Southern Urals

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Global comparison of massive sulfides
GEODE

Team:
Edited by Richard Herrington
Key input from Freiburg, Miass NHM and Orleans teams.

3.1 Age and tectonic/structural setting

3.1.1 Age of the VMS district

The Urals can be simply divided into the south, middle and arctic Urals (see Figure 1). Since all the productive VHMS deposits are currently located in the south Urals (with the exception of Safyanovka which may be considered to be on the borders with the middle Urals), this questionnaire has only be completed for the south Urals deposits. It should be noted that deformation and metamorphic grade increases northwards (which includes the middle Urals Tagil Silurian arc sequence) which serves to complicate geological relationships and disrupts deposit continuity so there is some geological logic to this decision!

The south Urals can be further divided in what most authors (concensus at the workshop, summarised by Buschmann and Zaykov) can agree on as three distinctive zones of massive sulphide development. These occur as zones sub-parallel to the Main Uralian Fault (representing the main Palaeozoic subduction suture) and are from west to east:

I – Sakmara Zone (SZ), II – Main Uralian Fault Zone (MUFZ) and III – Mednogorsk Island Arc System (MIAS)

Geochronology

I – Sakmara Zone (SZ)

Mineralogical dates:

K/Ar in sericites

Yaman Kasy: single K-Ar date from hydrothermal sericites 421±3 Ma (Herrington et al. 1998)

Biostratigraphic dates

Blyava: Monograptid dates from host shales Llanvirnian (Silurian)
(Maslov, Herrington et al. 1998 and unpublished data of Little)

II – Main Uralian Fault Zone (MUFZ)

No data known to teams on a deposit scale (work in progress by Freiburg team). Paleaontological work is patchy in this zone and has not been compiled.

III – Mednogorsk Island Arc System (MIAS)

K/Ar in sericites

(summarized by Buslaev & Kaledanov in Prokin et al., 1992, and references therein; with discussion of coherence to model ages of samples and confidence range of isochrons)

Podol(skoye): two isochrons of 360 ± 24 Ma and 328 ± 17 Ma;
remarks: the authors relate the 360 ± 24 Ma to the deposit formation since younger date would appear to be too young biostratigraphically. cf. remarks on the Gai deposit below
Yubilei(noye): 347 ± 20 Ma considered to be an overprint age by the authors

Makan(skoye) ore field: 338 ± 19 Ma considered to be overprinting by the authors

Gai: 376 ± 13 Ma and younger (cf. also Prokin & Buslaev, 1999); Comments: the 376 ± 13 Ma event is considered by authors to relate to ore-formation; later dates too young litho and biostratigraphically. Note: comments by German and UK teams: if these K/Ar data are correct, this age well fits the mean of the 376 Ma Frasnian/Famennian boundary. This also fits the changeover to flysch deposition representing arc-continent docking. It also fits the dates from the exhumed Maksyutov Complex (376.5 Ma) high-pressure rocks which represent exhumed subducted continental crust.

Bakr-Tau: two isochrons at 332 ± 4 Ma and 317 ± 8 Ma, considered by the authors to be overprint ages.

Tubinsk group (Baimak area): 341 ± 1 Ma; again considered to be overprinting based on litho- and biostratigraphic grounds.

Molodyezh(noie): two isochrons at 390 ± 2 Ma and 329 ± 3 Ma; The date of 390 ± 2 Ma fit well the litho- and biostratigraphic constrained Eifelian age of the Karamalytash Formation which hosts the deposit.

Alexandrinka: 301 ± 13 Ma considered to be overprinting

Biostratigraphic dates
Base mainly on conodonts, pioneered by Maslov (Maslov et al., 1993 and Artyushkova & Maslov, 1998, and references therein), the VHMS-hosting Baimak-Buribai Formation, comprises parts serotonin and patulus zones of the International Standard Conodont Scale that correspond to the upper(most) Emsian (ca. 400 - 395 Ma). Using lithostratigraphic comparisons, the VHMS-districts of the Baimak and Buribai districts and that of the Gai and Orsk districts are assigned to the same stage. The VHMS deposits in the Karamalytash Fm. (and its equivalents at Alexandrinka in the east MIAS) are in the costatus, australis, and kockelianus zones of the International Standard Conodont Scale that correspond to the upper part of the Lower Eifelian up to the uppermost Eifelian (ca. 392 - 387.5 Ma). This covers the following deposits: Uzynkyr-Sibay Zone; Sibay; Uchaly-Alexandrinsk Zone; Uchaly, Uzelga, Molodyeznnoe, Alexandrinka. The deposits in the Sakmara Zone (Blyava and Yaman Kasy) are Silurian based on graptolite fauna recovered from Blyava pit and a single sericite date of 412 Ma at Yaman Kasy (Herrington unpublished data).

Lead isotope data of ores
Russian data is summarized by Ershov & Prokin in Prokin et al., 1992; with detailed discussion of models used. Most of this work contains a discussion of lead sources, less relevant to absolute ages of ores. Note, there are many unpublished data produced by the BRGM which we hope to shortly include in this questionnaire. Studies are also ongoing in Freiburg.

Zircon (or monazite) age determinations from host rocks of VMS deposits
No current data although there are studies underway in Ekaterinburg and now Freiburg. New work is planned for 2000/2001.

3.1.2 Current interpretations of the tectonic setting

Initiation of the ‘Urals Palaeocean’ started at ca. 460 ma (O2-3) was marked by sub-alkaline basalts and cherts in its first stage (the epicontinental rifting referred to in Savlieva & Nesbit 1998). The geochemical signature (REE) of these volcanics is interpreted as either MORB or sub-alkaline depending on which paper you read. These rocks may represent peripheral, early phase spreading and these units are still preserved in the foldbelt. The Tagil zone and the now accreted Sakamara zone shows that the first island-arc volcanics were in the Silurian, and associated with these are the first VHMS deposits. Arcs formed in convex form around the Siberian continent ca. 420 Ma and allochthons of the early oceanic sequence became overthrust towards the east. In the Llandoverian, new crust was still forming and on the eastern side of the central Urals foldbelt there are slivers of an Ordo-Silurian sequence east of the much later Magnitogorsk arc sequences. This suggests that the entire Magnitogorsk arc sequence had no underlying crust other than ophiolites of Silurian age.

Caledonian collision between Baltica and Siberia started around 390 Ma. This marks initiation of the
Magnitogorsk island arc which shows first alkaline basalts, then cherts, sandstones, slope facies, axial facies derived from the arc, and associated plutonic rocks. High pressure metamorphism at 376.5 Ma indicated the time when the East European craton was at its deepest within the subduction zone. The arc sequences are seen to collide with the East European Continent diachronously, at around ca. 360 Ma in the southern Urals; later, in the Carboniferous, in the central Urals. This is shown by the development of a flysch basin in the central-south Urals (foreland basin?). Then there is an easterly shift and then apparent switch in polarity of subduction prior to final continent/continent collision.

The Upper Emsian (circa 400 Ma) boninites at the W margin of the MZ record the onset of eastward intra-oceanic subduction, followed by an eastward temporal and spatial progression of several arc-volcanic complexes. The approximately N-S trending complexes are (from W to E): Baimak-Buribai, Irendyk Complex, Karamalytash Complex and Ulutau Complex. Condensed sections of cherts stratigraphically separate or locally represent the arc-volcanic complexes. By approach of the EEP continental margin to the subduction zone, the arc-continent collision commenced. Arc-related VHMS deposits are confined to the Baimak-Buribai and the Karamalytash Complexes. Arc-continent crustal docking is recorded by spreading of Famennian flysch deposits (Zilair Formation; onset circa at 375 Ma) from the arc platform across the MUFZ onto the eastern margin of the Eastern European Plate. The arc-continent collision in the SE Urals resulted in the attachment of a shallow crustal accretionary complex comprising the MUFZ and marginal areas of East European Plate. Allochthonous slices rooted in the MUFZ were intercalated to accretionary slices like the Sakmara Zone which were developed marginal to the East European Plate. Other complexes may be thrusted onto the margin of the East European Plate such as the Krakà nappe. The allochthonous oceanic fragments of the Sakmara Zone contain the Cu-Zn VHMS deposits of the Mednogorsk district. Contemporaneous? oceanic fragments in the MUFZ and elsewhere across the Mednogorsk area display a condensed pelagic chert deposition typical of ‘Oceanic Layer 1’ for aged oceanic crust, which contrasts with the Sakmara Zone which probably represents original spreading of the Uralian ocean (evidence also from the extensive ophiolite hosted chromite deposits at Kempirsai, Kazakhstan). The MUFZ contains several small uneconomic serpentinite-hosted massive sulphides of debatable origins.

The proposed evolving sequence indicates the opening of a small ocean east of the Magnitogorsk arc (against the Kazakh plate?) followed by westwards dipping subduction of this ocean beneath the Magnitogorsk arc, closing in the late Devonian possibly. By Upper Carboniferous times a large flysch basin lay off to the west with the main Urals area covered by an extensive limestone sequence. In the late Permian, a series of granitoids were intruded along the axis of the Urals. Tethyan faunas are recognised by the end of the Permian in places. In Trias times, ‘trap’ volcanism and alkaline dykes are noted with salt domes in western Bashkíria.

3.1.3 Tectonic interpretation

Much of the large scale geotectonic interpretations are based on the mapping of transects and new seismic data from the Europrobe project. Much of the above discussion is based on work of Victor Puchkov and his group from Ufa (see Puchkov 1997), Dennis Brown & collaborators (Brown et al. 1998, Brown & Spadea 1998). The review also calls upon these publications:
Yazeva, R.G. & Bochkarev, V.V. (1998): Geology and Geodynamics of the southern Ural (an attempt of geodynamic mapping). Russian Academy of Sciences, Uralian Departement, Institute of Geology and Geochemistry, Ekaterinburg. 203 p. (in Russian; English summary, table and figure captions)
Zaykov, V.V., Maslennikov, V.V. & Zaikova, E.V. (1993): Volcanism and metalliferous deposits of the Devonian
Deposit-Scale Structural Mapping & Interpretation
This database is considered to be the weakest link of all possibly. The Urals has a published tectonic map at 1:000000 scale (1977). Some of the areas are mapped at better scales 1:200000 and 1:50000 but these need to be compiled. Local information on the deposit scale is good from drill cores (50m x 50m grids although complimentary deposit-scale structural studies have not been carried out. Some attempt to combine volcanic geochemistry, spatial distribution and regional deformation patterns has been undertaken by Yazeva & Bochkarev (1998).

Gravity and/or magnetic data
Gravity and magnetic maps are produced at 1:50000 and 1:20000 scale and are largely in the hands of the mining companies and need to be acquired/reviewed.

Seismic sections
URSEIS, R114 & R115 deep seismic profiles cross the accretionary complex into the arc and show the structure in cross section.

Chemistry of volcanic rocks
Most earlier Russian publications contain analyses of major elements and a few trace elements (wet chemistry and XRF). Not many studies analysed for discriminator elements and practically no petrogenetic isotopic indicator studies have been done Yazeva & Bochkarev (1998). Good modern studies are underway with published data in papers from Spadea’s group in particular see Spadea et al. (1998) and Brown & Spadea (1999). There is a recognisable real need to compile this data!

Geochemical-tectonic classification
Largely based on major (therefore often mobile) elements (e.g. Seravkin et al., 1992).

3.1.4 Comprehensive and high quality database of volcanic geochemistry to assist with tectonic interpretation

Number of whole-rock/trace analyses of least-altered rocks / Type and quality of trace element data / Available isotope data?

There are many older Russian analyses of variable quality and methodologies. Mostly this is by emission spectroscopy which is not of a suitable quality. Some studies are by atomic absorption and neutron-activation methods (Surin in the east Magnitogorsk arc and Seravkin in the Sakamara Zone). Data for the granitoids is much better (see for example Fershtater et al. 1997) and also for metalliferous sediments (Maslenikov). Some new data on the arc rocks of magnitogorsk is emerging (Gorozhanina 1991). Again this area needs developing!

The Freiburg group has ca. 90 XRF and ICP-MS analyses of least altered volcanic rocks from the S Urals (MIAS: Molodyezhnoye, Baimaik area, Buribai area, cores from Alexandrinka ore field; MUFZ: Ishkinino area; Mednogorsk district: Blyava open pit). The majors are by XRF (mixed quality). Higher quality ICP-MS data were made by ACME (Canada). This data is currently being compiled.

The NHM group has analysed ca. 30 rocks from the Sakamara zone (Yaman Kasy) by wet-chem ICP-AES, ICP-MS (REE). This data is being submitted for a paper currently. There is also additional data from the Magnitogorsk arc (around 10 unpublished analyses). Whole rock and mineral Sr-isotope, Sm-Nd analyses are contemplated.

There are a few Sm-Nd and Sr data in Ronkin et al. (1989), Pb isotopes, much improved, by Tesalina et al. (1998).

3.1.5 District scale and deposit scale ore-fluid plumbing structures

Identification
Earlier attempts at this were made by Prokin (1977). Baranov has studied the East Magnitogorsk Island
Arc based on extensive core logging. It is not known whether this is published. Maslennikov has worked on the regional ore-fluid plumbing structures in the Buribai area by mapping and sedimentological analysis. This was confidential work for a local mining company.

### 3.1.6 Detailed structural studies of deposits

There are a few controversial studies suggesting linear alignments of deposits in the Uchaly, Uzelga and Molodyezhnnoe region (see Zaykov et al. 1993). The Makan and Barsuchy Log deposits are interpreted to having formed around a caldera (Seravkin 1986). An orthogonal grid for the arrangement of the deposits in the Alexandrinka region is suggested, relating to major basement controlling structures (Tesalina et al. 1999).

### 3.1.7 Further research needed to improve tectonic interpretation

- sound and detailed stratigraphy (high resolution dating)
- develop comprehensive analytical database of volcanic and sedimentary facies related to mineralisation (discriminant elements currently missing!).
- geotectonic parameters of ores (lead isotopes, Re-Os etc.)
- architecture of volcanic and sedimentological sub-basins, particularly further data of constraining water depth (fluid inclusions)
- related studies of stratigraphically under-/overlying units and their lateral development, including VHMS-barren levels
- detailed facies analyses of host edifices, particularly nature of host structures (extensional?)
- determine composition and role of subvolcanic plagiogranites, establish relationships between extrusive and intrusive suites

### 3.1.8 Key references


Yazeva, R.G. & Bochkarev, V.V. (1998): Geology and Geodynamics of the southern Urals (an attempt of geodynamic mapping). Russian Academy of Sciences, Ural Branch, Institute of Geology and Geochemistry, Ekaterinburg. 203 p. (in Russian; English summary, table and figure captions)

Trace elements in minerals and rocks of the Urals/ Sverdlovsk:Uralian Science Centre of Academy SSSR, 1980 (scientific collection in Russian)
Microelements in magmatic, metamorphic and ores formation of the Urals, Ufa: Bashkirian Science Center of Academy SSSR, 1991 (in Russian).

3.2 Volcanic architecture

3.2.1 Scales geological maps district deposits

The usual mapped scale is at 1:50,000; there are maps at smaller scale for key features. Maps at 1:50000 and 1:25000 have been completed for most districts and at a scale of 1:10000, 1:5000, 1:2000 for the VHMS deposits. A comprehensive systematic stratigraphy has been established for the ore districts but there are some discussions on their ages!

Comprehensive systematic stratigraphy
Fundamentals are established in the belt with the best coverage in the MIAS. Very little control in the MUFZ. Cross referencing to published maps very difficult.

3.2.2 Relation of VMS deposits to volcanic facies

This has not been systematically studied and only two workers have published anything on this: Seravkin and Maslennikov. Both these workers imply caldera models, Maslennikov’s sedimentological studies would appear to have the potential to bear more fruit.

Ratios of volcanoclastics versus flows
Perceived ratios of volcanoclastic rocks versus coherent lava flows in the deposit areas is <1:10 (Maslennikov), supported by the unpublished views of many of the SGA fieldtrip attendees! Some deposits are black shale-hosted (e.g.Amurskoe) or in flyschoid sediments associated with ophiolites (e.g. Mauk). The largest VHMS deposits are localised at two or three stratigraphic levels in the same region (e.g.Gai, Uzelga, Sibay, Makan, Yubileynoye). In the southern mostUrals, the roofs of plagiogranite intrusions have been drilled below of the VHMS deposits (e.g. Makan (Oktyabrskoe), Tash-Tau and Podolskoe). There are abundant xenoliths of the plagiogranites in the host volcanic flows and reworked granitoid clasts inherited into flow breccias.

Occurrence at single stratigraphic position
In the MIAS region, see section 1.1
In the MUFZ, the precise stratigraphic position of the sulphide bodies is unknown therefore this is impossible to decide.

In the SZ, there are only preliminary data, suggesting a Silurian age (Little et al. 1997) which contradicts the assumptions of several lithostratigraphers, but nor ored deposit geologists in the region.

3.2.3 Composition of the VMS host package

West MIAS: andesites-felsics
East MIAS: felsics-basalts
MUFZ: serpentinites (ultramafics) and basalts
SZ.: andesites-felsics
Change in volcanic composition at or close to the ore position
Often distinct changes at the ore horizon. Rhyolitic domes present in many deposits. This has not been
adequately compiled yet.

3.2.4 Interpreted range of water depth during deposition of the volcanic succession and immediate host rocks

There is a lot of contradiction in the Russian literature. This reflects a general lack of systematic, reliable
analysis of volcanic, sedimentological, and paleontological facies. For example, many have interpreted
the shallow water conditions for VHMS formation due to presence of tuffs, conglomerate and ignimbrite facies; red-rock alteration of coherent lava flows and the occurrence of limestone reefs (Greshner et al. 1976). However, this may be incorrect interpretation (is likely to be) since others (Koroteev et all, 1986, Maslennikov, 1999) disagree. There is very little fluid inclusion evidence (Herrington et al. 1997, Tesalina et al. 1999) which suggest deep water (>1 km) conditions.

• Criteria to estimate water depth

West MIAS: lack of carbonate sediments

East MIAS: reworked fossiliferous carbonates in volcanic sequence above ore body of Molodyezhnoe, Uzelga. At Uzelga, upper orebody immediately capped by fossiliferous limestone; Fossils ‘normal’ for sequence (e.g. Trilobites). Maslennikov points to non-reefal carbonates at level of VHMS.

MUFZ: associated sediments display features of pelagic sediments (either radiolaritic cherts/shales or sandstones with abundant radiolarians and sponge spicules)

SZ: Fluid inclusions from Yaman Kasy indicate non-boiling fluid, 350°C, at least 1km water depth (Herrington et al. 1998). Radiolarian cherts in mineralized package (Little et al. 1998).

3.2.5 Further research needed to define relationships between ore formation and volcanic architecture?

Systematic modern facies analyses in association with petrological studies of volcanic rocks. Further data is needed to confirm the emerging view that the deposits and their volcanic facies formed deep.

3.2.6 Key references

In addition to those in 3.2.3:


3.3 Styles of ore deposits
### 3.3.1 VHMS deposits

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<th>Zn%</th>
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<th>Au (g/t)</th>
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</table>

More than 90 VHMS deposits of less than 1 million tonnes are known in the district.

### 3.3.2 Degree of metamorphism, deformation, recrystallization in the ores.

Prokin et al. (1988) subdivided the Ural-type deposits into five relevant categories:
- undeformed and slightly deformed deposits (e.g. in East MAS Uzelga region and in SZ Komsomol'skoye)
- deformed deposits hosted by massive rocks (e.g. in West MIAS Makan ore field and Gai, in East MIAS at Sibai, Molodyezhnoye, and Uchaly)
- deposits that were deformed in zones of cleavage (shear zones?)
- deposits that were deformed in zones of cleavage with redistribution of elements
- metamorphosed deposits

The observation is that regional metamorphism does not vary significantly in the MIAS, MUFZ or SZ ore districts. However, deformation does. It is clear many deposits have significant overprinting by deformation (for example there is an almost ubiquitous 330-290 Ma event in cross-cutting structures (related to a later granitoid event). A subvolcanic overprint is invoked to account for the polymetallic nature of the Baimak-type deposits (Salikhov et al., 1997). Others consider these to be related to the granitoid bodies (Prokin 1999).

**Varying from deposit to deposit in the district?**

This is likely, certainly true in the Uchaly-Uzelga-Molodyezhnoe district. Many deposits show isolated overprinting events in parts of the deposits.

### 3.3.3 VMS deposit types

Cu-Zn types of deposits predominate in rhyolite-basalt assemblages in the Urals (see Prokin & Buslaev for this list referred to as ‘Urals-type’ deposits.

Cu type is typical for basalt-only sequences (Letnee, Ivanovskoe, Dergamish, Jarly-Asha).

There are (Fe) Pyrite-only deposits at Andreevskoe, Kul-Yurt-Tau and Gaiskoe no 3 orebody.

The Urals deposits are generally low in Pb (Usually < 1%), but those containing lead can be can be subdivided as follows:

1) Cu deposits (Cu ratio >60): Shemur (64), Chernushinskoe (70), Krasnogvardeyskoe (75), Tash-Tau (76)
2) Zn-Cu deposits (Cu ratio <60): Tarnyer (25), Noviy Shemur (44), Mauk (54), Blyava (57), Yaman-Kasy (32).
3) Py deposits (Cu<0.6 weight%, Zn<0.78 weight%, Zn<0.78, Pb<0.3 weight%, Zn<0.78): Ayvinskoe, Akkyrpyskoe, Andreevskoe, Aramilmskoe, Balaminskoe, Barninskoe, Beltovoe, Vostochnoe, Znamenskoe, Zyzelskoe, Klyuchevskoe, Knaly-Kul'skoe, Kolchedannoe, Kul-Yurt-Tau, Kultimskoe, Lomovskoe, Novo-Ayvinskoe, Pysavevoskoe, Semenovskoe, Starolevinskoe, Pyuminskoe, Yuzhniy Kaban, >lukskoe, Yaborovskoe, Yasvinskoe

66
4) Ba-Zn (Cu < 0.6; Zn>0.78, Ba > 0.23) Balta-Tau (massive sphalerite and massive barite) (Ovchinnikov, Lutkov, 1983)
5) Ba (Ba>0.23, Cu < 0.6, Zn <0.78, Pb < 0.3): Vozdvizhinskoe, Murtazinskoe
6) Pb-Zn (Amurskoe)

3.3.4 Are stringer zones present or economic? What is their mineralogy? Are there any deposits that comprise only stringer sulfides?

There are stringer zones in many deposits. In some deposits they are of economic significance. They were exploited at Uchaly and are a major ore-type at Bakr-Tau and Alexandrinko deposits. There are no stringer zones in some of the deposits (e.g. Letnee and Zimnee). The mineral composition of the footwall veins: pyrite, chalcopyrite, sphalerite, tennantite, Barite, quartz, hessite, gold, galena. In literature (Tzherkasov in Maslov et al., 1993), stringer zone VMS occurrences are mentioned for stratigraphic levels that probably correlate with the Ulutau Formation.

3.3.5 What are the major textures in the massive sulfides – massive featureless, banded, brecciated? Are these textures interpreted to be primary or deformation-related. Key evidence?

The VHMS deposits can be subdivided by the predominance of massive, banded and brecciated textures
1) Massive with minor brecciation (compact) – Ozernoe, Uzelga, Molodezhnoe, Uchaly, Ivanovskoe, Sibay, Yaman-Kas, Blyava, Noviy Macan. In this type of VHMS deposits well preserved colloform textures are widespread.
2) Strongly brecciated and banded (Oktyabrskoe, Alexandrinkoe, Bakr-Tau, Balta-Tau, III Internacionala, Saphyanovskoe, Dzhusa)
3) Banded (Mauk, Amurskoe, Zimnee)


Some of the banded textures have been interpreted as metamorphic (Phenishniy, 1984)

3.3.6 Did most deposits form on the seafloor or by replacement below the seafloor or a combination of both? Key evidence? If sub-seafloor, how far below the seafloor? Evidence?

The most of the VHMS deposits form on the seafloor. The evidence is clastic sulphide facial range and rhythms. Deposits in the MIAS, and SZ (Sibay and Yaman Kasy respectively), clearly formed on the seafloor (vent faunas). Further deposits have described vent faunas also supporting a seafloor position. A few stratiform bodies were formed by seafloor replacement of sediments on the flanks of the mounds (Alexandrinskoe, Oktyabrskoe) and fauna (Sibay, Yaman-Kas, Safyanovka), largely during zone refinement on the seafloor. Evidence of metasomatic ores are the presence xenoliths in hanging wall lava flows.

3.7 Formation on the seafloor or replacement below the seafloor or combination of both?

- Key evidence
Includes (i) hydrothermal vent community fossils and/or chimney fragments (your data); (ii) lateral intercalations of reworked ores and pelagic sediments; (iii) reworking of the top of the ore body by volcanic cover rocks, (iv) covering of the baritic hanging wall by volcanic rocks;

West MIAS: Tash-Tau (i and iii); Sibay (i and ii) East MIAS: Molodyezhnoye (iii+iv), Uchaly (iii), Alexandrinka (i and iv), Safyanovka (i)
MUFZ: not known
III: Yaman-Kasy (i and ii)
Seafloor VHMS deposits formed as mounds and clastic sulphides (Zhabin et all, 1974; Maslennikov, 1991; Zaykov, 1991, Zaykov, Maslennikov, 1986, Maslennikov, Zaykov, 1991). Fragments of the structures of chimneys have been found in various deposits (Maslennikov, 1991, Herrington et all, 1998). It should be noted that a brine pool model was put forward by Scripchenko (1972).

### 3.3.8 Key references (incomplete)


for part of Baimak area:


Zaykov et al. 1993 (Yaman Kasy)

### 3.4 Exhalites

#### 3.4.1 Are they at the same stratigraphic level?

There are hematite and quartz “exhalites” in many place of the Urals, often associated with Mn- deposits. The usual position for these exhalites is the boundary between basalts and andesites in footwall rocks and shales and cherts in hanging wall to stratiform Mn deposits. Zaykova, 1991 Zaykov 1991 and Maslennikov, 1991 use Si/Al and (Mn+Fe)/Ti ratios to assess the exhalative component in the hematite-quartz horizons. Seafloor alteration of basalts has been suggested as the main mechanism for the formation of the hematite-quartz horizons (Purkin and Denisova 1986). Newer models of near-vent seafloor alteration of hyaloclastites and/or distill halmyrolysis of carbonate-hyaloclastites and sulphide-hyaloclastites admixtures has been proposed for formation of some of these horizons (Telenkov, Maslennikov, 1995, Maslennikov, 1999) with the observation of bacterial activity (Telenkov, Maslennikov, 1995).

In the hanging wall of some deposits there are black shales with abundant pyritic layers (Blyava-SZ; Uchaly and Talgan -East MIAS; Buribay-West MIAS VHMS deposits). The Amurskoe deposits are entirely hosted within black shales. Limestones occur in the handing wall of Talganskoe, Uzelginskoe and XIX Parts’ezda deposits (East MIAS).

#### 3.4.2 Are they developed at other levels?

Exhalites are developed above and peripheral to sulphides (e.g. gossanites in Molodeznoe, Talganskoe, Sibay, Yaman-Kasy, Letnee, Zimnee) or in foot wall and handing wall Units (jasperites in basalts and Mn – deposits)

#### 3.4.3 Can the exhalaties be followed along strike?

The gossanites can be mapped along strike for 200 – 500 m (Uzelga, Talganskoe, Molodezhnoe) to more than 1 km (Zimnee, Mauk). Gossanites can be distinguished from jasperites on the grounds of textural, structural and geochemical features.
3.4.4 Is there a geochemical database?


3.4.5 Key references


3.5 Alteration facies

3.5.1 Have assemblages been identified?

This has been done but there is no clear differentiation between seafloor processes, diagenesis, hydrothermal alteration or metamorphism. Thus the best use of the data is as facies associations of minerals.

Mineral assemblages in altered rocks and ores on VHMS deposits in the Urals (Rusinov et all in Mednocolchedannie, 1992)

<table>
<thead>
<tr>
<th>Metamorphic facies</th>
<th>Grade of metamorphism</th>
<th>VHMS deposit s example</th>
<th>Typical ore minerals</th>
<th>Typical minerals of alteration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prenite-pumpelliite</td>
<td>Prenite</td>
<td>Low</td>
<td>Dy+Ms+Cr+Bo+Sf</td>
<td>Q+Chl+Gm+Py+Se (1M)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>High</td>
<td>Dy+Po+Cr+St+Mt+Sd</td>
<td>Q+Chl+Py+Se (1M+2M2)</td>
</tr>
<tr>
<td>Pumpeilliit-actinolite</td>
<td>Low</td>
<td>Uchaly</td>
<td>Dy+Cr+Sf+Tt</td>
<td>Q+Chl+Py+Se (2M2)+Tur+Aks+Fuk</td>
</tr>
<tr>
<td>High</td>
<td>Gaiskoe, Kaban</td>
<td>Dy+Cr+Sf</td>
<td>Q+Chl+Py+Se (2M2)+Gipsus (anhydrite)</td>
<td></td>
</tr>
<tr>
<td>Green schists</td>
<td>Epidote-chlorite</td>
<td>Levicha</td>
<td>Dy+Cr+St+Tt</td>
<td>Q+Chl+Py+Se (2M2)+Gipsus (anhydrite)</td>
</tr>
<tr>
<td>Epidote-amphibolite</td>
<td>-</td>
<td>Mauk</td>
<td>Dy+Po+Mt+Cr+St+Cu+Val</td>
<td>amf+Bi+Gar+Mica(2M2)+Mt+Oligoclas</td>
</tr>
</tbody>
</table>

3.5.1 What (if any) is the immediate footwall alteration mineralogy and zonation? Is the footwall alteration more commonly in stratabound zones or as pipes? What is the depth extent and surface area relative to the deposit?

There is little hard evidence published for the deposits themselves. There are generalised reviews in Prokin & Buslavev (1998) which suggest the large Cu-Zn deposits have generally pipe-like alteration cores. The core is sericite-quartz-pyrite directly under the massive lenses passing to chlorite-sericite-quartz plus pyrite (+ carbonate). Only weak alteration is noted into the hanging wall of deposits (epidote, hematite, barite, sericite). There are distinct metal zonations around the deposits (see Baranov 1987) with hanging wall enrichments of Pb, Hg, Ba and Hg. Pyrite is geochemically anomalous in the alteration zones, particularly w.r.t. Zn, Cu, Ag and Co. Alteration and geochemical haloes have been compared to Caledonide deposits in Scandinavia.
3.5.3 What (if any) is the extent and mineralogy of hangingwall alteration? Give morphology, dimensions and mineral zonation.

The hangingwall alteration is often marked by hematite, chlorite, illite and epidote, pumpelliite, and prehnite, zeolite,. More rarely pyrophyllite and sericite.

3.5.4 What particular alteration indices (vectors to ore) have been tested or proposed?

Simple use of degree of hydrothermal alteration which ususally means sericitisation.
The seafloor alteration style around the sulphide deposits (hematitisation, silicification, baritisation) (Maslennikov, Zaykov, 1991).
Presence of epigenetic veins with sulphides and sulphosalts; hanging-wall hematitisation.

3.5.5 Has a single database of alteration geochemistry been compiled for the district? (number of samples?). By whom? and is it available?

No.

3.5.6 Is there a database of whole rock oxygen isotopes? (number of samples?) Is data available on H or C isotopes?

No.

3.5.7 Have deep semi-conformable alteration zones been identified? What is their dimension, mineralogy, and chemical characteristics? Is there evidence for metal depletion?

Semi-conformable alteration has been described at Sibai. Carbonate may form regional haloes to some of the deposits judging by published sections (e.g. Safyanovka).

3.5.8 Is alteration geochemistry used to assist exploration in the district?

Simply the use of sulphur and barite geochemistry in volcanic rocks.

3.5.9 List key references


3.6 Hydrothermal geochemistry

3.6.1 Are there systematic published studies on the mineralogy, mineral paragenesis and mineral chemistry of the ores and altered host rocks. Which deposits?
The Urals deposits are favorable to study diversity of hydrothermal altered rocks. There are systematic published data on mineralogy for many big deposits (Sibay, Gaiskoe, Molodezhnoe, Uchaly, Uzelga et al.)

3.6.2 Are the temperature, salinity and chemistry of the ore fluid well constrained from deposit data? What is the quality of primary fluid inclusion data?

Decrepitation temperatures in sulphide and homogenisation data on quartz data is published (Mednocolchrdanie, 1992). The only known modern fluid inclusion studies are Bailly et al. (1999), Herrington et al. (1998).

3.6.3 Is there any evidence for fluid boiling, give details?

Baranov (1987) suggests there is (ref in previous section). Not seen at Alexandrinka or Yaman Kasy (see refs below)

3.6.4 What hydrothermal thermodynamic modelling has been attempted? What modelling software was used (if any)?

There are some preliminary thermodynamic interpretations. For example, Moloshag et al, 1997 has estimated the PT of orebody formation using mineral geothermometers

3.6.5 What additional information is required to develop robust geochemical models?

More data! Fluid inclusion data particularly.

3.6.6 List key references

Mednokolchedanie…, 1988, 1992
Moloshag, Gulyaeva, Grabezhev, 1997, Sulphide geothermometry of ore metasomatic system of the Urals // The metallogeny of the ancient and modern oceans.

3.7 Source of fluids, sulfur and metals

In Russian literature detailed studies of several deposits and reconnaissance studies (e.g. Prokin & Buslaev, 1999) published.

3.7.1 How extensive is the S isotope database on ores, sulphates and host rocks (numbers of analyses)? What is the range of δ34S? Do the massive sulphides and stringer zones have the same mean value and range? What is the interpreted source(s) of sulphur?

There are a lot of isotopic data for Uralian type of the deposit, but a few data for Baymak (kuroko type) and Cyprus type: Yaman-Kasy, Podolskoe, Uzelga, Severnoe, Andreevskoe, Ozernoe, Severo- Karpushinskoe, Gayskoe, Vishnevskoe, Levinga XI, Mauk, III International, Galkinskoe, Kaban-III, Blyava, Bakr-Uzyak, Yubileynoe, Deptyarshoe, Molodezhnoe, Macan, Priorskoe, XIX parts'ezda, Sybayskoe, Belorechenskoe, p'yanko-Lomovskoe, Kaban , Krasnogvardeyskoe, Uchaly, Chernushinskoe, Neyvo-Shaytanske, Tarn'erskoe, Valentorskoe et al.
The average of $bS34$ is 2.4 from 5 to 5 common but sometimes more dispersed in layered sulphides. The deposits with a $b34S$ from +5 to –18%o are Zyuzelskoe and Leviha XIV. There are no systematic comparison of massive sulphides and stringer zone.

There is an ongoing modern study (B.Spiro, A. Lein, Maslennikov V). Recent investigation of sulphur isotope in supergene zone shows isotope fractionation by bacterial reduction from 2.5 in primary sulphides to –18 in secondary ones.

3.7.2 How extensive is the Pb isotope database on ores and host rocks (number of analyses and range of $206/204Pb$ and $207/204Pb$ ratios on ores?). What is the interpreted source of metals?

The first data were published in 1960 (Vinogradov et al., 1960). They showed a common, single source for Pb source and same evolution of the Pb isotopic composition in the Urals and Altai regions. A review of the diversity of Pb isotope composition of the Urals VHMS deposits (Ershov, Nayritdinov, 1985) which was used for geodynamic interpretation (Mednokolchadanie, 1992). There are databases from Ivanovskoe, Yuluk, Yulaly, Orskoe, Yaman-Kasy, Podolskoe, Karpuhinskoe, Gaiskoe, Vishnevskoe, Leviha XI, Maik, III International, Galkinskoe, Kaban-III, Bakr-Uzyak, Voroshilovskoe, Degtyarskoe, Yuzhkno-Kuznechiinsko, Kalatinskoe, XIX parts’ezda, Sybayskoe, Bolorechenskoe, Kaban – V, Krasnogvardeyskoe, Uchaly – 25 analyses (Mednokolchadannie,..., 1992). It was suggested that there is a correlation of Pb isotopic composition with thickness of granite crust, alternatively this could suggest an evolution towards melting of subducted sediments with time?. The Cu-Zn and polymetallic deposits are characterised by Pb isotopic compositions between orogen and mantle. The basalt hosted Cu only deposits – mantle source. There are also the data about Pb isotopic composition in Pb-Zn mineralization from Bashkirskiy antiform (Neymark, 1988, in Russian).

The BRGM (Orgeval) in collaboration with IMIN (S.Tessalina, V.Zaykov) has some data (50 analyses) of lead isotopic composition in galena and sulphide ore from several VHMS deposits (Alexandrinskoe, Balta-Tau, Bakr-Tau, Tash-Tau, Yaman-Kasy, Barsuchiy Log, Sibay, Yubileynoe, Podolskoe, Uchaly, Molodejnoe, Safianovskoe, Maik, Ishkinino, Ulay, Ivanovskoe). A range of $206/204Pb$ ratio on ores is: from 17.44 up to 18.4. The range of $208/204Pb$ ratio is: from 37.2 up to 37.84. The new thesis (Tessalina and al.) about the stages of mineralization in some Urals VMS has been prepared (not published yet) for Goldschmidt Conference-2000. There are no published data on lead isotopic composition of the Uralian VHMS host rocks.

3.7.3 Is there any other isotopic data (Os/Ir, Sm/Nd, Sr) that may assist in determining the source of metals?

Re/Os isotopic composition of some Urals VHMS (Alexandrinskoe, Dergamish, Ivanovskoe..) has been studied by IPGP in Paris (A.Guannun) in collaboration with BRGM (J-J Orgeval) and IMIN (S.Tessalina). The Re/Os studies confirm the mantle origin of Ivanovskoe and Dergamish deposits, related with ultramafic complexes. The isochrone for Dergamish deposit has been obtained. The thesis in RST-2000 Conference (in French) about Re/Os isotopic composition of some Urals VMS has been published. Other thesis about Re/Os dating of Dergamish deposit has been deposited for Goldschmidt Conference-2000. Age – K/Ar isotopic analyses of the sericite from metasomatic rocks bellow the ore bodies of some Urals VMS deposits were carried out (Mednokolchadannie..., 1992, Little et al. 1997). One of the acknowledged problems is the multiple overprinting seen at some deposits.

3.7.4 Is there any evidence for magmatic fluid/metal input? If so what is the key evidence?

Many have used S to propose evidence of magmatic metal fluid input

3.7.5 What further research is required to determine the source of fluids, sulfur and metals?

Much more isotopic study. Wholerock Sm-Nd, Sr, O and mineral Sr. Basically very little modern work has been done
3.7.1 List key references


3.8 Subvolcanic intrusions

3.8.1 Have syn-volcanic intrusions been identified and are they associated with VMS deposits? What is their composition and are they composite?

Syn-volcanic felsic intrusions appear to abound in the Baimak area and probably in the ore districts at the SE flank of the MIAS. In the Baimak area, a relationship between mighty felsic porphyres that cross-cut and cover the VMS-hosting sequence and ‘plagiogranite’ intrusions is postulated (Salikhov et al., 1997). There are quartz –albite ‘plagiogranites’ below the Oktyabrskoe, Podolskoe and Tash-Tau deposits and some Middle Urals deposits. There are some dacite shallow subvolcanic domes which are shallow in the footwall of some deposits (Uzelga).

3.8.2 Classify them as shallow (<1000 m from the lowest VMS horizon), epizonal (1000-3000 m) or deep (>3000 m). Is there more than one level present? What is their geometry and dimensions.

The ‘plagiogranite’ intrusions in the Baimak area and in the Buribai would appear to be shallow to epizonal (new work in progress).

3.8.3 Are they hosted by comagmatic volcanics? Underlying basement?

They hosted by comagmatic volcanics

3.8.4 Evidence?

Association and chemistry only.

3.8.5 Are they related to district-scale alteration zones? Key evidence?

They related to district-scale alteration zones.

3.8.6 Do they contain extensive areas of alteration? Do they contain base-metal and/or gold occurrences?

They contain extensive areas of alteration. They contain base-metal and gold occurrences (for example Kurosan cluster of gold deposits, Bereznyaki, Micheevka ‘copper porphyry’ deposits).

3.8.7 List key references

3.9 Hydrogeological Modelling

None known of!

3.10 Exploration criteria

3.10.1 How where the known deposits found? Provide a list with dates and the key methods. (eg. outcropping gossan, gravity, magnetics, soil geochemistry etc.)

Many deposits had well-developed gossans (“iron cap”). Some were buried by cover (e.g. Yubileynoye, Guy), some actually outcropped (e.g. Letneye, Alexandrinka, Safyanovka, Barsuchiy Log). Some of these gossans show highly enriched precious metals of economic interest. Techniques used in discoveries include: Prospecting; e.g. Uchaly, Sibai, Buribai, Alexandrinka, Chernushinskoe (all had outcropping gossans); Water and soil geochemistry (e.g. Gai); Geophysics – Chargeability (e.g. Podolskoe). The massive sulphides are mainly located within zones of high gradients within regional gravitational fields (Prokin & Buslaev 1999). The large deposits of Uchaly, Sibay and Gai are characterized by positive gravity anomalies of 1.5 to 3.5 mgals. It is claimed that some of the deposits have been found by this method.

3.10.2 Currently, what are the key methods used by companies to identify 1) prospect areas, and 2) drill targets?

Mainly, geophysics (chargeability – electrical methods) and geochemical (primary and secondary dispersion halo) methods are used. This is linked to geological interpretation of ‘structure’ for definition of drilling targets.


Everything is apparently available and the belt is believed to have been well covered with simple geophysics and reconnaissance geochemistry, although the Urals team does not have access to this and the charges for the various datasets is unknown. Some western mining companies (BHP, Rio Tinto) may have acquired geophysical datasets.

3.10.4 What percentage of the volcanic district is under shallow cover? Have any deposits been discovered in the covered areas?

It is pertinent to mention that most of the worked deposits in the northern region of the south Urals (both formerly exploited and now in exploitation) were outcropping or only under shallow cover (This includes Uchaly, Sibai, and the whole Karabash group further north). This may be 20% of the region. Most of the newly ‘discovered’ deposits have been found under cover (generally within 600 m of surface). There are a number of ‘blind’ discoveries (e.g. Uzelga, Chebachye, Molodeznoe, Novy Uchaly, Podolskoye), where discovery has resulted from drilling target stratigraphy in areas defined by other methods. In the case of Uzelga and Novy Uchaly this has been by extrapolating mine stratigraphy into new areas. In the case of Podolska, this is the drilling of a geophysical anomaly over target stratigraphy. This comprises 80% of the region.

3.10.4 What exploration methods need to be considered or further researched in your district?

Facies mapping ‘sub-basinal’ sediments overlying sulphide deposits. Pilot studies in the Buribai region
show that these sediments containing reworked sulphide debris can outline the small structural basins which control volcanism and hydrothermal systems.

**Geophysics**

This is currently at what might be considered a primitive stage. None of the more modern methods used in the west have been systematically tried here (TEM, gravity etc.).

**Geochemistry**

Since the hanging wall stratigraphy is generally what you see in the covered areas, a geochemical database of the sediments overlying the ore package which may have a geochemical fingerprint of underlying mineralisation should be compiled.

Very little alteration geochemistry has been done which would help to define the scale of the hydrothermal systems, target new areas and provide potential ore vectors.

Investigation of the relative roles of submarine and terrestrial supergene processes since these result in higher value precious-metal rich massive sulphides.

### 3.10.6 List key references

Again see Prokin & Buslaev 1999 for the best introduction.

Other new work on secondary mineralisation:


### 3.11 Research strengths for your VMS district

- Tectonic and structural setting: 3
- Volcanic architecture: 4
- Styles of deposits: 1
- Exhalites: 3
- Alteration facies: 2 to 4
- Hydrothermal geochemistry: 3
- Sources of S and other metals: 3
- Hydrogeological modeling: 5
- Subvolcanic intrusions: 4

### 3.12 List of twelve key references

**Key references (please add these to the current list if not already on!**

**Regional geology of the southern Urals:**

Latest book by Puchkov, reference to be found!

Devonian structural evolution between margin of EEP, MUFZ, and W flank of MIAS:


Litho- and conodont-biostratigraphy of the MIAS/MUFZ/SZ district:


History/geochemistry of volcanism of the MIAS:
Yazeva, R.G. & Bochkarev, V.V. (1998): Geology and Geodynamics of the southern Ural (an attempt of
gеодynamic mapping). Russian Academy of Sciences, Ural Branch, Institute of Geology and
Geochemistry, Ekaterinburg. 203 p. (in Russian; English summary, table and figure captions)

Styles of deposits:
14, 1-69.