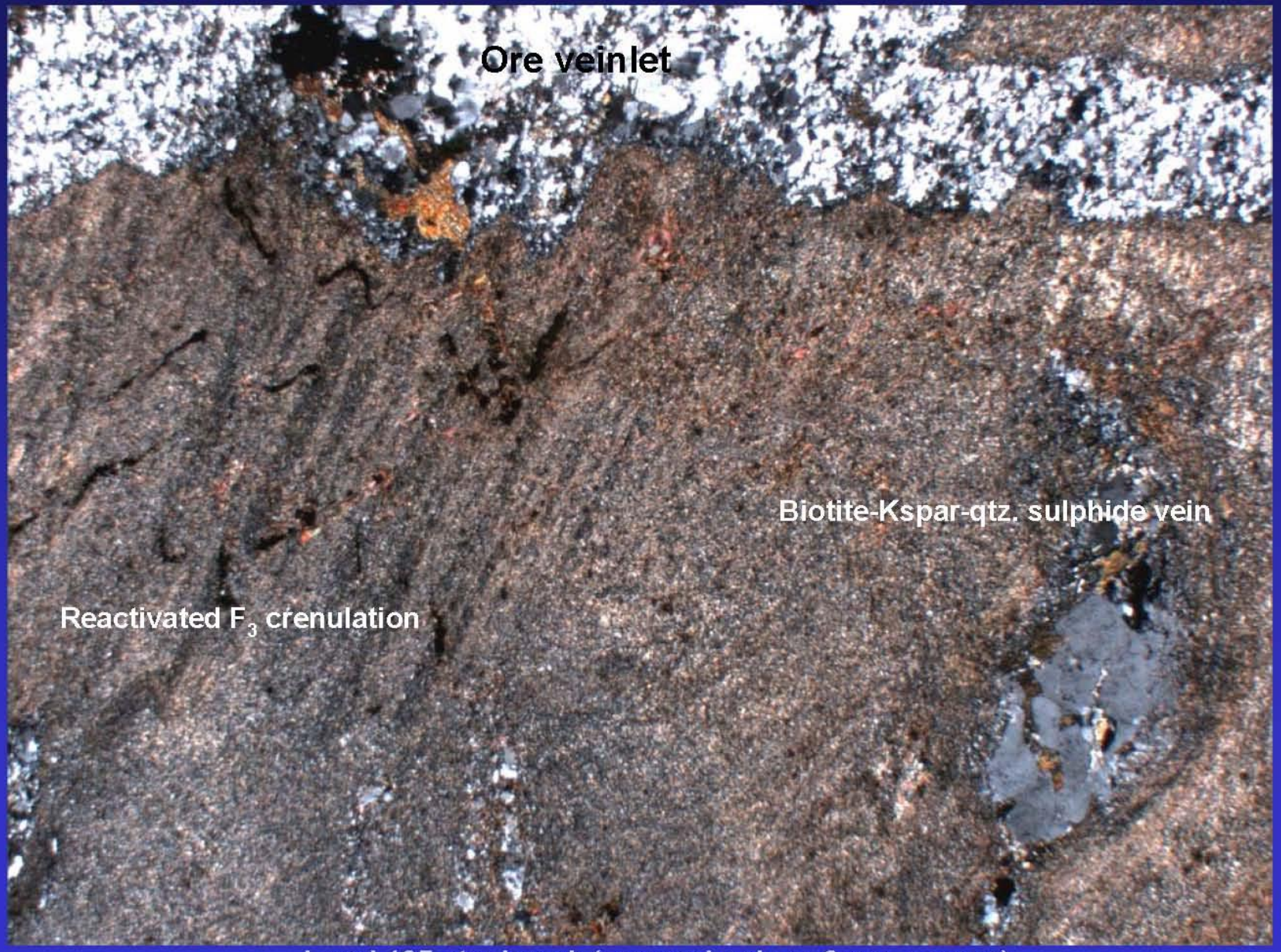
Biotite-Kspar alteration around flat vein overprinted by patchy sericitic alteration



Arsenopyrite bearing, Kspar-biotite alteration (1mm. Across)

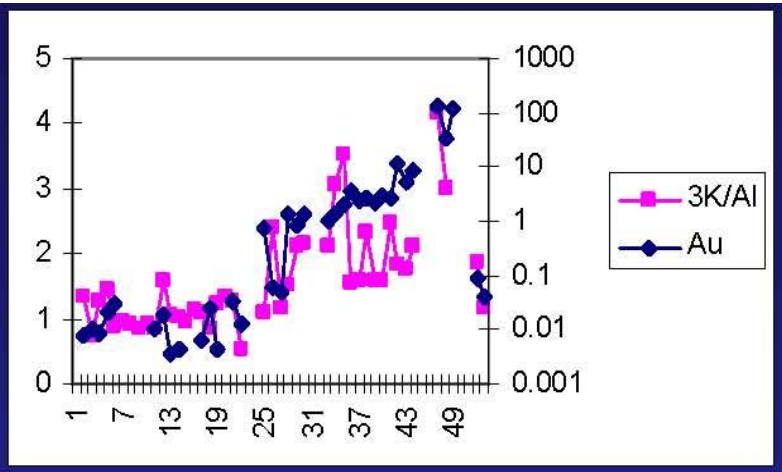
Arsenopyrite bearing, Kspar-quartz vein in Kspar-biotite metasomatite

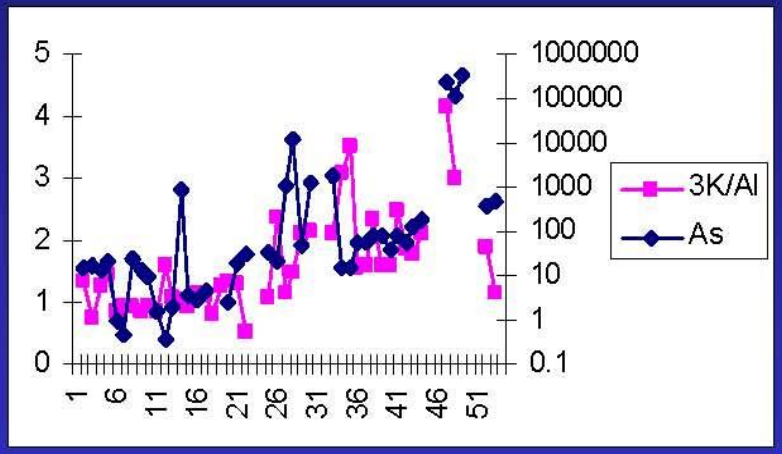
Mineralised veinlets & biotite-Kspar alteration

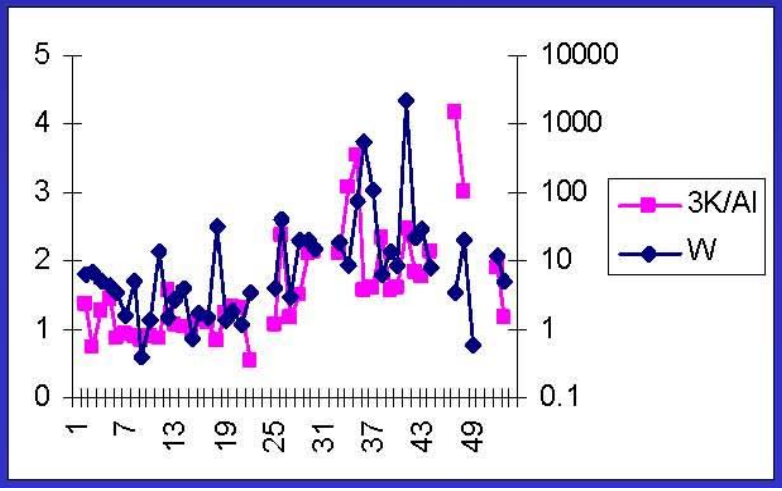


Level 135 stockwork (crossed polars, 3mm. across)

Potassic alteration versus Au, As, W





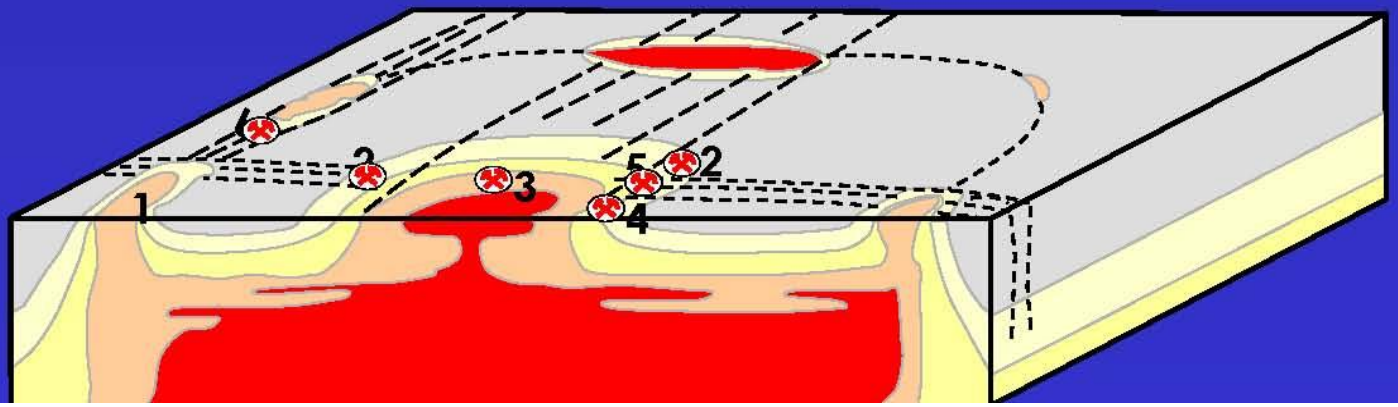


Muruntau: gold mineralisation & alteration

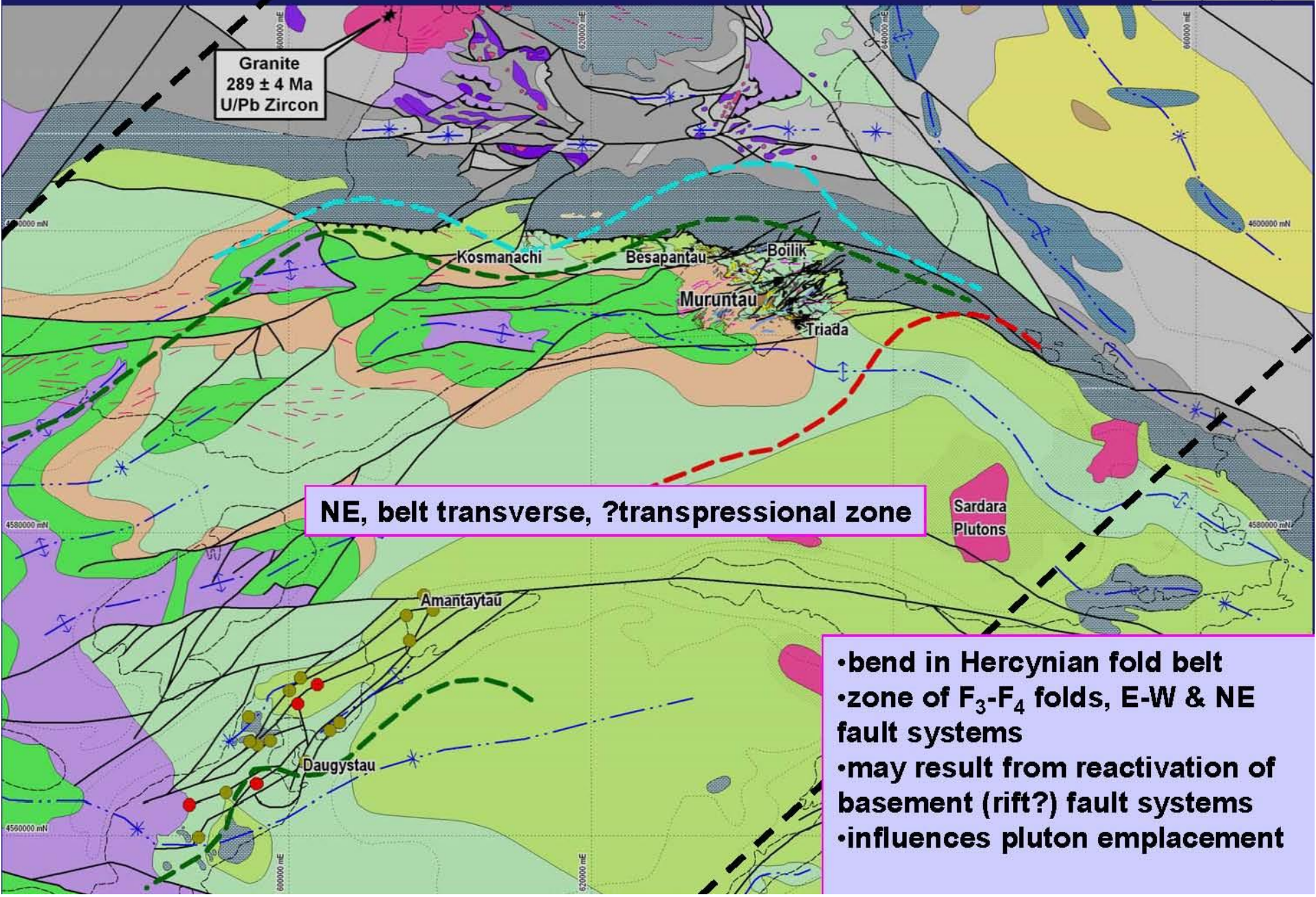
- **Main stage gold mineralisation (>95% Au?)**
  - is accompanied by medium temperature (biotite +/-amphibole stable; 400-450^{0}C), K-feldspar- & sulphide (I: asp+/-po,py))- bearing alteration that
  - overlapping and thermally compatible with medium grade thermal metamorphism
    - same age as underlying pluton
    - Re-Os age on arsenopyrite ~286 Ma., overlaps with hornfels & potassic alteration and pluton dates
  - predates and is locally overprinted by retrograde sericitic & sulphidic(II) alteration
    - mainly related to late faults & fracture systems

Muruntau: key factors (pluton-related)

- in the roof zone thermal aureole of a late orogenic (Hercynian, ~285 Ma.) granitoid pluton
  - above the (E-W) edge of the pluton
- related medium grade thermal metamorphism produced massively textured hornfelses
  - amenable to widespread fracturing attending weak syn-metamorphic (N-S) deformation
- medium temperature, (Au, As, Sb, Mo, W, Bi & S)- enriched, moderately oxidised, ultimately pluton-derived fluids
  - fault & fracture-controlled infiltration into the highly reduced, metasedimentary package

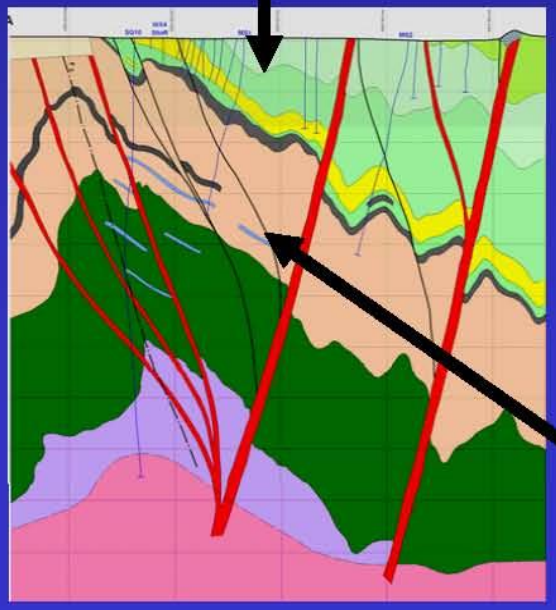


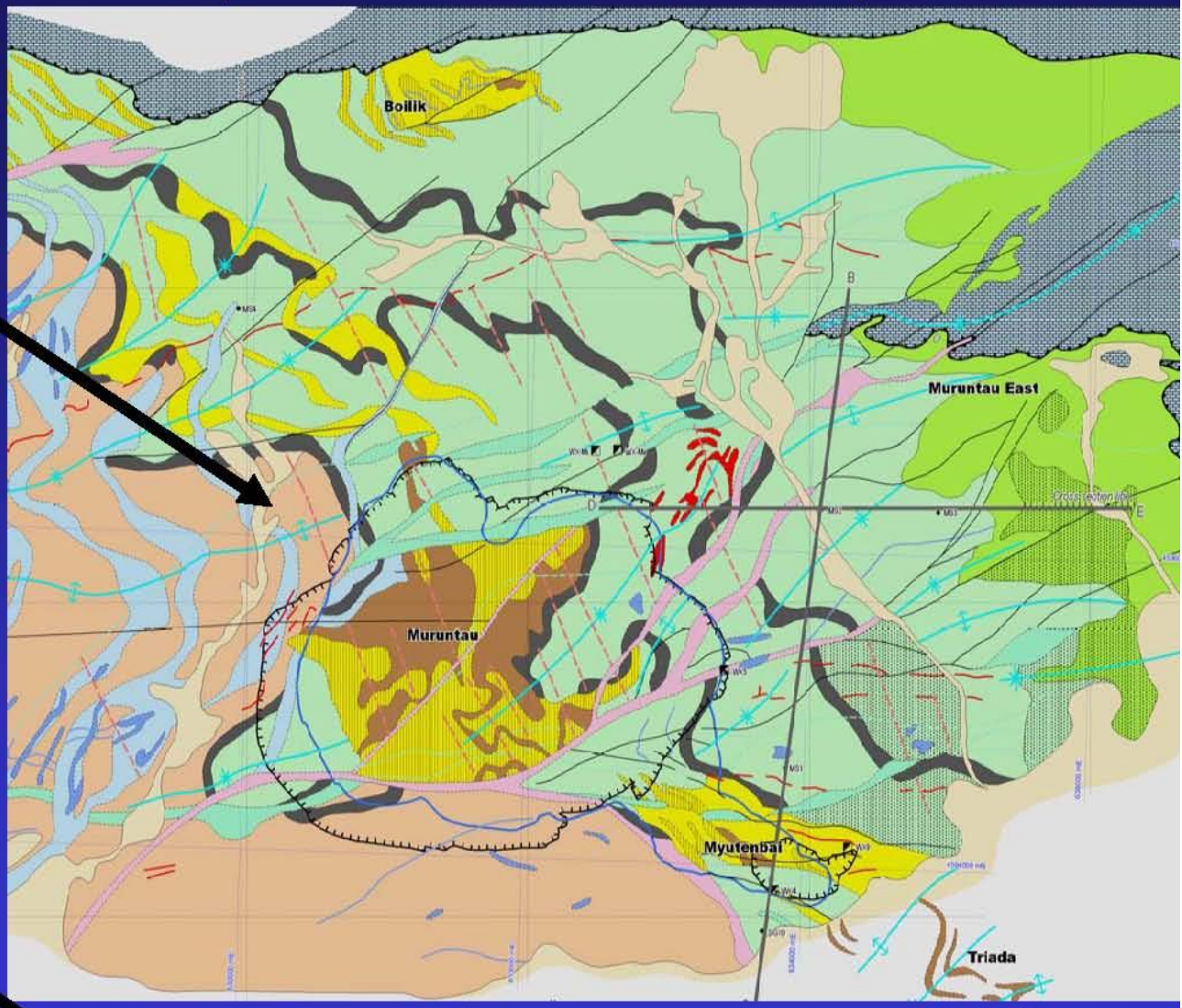
The Muruntau-Daugystau transpressional zone



Muruntau: key factors (structural architecture)

- broad structural culmination from the interference of a D_2 antiformal zone with D_3-D_4 minor folds
  - –shallowly dipping layering & foliation
  - –not a shear zone, but a fold-fault system

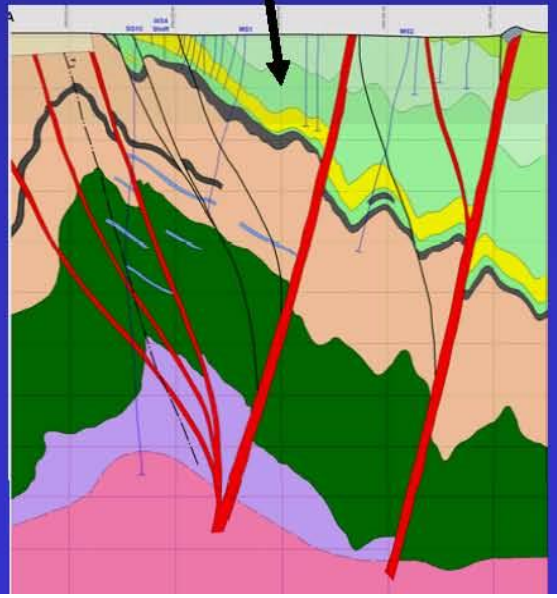


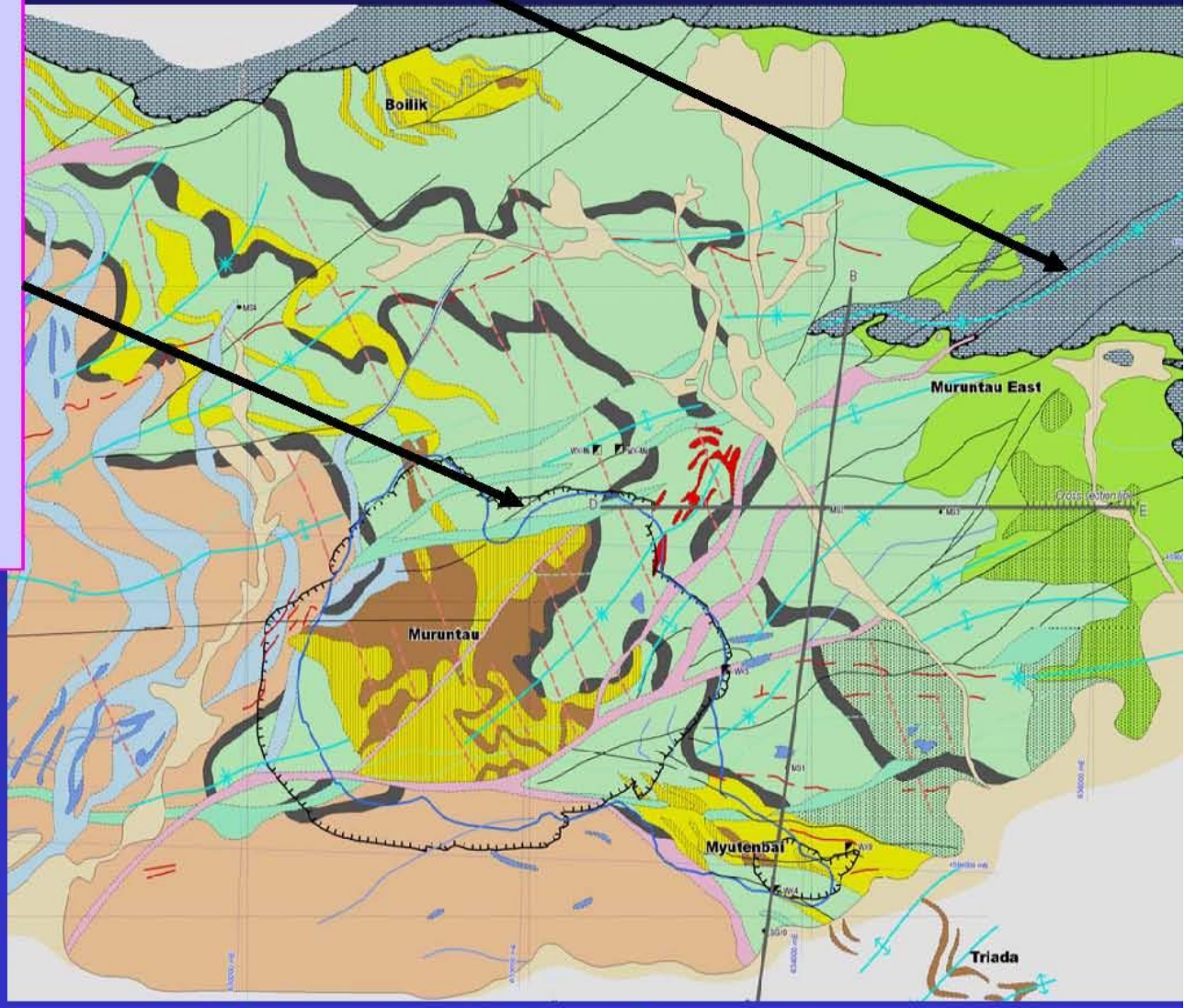


- reactivation of this fold-fault system attending pluton emplacement & crystallisation

district-wide cap/ hydrothermal seal (the carbonate-dominated D-C_1 unit)

- a well layered siliciclastic, metasedimentary package (BS_3) containing
  - –highly carbonaceous pelites (which partition strain, act as local 'screens', and sources of reductant)
  - –interbedded with psammites & psammopelites which focus fracture & veining



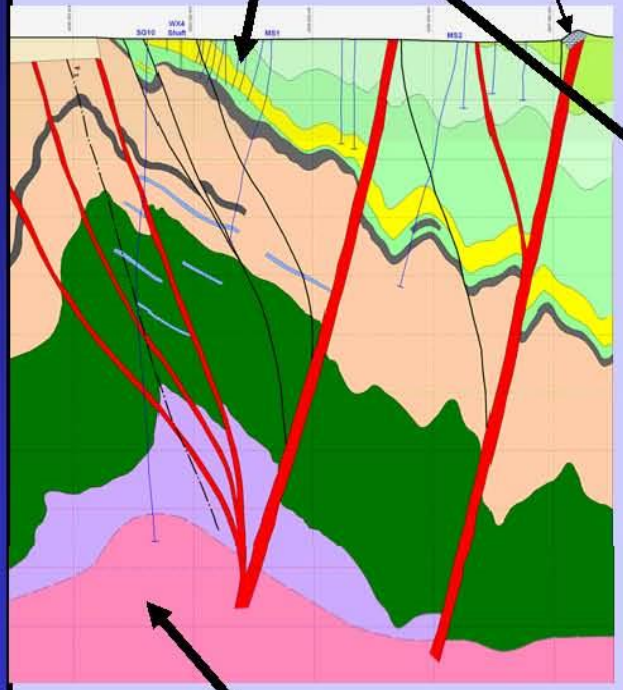


Muruntau: key factors (lithological architecture)

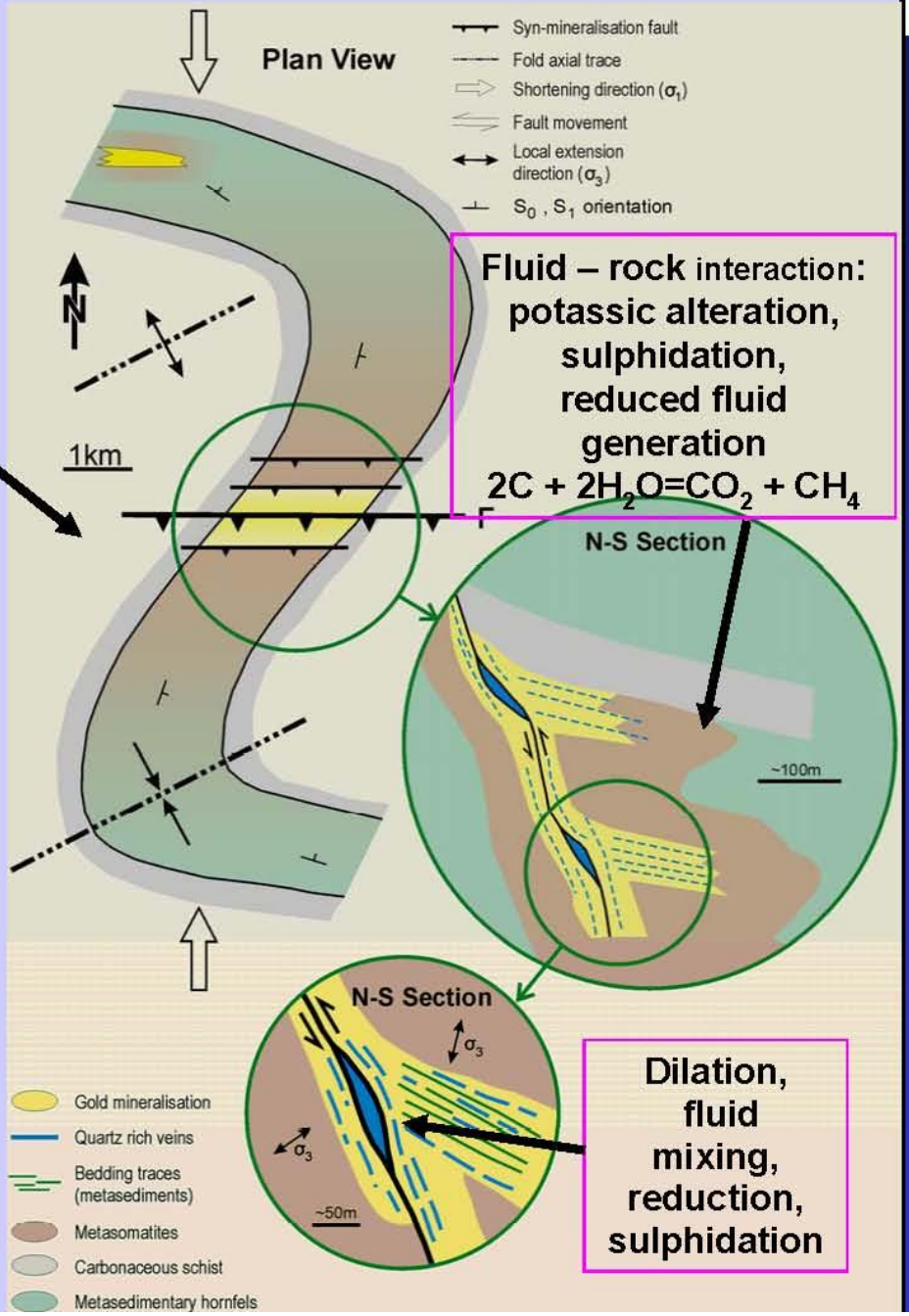
Muruntau: system model

Fluid migration along steep fault- & stratabound fracture systems

Cap

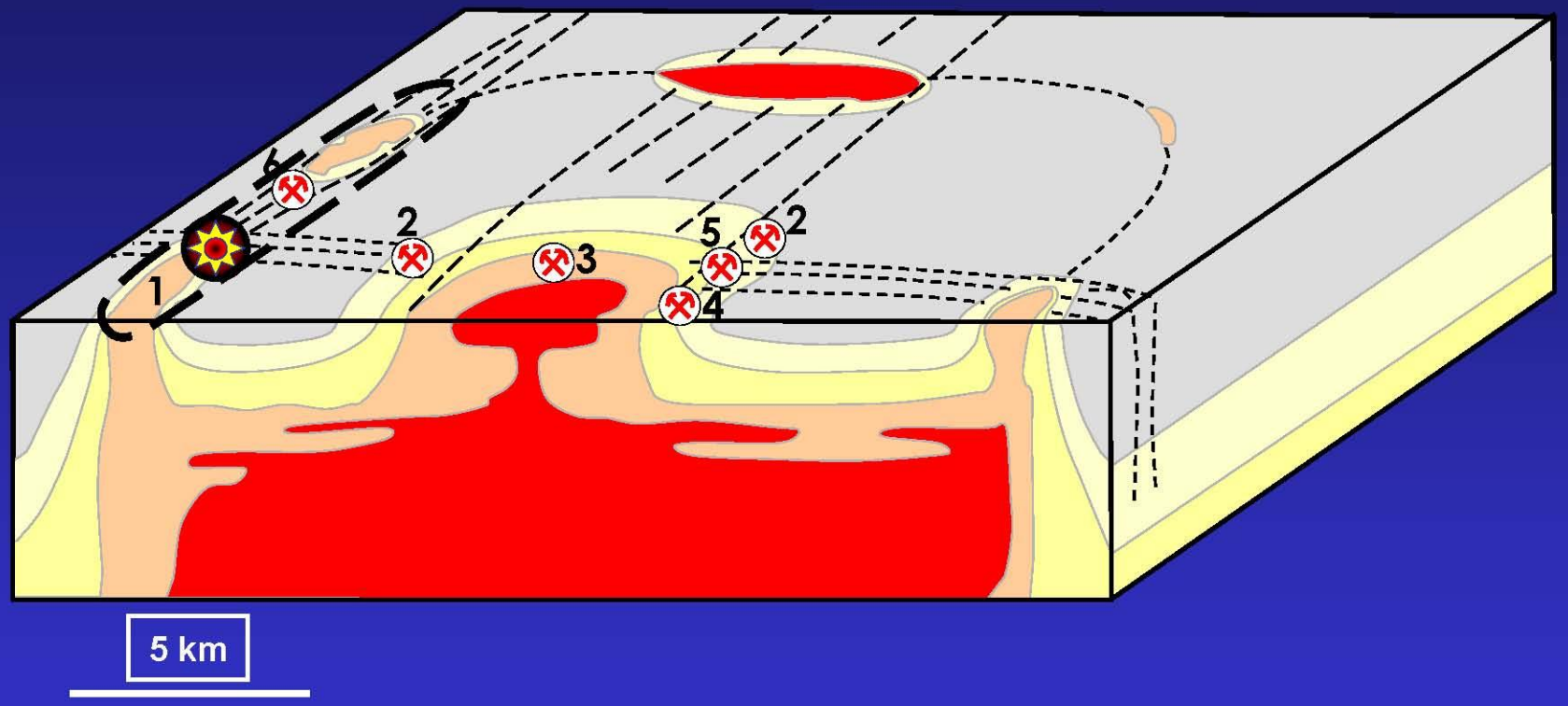


Main fluid source: 280Ma. granitoid pluton



Thermal Aureole Gold (TAG; pluton-related) systems

`Olga oltin marchamat`



Granitoid pluton
Thermal aureole
Country rocks
Key structural zones

GOLD DEPOSIT SETTINGS

1 Fort Knox
2 Sukhoi Log, Kumtor
3 Pogo, Vasilkovskoye
4 Granites-Tanami
5 Morila
6 Obuasi, Telfer, Muruntau