The Muruntau auriferous system

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....for facilitating and contributing to this study

‘olga oltin marchamat’
• World’s biggest gold deposit (outside the Witwatersrand): >100 Moz. @ >2 g/t Au
• Past (~ 53 Moz.) & present production (>2 Moz. 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 deposits hosted in Besopan (BS₃)

- Muruntau & other mineralised systems underlie a district wide D-C₁ carbonate-dominated unit
  - that contains little mineralisation & veining reflecting its role as
  - a regional, low permeability, seal/cap on hydrothermal systems
Muruntau district: lithostratigraphy

• **BS₃**: 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 BS₃ 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 (CH₄-bearing fluids)

• BS₃ or similar packages, key exploration targets
Muruntau: surface geology (1963)

- Carbonaceous units
- Ore zones

1 km. grid
**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

- **$D_2$:** N-S shortening
  - crenulates $S_1$, steep axial surfaces, E-W fold axes
  - mesoscopic to regional folds (eg Dzhanbulak antiform)

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

$F_3$ 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 e.g. Telfer, Sukhoi Log
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.)
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)

<table>
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<tr>
<th>Depth (m)</th>
<th>Facies</th>
<th>Type of Rocks</th>
<th>Metamorphic rocks</th>
<th>Calcic rocks</th>
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<td>Quartz + plagioclase + biotite</td>
<td>Calcite + dolomite + actinolite + quartz</td>
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Muruntau Geological Museum
Bouger gravity, geology & gold deposits

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

3D Muruntau Pit Plan, Au Grades and Geology

- Sulphide-sericite alteration
- Felsic dyke
- Quartz vein
- Metasomites
- Fault/shear zone
- Fault
- Layering trends
- F3 fold
- F4 fold
- Pit outline (2000)
- Sample location

Pit Grade
- 1.0 - 1.5 g/t Au
- 1.5 - 2.0 g/t Au
- 2.0 - 4.0 g/t Au
- 4.0 - 8.0 g/t Au
- >8.0 g/t Au

Data from NGMK
Higher Au grade zones

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

Data from NGMK
Level 315: Au grades & interpreted faults

Post-ore faults (NE)

Ore-related faults (EW)

Data from NGMK

SEG Perth 2004: Muruntau
Muruntau pit: ore zones

'Structural S0' and 'S3'

'Central vein'

'Stockwork'
Level 150: Au grades & pit geology

- Au grades low in C pelites
- High grades mainly in stockwork
- Ore zones cross cut F₃, F₄ 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

- Carbon depletion
- Kspar-biotite – sulphide alteration

MS-3 1494m.

3cm.

Level 140m. Muruntau pit
Kspar-Bio alteration & mineralisation

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

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

Arsenopyrite bearing, Kspar-biotite alteration (1mm. 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°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

- bend in Hercynian fold belt
- zone of F3-F4 folds, E-W & NE fault systems
- may result from reactivation of basement (rift?) fault systems
- influences pluton emplacement
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
a well layered siliciclastic, metasedimentary package (BS₃) containing

- highly carbonaceous pelites (which partition strain, act as local ‘screens’, and sources of reductant)
- interbedded with psammites & psammopelites which focus fracture & veining

district-wide cap/ hydrothermal seal (the carbonate-dominated D-C₁ unit)

Muruntau: key factors (lithological architecture)
Muruntau: system model

Fluid migration along steep fault- & stratabound fracture systems

Main fluid source: 280Ma. granitoid pluton

Fluid – rock interaction: potassic alteration, sulphidation, reduced fluid generation

\[ 2C + 2H_2O = CO_2 + CH_4 \]

Dilation, fluid mixing, reduction, sulphidation

Cap
Thermal Aureole Gold (TAG; pluton-related) systems

Olgar oltin marchamut

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

Legend:
- Granitoid pluton
- Thermal aureole
- Country rocks
- Key structural zones

Scale: 5 km