PGC
PUBLISHING

Seltmann, R. and Porter, T.M., 2005 - The Porphyry Cu-Au/Mo Deposits of Central Eurasia: 1. Tectonic, Geologic & Metallogenic Setting and Significant Deposits; *in Porter, T.M. (Ed.), Super Porphyry Copper & Gold Deposits: A Global Perspective*; PGC Publishing, Adelaide, v. 2, pp 467-512.

THE PORPHYRY Cu-Au/Mo DEPOSITS OF CENTRAL EURASIA 1. TECTONIC, GEOLOGIC AND METALLOGENIC SETTING, AND SIGNIFICANT DEPOSITS

[1]Reimar Seltmann and [2]T. Mike Porter

[1]*Centre for Russian and Central EurAsian Mineral Studies, Department of Mineralogy, Natural History Museum, London, UK.*
[2] *Porter GeoConsultancy Pty Ltd, Adelaide, South Australia*

Abstract - Major porphyry Cu-Au and Cu-Mo deposits (e.g. *Oyu Tolgoi* in Mongolia - >2.3 Gt @ 1.16% Cu, 0.35 g/t Au and *Kal'makyr-Dalnee* in Uzbekistan - >5 Gt @ 0.5% Cu, 0.4 g/t Au) are distributed over an interval of almost 5000 km across central Eurasia, from the Urals Mountains in Russia in the west, to Inner Mongolia in north-eastern China, to the east. These deposits were formed during a range of magmatic episodes from the Ordovician to the Jurassic. They are associated with magmatic arcs within the extensive subduction-accretion complex of the Altaid and Transbaikal-Mongolian Orogenic Collages that developed from the late Neoproterozoic, through the Palaeozoic to the Jurassic intra-cratonic extension, predominantly on the palaeo-Tethys Ocean margin of the proto-Asian continent, but also associated with the closure of two rifted back-arc basins behind that ocean facing margin. The complex now comprises collages of fragments of sedimentary basins, island arcs, accretionary wedges and tectonically bounded terranes composed of Neoproterozoic to Cenozoic rocks.

The development of these collages commenced when slivers of an earlier Proterozoic subduction complex accreted to the palaeo-Tethys Ocean margin of the combined Eastern Europe and Siberian cratons were rifted from the main cratonic mass. These slivers were the contiguous Karakum and Altai-Tarim micro-continents, which became separated from the main cratonic mass by oceanic spreading that created the Khanty-Mansi back arc basin. Subduction of the palaeo-Tethys Ocean beneath these micro-continents and the adjacent back-arc basin produced the overlapping late Neoproterozoic to early Palaeozoic Tuva-Mongol and Kipchak magmatic arcs. Contemporaneous intra-oceanic subduction within the back-arc basin from the Late Ordovician produced the parallel Urals-Zharma magmatic arc, and separated the main Khanty-Mansi back-arc basin from the inboard Sakmara marginal sea. By the Late Devonian the Tuva-Mongol and Kipchak arcs had amalgamated to form the Kazakh-Mongol arc which extended over the whole palaeo-Tethys Ocean margin of the combined cratonic mass, while magmatic activity continued on the Urals-Zharma arc. During the mid Palaeozoic the two main cratonic components of the proto-Asian continent, the Siberian and Eastern European cratons, began to rotate relative to each other, "drawing-in" the two sets of parallel arcs to form the Kazakh Orocline between the two cratons. During the Late Devonian to Early Carboniferous, the Khanty-Mansi back-arc basin began subducting beneath the oroclinally infolded outer island arc mass to form the Valerianov-Beltau-Kurama arc. At the same time the palaeo-Pacific Ocean began subducting below the Siberian craton to form the Sayan-Transbaikal arc, which expanded by the Permian to become the Selanga-Gobi-Khanka arc which for a period was continuous with the Kazakh-Mongol arc. By the Mid to Late Permian, as the Kazakh Orocline had continued to develop, both the Sakmara and Khanty-Mansi back-arc basins had been closed and the collage of cratons and arcs were sutured by accretionary complexes. During the Permian and Triassic the North China craton approached and docked with the continent, closing the Mongol-Okhotsk sea (an embayment on the palaeo-Pacific margin) to form the Mongolian Orocline. Subduction and arc building activity on the palaeo-Pacific Ocean margin continued to the Mid Mesozoic as the Indo-Sinian and Yanshanian orogenic cycles.

Significant porphyry Cu-Au/Mo and Au-Cu deposits were formed during the: Ordovician in the Kipchak arc (e.g. *Bozshakol* Cu-Au in Kazakhstan and *Taldy Bulak* porphyry Cu-Au in Kyrgyzstan); Silurian to Devonian in the Kazakh-Mongol arc (e.g. *Nurkazgan* Cu-Au in Kazakhstan; *Taldy Bulak-Levoberezhny* Au in Kyrgyzstan); Devonian in the Urals-Zharma arc (e.g. *Yubileinoe* Au-Cu in Russia); Devonian in the Kazakh-Mongol arc (e.g. *Oyu Tolgoi* Cu-Au, and *Tsagaan Suvarga* Cu-Au, both in Mongolia); Carboniferous in the Kazakh-Mongol arc (e.g. *Kharmagtai* Au-Cu in Mongolia, *Tuwu-Yandong* Cu-Au in Xinjiang, China; *Koksai* Cu-Au, *Sayak* skarn Cu-Au, *Kounrad* Cu-Au and the *Aktogai Group* of Cu-Au deposits, all in Kazakhstan); Carboniferous in the Valerianov-Beltau-Kurama arc (e.g. *Kal'makyr-Dalnee* Cu-Au and *Kochbulak* epithermal Au, both in Uzbekistan; *Benqala* Cu-Au in Kazakhstan); Late Carboniferous to Permian in the Selanga-Gobi-Khanka arc (e.g. *Duobaoshan* Cu-Au in Inner Mongolia, China); Triassic in the Selanga-Gobi-Khanka arc (e.g. *Erdenet* Cu-Mo in Mongolia); and Jurassic in the Selanga-Gobi-Khanka arc (e.g. *Wunugetushan* Cu-Mo in Inner Mongolia, China).

In addition to the tectonic, geologic and metallogenic setting and distribution of porphyry Cu-Au/Mo mineralisation within central Eurasia, a description of the setting, geology, alteration and mineralisation recorded at each of the deposits listed above is included within this paper.

Introduction

The Altaid tectonic collage (Sengör *et al.,* 1993; Sengör and Natalin, 1996; Yakubchuk, 2004), also known as the Central Asian Orogenic Belt (Jahn *et al.,* 2000), combined with the Transbaikal-Mongolian orogenic collage (Yakubchuk, 2002, 2005), stretch across central Eurasia for almost 5000 km. These combined collages are also known from the Russian literature as the Ural-Mongolian belt (*syn.* Central Asian fold belt in its Palaeozoic part) and Baikalides (Zonenshain *et al.,* 1990; Mossakovskiy *et al.,* 1993). They extend (Fig. 1) from the Urals Mountains in Russia and Kazakhstan in the west (*syn.* Uralides; see Shatov *et al.,* 2003; Herrington *et al.,* 2005) through Kazakhstan, Uzbekistan, Tajikistan, Kyrgyzstan, Xinjiang in northwestern China, and parts of Mongolia (forming the Tien Shan Mineral Belt; see Windley *et al.,* 1990; Allen *et al.,* 1992; Jun *et al.,* 1998; Shayakubov *et al.,* 1999; Shatov *et al.,* 2001; Seltmann *et al.,* 2000, 2001; Mao *et al.,* 2003; and references therein) to Inner Mongolia in northeastern China and the adjacent regions further to the northeast (Jahn, 2004). They contain major porphyry Cu-Mo (e.g. Erdenet in Mongolia), Cu-Au (e.g. Oyu Tolgoi in Mongolia and Kal'makyr-Dalnee in Uzbekistan) and related epithermal gold ores, as well as some of the world's largest and richest orogenic gold accumulations (e.g. Muruntau in Uzbekistan). The same belt also embraces a variety of other mineralisation styles, including porphyry molybdenum and tungsten deposits, intrusion related tin, and volcanic, carbonate and sediment hosted base metals (Kudrin *et al.,* 1990; White *et al.,* 2001; Yakubchuk *et al.,* 2002, Seltmann *et al.,* 2004).

The porphyry Cu-Au/Mo and epithermal gold deposits are associated with magmatic arcs of the extensive Palaeozoic subduction-accretion complex that has subsequently been tectonically rearranged to form the Altaid and Transbaikal-Mongolian Orogenic Collages. This complex was progressively developed from the late Neoproterozoic, through the Palaeozoic to the early Mesozoic, predominantly on the Palaeo-Tethys Ocean margin of the proto-Asian continent, but also on the adjacent Palaeo-

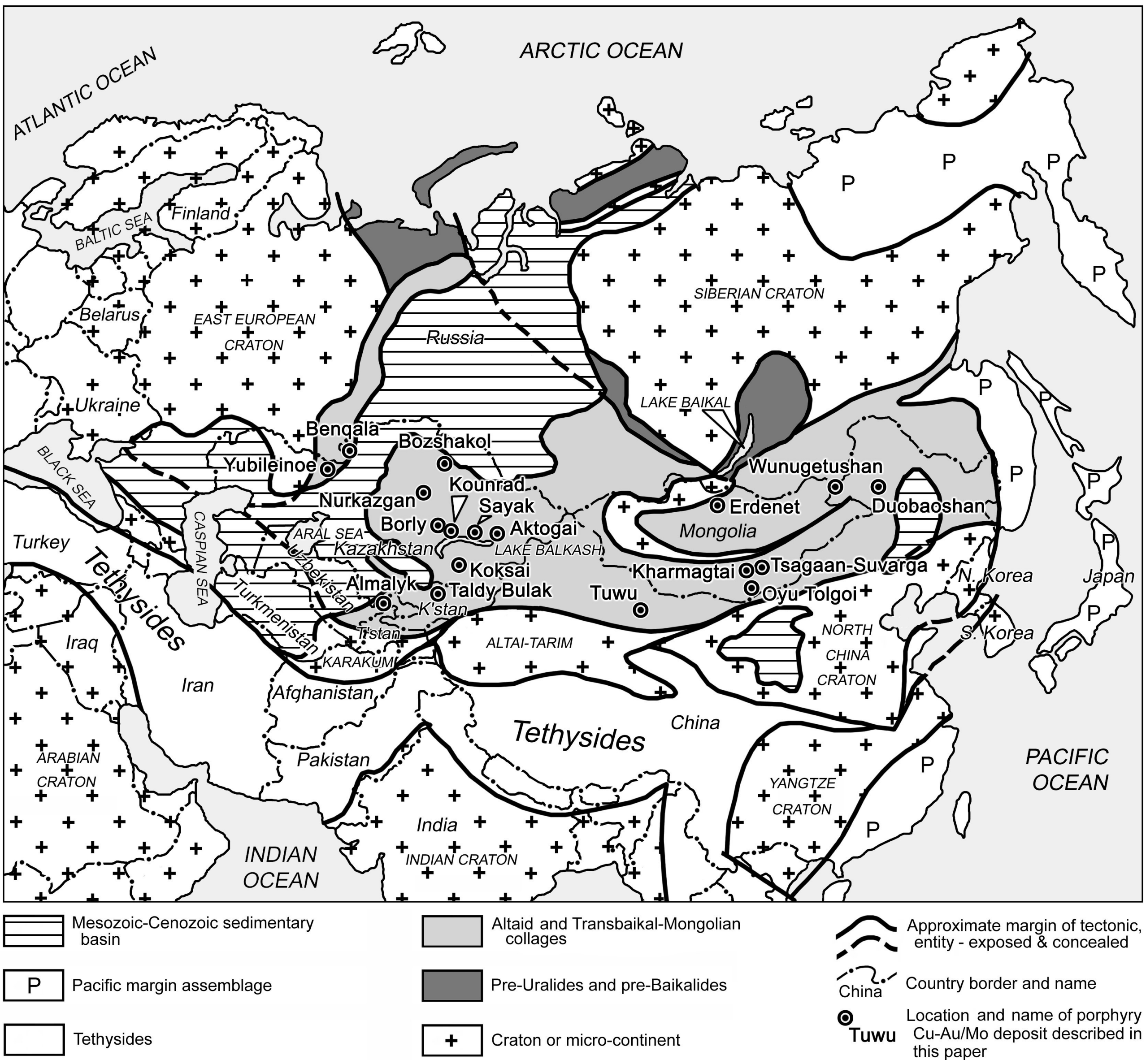


Figure 1: ***Location plan showing the tectonic elements of Eurasia and the porphyry Cu-Au/Mo deposits described in this paper.*** Note that T'stan = Tajikistan, K'stan = Kyrgyzstan. Tectonic subdivisions in part after Yakubchuk (2005) and a variety of other sources.

Table 1: *Tonnage, grade and age statistics of a selection of the more significant porphyry Cu-Au/Mo and related epithermal Au deposits of the Altaids and Transbaikal-Mongolian Orogenic Collages in central Eurasia.* Refer to Fig. 1 for locations.

Deposit	Location	Tonnage	Grade			Contained Metal		Age
Bozshakol (a,b)	Kazakhstan	1.0 Gt	0.67% Cu		0.05 g/t Au	6.7 Mt Cu,	49 t Au	481 Ma
Andash (a)	Kyrgyzstan	n.a.	0.4% Cu		2.64 g/t Au		60 t Au	Ordovician
Taldy Bulak (a,b)	Kyrgyzstan	540 Mt	0.27% Cu		0.5 g/t Au	1.4 Mt Cu,	270 t Au	Ordovician
Nurkazgan (a)	Kazakhstan	na	1 to 3% Cu		0.4 to 1 g/t Au	1.5 Mt Cu,	65 t Au	410 Ma
TB Lev.$^{\text{Mesoth-Porph}}$ (a,f)	Kyrgyzstan	18.7 Mt	0.2-0.3% Cu		6.9 g/t Au		129 t Au	Devonian
Yubileinoe (a)	Kazakhstan	~ 10 Mt	0.42% Cu		4 to 5 g/t Au	<0.05 Mt Cu,	45 t Au	~380 Ma
Oyu Tolgoi (c)	Mongolia	2.3 Gt	1.16% Cu		0.35 g/t Au	>27 Mt Cu,	>810 t Au	370 Ma
Tsagaan Suvarga (b,e)	Mongolia	240 Mt	0.53% Cu	0.02% Mo		1.3 Mt Cu		325-365 Ma
Kharmagtai (c)	Mongolia	n.a.	0.5 to 0.8% Cu		0.7 to 1.25 g/t Au	n.a.		~330 Ma
Tuwu-Yandong (g)	China, (Xin)	n.a.	~0.7% Cu		~0.15 g/t Au	7 Mt Cu		330 Ma
Koksai (a.b)	Kazakhstan	320 Mt	0.52% Cu		0.12 g/t Au	1.6 Mt Cu,	37 t Au	Carbonif
Sayak $^{\text{Sk}}$ (a)	Kazakhstan	55 Mt	1.1 -3.2% Cu		0.2-2.1 g/t Au	1 Mt Cu,	30 t Au	330 Ma
Kounrad (a,b)	Kazakhstan	>800 Mt	0.62% Cu		0.1-0.76 g/t Au	5 Mt Cu,	600 t Au	330 Ma
Aktogai Group (a)	Kazakhstan							~320 Ma
Aktogai (a,b)		1.5 Gt	0.39% Cu	0.01% Mo,	0.03 g/t Au	6 Mt Cu,	45 t Au	
Aidarly (a,b)		1.1 Gt	0.38% Cu	0.01% Mo,	0.013 g/t Au	4.2 Mt Cu,	14 t Au	
Benqala (a)	Kazakhstan	~100 Mt	0.42 -0.55% Cu		0.3 g/t Au		30 t Au	Carbonif.
Kalmakyr-Dalnee(a)	Uzbekistan	> 5 Gt	0.47-0.51% Cu		0.35 - 0.6 g/t Au	>21 Mt Cu,	>2650 t Au	~315 Ma
Kochbulak $^{\text{Epith}}$(a)	Uzbekistan	~11 Mt	-		12 g/t Au		135 t Au	280-290 Ma
Kyzylalma $^{\text{Epith}}$(a)	Uzbekistan	~20 Mt	1.62% Cu		8 g/t Au		165 t Au	280-290 Ma
Duobaoshan (b)	China, (I.M.)	508 Mt	0.47% Cu		0.14 g/t Au	2.4 Mt Cu,	70 t Au	292 Ma
Tongshan (b)	China, (I.M.)	180 Mt	0.47% Cu	0.023% Mo		0.8 Mt Cu,	0.04 Mt Mo	~290 Ma ?
Erdenet (d,e)	Mongolia	1.78 Gt	0.62% Cu	0.025% Mo		11 Mt Cu,	0.45 Mt Mo	240 Ma
Wunugetushan (b)	China, (I.M.)	495 Mt	0.45% Cu	0.09% Mo		2.2 Mt Cu,	0.45 Mt Mo	188-182 Ma

Abbreviations: Gt = billion tonnes; Mt = million tonnes; t = tonnes; $^{\text{Sk}}$ = skarn; $^{\text{Epith}}$ = epithermal; $^{\text{Mesoth-Porph}}$ = mesothermal to porphyry Au; Carbonif. = Carboniferous; Xin = Xinjiang; I.M. = Inner Mongolia; TB Lev. = Taldy Bulak Levoberezhny; n.a. = not available.

Source: (a) Seltmann *et al.,* (2004) and references cited therein; (b) Mutschler *et al.,* (2000) and references cited therein; (c) Ivanhoe Mines, (2005); (d) Gerel & Munkhtsengel, (2005); (e) Watanabe & Stein, (2000) ; (f) Central Asia Gold, (2005): (g) Han, (2003).

Pacific margin and associated with the closure of rifted back-arc basins behind the ocean facing margins. Porphyry style ores were emplaced from Ordovician times to the Jurassic, although the most prolific interval of ore deposition, including the largest deposits, was during the Late Devonian and Early Carboniferous (Yakubchuk *et al.,* 2002).

By the early Mesozoic, subduction on the Palaeo-Pacific Ocean margin had become more significant, accompanied by the collision of the North China and Yangtze cratons, with late Permian and Triassic porphyry deposits being emplaced in what is now eastern China and Mongolia. Following the closure of the Tethys Ocean and the Indo-Asian collision during the Cenozoic, activity within the main Altaid Orogenic Collage was restricted to uplift associated with the ongoing Himalayan Orogeny (Yakubchuk *et al.,* 2002).

Table 1 lists tonnage, grade and age details of a selection of representative porphyry and epithermal deposits within the Altaid and Transbaikal-Mongolian Orogenic Collages. The emplacement location of each of these deposits is shown on Fig. 1 and the palinspastic reconstruction of central Eurasia on Fig. 3. The geology and mineralisation of most of the porphyry deposits in Table 1 are summarised later in this paper, while one of the largest, Kal'makyr-Dalnee is the subject of part 2 by Golovanov *et al.,* (2005, this volume).

While this paper is primarily concerned with porphyry style mineralisation, mention is also made of some representative epithermal gold deposits found in proximity, and possibly related to, major porphyry deposits. It is now generally appreciated that in many cases within magmatic arcs, there is a close relationship between the development of porphyry-style Cu/Au and measurably younger epithermal Au deposits. Porphyry-style mineralisation forms at depths of 1 to 2 km under conditions of confinement (Richards, 2005, this volume), while epithermal gold is precipitated at shallower, near surface levels, when the system is subsequently allowed to vent to the surface (Corbett, 2004). As such, the epithermal deposit may be seen as a late phase of the same hydrothermal system that formed porphyry style mineralisation. In many magmatic arcs, epithermal gold deposits are telescoped onto either economic porphyry Cu/Au systems (e.g. Lepanto-Far Southeast in the Philippines; Hedenquest *et al.,* 1998) or incipient porphyry systems (e.g. Lihir in Papua New Guinea; Kidd and Robinson, 2004) which were developed at greater depths and at an earlier stage in the development of an intrusion related hydrothermal system.

The main focus of this review paper is on the tectonic, geologic and metallogenic setting, and the occurrence of porphyry Cu deposits with accompanying gold or molybdenum within central Eurasia. It summarises the palinspastic reconstruction and tectonic history of the Altaid and Transbaikal-Mongolian Orogenic Collages, from eastern Europe to the Pacific coast, and the temporal and spatial distribution of porphyry Cu-Au/Mo both within these collages. There is also a description of the geology, alteration and mineralisation of each of the key deposits in the region.

Tectonic Architecture

The Altaid and Transbaikal-Mongolian Orogenic Collages, as currently mapped, are made up of fragments of sedimentary basins, island arcs, accretionary wedges and tectonically bounded terranes composed of Neoproterozoic to Cenozoic rocks (Fig. 2). These collages are the product of a complex sequence of processes resulting from subduction, collision, transcurrent movement and continuing tectonism over the interval from the mid Neoproterozoic to the present. The pattern was further complicated by the late overprint of the Alpine-Himalayan deformation related to Indo-Asian collision between Gondwana and Asia (Yakubchuk *et al.,* 2002).

Fig. 3 is a palinspastic reconstruction of central Eurasia, updated from Yakubchuk *et al.,* (2002) and Seltmann *et al.,* (2004). It illustrates an interpretation of the evolution of the Palaeozoic subduction-accretion complex on the Palaeo-Tethys Ocean margin of the proto-Asian continent from the late Neoproterozoic to the end of the Permian. Yakubchuk *et al.,* (2002) postulate that the collage represents three sub-parallel island arcs, the late Neoproterozoic (Vendian) to early Palaeozoic Tuva-

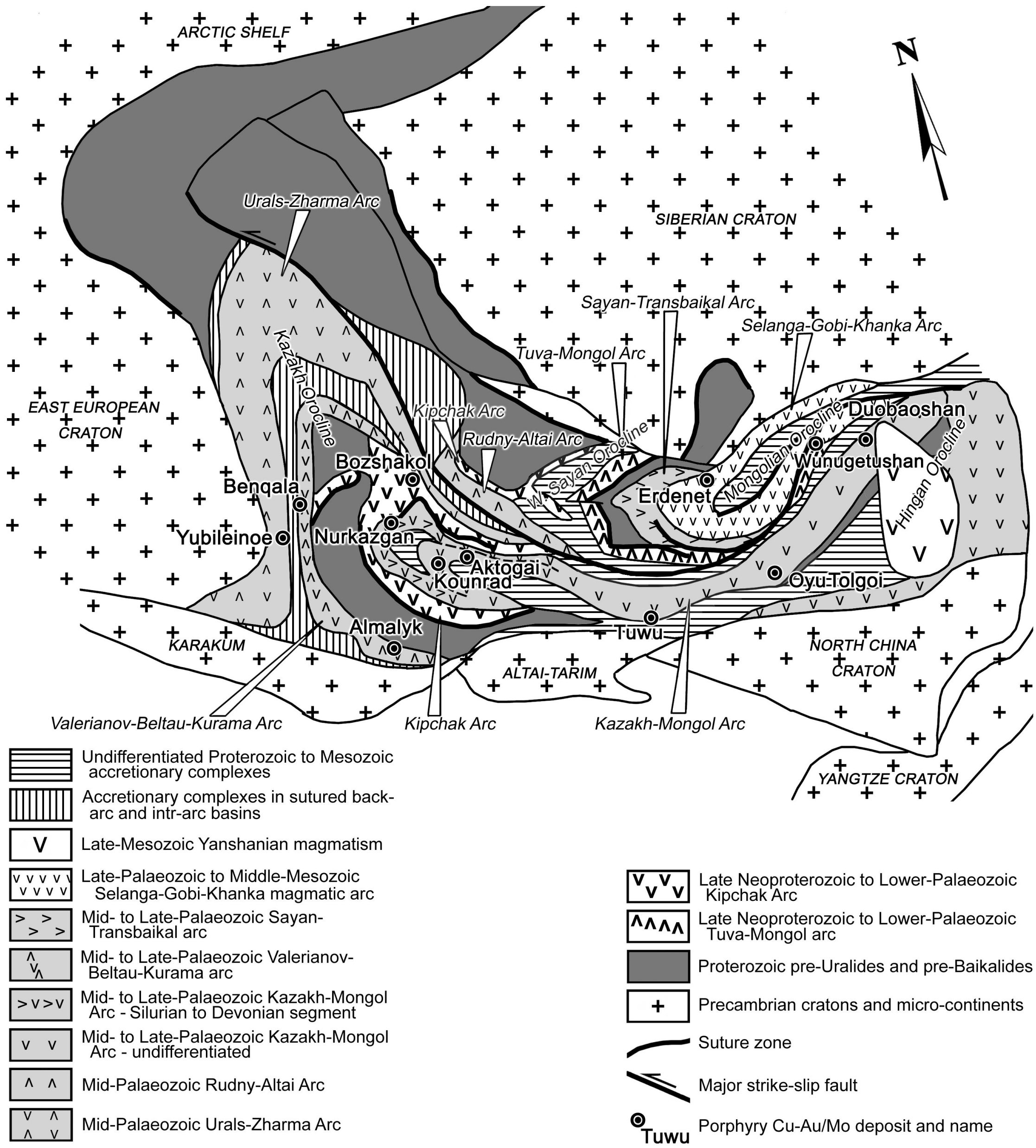


Figure. 2: ***Simplified tectonic map of the Altaid and Transbaikal-Mongolian Orogenic Collages in central Eurasia,*** showing the location of selected porphyry Cu-Au/Mo deposits, after removal of Mesozoic-Cenozoic basins and superficial cover. See Fig. 1 also for additional deposits and Fig. 3 for a palinspastic reconstruction of the sequence of tectonic events that produced this configuration. Modified after Yakubchuk (2005) and Seltmann *et al.,* (2004).

Mongol, Kipchak and Urals-Zharma (also known as the Mugodzhar-Rudny Altai) arcs. Each is separated by accretionary complexes formed during the subduction of the oceanic crust of the main Palaeo-Tethys Ocean and two principal back-arc basins - the Khanty-Mansi back-arc basin and the Sakmara marginal sea. These elements are followed by continued activity on the Urals-Zharma arc and by the younger Kazakh-Mongol and Valerianov-Beltau-Kurama arcs, developed in the middle Palaeozoic to early Carboniferous and early Carboniferous to Permian respectively. These younger arcs were related to continued subduction of the Palaeo-Tethys Ocean and the oceanic crust of the Khanty-Mansi and Sakmara back-arc basins. By the late Permian, both of the back basins were closed and sutured with the development of substantial accretionary wedges separating the sequences representing those magmatic arcs (Yakubchuk *et al.,* 2002; Seltmann *et al.,* 2004).

The development of the collages was further complicated by the relative rotation of the two main building blocks of the proto-Asian continent, the Siberian and Eastern European cratons. The clockwise rotation of the Siberian craton relative to Eastern Europe produced the oroclinal bending of the tectonic framework evident during the late Palaeozoic on Fig. 3, resulting in the Kazakh Orocline, now located between the two cratonic blocks (Yakubchuk *et al.,* 2002).

The tectonic history of the region may be summarized as follows, mainly after Yakubchuk *et al.,* 2002; Seltmann *et al.,* 2004, and references cited therein, except where otherwise noted.

Archaean to Early Neoproterozoic

Archaean to Palaeoproterozoic crystalline basement occurs both within the Eastern Europe and Siberian cratons, the Arctic Shelf flooring part of the current Arctic Ocean (but originally connected the two cratons), and in several elongate, tectonically bounded terranes within the Altaid Orogenic Collage, e.g. the Altai-Tarim and Karakum micro-continents (see Fig. 3). The crystalline suites within these latter terranes have been dated at 2800 to 1780 Ma (Pb-Pb and U-Pb) and comprise crystalline gneisses, schists and amphibolites, with rare marble and quartzite. These terranes are believed to represent slivers rifted from the larger cratons and subsequently accreted during the Palaeozoic. They are overlain by poorly age constrained Mesoproterozoic sequences of shallow-marine carbonates and terrigenous rocks which have been variably metamorphosed to sub-greenschist, up to amphibolite facies.

The most extensive Precambrian sequences were deposited during the Neoproterozoic when the Eastern Europe and Siberian cratons were part of the super-continent Rodinia. During the Vendian (650 to 570 Ma) subdivision of the late Neoproterozoic, a single orogen occupied the active flank of Rodinia. This orogen was represented by the post 1100 Ma Baikalides and 800 to 550 Ma pre-Uralides, subsequently dismembered and dispersed as tectonic slivers throughout the region. This Vendian orogen was the result of collision and suturing of Neoproterozoic back-arc basins, and was flanked on its ocean-ward margin by the Precambrian Karakum and Altai-Tarim micro-continents and the Precambrian slivers of Kazakhstan. All have subsequently served as basement for Palaeozoic magmatic arcs facing the palaeo-Tethys Ocean. At the same time, the Tuva-Mongol magmatic arc separated the proto-Pacific and proto-Tethys oceans, developed over Precambrian basement slivers (Fig. 3).

Late Neoproterozoic to Middle Ordovician

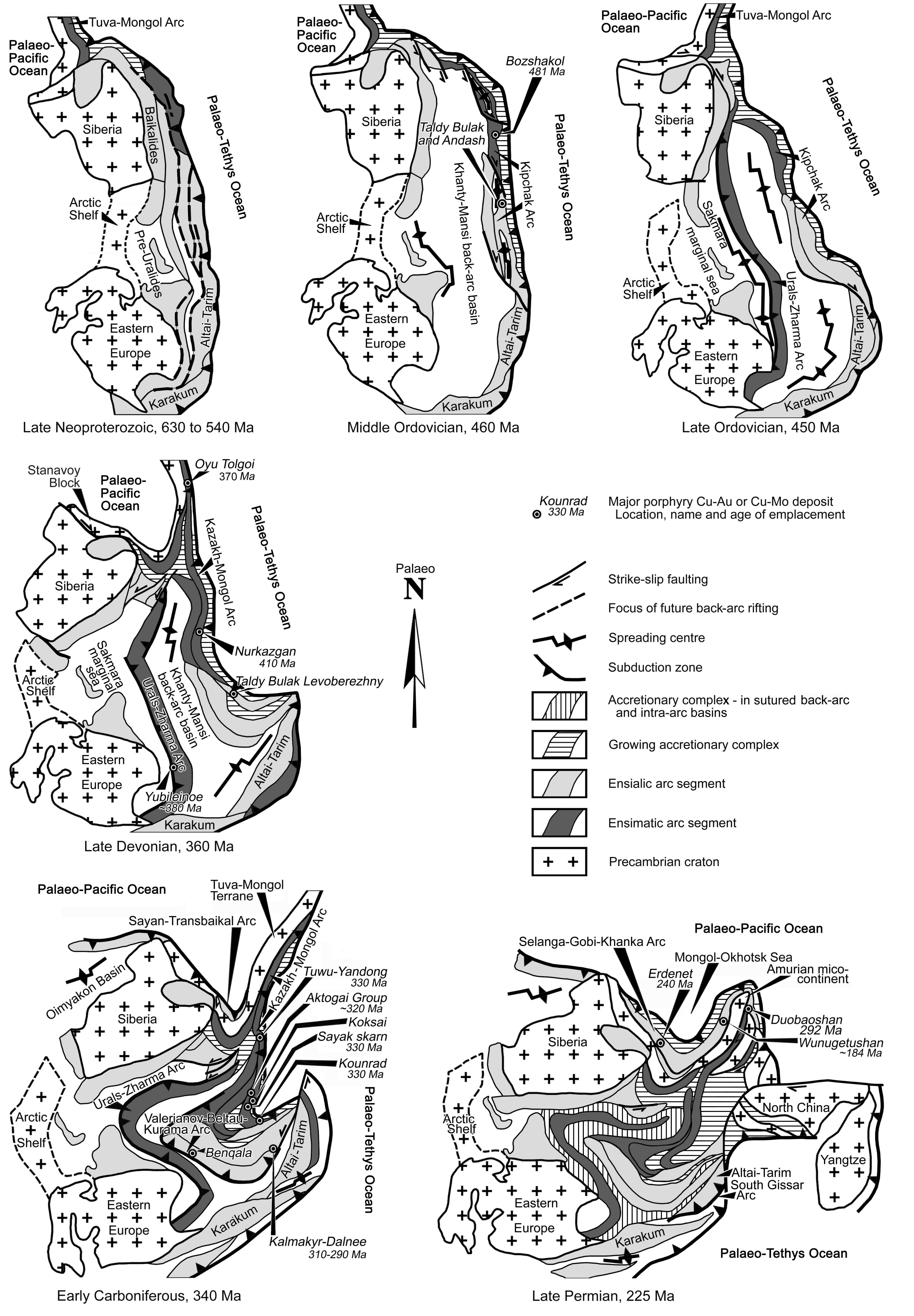
During the latest Neoproterozoic, the orogen flanking the active margin of Rodinia was subjected to subduction related processes which initiated back-arc rifting along a number of incipient spreading centres. The succeeding back-arc spreading led to the formation of the broad Khanty-Mansi back-arc basin, separating the combined Eastern Europe and Siberian cratons from the interpreted contemporaneous subduction on the active margin that was building the Kipchak magmatic arc. This back-arc spreading also resulted in the Karakum and Altai-Tarim micro-continents and other Precambrian slivers being separated from the main Baikalide and pre-Uralide elements, and becoming the basement for the southern continuation of the Kipchak arc (Yakubchuk *et al.,* 2002; Seltmann *et al.,* 2004). Magmatic activity continued on the Tuva-Mongol arc, contemporaneously with the Kipchak arc, although the latter was developed behind the former at their overlap (Yakubchuk, 2005). However, while Kipchak Arc volcanism is evident, particularly in Kazakhstan, the arc may not have been as extensive as shown on Fig. 3.

During the early Palaeozoic, as a result of spreading between Siberia and Laurentia, the Siberian craton commenced a clockwise rotation relative to the Eastern Europe craton. This in turn led to intra-arc spreading within segments of the Kipchak arc (Fig. 3 - Middle Ordovician) and the development of a strike slip faulting pattern longitudinally compressing the Kipchak arc. Continued rotation (clockwise of Siberia and anti-clockwise of Eastern Europe) caused the closure of the intra-arc basins of the Kipchak arc, and then its segmentation (Fig. 3 – Late Ordovician) (Yakubchuk *et al.,* 2002).

Late Ordovician to Late Devonian

By the Late Ordovician, continuing spreading of the Khanty-Mansi back-arc basin had produced a wide back-arc sea. At this stage, a new intra-oceanic subduction zone was initiated, forming the new Urals-Zharma (or Mugodzhar-Rudny Altai) magmatic arc which split the broad back arc sea into the Khanty-Mansi and Sakmara basins, both of which had continuing active spreading centres (Fig. 3). The polarity of the magmatic arc is a subject of discussion, although it is currently thought to relate to 'east-directed' subduction of Sakmara basin oceanic crust below the Khanty-Mansi basin (Yakubchuk *et al.,* 2002).

Continued relative rotation of the East Europe and Siberian cratons resulted in the commencement of oroclinal bending of the Kipchak and Urals-Zharma arcs. With oroclinal bending, the subduction zone responsible for the Urals-Zharma arc split, with opposite polarities in the north and


Tuva-Mongol Arc
Palaeo-Pacific Ocean
Siberia
Baikalides
Palaeo-Tethys Ocean
Arctic Shelf
Pre-Uralides
Eastern Europe
Altai-Tarim
Karakum
Late Neoproterozoic, 630 to 540 Ma
Palaeo-Pacific Ocean
Bozshakol
481 Ma
Siberia
Taldy Bulak and Andash
Palaeo-Tethys Ocean
Kipchak Arc
Khanty-Mansi back-arc basin
Arctic Shelf
Eastern Europe
Altai-Tarim
Karakum
Middle Ordovician, 460 Ma
Palaeo-Pacific Ocean
Tuva-Mongol Arc
Siberia
Palaeo-Tethys Ocean
Kipchak Arc
Sakmara marginal sea
Urals-Zharma Arc
Arctic Shelf
Eastern Europe
Altai-Tarim
Karakum
Late Ordovician, 450 Ma
Stanavoy Block
Palaeo-Pacific Ocean
Oyu Tolgoi
370 Ma
Kazakh-Mongol Arc
Palaeo-Tethys Ocean
Siberia
Sakmara marginal sea
Arctic Shelf
Nurkazgan
410 Ma
Taldy Bulak Levoberezhny
Khanty-Mansi back-arc basin
Urals-Zharma Arc
Eastern Europe
Yubileinoe
~380 Ma
Altai-Tarim
Karakum
Late Devonian, 360 Ma
Palaeo
N
Kounrad
330 Ma
Major porphyry Cu-Au or Cu-Mo deposit
Location, name and age of emplacement
Strike-slip faulting
Focus of future back-arc rifting
Spreading centre
Subduction zone
Accretionary complex - in sutured back-arc and intra-arc basins
Growing accretionary complex
Ensialic arc segment
Ensimatic arc segment
Precambrian craton
Palaeo-Pacific Ocean
Tuva-Mongol Terrane
Sayan-Transbaikal Arc
Kazakh-Mongol Arc
Oimyakon Basin
Tuwu-Yandong
330 Ma
Aktogai Group
~320 Ma
Koksai
Sayak skarn
330 Ma
Kounrad
330 Ma
Siberia
Urals-Zharma Arc
Valerianov-Beltau-Kurama Arc
Benqala
Arctic Shelf
Altai-Tarim
Palaeo-Tethys Ocean
Eastern Europe
Karakum
Kalmakyr-Dalnee
310-290 Ma
Early Carboniferous, 340 Ma
Palaeo-Pacific Ocean
Selanga-Gobi-Khanka Arc
Mongol-Okhotsk Sea
Erdenet
240 Ma
Amurian mico-continent
Duobaoshan
292 Ma
Wunugetushan
~184 Ma
Siberia
Arctic Shelf
North China
Yangtze
Altai-Tarim
South Gissar Arc
Eastern Europe
Karakum
Palaeo-Tethys Ocean
Late Permian, 225 Ma

south (Fig. 3). At the same time, the Kipchak magmatic arc front was migrating to the southeast (and ocean-ward), into the growing subduction-accretionary complex. The strike slip faulting that accommodated the rotation and oroclinal development and disrupted the arc, also resulted in the amalgamation of the Kipchak and Tuva-Mongol arcs into the single, continuous Kazakh-Mongol arc. By the Late-Devonian, a substantial accretionary complex had formed in front of this new composite arc).

The Rudny-Altai arc, which is juxtaposed across the continental scale Late Permian to Triassic Trans-Eurasian strike-slip fault with the eastern section of the Urals-Zharma arc (Fig. 2) is now regarded as a fault offset of the Kazakh-Mongol Arc (Yakubchuk, 2005).

Towards the end of the Middle Palaeozoic, subduction was initiated on the margin of the palaeo-Pacific Ocean with the Siberian Craton and parts of the adjacent Tuva-Mongol terrane to produce calc-alkaline volcanic rocks of the Sayan-Transbaikal arc (Figs. 2 and 3).

Carboniferous to Mesozoic

Oroclinal bending persisted into the Early to Middle Carboniferous as the cratons continued to rotate. This activity was accompanied by further southeastward migration of the subduction-related magmatism of the Kazakh-Mongol arc. Subduction continued below the Urals-Zharma arc, closing the Sakmara basin, while a new east-directed subduction zone was activated during the Late Devonian, consuming oceanic crust of the Khanty-Mansi back-arc basin below the extinct Kipchak arc to form the Valerianov-Beltau-Kurama arc. During the Middle- to Late-Carboniferous, subduction had closed both back-arc basins, the Urals-Zharma arc had collided with both of the cratons and with the Kazakh-Mongol arc. These closures resulted in extensive suture zones occupied by the development of substantial accretionary complexes (Yakubchuk *et al.,* 2002).

During the Permian, oroclinal bending and suturing of back-arc basins continued in the west of the Palaeozoic orogenic collage that is known as the Altaids. The main orocline that had developed between the Siberian and East Europe cratons is known as the Kazakh Orocline. Arc development was now concentrated on the Palaeo-Tethyan margin to the east, and on the Palaeo-Pacific margin which had commenced during the Carboniferous (Yakubchuk *et al.,* 2002).

Compression on the Palaeo-Tethys ocean margin led to the obduction of ophiolite complexes over the Precambrian Karakum and Altai-Tarim micro-continents and the accompanying development of nappe structures, north-verging under-thrusting of the Karakum and Altai-Tarim micro-continents below the Valerian-Beltau-Kurama arc, and to closure of the small back-arc basin between the latter two micro-continents via the South Gissar subduction zone (Fig. 3 - Late Permian) (Yakubchuk *et al.,* 2002).

On the Palaeo-Pacific Ocean margin, the subduction that had produced the Sayan-Transbaikal arc had expanded to produce the 3000 km long Selanga-Gobi-Khanka magmatic arc (Figs. 2 and 3). This coincided with remnants of the elongate Tuva-Mongol arc and its basement (the Tuva-Mongol terrane of Fig. 3) being dislocated by strike slip folding and telescoped to form the composite Amurian micro-continent, separated from the Siberian craton by the gulf-like Mongol-Okhotsk sea which was open to the north into the Palaeo-Pacific ocean. The Amurian micro-continent was composed of Lower Palaeozoic back-arc, fore-arc and volcanic rocks of the Tuva-Mongol arc, slivers of Meso- to Neoproterozoic basement metamorphics, separated by intra-arc suture related accretionary wedge sequences which include Late Neoproterozoic (Vendian) to Early Cambrian ophiolites. All of these have been welded by voluminous Late Carboniferous to Permian granites (Yakubchuk, 2005; Zonenshain *et al.,* 1990).

The Selanga-Gobi-Khanka magmatic arc extended from the palaeo-northern margins of the Siberian craton, around the shore of the Mongol-Okhotsk sea to the palaeo-eastern margin of the Amurian micro-continent, to the North China craton. It briefly overlapped with the last stages of the Kazakh-Mongol arc, with which it was subsequently juxtaposed by strike-slip faulting. Magmatic activity on the Selanga-Gobi-Khanka magmatic arc continued to the Middle Jurassic, and although the majority of its volcanic sequences have been eroded, widespread granites of the arc's root zone reflect its extent (Fig. 2) (Yakubchuk, 2005).

From the Carboniferous, and into the Triassic, the Mongol-Okhotsk sea (bordering section of the Selanga-Gobi-Khanka magmatic arc) progressively closed from palaeo-south to north in a scissor like fashion, with the intervening oceanic crust being mainly subducted to the west, below the Siberian craton (Lamb and Cox, 1998; Watanabe and Stein, 2000; Zonenshain *et al.,* 1990). Collision between the Siberian craton and the Amurian micro-continent was not finalised until the late Triassic to early Jurassic (Zonenshain *et al.,* 1990). This closure was accompanied by the approach and collision of the North China craton from the palaeo-east in the Permian, and its rotation and amalgamation with the Amurian micro-continent during the Mesozoic as the latter was sandwiched between the North China and Siberian cratons (Yakubchuk *et al.,* 2002; Zonenshain *et al.,* 1990). The approach and collision of the North China craton corresponded to the Triassic Indo-Sinian orogeny in East Asia. Subduction was subsequently focussed of along what is now the east coast of Asia and the transition to the Jurassic to Cretaceous Yanshanian orogeny in the region. The Yanshanian Orogeny resulted in the development of volcanic piles (Fig. 2) over the extinct Kazakh-Mongol and Selanga-Gobi-Khanka magmatic arcs (Yakubchuk, 2005).

A second major oroclinal structure was developed in what is now southeastern Siberia, Mongolia and northeast China,

Figure 3 (on facing page)**:** ***Palinspastic reconstruction of the Central Asian Orogenic Belt, showing selected major porphyry Cu-Au/Mo, related epithermal Au, and major orogenic Au deposits of the Tien Shan Mineral Belt.*** Modified and updated after Yakubchuk *et al.,* (2002) and in Seltmann *et al.,* (2004).

occurring as a mega- 'S' shaped structure, incorporating the Mongolian and Hingan oroclines shown on Fig. 2. This structure was largely a response to compression during the Triassic to Mid Jurassic Indo-Sinian and Yanshanian orogenic cycles as the North China and Siberian cratons converged, sandwiching the Amurian micro-continent and closing the Mongol-Okhotsk sea (the latter forming the Mongol-Okhotsk Suture Zone - MOSZ), and by sinistral offset of hundreds of kilometres along the Late Permian to Triassic Trans-Eurasian strike-slip fault (Fig. 2) (Yakubchuk, 2005).

Mesozoic to Cenozoic

Following late Palaeozoic tectonism, the Mesozoic was largely characterised by uplift, particularly in the Kazakh Orocline, and by the development of large dextral strike-slip fault zones with offsets of up to 70 to 100 km (Yakubchuk 2005). This strike-slip faulting may in part represent reactivated Palaeozoic structure, although the bulk of the dislocation was during the late Jurassic and Cretaceous, with some continuing to the present. In Kazakhstan and central Asia, these faults largely strike to the northwest, swinging to east-west in northwestern China, to northeast to northerly in Mongolia and northeastern China where displacements of from 100 to 700 km are estimated. Movement is dextral on the northwest set to the west, and sinistral in the northeast conjugate set in the east. This activity has been largely attributed to the amalgamation of the North China and Yangtze cratons and by continued compression between the rotating and converging Siberian and East Europe cratons and corresponds with the Jurassic to Cretaceous Yanshanian orogeny mentioned previously.

Intra-cratonic basins formed within central Asia during the Mesozoic to Cenozoic extension in three stages, namely the Late Triassic to Middle Jurassic, Late Jurassic to Eocene and Oligocene to Quaternary. The boundaries of these basins were influenced by the strike-slip faulting described in the previous paragraph (Yakubchuk *et al.,* 2002).

In the late Cenozoic the area was affected by the Alpine-Himalayan orogeny associated with the progressive Indo-Eurasian collision as Gondwana approached and the Tethys Ocean was closed (Yakubchuk *et al.,* 2002).

Distribution of Porphyry Cu-Au/Mo and Au Deposits

Within the Altaid and Transbaikal-Mongolian Orogenic Collages of central Eurasia, porphyry Cu-Au/Mo and epithermal gold deposits have been emplaced in magmatic arcs ranging in age from Ordovician to early Mesozoic, and from the Urals Mountains in the west to northeast China in the east. The key settings, which except where otherwise cited, are summarised as follows from Seltmann *et. al.,* 2004, and references cited therein.

Kipchak and Tuva-Mongol Arcs

The outboard Kipchak arc was developed marginal to the Palaeo-Tethys Ocean during the early Palaeozoic and is composed of segments with ensialic basement and others built on ensimatic precursors. Porphyry Cu and VHMS mineralisation were emplaced in ensimatic segments of the arc, localised within intra-arc basins that developed in response to stresses imposed by the rotation of the Siberian craton during the middle Ordovician. The best example is the 481 Ma *Bozshakol* Cu-Au porphyry deposit – see Table 1 for size and grade statistics (Yakubchuk *et al.,* 2002; Mutschler *et al.,* 2000).

Early Palaeozoic (Caledonian - Ordovician to Silurian) porphyry Cu-Mo and Mo-Cu mineralisation is exploited in the Altai-Sayan region of Russia, on the limbs of the West Sayan Orocline, as shown on Fig. 2. The best example is the *Sorsk* Mo-Cu deposit, located 300 km southwest of Krasnoyarsk (Pokalov, 1977), where the head grade in 1992 was 0.051% Mo, 0.06% Cu. Other porphyry Cu-Mo deposits within the Altai Sayan region, and which Zvezdov *et al.,* (1993) attribute to the Tuva-Mongol Arc, include *Aksug* and *Kyzyk-Chadyr.*

Urals-Zharma Arc

The Urals-Zharma (previously known as the Mugodzhar-Rudny Altai) and Kipchak arcs were initially contemporaneous, although the former continued to develop after the cessation of activity on the Kipchak arc. The remnants of this extensive volcanic belt are exposed in the Urals Mountains on the current eastern flanks of the Eastern Europe craton, and on the western margin of the Siberian craton. The arc overlies subduction zones that consumed oceanic crust of both the Khanty-Mansi and Sakmara back-arc basins and is largely developed on ensimatic basement.

The arc is most notable for the large VHMS deposits it hosts in the Urals, although it also has associated porphyry Au mineralisation as at the ~380 Ma *Yubileinoe* porphyry Au deposit (Table 1) in Kazakhstan Urals, and igneous related orogenic gold deposits.

Kazakh-Mongol Arc

The middle to late Palaeozoic Kazakh-Mongol arc was developed over, and seaward of, the extinct Kipchak arc, also marginal to the Palaeo-Tethys Ocean. During its development the arc continued to migrate sea-ward, such that in places, as in southern Kazakhstan, there are two belts of volcanics, an earlier 'Devonian' and a younger Upper Palaeozoic 'Balkhash-Ili' zone which is a further 300 km toward the ocean. Both segments host gold rich porphyry and skarn mineralisation, although the former are more gold rich and smaller.

The most significant porphyry style deposit in the 'Devonian' Middle Palaeozoic segment of the arc is the Siluro-Devonian 410 Ma *Nurkazgan* Cu-Au deposit in Kazakhstan – (Table 1). The Middle Palaeozoic segment also hosts granite related gold deposits.

The Upper Palaeozoic 'Balkhash-Ili' zone contains a number of large tonnage porphyry deposits, including *Kounrad* (330 Ma), *Aktogai* (~320 Ma), *Aidarly* (~320 Ma), *Kyzilkia* (~320 Ma), *Koksai*, and the *Sayak skarn* (~320 Ma)*,* all of which are in Kazakhstan (Table 1).

Further to the palaeo-north, still within the Kazakh-Mongol arc is the giant *Oyu Tolgoi* Cu-Au deposit in southern Mongolia, which has been dated at 372 to 370 Ma (Late-

Devonian). The Early-Carboniferous *Tsagaan Suvarga* Cu-Mo and *Kharmagtai* Au-Cu deposits in southern Mongolia, and *Tuwu-Yandong* Cu-Au in eastern Xinjiang, China (dated at 330 Ma), are also within the Kazakh-Mongol arc. The two former deposits are located just to the north of Oyu Tolgoi, while Tuwu-Yandong lies between this Mongolian cluster and the deposits in Kazakhstan described in the previous paragraph.

Valerianov-Beltau-Kurama Arc

This arc is currently concealed by thick younger cover over much of its length. It was developed above an ensialic basement on the western margin of the earlier and extinct Kipchak arc and was active through several magmatic episodes in the Devonian but predominantly in the Early to Middle Carboniferous. Subduction associated with this arc consumed the oceanic crust of the Khanty-Mansi back-arc basin. Magmatic activity and porphyry-style mineralisation were broadly contemporaneous with the 'Balkhash-Ili' zone of the Kazakh-Mongol arc to the east.

The arc hosts the giant 320 to 290 Ma *Kal'makyr-Dalnee* and the much smaller *Benqala* porphyry Cu-Au systems in Uzbekistan and Kazakhstan respectively (Table 1). In addition to these porphyry deposits, the Almalyk district which includes the Kal'makyr-Dalnee porphyry system, also embraces the *Kochbulak* and *Kyzylalma* volcanic associated epithermal/stockwork deposits, both of which have been dated at 290 to 280 Ma.

Accretionary Complexes

Two styles of accretionary complex have been described within the Altaid Orogenic Collage. The first of these is principally a growing complex, generally ocean facing related to magmatic arc development. The second is found in sutured back-arc and intra-arc basins and marks the final stages after arc-arc and arc-basement block collision.

No significant porphyry style deposits are found within the accretionary complexes of the sutured back-arc and intra-arc basins, although they do host large and giant, non-arc related orogenic gold deposits within fold and thrust belts. The most significant of these are found in Uzbekistan, Kyrgyzstan and Kazakhstan and include the 286 Ma *Muruntau*. Other major orogenic gold deposits in the region (Fig. 20) have been dated at ~270 to 260 Ma. These are believed to be temporally and spatially related to syntectonic granitoid intrusions into metamorphosed Proterozoic and Palaeozoic sediments.

Pacific Margin

Subduction on the margin of the Palaeo-Pacific ocean commenced during the Carboniferous and became more strongly established in the Permian and into the Mesozoic with the development first of the limited Sayan-Transbaikal and then of the extensive Selanga-Gobi-Khanka magmatic arc. Porphyry style mineralisation was developed along this margin during the Permian and into the Triassic, both on the edge of the Siberian craton as the Mongol-Okhotsk Sea (an embayment of the Palaeo-Pacific coast) progressively closed in a scissors like fashion, and on the Amurian micro-continent which had been constructed from the telescoped Tuva-Mongol arc and associated terranes (Zonenshain *et al.,* 1990, Nie *et al.,* 2004).

The 292 Ma *Duobaoshan* Cu-Au and adjacent *Tongshan* Cu-Mo porphyry systems in Inner Mongolia, China, were emplaced during the waning stages of the Kazakh-Mongol arc, near its overlap with the Selanga-Gobi-Khanka arc on the Pacific margin. The 240 Ma *Erdenet* Cu-Mo deposit was formed in the Selanga-Gobi-Khanka magmatic arc on the northern limb of the Mongolian Orocline in Mongolia. A few hundred kilometres to the north of Erdenet, in the same arc in southern Siberia, Triassic porphyry stockwork (and related vein-type) Mo-W mineralisation is exploited in the *Dzhida ore field.*

The younger 184 Ma *Wunugetushan* Cu-Mo orebody in Inner Mongolia, China was emplaced during the closing stages of the Selanga-Gobi-Khanka magmatic arc on the southern arm of the Mongolian Orocline (Zonenshain *et al.,* 1990; Gerel *et al.,* 2005; Mutschler *et al.,* 2000; Qin *et al.,* 1997). Jurassic aged porphyry-style Mo mineralisation is mined at the *Zhireken* deposit (head grade 0.083% Mo in 1992) immediately to the north in southern Siberia. This deposit is part of the established Au-Mo district that includes the Baley-Taseyev epithermal gold district (Pokalov, 1977).

Descriptions of Significant Porphyry Cu-Au/Mo Deposits

The following summaries describe selected examples of the porphyry Cu-Au/Mo deposits of central Eurasia, representing the different ages and styles of mineralisation encountered across the continent from the Urals Mountains in Russia to near the Pacific Ocean coast in northeast China.

Bozshakol, Kazakhstan

The Bozshakol porphyry Cu-Au deposit is located near the town of Eqibastuz in northeastern Kazakhstan, approximately 1000 km north of Almaty. A resource of >1 Gt @ 0.67% Cu, 0.05g/t Au has been published (Mutschler *et al.,* 2000) while the proven reserves have been quoted as 176.2 Mt @ 0.72% Cu, 0.014% Mo, 0.28 g/t Au (Kudryavtsev, 1996). The deposit was emplaced in an ensimatic segment of the Kipchak magmatic arc during the during the Late Cambrian to Early Ordovician at approximately 481 Ma.

Geology

The Bozshakol district straddles an east to ENE trending anticline, which is on the limb of a larger regional anticlinorium that deforms a sequence of predominantly Lower to Middle Cambrian volcanogenic rocks of calc-alkaline to sub-alkaline composition, typical of an island arc setting. Some 5 to 15 km to the south of the ore deposit, the core of the anticlinorium exposes underlying late Neoproterozoic (Vendian) to Cambrian rocks of an ophiolite association and Proterozoic metamorphics. The Cambrian volcanogenic rocks are cut by a progression of Cambrian to Ordovician intrusives, ranging from gabbros through tonalite, granite and syenite and finally gabbro again. Mineralisation is associated with Middle Cambrian granitoids of this suite, mainly tonalites, with the bulk of the ore being hosted by the volcanic wallrocks to the intrusives. The volcanogenic and intrusive rocks are overlain by post-ore Ordovician sediments (Kudryavtsev, 1996).

Locally, the lowest sections of the Cambrian volcanogenic sequence are exposed in the core of the Bozshakol anticline, from the western flank of the orebody, to approximately 4 km to the northeast of the deposit. The sequence commences with 250 to 300 m of greenish-grey sandstone, siliceous siltstone, tuff and dacitic lavas with thin interlayers of pale jasper and andesitic flows. These are overlain by a 500 to 600 m thick unit, noted for the predominance of andesitic lavas and tuffs which host the northern section of the East Bozshakol deposit. The succeeding unit, also of Lower to Middle Cambrian age, comprises a further 1000 m of basaltic rocks that outcrop within the district as folded inliers (Kudryavtsev, 1996).

On the northern limb of the anticline the sequence is dominated by an up to 1500 m thick sedimentary-volcanogenic package that overlies the units described above. The volcanic suite of this package is composed predominantly of amygdaloidal and massive hornblende-pyroxene basaltic rocks. These are intercalated with compositionally similar layers of litho- and crystallo-clastic tuffs and thin bands of gritstone, sandstone, siltstone and siliceous rocks. The rocks of this limb have been simply folded, with dips averaging 40 to 45° (Kudryavtsev, 1996).

Intrusive rocks are areally less extensive than the volcano-sedimentary intruded sequence and have been subdivided into four groupings, as follows: i). an initial Middle Cambrian complex of gabbro and diorite occurring as small bodies in the central and eastern part of the district; ii). a spatially separated, closely succeeding Middle Cambrian Bozshakol granitic complex, exposed at surface as quartz-diorite and tonalite stocks, including the main Bozshakol intrusion and others east and south of the deposit, as well as apophyses of porphyritic tonalite, dykes of tonalite porphyry and the more deep seated Dalnezapadny tonalite intersected in drilling at depths of 300 to 400 m; iii). a Middle Ordovician syenite complex, which includes the Ashchikol intrusion and a series of associated scattered dykes to its west and east; iv). an Upper Ordovician sub-

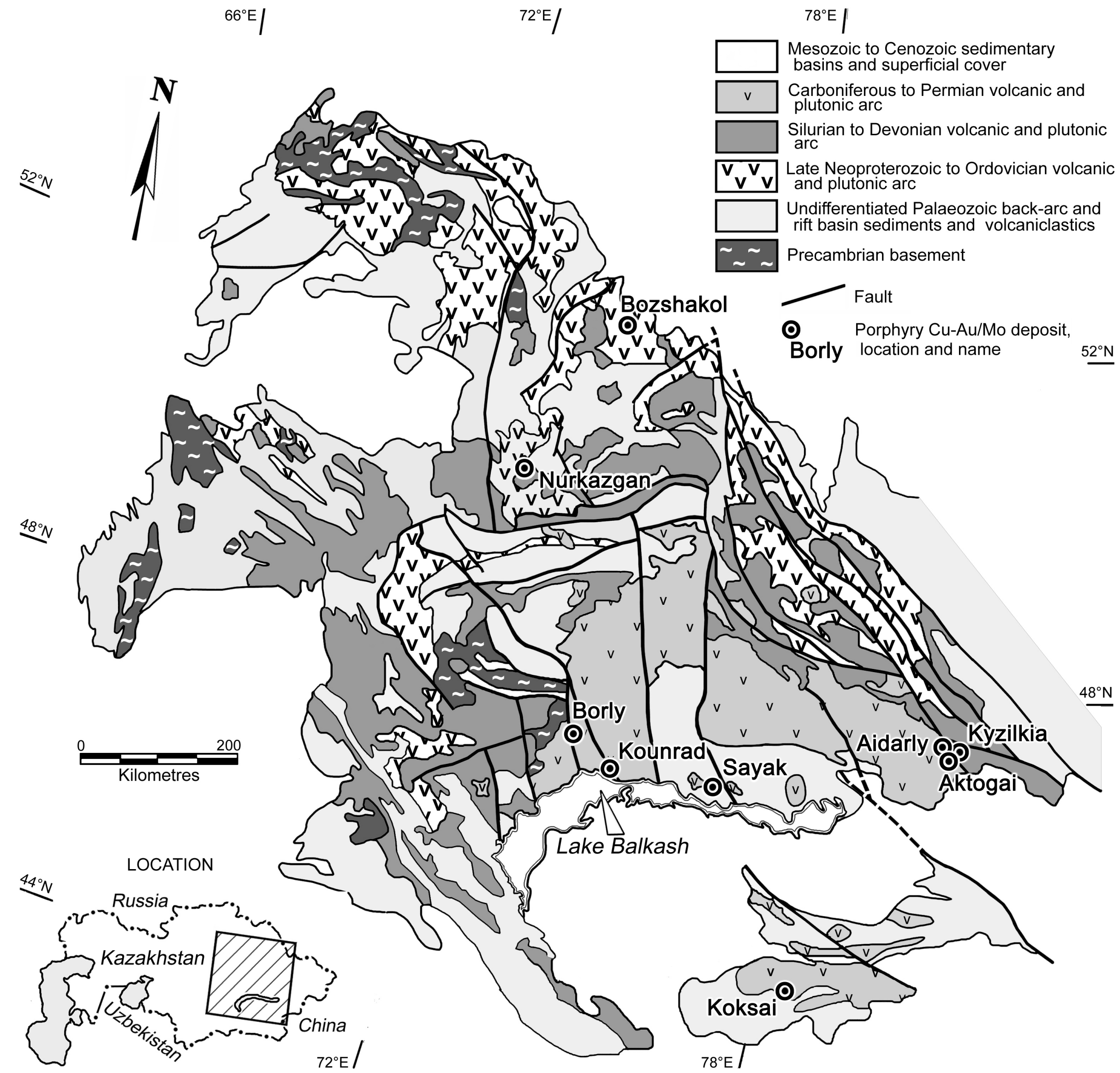


Figure 4: ***Geological summary of eastern Kazakhstan showing the structure and key porphyry Cu-Au/Mo deposits.*** After Heinhorst *et al.,* (2000); Kudryavtsev, 1996.

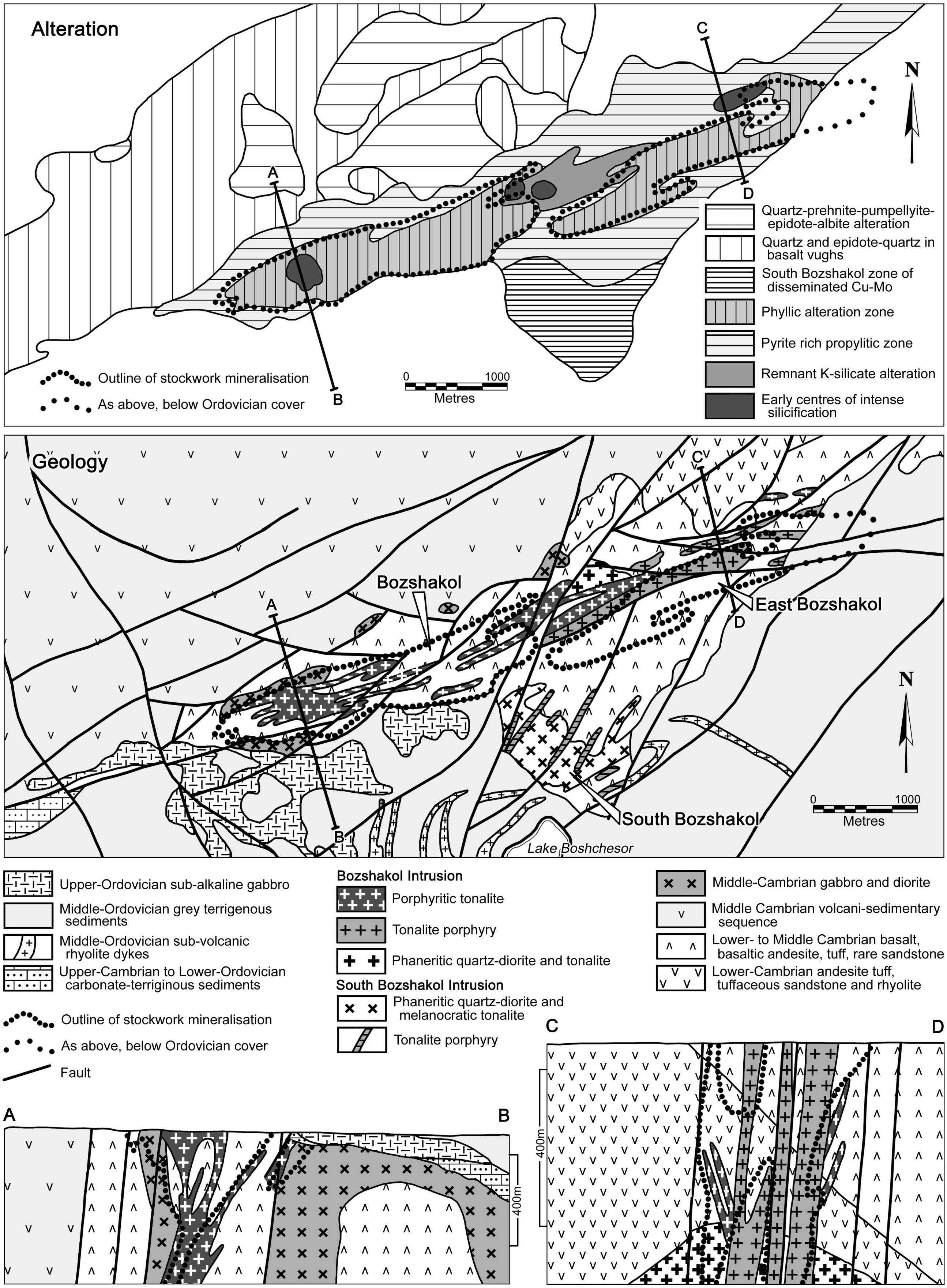


Figure 5: ***Geology, alteration and mineralisation at the Bozshakol porphyry Cu-Au deposit in northern Kazakhstan.*** The top diagram illustrates the alteration pattern surrounding and overlapping the ore deposit. The middle plan, covering the same area, shows the geology of the deposit and shares a common legend with the two representatiove cross sections, A-B through the main Bozshakol deposit and C-D through East Bozshakol. The two sections are at different scales and are located on both of the plans. The outline of the "commercial" stockwork zone is shown on both plans and sections as a common reference. Summarised from Kudryavtsev, (1996).

alkaline gabbro complex, known as the Southwestern Intrusive Sheet. The youngest magmatic activity in the district is represented by rhyolite sills within Middle Ordovician sediments (Kudryavtsev, 1996).

The core intrusive within the district is the Bozshakol Intrusion. Gravity data indicates it to be a sheet-like mass that can be traced over a distance of 7 km long by 0.5 to 0.7 km wide, underlying a corridor of outcropping, isolated granitoid stocks, dykes and apophyses, the largest of which separates the main Bozshakol and the East Bozshakol orebodies. The early phases of the Bozshakol Intrusion are represented by fine-grained hornblende diorite and diorite porphyry which cut Lower to Middle Cambrian volcanic rocks in the western part of the Bozshakol deposit. These early phases are cut in turn by medium- to coarse-grained quartz diorite and tonalite, and subsequently by porphyritic tonalite, the first of the ore related porphyry bodies (Kudryavtsev, 1996).

The porphyritic tonalite of the first mineralising phase is composed of up to 80% phenocrysts, most of plagioclase, set within a cryptic groundmass. In the western part of the Bozshakol deposit, it occurs as a steeply plunging stock some 300 m in diameter, with numerous faulted offsets across a northeast trending fracture set. In the East Bozshakol deposit it occurs as several lenticular dyke-like bodies (Kudryavtsev, 1996).

The second phase of ore-related granitic rocks are represented as tonalite porphyry dykes in the eastern part of the deposit. It differs from the earlier phase in that it has lesser phenocrysts - 30 to 40%, of which idiomorphic quartz is particularly prominent - in a fine-grained to crypto-felsic groundmass. This phase intrudes Lower to Middle Cambrian country rocks, but has only rarely been observed cutting Middle Cambrian lithologies. In the southeastern parts of the district, granitic rocks of the Bozshakol Intrusive are overlain by sediments containing Late Cambrian to Early Ordovician fossil fragments. In addition, grit bands within Middle Ordovician terrigenous sediments in the district contain mineralised pebbles of the ore bearing granitoids. Rb-Sr dating of the phaneritic tonalite yielded an age of 481 ± 23 Ma. These observations all suggest a latest Cambrian to Early Ordovician age of intrusion and mineralisation (Kudryavtsev, 1996).

The unconformably overlying Middle Ordovician sequence is largely restricted to the southeast of the deposit and is composed of grey carbonate–terrigenous sediments with lenses and horizons of gritstone, siliceous siltstone, and shale at the base. It partially covers the ore on the southern margin of the deposit and has only been affected by post ore hydrothermal alteration (Kudryavtsev, 1996).

Alteration and Mineralisation

The emplacement of the mineralised intrusives and the distribution of ore are controlled by a northeast trending fault set. A second, northwest striking set offset the mineralised system and divide it into four blocks – the eastern, central, western and far-western blocks. Ore grade mineralisation is restricted to the central block, which includes the main Bozshakol and South Bozshakol deposits. The eastern block only contains un-economic mineralisation within Lower Cambrian andesite and andesitic tuff. Minor lenses of ore grade intersected by drilling in the western block are pinched out, fault dislocated extremities of the main orebody in the central block. The far-western block contains disseminated Zn-Cu mineralisation within pyritic, propylitic altered hosts, principally Lower to Middle Cambrian mafic volcanic rocks. Overall, the Cu-Mo mineralisation is localised in altered volcanics adjacent to dyke-like apophyses from deeper intrusions of porphyritic tonalite and tonalite porphyry. It passes outwards into zones characterised by base metal enrichment and siderophile geochemical associations. The tonalite porphyry dykes are mineralised to a much lesser extent, while at depth some ore has also been found within phaneritic granite (Kudryavtsev, 1996).

The mineralisation in both the main Bozshakol orebody and at East Bozshakol represent an elongate stockwork zone with a steep, mostly northerly dip, and a northeast plunge. It lenses out into a series of fingers on the lateral (northeast and southwest) extremities and down dip, related to both faulting and the distribution of dykes (Fig. 5). The maximum length of the main orebody is 3 km, with a thickness of near 285 m at its widest point, and a down-dip extent of over 600 m. Bozshakol South has been traced for 425 m along strike, has a thickness of 33 m and persists down dip for 120 m. The mineralisation at East Bozshakol extends over a length of from 1.2 to 1.5 km, is 400 to 500 m wide and has a grade of 0.3 to 0.35% Cu (Kudryavtsev, 1996; Seltmann *et al.,* 2004 and sources quoted therein).

Ore grade mineralisation is located within the inner sections of the alteration system, largely associated with a phyllic assemblage of quartz-sericite-carbonate-chlorite in the volcanic hosts and by quartz-sericite within granitic rocks. Dykes of tonalite porphyry and adjacent narrow zones near their contacts have been affected by quartz-hydromica argillic alteration. However, while phyllic alteration dominates, all of the stockworks, particularly on their northern margins, show evidence of a biotite (potassic) phase. Potassic alteration is most marked in the central portions of the system, focused on the granitoid intrusions (Fig. 5), where K feldspar pseudomorphically replaces plagioclase within the granitoids, and forms veins and veinlets accompanied by quartz and less frequently by biotite. Fragments of this style of alteration are found within intra-ore hydrothermal breccias (Kudryavtsev, 1996).

These central zones, which form the elongate core of the mineralised system, are surrounded by shells of biotite enrichment and by a pyritised propylitic halo. Weak biotite alteration has been observed in Cambrian volcanics as much as 1 km distant from the orebody. Quartz-chlorite altered volcanics with abundant veinlets and disseminations of pyrite are developed closer to the orebody, while actinolite bearing varieties are localised closest to the intrusive contacts. These manifestation of propylitisation form a halo that is 6.5 km long and ranges from 0.4 to 1 km wide on the western part of the mineralised system, is up to 700 m wide in the east and 2.2 km wide in the central sections (Kudryavtsev, 1996).

The principal hypogene mineral assemblage comprises pyrite and chalcopyrite with accessory magnetite, molybdenite and sphalerite, and rare galena, marcasite, maghemite, mushketovite, martite, bornite, hematite, tetrahedrite, pyrrhotite, pentlandite, cubanite and other metallic minerals. The initial potassic alteration phase resulted in assemblages, listed in order of formation, of hematite-quartz, biotite-magnetite, pyrrhotite-chalcopyrite-pyrite, chalcopyrite with prehnite and molybdenite-chalcopyrite. The subsequent phyllic leaching produced pyrite, pyrite-molybdenite, pyrite-chalcopyrite-molybdenite, chalcopyrite-sphalerite and chalcopyrite-galena. In the western part of the deposit, cobalt, nickel and platinoid minerals and early gold are widely associated with the pyrrhotite-chalcopyrite assemblage. In addition, the chalcopyrite-sphalerite and chalcopyrite-galena associations contain electrum, tellurides and silver minerals. Post ore alteration minerals comprises quartz, zeolite and quartz-calcite veinlets (Kudryavtsev, 1996, and sources quoted therein).

The lower grade East Bozshakol mineralisation has a simpler suite of minerals, predominantly composed of pyrite, chalcopyrite, magnetite and molybdenite, with accessory hematite, martite, mushketovite, sphalerite, galena, tetrahedrite and pyrrhotite, and rare maghemite, barite, marcasite, and native gold and silver veinlets (Kudryavtsev, 1996, and sources quoted therein).

Fluid inclusion studies indicate temperatures of formation from 380 to 100°C, commencing with the higher temperatures typical of quartz-K feldspar alteration (380 to 320°C) and quartz-sulphide veining (320 to 180°C). The quartz-polysulphide mineralisation is characterised by temperatures of 220 to 100°C, while post ore veinlets were formed at 200 to 80°C (Kudryavtsev, 1996).

The upper 5 to 54 m of the orebody have been subjected to oxidation producing malachite-kaolinite-atacamite and goethite-malachite-clay assemblages. Over sections of the orebody, the zone of oxidation has been subjected to leaching to depths of as much as 35 m, to produce underlying supergene enrichment with a chalcanthite-chalcopyrite-covellite mineralogy over vertical thicknesses of from 5 to 60 m. This supergene enrichment was most intensely developed in the upper sections of the main Bozshakol ore deposit. Palaeo-supergene enrichment from the Cambrian is also recognised, preserved below the Late Cambrian to Ordovician cover on the south of the ore deposit, typified by the presence of barite. The next phase of supergene enrichment, which is only poorly developed, is of Mesozoic age and is characterised by the development of chalcocite and covellite veinlets (Kudryavtsev, 1996, and sources quoted therein).

Andash and Taldy Bulak, Kyrgyzstan

A group of gold rich, Ordovician age, porphyry related copper deposits define a 30 km long mineralised corridor in northern Kyrgyzstan (Fig. 6), approximately 120 km to the southwest of the capital, Bishkek. The principal deposits include porphyry style mineralisation at Taldy Bulak, Andash and Tokhtonysai and skarn ores at Aktash (Nikonorovet al., 2000; Jenchuraeva *et al.,* 2005). All are developed within rocks formed in the Lower Palaeozoic

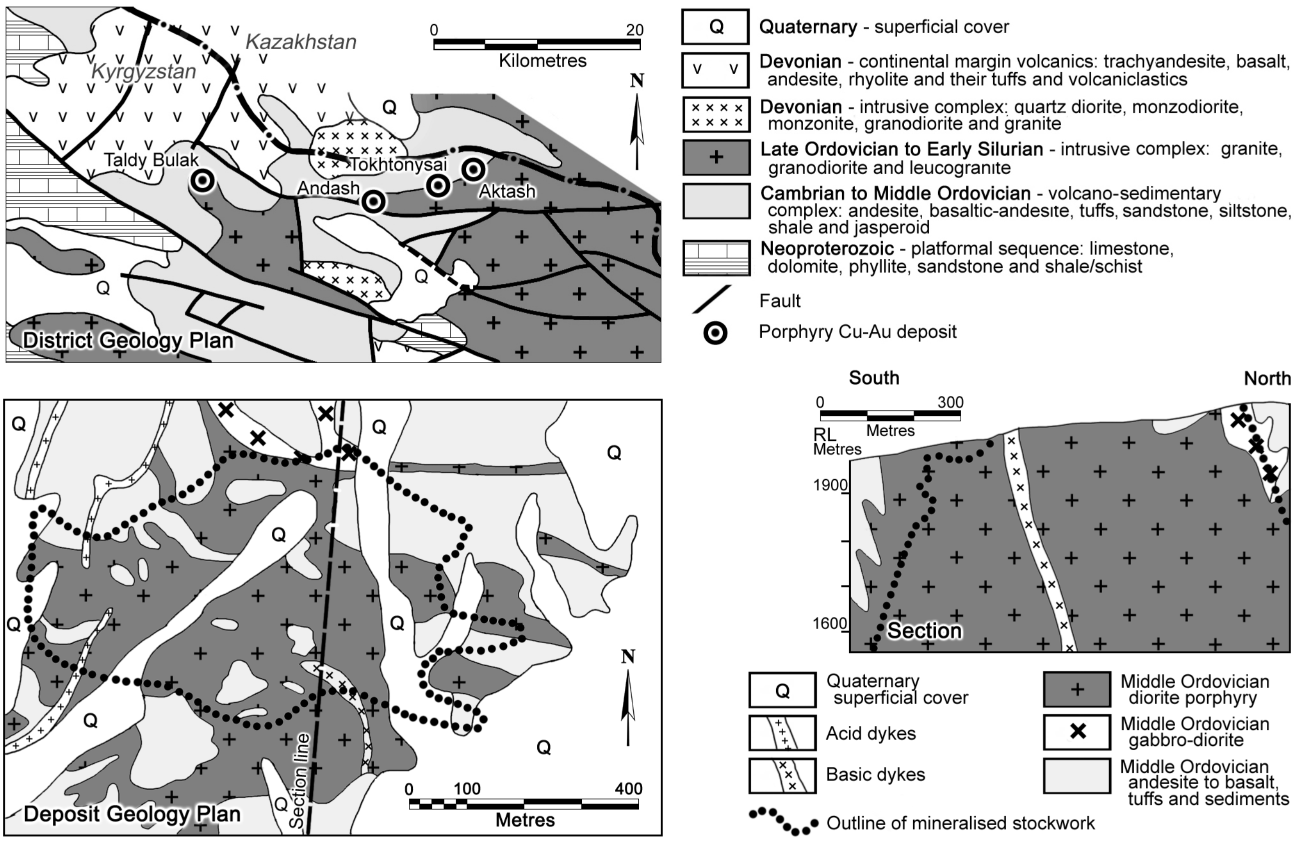


Figure 6: ***District scale geological plan showing the location of the Taldy Bulak, Andash, Tokhtonysai porphyry Cu-Au and Aktash skarn Cu-Au deposits (top) and a deposit scale geological plan (bottom left) and cross section (bottom right - location on deposit geology plan) through the Taldy Bulak deposit.*** After Jenchuraeva *et al.,* (2005).

Kipchak magmatic arc (Fig. 3), and are associated with Middle Ordovician diorite to monzodiorite porphyries which intrude Late Cambrian to Middle Ordovician island arc terriginous volcanogenic sequences (Seltmann *et al.,* 2004; Jenchuraeva, 1997).

Taldy Bulak, which is the largest of the group, is often confused with Taldybulak Levoberezhny (described later) in the available literature and on the web. It is quoted by Mutschler *et al.,* (2000) as containing a resource of 540 Mt @ 0.27% Cu, 0.5 g/t Au, 0.008% Mo, based on data sourced from the Metal Mining Agency of Japan (Kamitani and Naito, 1998; Hedenquist and Daneshfar, 2003). Mineralisation is predominantly hosted by a stock of Middle Ordovician diorite porphyry developed on the margin of a more extensive Late-Ordovician to Early-Silurian granite-granodiorite-leucogranite complex which intrudes a Late Cambrian to Middle Ordovician island arc sequence that locally comprises shale, siltstone, sandstone, conglomerates, tuffs and Middle Ordovician porphyritic andesite and basaltic-andesite. This latter sequence overlies a basement of Neoproterozoic platformal carbonate, sandstone, phyllite and shale, and is respectively overlain and intruded by Devonian basalt, andesite, rhyolite, tuffs and volcaniclastics and an intrusive complex of quartz diorite, monzodiorite, granodiorite and granite of a similar Devonian age.

The mineralised stock covers an area of approximately 1200x800 m at surface and comprises 50 to 70% plagioclase, 15% mafic minerals and 15% quartz. It has a complex shape, with an irregular contact characterised by numerous embayments and large xenoliths of the surrounding country-rock. The dense xenolithic zone near the outer contact resembles a breccia with a diorite porphyry matrix. The diorite becomes finer grained and more porphyritic in the vicinity of the xenolith zone where it also tends to have a higher gold grade. The stock includes an early phase, dark-grey gabbro-diorite and is cut by a series of late acid and basic dykes.

The main mineralisation is almost completely confined to within the diorite porphyry stock, occupying approximately 75% of its surface exposure, and is accompanied by dense fracturing and intense alteration. The fracturing, which reaches a density of as much as 150 to 200 per metre, is healed by grey quartz which forms five main, steeply dipping (70-90^0) mineralised veins sets, each with a differing trend direction, namely, 32^0, 70^0, 90^0, 140^0 and 170^0. The best mineralised set trends east-west. The veins vary from 0.5 to 25 mm in thickness.

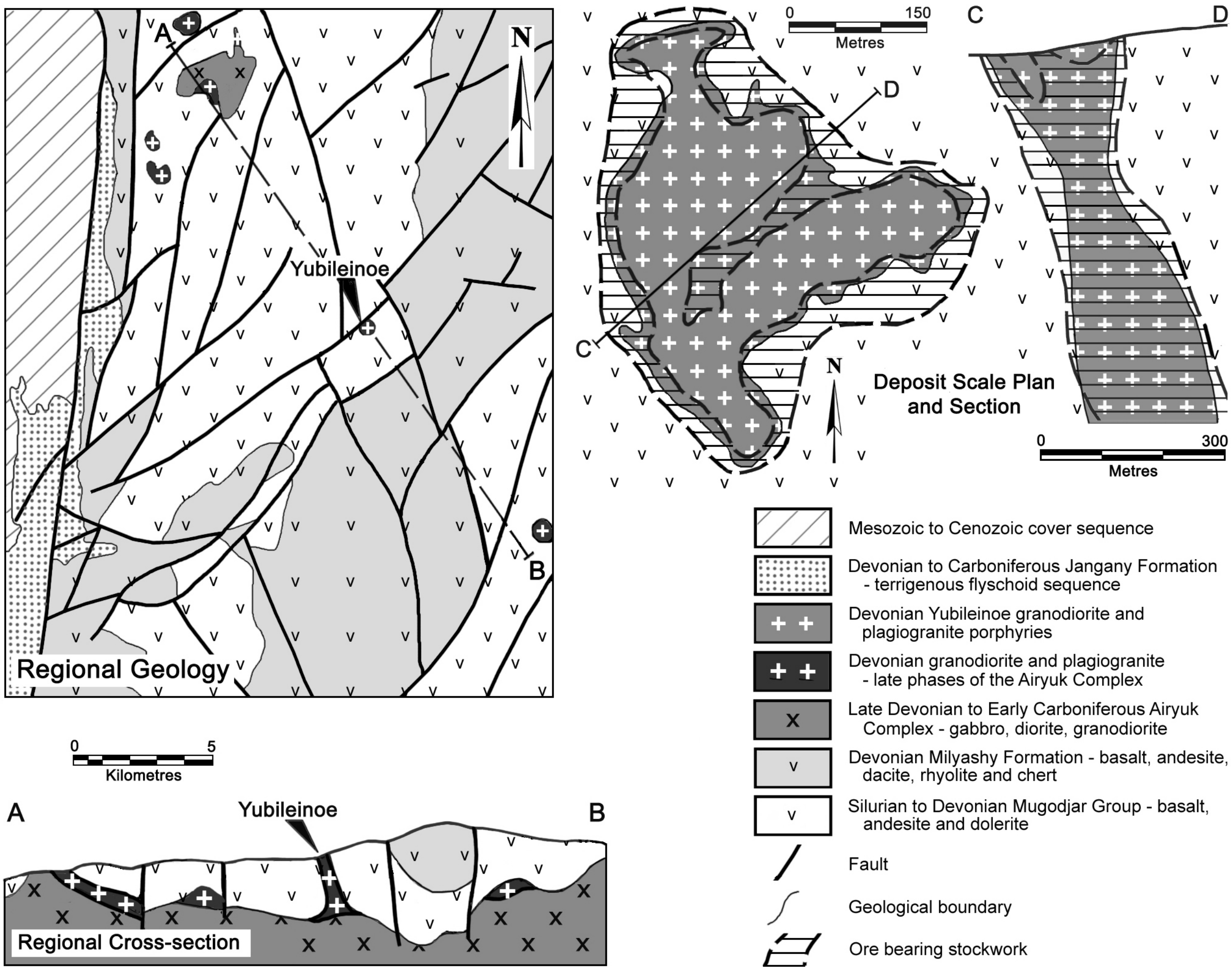


Figure 7: ***The Yubileinoe porphyry Au (-Cu) deposit in north-western Kazakhstan.*** The plan on the top left illustrates the regional scale geological setting, and the location of the stylised cross section A-B on the bottom left. The diagrams on the top right shows the outline of the mineralised intrusive at the Yubileinoe deposit, the outline of the ore bearing stockwork and the location of the generalised southwest-northeast cross section C-D through the deposit. After Shatov *et al.,* (2003) and Seltmann *et al.,* (2004).

The orebody has a general elliptical shape, defining an overall mineralised envelope with dimensions of 1100x700 m, enclosing three east-west trending lensoid developments of higher grade ore, comprising a northern 200x60 m, central 1200x25 to 170 m and southern 700x140 m zone. Mineralisation has been traced to a depth of 500 m below the surface.

At *Andash,* 15 km to the east of Taldy Bulak, similar mineralisation is present as a flat dipping, 400 x 200 m stockwork within a granodiorite to diorite porphyry host, associated with pipe- to lens-like explosive breccia zones which have been silicified to form "quartzose metasomatites". The principal alteration types recorded include quartz-feldspar, quartz-tourmaline, propylitic, phyllic and argillic. Copper mineralisation is generally related to zones of quartz-sericite-chlorite alteration, while gold is associated with quartz-tourmaline veining and argillic altered zones. The principal metallic minerals include pyrite, chalcopyrite, magnetite and hematite with minor sphalerite, tetrahedrite, galena and pyrrhotite. Gold is closely associated with pyrite, and occurs at grades of around 2.6 g/t Au with 0.4% Cu (Seltmann, *et al.,* 2004).

Nurkazgan (or Samarka), Kazakhstan

The Nurkazgan porphyry Cu-Au deposit is located in northeastern Kazakhstan, 240 km southwest of Bozshakol. It was emplaced during the Late Silurian to Early Devonian (410 Ma), in the 'Devonian' segment of the Kazakh-Mongol magmatic arc, and has a resource of 65 tonnes of Au and 1.5 Mt of Cu at grades of 1 to 3% (averaging 1.2%) Cu and 0.4 to 1 g/t Au. The ore deposit is hosted by monzonite to granodiorite porphyries of the Turkulamsky Massif intruding wall rocks of the Late Silurian to Devonian Zharsorskaya suite that comprise: i). a lower unit of andesitic to basaltic agglomeratic tuffs, lavas and auto-magmatic breccias with rare interbeds of andesitic porphyry, tuffs, tuffaceous siltstones and tuffites; ii). an upper sequence of andesitic to dacitic tuffites, tuffaceous conglomerate-breccias, tuffs and lavas with lenses of tuffaceous sandstones and conglomerates (Seltmann *et al.,* 2004).

The mineralised intrusives and country rocks are overlain by units of the terriginous, post-ore, Middle Devonian Konyrskaya suite, comprising red tuffaceous sandstones with lenses of boulder to pebble conglomerate, grits and siltstones. Mineralisation took place as: i), initial porphyry-style Cu, accompanying an early monzonite and ii), an overprinting, high grade, high sulphidation Cu-Au phase related to the intrusion of a late stage porphyritic diorite and numerous associated breccia pipes. The early porphyry-style mineralisation is predominantly composed of disseminations and stockworks of chalcopyrite, pyrite and molybdenite with grades of 0.3 to 0.5% Cu. It is accompanied by potassic alteration comprising K feldspar and biotite, and is surrounded by a propylitic halo characterised by chlorite and epidote. The overprinting high sulphidation phase, and its associated porphyritic diorite and breccia pipes, are localised in the core of the earlier monzonite intrusive and porphyry mineralisation. This phase is represented by a chalcocite-covellite-tetrahedrite assemblage with sericite-chlorite-carbonate alteration and has grades of >1 to 1.5%, locally to 3% Cu, and 1 g/t Au. The high grade zone has an areal extent of at least 600 x 600 m and is restricted to depths of more than 200 to 300 m below the surface. At 700 m it has contracted to a steep 20 to 30 m wide band averaging 3% Cu. Mineable high grade ore has been delineated to a depths of 1400 m (Seltmann *et al.,* 2004).

Yubileinoe, Kazakhstan

The Yubileinoe deposit is located in western Kazakhstan, some 200 km southeast of the city of Aqtobe. It lies within the Magnitogorsk - Mugodzhar zone of the Urals, just east of the major north-south trending West Mugodzhar deep regional fault, and was emplaced within the ensimatic Urals-Zharma magmatic arc at approximately 380 Ma in the Middle Devonian (Fig. 3). The host porphyry was intruded at the intersection of the Aulinskaya and Treshchinnaya faults which strike northeast and northwest respectively. It is a small to medium sized Au rich porphyry-style deposit with accompanying low grade Cu (Table 1).

Mineralisation is associated with a 250 to 300 m diameter stock of plagiogranite porphyry. This stock is assumed to be an apophysis of a local concealed cupola of gabbrodiorite/granodiorite that in turn is part of the larger Late Devonian to Early Carboniferous Airyuk Intrusive Complex (Fig. 7). The mineralised stock was intruded into a sequence of Siluro-Devonian volcanics and sediments that are part of the tholeiitic mafic volcanic dominated Mugodzhar Group which is overlain by the Mialyshy, Qundyzdy and Janghany Formations that comprise island arc volcanics and sediments (Shatov *et al.,* 2003).

Ore mineralisation accompanies a stockwork developed within both the plagiogranite porphyry and its mafic volcanic wall rocks (Fig. 7), and has been drill tested to more than 600 m below surface where it is still open at depth. Skarn, potassic and phyllic alteration are present within the orebody, although the latter predominates and is directly related to the stockwork and disseminated Au-Cu porphyry mineralisation. The principal metallic minerals are magnetite, pyrite, chalcopyrite, arsenopyrite, tetrahedrite, stibnite and native gold, with minor sphalerite, galena, scheelite, molybdenite, bornite, hematite (martite), rutile, ilmenite, anatase, and cinnabar.

Four ore zones have been delineated within the larger zone of stockwork mineralisation shown on Fig. 7. The Central orebody, located within the core of the stock, is the largest and the richest of the four, with grades of from 5 to 10 g/t Au. The Western orebody lies along section of the western outer margin of the plagiogranite stock. It is 80 to 240 m long and 10 to 25 m thick, with grades ranging from 3.5 to 6.7 g/t Au, and has been traced to a depth of over 110 m. The Northern orebody is hosted by the wallrock volcanics, and follows the northeastern contact of the stock. It has surface dimensions of 80 x 16 to 37 m and has been traced to a depth of 100 m, with from 3.4 to 8 g/t Au. The Southeastern orebody straddles the contact of the plagiogranite porphyry stock, and carries 3.8 to 11 g/t Au. It is 60 to 120 m in length and from 10 to 121 m in thickness. The average grade is 4 to 5 g/t Au, 0.42% Cu and 65 g/t Ag (Seltmann *et al.,* 2004, and references cited therein).

Taldy Bulak Levoberezhny, Kyrgyzstan

The Taldy Bulak Levoberezhny deposit is located in northern Kyrgyzstan, approximately 120 km to the southeast of the capital, Bishkek. The deposit is a granitoid-related mesothermal vein/stockwork associated with Devonian diorite porphyry and Carboniferous sub-alkaline diorite-monzonite porphyry dyke swarms. While it has some porphyry style characterisitcs, it has not been conclusively classified as a porphyry style deposit. It lies within the Boordu-Taldy Bulak zone of the western Aktyuz-Boordu Metallogenic Province. The province is characterised by Baikalian and Caledonian Orogeny structures, while Palaeoproterozoic basement is intruded by Meso- to Neoproterozoic igneous rocks. The Boordu-Taldy Bulak zone comprises a 20 x 30 km diameter volcanic dome-like structure, the central point of which is occupied by the deeply eroded core of a Palaeozoic volcanic edifice. Within and peripheral to this structure, Palaeoproterozoic metamorphics and Lower Palaeozoic volcano-sedimentary rocks are overlain by Devonian, Carboniferous and Lower Permian volcanic and volcano-sedimentary complexes. Throughout the domal structure, there are abundant Middle to Late Palaeozoic mafic to felsic subvolcanic intrusions, occurring as dykes, sills and stocks controlled by deep-rooted faults, representing the root zones of the various overlying volcanic sequences of the Kipchak and Kazakh-Mongol magmatic arcs. Late Tertiary dolerite dykes cut all of the preceding rocks (Chisholm, 2003).

The Taldy Bulak Levoberezhny deposit is located on the margin of a folded and deeply eroded 2 x 4.5 km horst of Palaeoproterozoic basement, cut by sub-volcanic intrusive rocks. The principal lithologies of the basement are a greenschist, amphibolite and mafic migmatite suite overlain by felsic gneiss and mica schist. The mafic and felsic Palaeoproterozoic basement suites are separated by a tectonic contact and are intruded by a sub-volcanic complex of Devonian to Carboniferous diorite to monzonites, which are considered to be almost synchronous with, and genetically and spatially associated with the Au-Cu mineralisation. The area is structurally complex with at least five generations of faulting and large 'crush zones' of brecciated material that dip at 30 to 40º and have focussed mineralisation. These 'crush zones' are believed to be original thrusts which have been reactivated by shearing and/or by subsequent hydrothermal activity (Chisholm, 2003).

The bulk of the mineralisation occurs within a 200 to 300 m thick tabular 'melange zone' (Fig. 8) which represents one of the 'crush zones'. The 'melange' comprises highly altered rocks that dip at 35 to 40º to the southwest and can be traced for 1.2 to 1.5 km along the southwestern limb of a large antiform, before splitting into a series of horsetails down plunge. It appears to occupy the thrust contact between the Palaeoproterozoic mafic and felsic suites. The 'melange' has been altered to quartz-sericite, quartz-carbonate and quartz-tourmaline assemblages, and intruded by both Devonian diorite porphyry and Carboniferous sub-alkaline diorite-monzonite porphyry (no dating evidence provided). The porphyries have been altered to quartz-sericite. The orebody occurs as a stockwork of sulphide and quartz-tourmaline veining in a zone of sulphide rich, intense multiple brecciation. Lesser mineralisation is associated with faults and tectonic breccias (Chisholm, 2003; pers. comm. John Leishman).

The main gangue minerals within the ore are quartz (45 to 60%), muscovite-sericite (up to 55%), carbonates (up to 30%), tourmaline (up to 40%), fuchsite (1 to 5%) and other chlorites (up to 10%), with lesser barite, fluorite, apatite (0.1 to 1%), feldspar (albite, K feldspar), epidote, pyroxene, amphibole, garnet and traces of topaz. Sulphides comprise 2 to 40% of the mineralised zone, 95% of which is pyrite. Other sulphides present include chalcopyrite, galena, arsenopyrite and sphalerite. Gold is found as small

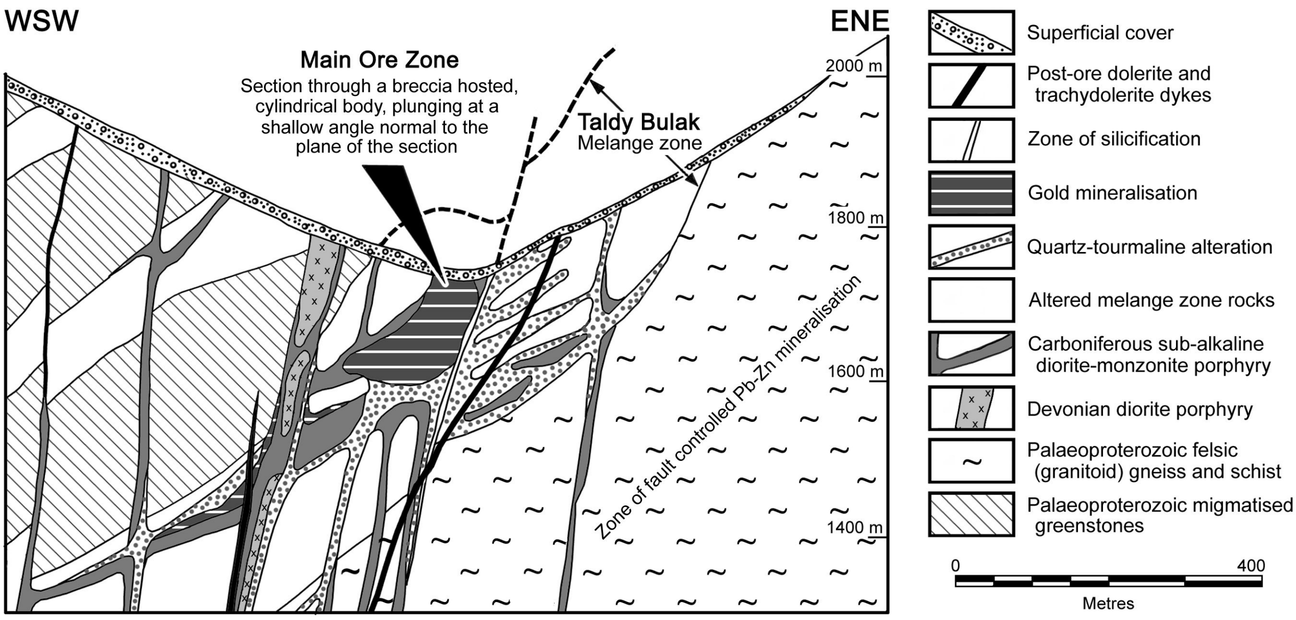


Figure 8: ***Representative cross section through the Taldy Bulak Levoberezhny porphyry related Au deposit in northern Kyrgyzstan showing geology, alteration and mineralisation.*** After Chisholm, (2003).

grains of native gold up to 0.4 mm but generally in the 0.01 to 0.1 mm ranges, occurring along grain boundaries, interstitial fractures and to a lesser extent as lamellae within sulphide minerals. Some 46% of the gold is free, 23% occurs as coarser grains with sulphides, 21% as fine inclusions in sulphides, 4% in quartz and 6% in carbonates. At a cutoff of 1 g/t Au, the main deposit contains resources and reserves, in various grade and resource classifications, totalling 18.7 Mt at an average grade of 6.9 g/t Au, for 129 tonnes of gold (Central Asia Gold, 2005) with 4 to 5 g/t Ag and 0.2 to 0.3% Cu (Chisholm, 2003; Seltmann *et al.,* 2004 and sources quoted therein).

The main high grade gold orebody has the form of a tapering pipe which has been disrupted by faulting and becomes less continuous down plunge. It plunges at between 8 and 40º, steepening with depth, at an azimuth of 300º, has a long axis of 570 m and is 30 to 60 m in diameter. Seven zones of mineralisation, both within this and adjacent pipes, have been identified, two of which make up the quoted resource (Chisholm, 2003).

Malyukova (2001) describes the deposit in detail and notes that while it shares some characteristics with mesothermal Au mineralisation, it has similarities with Au-bearing tourmaline breccia pipes in the porphyry copper belt of Chile. Malyukova (2001) concludes that the deposit may be referred to as a gold-sulphide-quartz-tourmaline type of porphyry gold deposit on the basis of specific features, including i). high abundance of pyrite mainly occurring in quartz-tourmaline altered rocks, ii). veined, disseminated and stringer style mineralization, iii). extensively developed phyllic (and potassic) alteration that predates the tourmalinisation, iv). relation of ore to minor intrusions, v).great vertical extent of ore mineralization, and vi). occurrence of basic volcanics as host rocks.

Aktogai Group, Kazakhstan

The Aktogai (Aqtogai) group of porphyry Cu-Mo-Au deposits, Aktogai, Aidarly and Kyzilkia are located in the 'Balkhash-Ili' zone of the Upper Palaeozoic Kazakh-Mongol magmatic arc, northeast of Lake Balkhash in southeastern Kazakhstan, and some 450 km NNE of Almaty. Together they have resources of more than 2.5 Gt of ore containing over 10 Mt of Cu and near 60 tonnes of Au (Mutschler *et al.,* 2000). See Table 1 for more details.

Geology

The three main deposits of the Aktogai district are associated with stock-like granodiorite and plagiogranite porphyries intruding the extensive laccolith like Late Carboniferous Koldar Pluton and large rafts of Carboniferous volcano-sedimentary rocks within the pluton. The volcano-sedimentary rafts are composed predominantly of andesites, dacites and rhyolites, and their tuffs (Zvezdov *et al.,* 1993; Bespaev and Miroshnichenko, 2004).

The ***Aktogay*** deposit is confined to the eastern part of the Central Aktogai raft of volcanics (Fig. 9) and the enclosing pluton. The raft is intruded by a stock like body of porphyritic granodiorite which also cross-cuts diorite, quartz-diorite and granodiorite of the Koldar pluton. The porphyritic granodiorite is in turn, cut by an elongate stock composed of ore-bearing granodiorite and plagiogranite porphyries, accompanied by a series of pipe-like bodies of explosive breccia with quartz-biotite and sericite-tourmaline matrices. The ore bearing stockwork occurs in the outer contact zone of the porphyry stock, forming a hollow, downward tapering conical body, which pinches out at depth into a series of linear west to northwest trending mineralised zones. At the surface, the orebody has an elliptical annular shape, partially opened to the west, with a maximum diameter of approximately 2500 m, and a radial width of 80 to 530 m (Zvezdov *et al.,* 1993; Seltmann *et al.,* 2004).

Alteration and Mineralisation

All rocks in the orebody area, with the exception of late mafic dykes, have been altered. The barren core of the cone/annulus is occupied by a siliceous zone, comprising quartz bodies surrounded by a dense stockwork of barren quartz veinlets, and a thin zone of sericite-quartz alteration. Towards its margins, the silicified core passes out into a thick zone of early potassic alteration, comprising K feldspar and biotite, that encompasses the main annular orebody. Included within this potassic zone are several linear intervals which are poorly mineralised, but intensely K feldspar altered, and flanked by a wide halo of biotite. Phyllic alteration, characterised by quartz-(carbonate)-chlorite-sericite, appears as impersistent, thin linear zones, confined to the contacts of granodiorite porphyry apophyses and to zones of fracturing along the flanks of the orebody. The periphery of the porphyry copper system is occupied by a large propylitic halo containing epidote-amphibole and albite-chlorite-prehnite (Zvezdov *et al.,* 1993).

The mineralised system exhibits an outward zonation from bornite-chalcopyrite at the centre to chalcopyrite-pyrite to a pyritic halo on the outer margins. Cu and Mo overlap, while Pb-Zn is confined to zones of carbonatisation on the flanks of the orebody. The paragenetic sequence is as follows: i). magnetite; ii) pyrrhotite-cubanite; iii) quartz-pyrite; iv) quartz-(magnetite)-bornite-chalcopyrite; v) quartz-molybdenite-pyrite-chalcopyrite; vi) quartz-(pyrite)-bornite-chalcopyrite-chalcocite; vii) quartz-sericite-pyrite; viii) quartz-galena-sphalerite-chalcopyrite-pyrite-tennantite; ix) post ore zeolite-carbonate. Quartz is the dominant gangue mineral within the stockwork veins, although K feldspar and biotite are also found in early veins, while late veins carry chlorite, epidote, prehnite and carbonate. Fluid inclusion studies indicate that the early quartz-K feldspar veinlets were formed at between 490 and 320°C, while the late sulphide-quartz veinlets range from 320 to 180°C (Zvezdov *et al.,* 1993, and references cited therein).

The ***Aidarly*** deposit is located approximately 4 km to the WNW of Aktogai, and falls within the same 8 x 2 km, WNW elongated sulphidic alteration halo. It is centred on a small, north-west trending stock of ore bearing granodiorite porphyry which intrudes diorite, quartz diorite and granite phases of the Koldar pluton. The granodiorite porphyry stock has steep contacts, characterised by numerous apophyses, and is accompanied by a series of fault controlled dykes of the same composition with northeast and northwest orientations. All of these intrusives are cut by late quartz diorite and dolerite dykes. Small tubular breccia bodies near the granodiorite porphyry are composed of mineralised rock fragments, cemented by rock flour (Zvezdov *et al.,* 1993).

Mineralisation is confined to the outer margins of the stock and the surrounding Koldar pluton, and closely follows the trend of the stock. At surface, the orebody outcrops as a north-west elongated annulus, surrounding a slightly mineralised granodiorite-porphyry. As at Aktogai, the orebody resembles a downward tapering, hollow, truncated cone, with a barren core occupied by poorly mineralised granodiorite porphyry and a zone of silicification. Alteration and mineral zoning is similar to that described at Aktogai. The outcropping granodiorite porphyry has been subjected to slight silicification and sericitisation. At a depth of 600 m the porphyry has a barren core of intense silicification, with scattered anhydrite in its outer margins.

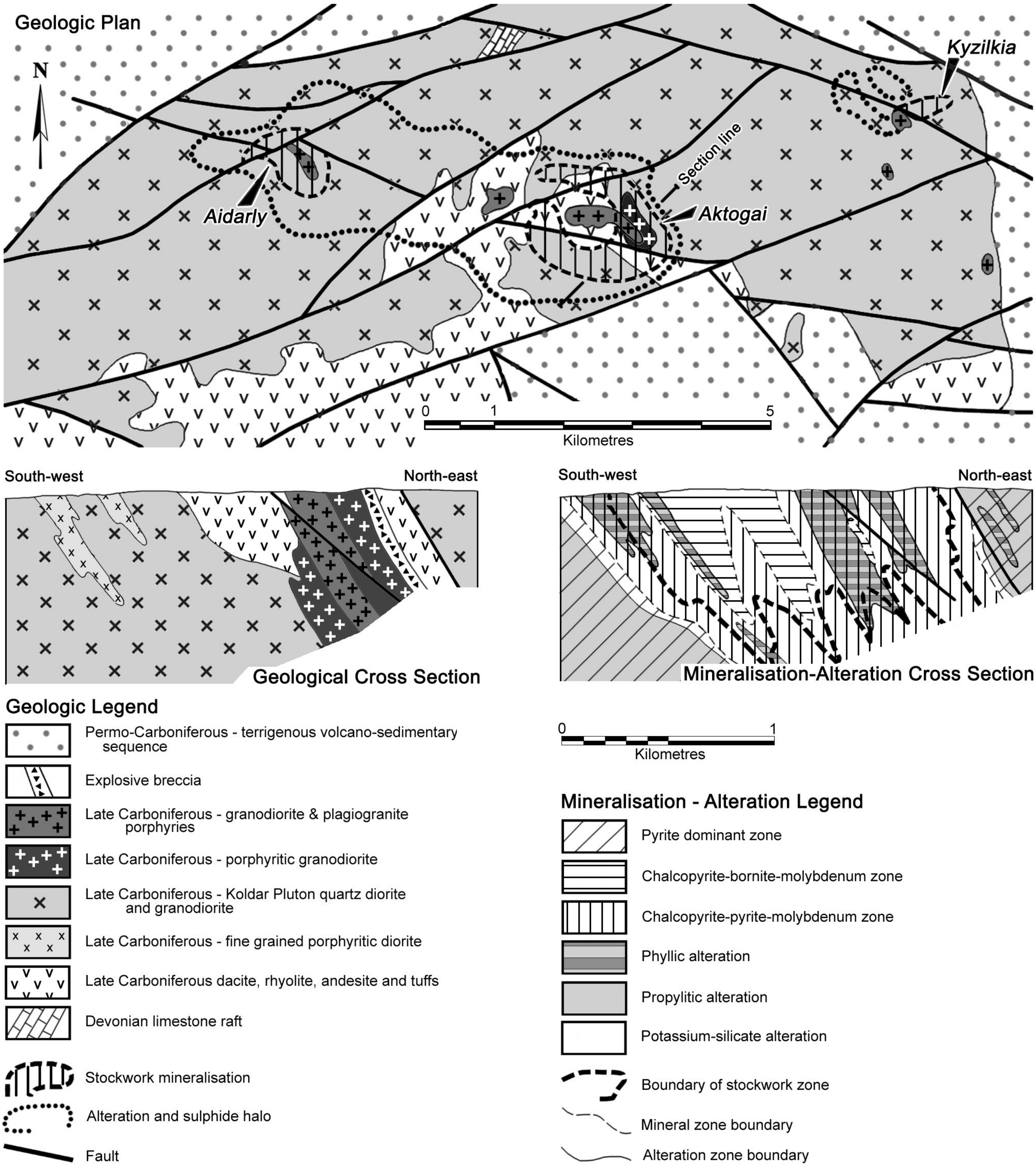


Figure 9: ***Geology, alteration and mineralisation at the Aktogai Group of porphyry Cu-Au deposit in southeastern Kazakhstan.*** The geology and lateration-mineralisation are also separately shown on a NE-SW oriented section through the Aktogai deposit. After Zvezdov, *et al.,* (1993).

Towards the periphery of the porphyry system the silicification passes outward into potassic alteration of quartz-K feldspar-biotite. Higher in the system, at intermediate and near surface depths, this pattern is overlain by a zone of phyllic alteration characterised by quartz-sericite-chlorite-carbonate, with occasional tourmalinisation. The potassic zone is in turn surrounded by a wide halo of propylitic alteration (Zvezdov *et al.,* 1993).

The orebody takes the form of a Cu-Mo stockwork concentrated in the early potassic zone and overprinted by the phyllic alteration. Although most aspects of the mineralisation and alteration are similar to that described above for Aktogai, the deposit differs in that it has a more extensive and better developed polymetallic (Pb-Zn) veinlet and vein mineralisation zone on its outer margins. These comparisons suggest that the Aidarly deposit is less deeply eroded than Aktogai (Zvezdov *et al.,* 1993).

The small ***Kyzylkia*** deposit is 4 km to the east of Aktogai, on the opposite side to Aidarly (Fig. 9). It appears to have been more deeply eroded than either of the other two, supporting the implication of deep erosion in the east, shallowing to the west within the Aktogay district. At Kyzylkia Cu-Mo mineralisation is associated with a small granodiorite porphyry stock intruding the granodiorites of the Koldar Pluton. Orebodies are present as a series of *en echelon* like zones of stringer chalcocite-bornite-chalcopyrite ore accompanied by erratic K-silicate and phyllic alteration (Zvezdov *et al.,* 1993).

Kounrad (or Konyrat, Qonyrat), Kazakhstan

The Kounrad porphyry Cu-Au deposit (also known as Qonyrat or Konyrat) is located in the 'Balkhash-Ili' zone of the Upper Palaeozoic Kazakh-Mongol magmatic arc (Fig. 3). It is 10 km north of the town of Balqash on the northern shore of Lake Balkhash, in Kazakhstan and 450 km NNW of Almaty (Fig. 4). Kounrad is the largest of a group of deposits, in the district, which also include Kaskyrkazgan and Ken'kuduk. Prior to mining, the Kounrad deposit is believed to have totalled more than 800 Mt of ore averaging 0.62% Cu, and locally up to 0.76 g/t Au. Much of the ore removed from the open pit up until 1996, when it covered an area of 2.2 x 1.8 km and was 330 m deep, was supergene enriched to depths of 54 to 450 m below the surface (generally 150 to 200 m thick), with grades of up to 1% Cu. The remaining reserves in 1996, primarily of hypogene mineralisation, were 220 Mt @ 0.35% Cu, 0.1 g/t Au, 0.005% Mo (Seltmann *et al.,* 2004; Mutschler *et al.,* 2000; Kudryavtsev, 1996; Zvezdov *et al.,* 1993). See Table 1 for additional details.

Geology

The Kounrad ore deposit is related to the intrusion of Middle Carboniferous (~330 Ma) granitic bodies into a sequence of Late Devonian (Famennian) to Early Carboniferous (Tournaisian) sedimentary, volcano-sedimentary and volcanic units and coeval pre-orogenic granitic rocks, as well as early orogenic Middle Visean (Early Carboniferous) volcanics and associated intrusives. Late Carboniferous granites of the East Qonyrat pluton that are found to the northeast of the deposit are post ore and late orogenic. The upper contact of the East Qonyrat pluton dips to the southwest at around 50° to pass below the ore deposit (Kudryavtsev, 1996).

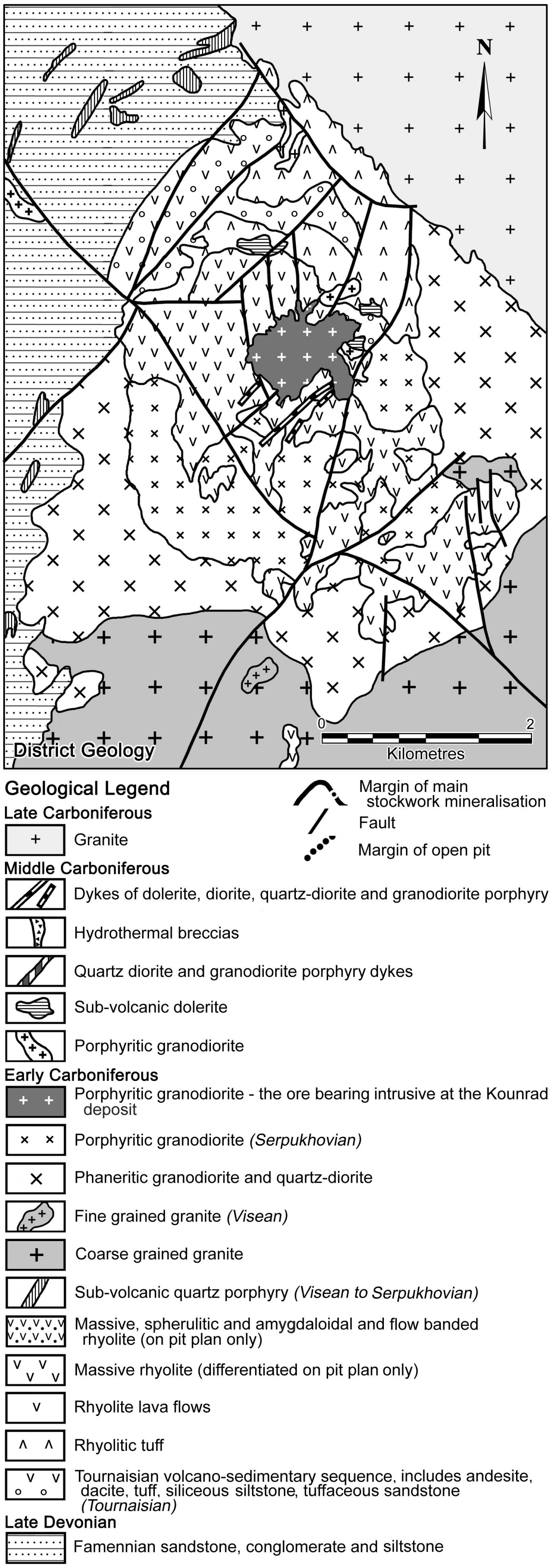
The volcano-sedimentary sequence commenced with a monotonous grey to greenish-grey polymict sandstone of Famennian age, which passes upwards into Lower Tournaisian greenish-grey tuffaceous sandstone and siliceous siltstone, with intercalated dacitic and andesitic volcanics and thin lenses of crinoidal limestone. Andesitic tuffs and lavas increase and predominate in the upper sections of the latter unit. In the western part of the district, the Tournaisian is more than 1000 m thick and is overlain by intensely altered felsic volcanics which define a domal structure, the core of which is occupied by the mineralised porphyritic granodiorite.

The felsic pile is composed of a lower massive rhyolitic tuff, overlain by flow banded, spherulitic and amygdaloidal rhyolitic lava flows and finally by flow banded rhyolitic lava through which the mineralised granodiorite porphyry has been intruded. The upper two units are up to 700 m in thickness (Kudryavtsev, 1996) and have been altered to highly aluminous "secondary quartzite" composed of quartz, quartz-alunite, quartz-sericite and diaspore-pyrophyllite which are the result of syn- and post-volcanic activity (Zvezdov *et al.,* 1993).

The granitoid rocks in the district are subdivided into the following, from oldest to youngest: i). Early Carboniferous (Visean) coarse-grained biotite-hornblende plagiogranite which is found in the southern part of the district where it is part of the large Toqrau pluton. ii). A late Lower Carboniferous (Serpukhovian/Namurian) complex composed of diorite, medium-grained granodiorite and the early porphyritic granodiorite (the main mineralising intrusive dated by the K-Ar method at approximately 335 Ma). iii). Late, porphyritic granodiorite to tonalite (324 Ma) and associated dykes, which in order of emplacement are composed of granodiorite porphyry, quartz-diorite porphyry and dolerite of Middle Carboniferous age. All are intra-ore and are consequently both mineralised and altered. The dykes are a few, to a few tens of metres in thickness and may be up to 1 km in length. iv). Late Carboniferous, coarse-grained, post mineralisation granitic rocks of the 300 to 285 Ma East Qonyrat pluton (Kudryavtsev, 1996).

The main structural elements of the district are northwest and northeast trending faults which control the direction of dykes and intrusive margins (Kudryavtsev, 1996). The main ore deposit is related to the northeast elongated, 1100 x 700 to 800 m northern stock of early porphyritic granodiorite, which intrudes Tournaisian volcano-sedimentary rocks on its eastern margin, and altered felsic volcanics on the remainder of its perimeter. The mineralised stock has undulose steep to vertical contacts and tapers slightly with depth. The contact has numerous dyke like apophyses of granodiorite porphyry extending up to 250 m outward from the main stock margin (Kudryavtsev, 1996).

Breccia pipes and pebble dykes of several stages are widespread, but are best developed in the eastern part of



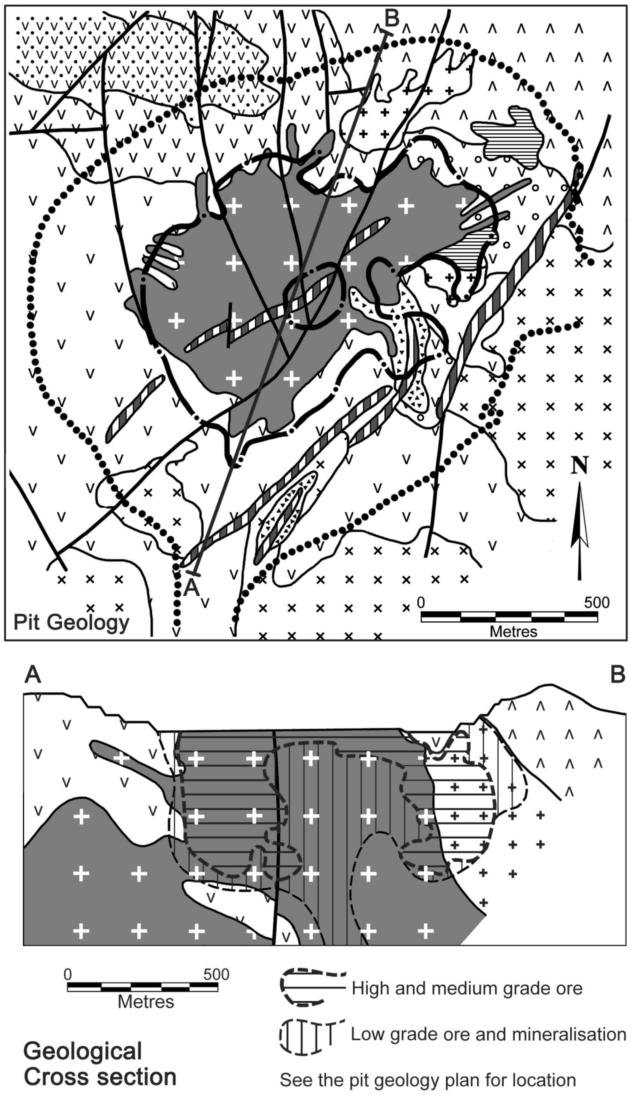


Figure 10a: ***District and pit scale geology and distribution of ore at the Kounrad porphyry Cu-Au deposit in south-eastern Kazakhstan.*** The common point of reference is the host porphyritic granodiorite. Cross-section A-B is located on the pit geology plan. After Kudryavtsev, (1996), Zvezdov, *et al.,* (1993) and Samonov and Pozharisky (1977).

the deposit. The early hydrothermal breccias contain sub-rounded clasts from a few centimetres to 1.5 metres across, composed predominantly of variably altered early porphyritic granodiorite, with lesser altered volcanics and quartz-andalusite rocks. The matrix comprises a quartz-sericite aggregate containing sulphides. The early breccias are cut by diorite porphyry dykes and by late breccias which are characterised by angular clasts of no more than 15 to 20 cm across of the same lithologies as in the early breccias, but in addition include fragments of the dykes that cut those breccias. The early granodiorite porphyry clasts are mineralised. The late breccias are cemented by a phyllic altered sand sized matrix with finely disseminated sulphides and veinlets of grey to white quartz containing barite and sulphides. These are in turn cut by 0.15 to 2 m thick pebble dykes that are widespread in the eastern part of the deposit. The pebble dykes may be several hundred metres in length and contain well rounded fragments cemented by a sandy to silty matrix and in addition to the lithologies of the mine area, contain exotic granite and granophyre clasts (Zvezdov *et al.,* 1993; Kudryavtsev, 1996).

Mineralisation and Alteration

The Kounrad ore deposit is largely restricted to the early granodiorite porphyry body, with lesser mineralisation in the enclosing country rocks and virtually none in the

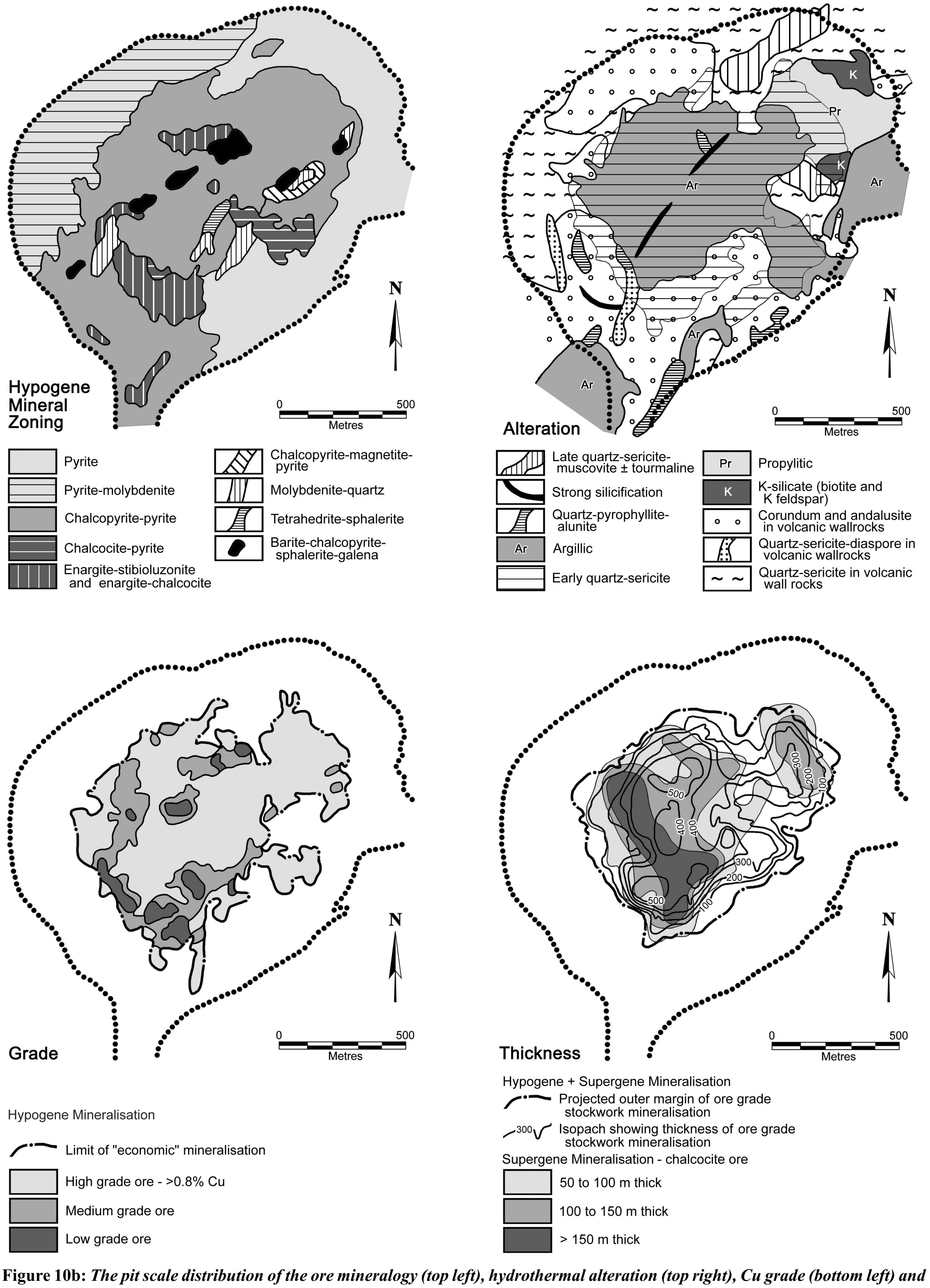


Figure 10b: ***The pit scale distribution of the ore mineralogy (top left), hydrothermal alteration (top right), Cu grade (bottom left) and the thickness of both the total orebody and the superimposed supergene enrichment blanket (bottom right) at the Kounrad porphyry Cu-Au deposit in south-eastern Kazakhstan.*** The common point of reference between the four plans and the pit geology shown on Fig. 9a (all of which are at the same scale) is the open pit pit outline. Note that the 'dot and dash' outline shown on most plans relates to the limit of ore and/or the mineralised stockwork, depending on the plan - and as a consequence is a little different on each. After Kudryavtsev, (1996), Zvezdov, *et al.,* (1993) and Samonov and Pozharisky (1977).

silicified rhyolites. It has a generally northwest elongation, reflecting the orientation of the host intrusive, with dimensions of approximately 725 x 1050 m. Higher grade hypogene mineralisation (>0.8% Cu) is concentrated towards the outer margin approximating an annular shape with a lower grade (<0.8% Cu) core (Fig. 10b). This higher-grade annulus coincides with the more heavily fractured outer sections of the host granodiorite porphyry. The bulk of the mineralisation is present as uniformly disseminated sulphide grains which vary from several µm to several mm, averaging 0.2 to 0.5 mm, and as ore bearing stockwork veinlets of grey, greyish-white and white quartz containing sulphides and ranging from several tenths of a mm to 100 mm in thickness. Individual veins may be as long as several metres, and rarely up to a few tens of metres. At deeper levels stockwork veins are reported to thicken, although their frequency diminishes. The ore stockwork takes the form of a 200 to 400 m thick, sub-horizontal layer with an undulose lower surface, and thicker cores of high grade related to downward protrusions of the base of the zone. This morphology has been interpreted to represent a series of overlapping downward tapering cones (Kudryavtsev, 1996).

Hypogene mineralisation has been overprinted by a pronounced *supergene* profile, comprising an oxidised cap of from 2 to 50 m in thickness, averaging 20 m, underlain by a preserved leached zone of 7 to 56 m, averaging 32 m in thickness. Below the leached zone, a supergene enriched chalcocite blanket extends to depths of 350 to 450 m in the western apart of the orebody, to 54 to 144 m below the surface in the eastern part (Kudryavtsev, 1996). The oxide cap contains hematite, jarosite and other limonites, cuprite, melaconite, native copper, brochantite and chrysocolla, while the zone of secondary enrichment is characterised by chalcocite and covellite (Zvezdov *et al.,* 1993).

The primary sulphide assemblage within the disseminated and stockwork ore comprises: pyrite, chalcopyrite, molybdenite, enargite, tetrahedrite and hypogene chalcocite, with accessory sphalerite, galena, bornite and magnetite, and rare covellite, arsenopyrite, marcasite, pyrrhotite, idaite, colusite, native silver, native gold, tennantite, famatinite, luzonite, stibio-luzonite, ranerite, altaite, valleriite, cubanite, sternbergite, hematite. Although Cu is dominant Mo is present with a Cu:Mo ratio of close to 110 in the hypogene mineralisation. Within the breccia pipes described above, the quartz-sericite matrix of the early breccia contains pyrite, chalcopyrite, bornite, tetrahedrite and molybdenite. The late breccias carry barite, chalcopyrite, molybdenite and rarely sphalerite and galena in a phyllic altered matrix (Kudryavtsev, 1996).

The sulphide zoning illustrated on Fig. 10b outlines the distribution of nine assemblages, as follows: i) *Pyrite* within the older granitoids surrounding the mineralised porphyritic granodiorite plug on the eastern side of the deposit; ii). *Pyrite-molybdenite* within silicified rhyolites of the felsic volcanic suite on the northwestern margin of the mineralised porphyritic granodiorite plug; iii). *Pyrite-chalcopyrite* within silicified rhyolites of the felsic volcanic suite on the northwestern margin and within the mineralised porphyritic granodiorite plug (i.e. including the main orebody); iv). *Pyrite-chalcocite* corresponding to part of the higher-grade annular ore zone within the host porphyritic granodiorite; v). *Enargite-stibioluzonite* and *enargite-chalcocite,* also occurring within the higher-grade annular ore zone, hosted by both the silicified rhyolites and porphyritic granodiorite, on either side of their mutual contact on the western side of the orebody; vi). *Chalcopyrite-magnetite-pyrite,* as a localised elongate zone coinciding in part with the northeast oriented string of occurrence of the following three assemblages; vii). *Molybdenite-quartz,* occurring as generally northeast elongated and aligned localised zones within the pyrite-chalcopyrite zone and hosted by both the silicified rhyolites and porphyritic granodiorite; viii). *Tetrahedrite-sphalerite*, as for vi.; ix). *Barite-chalcopyrite-sphalerite-galena,* as for vi. (Kudryavtsev, 1996, and references quoted therein).

Alteration and mineralisation has been subdivided into three stages, as follows: i) *Early syn- to post-volcanic alteration related to fumarolic-sulfataric activity* during the final stages of volcanism, prior to the emplacement of the mineralised early porphyritic granodiorite. This phase affects the rhyolites of the felsic volcanic suite and comprises quartz-sericite, quartz-sericite-diaspore assemblages. It is considered to have possibly continued during the emplacement of the intrusive phase. This phase produced a screen of non-reactive volcanics that were to subsequently partially surround the mineralised intrusive and focus the deposition of ore. ii). *A second stage related to the intrusion of the early porphyritic granodiorite*. This phase modified the altered felsic volcanics adjacent to the intrusive contact to produce an assemblage of corundum-quartz, quartz-andalusite, quartz-sericite and propylitic minerals, with a late quartz-kaolinite argillic suite. Within the intrusive, alteration of the porphyritic granodiorite was characterised by quartz-sericite accompanying the main Cu-Mo mineralisation, with a propylitic pyritic outer zone.

Argillic alteration, related to the final stages of mineralisation is superimposed on quartz-sericite rocks, being most intense in the transition from preceding quartz-sericite to propylitic zones. The early breccia pipes formed during this same interval. This stage of mineralisation and alteration originated at temperatures of from 400 to 240°C, with the early barren veinlet quartz at 400 to 380°C, pyrite at 330°C and tennantite at 240°C. iii). *The final stage related to the late porphyritic granodiorite to tonalite and associated dykes.* This stage is also associated with ore development and is characterised by mica-quartz-tourmaline within the porphyritic granodiorite and associated felsic dykes, while albite, K feldspar and biotite were formed within the dolerite dykes. The muscovite-tourmaline assemblage of this stage was formed at 470 to 440°C, while the late milky-white quartz was precipitated when the system had cooled to around 210 to 160°C (Kudryavtsev, 1996; Zvezdov *et al.,* 1993).

Zvezdov *et al.,* (1993) point out that chalcopyrite ore is largely confined to the zones of phyllic and argillic alteration within the granodiorite porphyry, while molybdenite, enargite and pyrite are restricted to areas of argillic and phyllic alteration (with considerable accompanying chlorite) at the outer contact of the porphyritic granodiorite. Molybdenite increases with depth. They add that the galena-sphalerite association is a late feature and is controlled by northeast trending fractures across the Cu-Mo orebody.

Koksai and Borly, Kazakhstan

A number of other small to medium porphyry copper deposits are found around Lake Balkhash in Kazakhstan, both to the northwest and southeast of Kounrad. All lie within the 'Balkhash-Ili' zone of the Upper Palaeozoic Kazakh-Mongol magmatic arc and are associated with intrusives, similar to that described at Kounrad. They include Koksai and Borly, which are approximately 400 km southeast, and 50 km northwest of Kounrad respectively.

Koksai comprises approximately 320 Mt @ 0.52% Cu, 0.12 g/t Au (Table 1) and is associated with a porphyry laccolith cutting a sequence of Lower to Middle Carboniferous dacitic and rhyolitic lavas and tuffs, tuffaceous sandstones and sandstones which unconformably overlie Silurian basement. These are unconformably overlain in turn by Middle Carboniferous gritstones and tuffaceous sandstones with sub-volcanic rhyolite and andesite porphyries, and extrusive equivalents. The ore deposit is lens shaped, elongated in a WNW direction. Sulphides have been traced to a depth of 1000 m and comprise pyrite, chalcopyrite, magnetite, bornite and molybdenite. Alteration includes early silica-feldspar with associated chlorite, a subsequent acid quartz-sericite-chlorite stage and a late overprint characterised by calcite and sometimes barite (Seltmann *et al.,* 2004).

Borly is centred on the Carboniferous Borlinksy intrusive body which is an apophysis of the larger Kyzylzhalsky pluton. The intruded sequence includes Lower Carboniferous rhyolitic to dacitic tuffs, litho-crystalline tuffs, lavas and subvolcanic rocks, overlain by a Middle to Upper Carboniferous suite of dacitic and sometimes trachy-dacitic or andesitic to dacitic ignimbrites, vitro-tuffs, tuffaceous lavas, lavas and sub-volcanic masses. Two separate elongated ore zones have been delineated, both striking north to northwesterly and dipping steeply to the northeast. The central orebody is 800 m long, 15 to 340 m wide and has been traced to a depth of between 200 and 460 m, while the eastern zone is 260 x 50 to 150 m at surface and persists to a depth of 120 m. The principal alteration style accompanying mineralisation is quartz-sericite with associated chlorite and carbonates. The sulphide assemblage comprises pyrite, chalcopyrite and molybdenite with minor sphalerite, tetrahedrite, tennantite, galena, magnetite, bornite, chalcocite and pyrrhotite. The grade quoted averages 0.34% Cu, 0.011% Mo, 0.03 g/t Au (Seltmann *et al.,* 2004).

Sayak, Kazakhstan

The Sayak group of skarn deposits are located in the 'Balkhash-Ili' zone of the Upper Palaeozoic Kazakh-Mongol magmatic arc in eastern Kazakhstan (Figs. 3 and 4), which also embraces the large Kounrad, Aktogai Group and other porphyry Cu-Au-Mo deposits (Bespaev and Miroshnichenko, 2004). Sayak is approximately 140 km east of the Kounrad deposit, a few tens of kilometres north of Lake Balkhash, and 450 km NNW of Almaty. The skarns of the district are medium sized Cu-Au-Mo deposits hosted by a Middle Carboniferous carbonate unit, and related to Carboniferous (330 Ma) granodiorite intrusives, similar to those hosting the large porphyry copper deposits of the same magmatic arc. The deposits contain more than 1 Mt of Cu and 30 tonnes of Au (Seltmann *et al.,* 2004; Kudryavtsev, 1996). See Table 1.

Geology

The Sayak deposits are hosted within the Sayak Group, a sequence of marine volcanogenic-carbonate-terrigenous molasse sediments of Middle Carboniferous age (from middle Visean to middle Moscovian). The base of this sequence, is separated from the underlying Siluro-Devonian terrigenous sediments and pre-Silurian ophiolites by an angular unconformity, and the intervening Late Devonian (Famennian to the middle Visean) Alabiin Formation. The *Alabiin Formation* comprises 350 to 500 m of alternating greywacke-sandstone, siltstone, gritstone and tuffite, with thin layers of limestone which pass into calcareous sandstone. The succeeding basal unit of the Sayak Group, the *Buruntas Formation,* is made up of 650 m of intercalated greywacke, polymict and arkosic sandstone, conglomerate, tuffaceous sandstone and tuffite. The conformably overlying Late Carboniferous (Bashkirian to Moscovian age) *Tastyquduk Formation* totals 1300 to 1650 m in thickness and commences with a sequence of clastic sediments which progressively fine upwards from a basal conglomerate. The uppermost 200 m of this formation is a carbonate unit that hosts all of the skarns of economic significance within the district. It commences in the west with 1 to 2 limestone beds, increasing to 5 to 7 in the centre of the basin, coinciding with a proportionate increase in the thickness of the unit. The carbonates of the Tastyquduk Formation are conformably followed by the lower Moscovian *Kungheisayak Formation,* composed of a 150 m thick basal conglomerate, overlain by 1000 m of rhythmically intercalated greenish-grey and buff sandstone, siliceous siltstone, thin limestone and tuffite beds (Kudryavtsev, 1996).

The Sayak Group is more than 4000 m thick and is intruded by numerous sub-volcanic bodies of basic, intermediate and felsic composition. The sedimentary basin in which it was deposited, the Sayak Basin, is an asymmetric graben with steep southern and southwestern, and gentle northern slopes. The structure of the basin is complicated by several anticlinal flexures and abundant faulting. All of the known skarn deposits are associated with local anticlinal ore controlling structures (Kudryavtsev, 1996).

Five main composite plutons cut the Sayak Basin sequence, localised in the central axis and the southern and northern margins of the basin, namely, the Aqshoqy, Zhambas, Kungheisayak, Lebai and Umit plutons (Fig. 11). The latter two are accompanied by Cu-Mo mineralisation, both in skarns and as disseminated, low grade porphyry-style. Two extended dyke swarms are evident, a northeast trending swarm associated with the Kungheisayak intrusive, while a northwest aligned set that cuts the northeast faults is associated with the Umit pluton. The Umit and Lebai plutons are predominantly composed of granodiorite, although quartz diorite represents the initial phase of their intrusion. The other three plutons are tonalitic in composition, cutting initial phases of plagiogranite and hornblende-biotite granite. The tonalites of the Kungheisayak pluton fall within the age range of 347 to 307 Ma, while its plagiogranite is 314 to 310 Ma. In comparison, the granodiorite of the Umit pluton are 335 to 304 Ma (Kudryavtsev, 1996).

Alteration and Mineralisation

Mineralisation within the Sayak district is represented by i). hydrothermal skarn, ii). porphyry Cu and iii). veins. All of the mineralisation of economic significance however, is skarn-type, containing arseniferous Co-Au-Mo-Cu. The most important are in "near intrusion" locations on the northern contact of the Umit and western margin of the Lebai plutons, within a 2 to 3 km wide belt, hosted by Tastyquduk Formation carbonates. All are characterised by the presence of dyke swarms of diverse composition, systems of cross-cutting faults and fracture zones in anticlinal crests capped by impermeable tuffaceous siltstones. Individual orebodies have strike lengths of from 0.5 to 12 km, although the distribution of grade is very patchy, occurring as veins, or as sheet-, ribbon-, pipe- or pocket-like masses, or as irregular shapes (Kudryavtsev, 1996).

The deposits exhibit a zonation outwards from the intrusive contact along the host carbonate bed, as follows: i). An inner zone of magnetite, immediately outboard of the granodiorite contact, with Mo-Cu ores, native gold, and associated late garnet and pyroxene-garnet skarn alteration. Pre-skarn potassic and sodic alteration of alumino-silicate rocks are rare. Poorly mineralised endo-skarn alteration of the granodiorite plutons and dyke rocks was coeval with the skarn development. ii). The "middle part" of the ore-metasomatic zonation is represented by Au-Bi-Cu mineralisation associated with epidote- and actinolite-altered carbonates. The actinolite rich segment marks the outer rim of the ore deposit. iii). The "outer" propylitic transition to unaltered marble and limestone is characterised by quartz-calcite-chlorite alteration (Kudryavtsev, 1996).

The largest of the deposits of the Sayak district is Sayak-I (Sayak), developed on the western exo-contact of the Lebai pluton, and concentrated in a north to northwest trending anticlinal axis which plunges to the south. The fold is

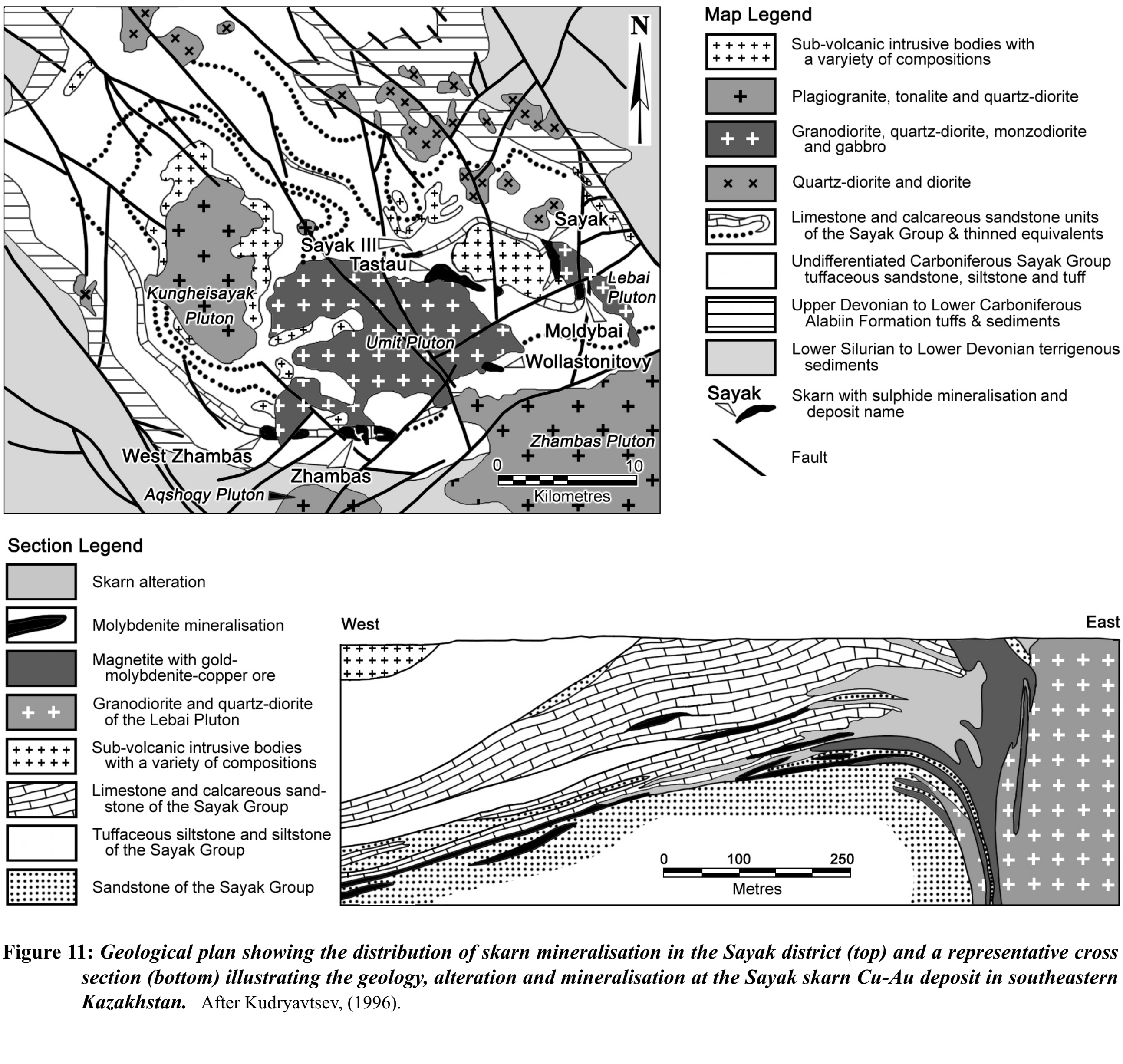


Figure 11: ***Geological plan showing the distribution of skarn mineralisation in the Sayak district (top) and a representative cross section (bottom) illustrating the geology, alteration and mineralisation at the Sayak skarn Cu-Au deposit in southeastern Kazakhstan.*** After Kudryavtsev, (1996).

asymmetric, with a gently dipping (<15°) western limb, opposite the pluton margin. In contrast, the eastern limb dips into the pluton at 25 to 30°, steepening to 60 to 90° at depth. The area also corresponds to the maximum development of the host carbonate of the upper Tastyquduk Formation which at Sayak-I totals 200 m in thickness. The host carbonate is composed of two beds which are 30 to 50 m and 130 to 150 m thick respectively, separated by a thin impersistent layer of tuffaceous siltstone and sandstone, and overlain by a thick bed of tuffaceous siltstone to siltstone. The axis of the mineralised fold is almost parallel to the pluton contact in the centre of the deposit, where the contact is near vertical, although, it shallows to the north. The pluton is composed of granodioritic adjacent to Sayak-I, while the dense array of dykes that cut the ore deposit are predominantly diorite porphyry and dolerite, with lesser granite and plagiogranite. These dykes are generally 3 to 5 m thick and of different relative ages, including pre-, intra- and post-ore (Kudryavtsev, 1996).

Contact metamorphism has hornfelsed the silicate lithologies and produced marbles from the carbonates, while metasomatic processes have formed the skarns over a width of 500 to 1000 m outboard from the intrusive contact, over a length of 3 km parallel to the pluton margin. Skarn alteration has also locally affected dykes of diorite and granodiorite. At the immediate intrusive contact, the limestone host is completely altered to skarn over a 40 to 100 m thickness parallel to the contact, forming a steeply dipping, generally tabular body. On its western margin, this skarn body splits into isolated sheets parallel to the host bedding, which finally give way to marble and recrystallised limestone at the rim of the skarn zone, down dip on the western limb of the fold (Fig. 11) (Kudryavtsev, 1996).

The main skarn is composed of pyroxene-garnet and pyroxene-feldspar. Post-skarn alteration is widespread, with quartz-actinolite-calcite-chlorite and epidote rich propylitic rocks well developed at the transition from skarn to marble and limestone. A major magnetite body formed on the northern part of the deposit almost simultaneously with the epidote- and actinolite-bearing alteration. Au-Mo-Cu mineralisation occurs in both skarn and magnetite hosts, as well as in actinolite and quartz-calcite-chlorite calc-silicate altered rocks, while a steeply dipping 10 to 15 m thick zone of poorly disseminated mineralisation occurs within the granodiorite intrusion. The bulk of the ore is concentrated as a complex "near contact" lode, dipping roughly parallel to the host carbonates and to the intrusive contact to a depth of 500 m. The Cu grades are highest in the centre of the lode, decreasing down dip and towards the margins. Mo mineralisation is best developed on the gently dipping west limb of the fold where it is hosted by the basal sections of the skarn and by altered sandstone in the footwall of the carbonate unit. These bodies extend for 350 to 750 m in a northeast direction, parallel to the fold axis, with widths of 25 to 60 m in the northeast and up to 250 m in the southeast. They average 0.35% Mo with 0.2 to 0.3% Cu (Kudryavtsev, 1996).

There is a well developed zonation within the orebody. Pyroxene-feldspar and pyroxene-garnet skarns contain magnetite rich ore and limited bornite-chalcopyrite, while the garnet skarn hosts molybdenite-bornite-chalcopyrite to the north. Arsenopyrite-cobalt mineralisation predominates in the outer actinolite and quartz-calcite-chlorite altered rocks. The intensity of mineralisation is related to the Fe/(Fe+Mn) ratio of the alteration minerals. The highest grades accompany skarns with 70-80 mol% andradite and 20-30 mol% grossular and high Fe pyroxene (>60 mol% hedenbergite). In contrast, the barren skarn has >60 mol% grossular and 5 to 25% hedenbergite. Similarly, rich Cu mineralisation accompanies Fe-rich epidote and chlorite of the thuringite series. The primary ores contain chalcopyrite, magnetite, bornite, pyrrhotite, arsenopyrite and cobaltite, with rare pyrite, molybdenite, marcasite, melnikovite-pyrite, native gold, galena, sphalerite, electrum, calaverite, petzite, sylvanite and nessite. Oxidation is only poorly developed, limited to depths of 10 to 15 m, accompanied by the formation of azurite, cuprite, chalcocite and scorodite (Kudryavtsev, 1996).

There is strong evidence to confirm that the metallic mineralisation post dates skarn formation. Fluid inclusion studies indicate a reverse temperature zoning of skarn and ore minerals. The earliest and highest temperature (590 to 540°C) gersdorffite-arsenopyrite-cobalt assemblage is found in the relatively low temperature (430 to 210°C) outer quartz-calcite-chlorite rocks. The medium temperature (540 to 470°C) emplectite-chalcopyrite-pyrrhotite assemblage is typically found in the middle epidote-actinolite (630 to 440°C) zone, while the relatively cool wittichenite-molybdenite-chalcopyrite mineralisation occurs in the high temperature (670 to 600°C) proximal skarn (Kudryavtsev, 1996).

In addition to Sayak-I, there are a number of other similar skarns with significant economic mineralisation, including Sayak-III and IV, and Tastau.

Kal'makyr – Dalnee, Uzbekistan

The contiguous Kal'makyr-Dalnee Cu-Au deposits of the Almalyk district in Uzbekistan, are located approximately 45 km southeast of the capital, Tashkent. Together, they represent the largest ore tonnage of the known porphyry systems of central Eurasia, containing >21 Mt of Cu and >2650 tonnes of Au in >5 Gt of ore, although they are rivalled by the higher grade Oyu Tolgoi deposits in Mongolia. They were emplaced within the Carboniferous Valerianov-Beltau-Kurama magmatic arc (Fig. 3) at approximately 320 to 290 Ma.

Kal'makyr has been mined on a large scale (up to 27 Mt of ore per annum) since 1954, while Dalnee, the down plunge continuation of the same mineralised system, has not yet been brought into production. Mineralisation at both is predominantly in the form of stockwork veining with lesser disseminations, and is associated with Late Carboniferous quartz monzonite porphyry plugs intruding earlier dioritic and monzonitic intrusive rocks of the same magmatic complex. The orebodies take the form of a cap like shell developed above and draped over the flanks of the related quartz monzonite porphyry stock. Alteration comprises an early K-silicate phase followed by albite-actinolite and peripheral epidote-chlorite-carbonate-pyrite propylites, overprinted by an abundant phyllic episode which is closely related to the final distribution of the ore. Associated mineralisation commenced with barren quartz-hematite veining, followed by quartz-magnetite, quartz-pyrite-molybdenite-chalcopyrite with the bulk of the contained gold, quartz-carbonate-polysulphide with lesser gold, then by zeolite-anhydrite, and finally carbonate and barite veining. The geology, mineralisation and alteration at Kal'makyr and Dalnee are described in more detail in part 2 of this pair of papers (Golovanov *et al.,* 2005 - this volume).

At Kal'makyr, the dominant hosts to ore are the monzonite and diorite wall rocks, with the quartz monzonite porphyry only containing ore in its outer margins, surrounding and/or overlying a barren core. The barren core is surrounded by an elongate annulus of high grade (>0.8% Cu, including 'eyes' of >1.4% Cu) hypogene mineralisation and within a broader annular zone with a radial width of 200 to 500 m which is reported (Sokolov, 1995) to average 0.7% Cu. This is in turn flanked by a broad halo of low grade mineralisation with grades of from 0.1 to 0.3% Cu (see Fig. 5 in Golovanov *et al.,* in this volume). The deposit is capped by an up to 70 m thick zone of variably developed oxidation, leaching and supergene sulphide enrichment which laterally varies from high grade oxide ore to leached capping overlying either supergene sulphides of a partially or wholly oxidised supergene blanket.

The historic production and reserves/resources at Kal'makyr, Dalnee and the Sarycheku orebody (18 km to the south) are summarised in Table 2. These figures also incorporate the halo of low grade mineralisation (0.1 to 0.3% Cu) that has not been differentiated from either past production or remaining reserve/resource estimates. Statistics available (e.g. Golovanov *et al.,* 2005, in this volume) are largely based on recovered grades and on tonnages treated at the metallurgical facilities. The figures listed in Table 2 attempt to provide data on the in *situ ore* and are based on discussions with mine staff and back-calculations taking into account metallurgical recoveries, but still incorporating the low grade mineralisation.

Kochbulak, Uzbekistan

The Kochbulak epithermal Au-Ag deposit is located in Uzbekistan, 30 km northeast of the giant Kal'makyr-Dalnee porphyry copper deposits and 55 km southeast of the capital, Tashkent. It was emplaced within the Carboniferous Valerianov-Beltau-Kurama magmatic arc (Fig. 3) at approximately 290 to 280 Ma, and prior to mining contained approximately 135 tonnes of gold at an average grade of 12 g/t Au, 120 g/t Ag. See Table 1.

Kochbulak is not a porphyry Cu/Au deposit. However, it is hosted by the same magmatic arc that has produced the giant Kal'makyr and Dalnee deposits a few tens of kilometres to the southwest in the Almalyk district, and is less than 20 M.y. younger than the 315 to 290 Ma age of mineralisation at Kal'makyr (Seltmann *et al.,* 2004, Golovanov *et al.,*2005, in this volume). In the light of the comments on the inter-relationship between porphyry Cu-Au and epithermal Au deposits in the Introduction to this paper, it is reasonable to imply that Kochbulak might represent the higher level, late phase of a hydrothermal system, similar to that which produced the giant porphyry deposits of the Almalyk district, and as such provides a broader appreciation of the porphyry systems being discussed in this paper. It is therefor described here as an example of the magmatic arc hosted epithermal deposits of central Eurasia. It must be stressed that it is not representative of all epithermal deposits in the belt. An exploration model currently controversially discussed among local researchers emphasises that the setting of Kochbulak relates to a stratovolcano, having similarities with Mt. Pinatubo or Bingham Canyon, and may host mineralised porphyry systems at depth, thus qualifying for the continuum model addressed by Cole (2000) and further elaborated in Yakubchuk *et al.,* (2002).

Geology

The Kochbulak gold deposit is located within the Karatash caldera at the intersection of the South Angren and Lashkerek-Dukent fault zones. The caldera is filled by: i). The Middle to Upper Carboniferous Akcha Formation

Table 2: ***Historic production and resource/reserve statistics for the Kal'makyr, Dalnee and Sarycheku porphyry Cu-Au deposits of the Almalyk district, Uzbekistan.*** The 'Ore' column represents the millions of tonnes of ore treated, excluding any stockpiled, while the 'recovered' columns are based on the tonnes of metal obtained after losses in the concentrator and smelter. The '*in situ* ore' columns are the grade and tonnes of metal contained in the original ore and assume a metallurgical recovery of between 75 and 80% of the contained Cu. The Sarycheku figures combine both production and resources. Estimates based on information from Kal'makyr mine geologists, pers. comm., and from Golovanov, *et al.,* (2005, this volume).

	Ore	**Recovered**							**In situ ore**	
	Mt	**Cu**%	**Au** g/t	**Mo**%	**Ag** g/t	**Cu** Mt	**Au** t	**Mo** Kt	**Cu**%	**Cu** Mt
Kalmakyr										
Mined	775 to 700	0.38 to 0.42	0.51 to 0.6	0.006	2.5	2.94	650	38.34	0.49 to 0.54	3.6
Remaining	1750 to 1650	0.38 to 0.4	0.5 to 0.6	0.006	2.5	6.6	900	104	0.49 to 0.51	8.5
Oxide dump	140	0.27	0.65	0.006	2.5	0.378	91			0.38
Low grade	1700	0.17				2.8				
Dalnee	2800 to 2500	0.36 to 0.4	0.35 to 0.5	0.004		10.2	995	105	0.46 to 0.51	13
Sarycheku	200	0.5	0.09	0.0075		1	18	6.9	0.64	1.25
TOTAL	5665 to 5000	0.37 to 0.40	0.4 to 0.53	0.006		21	2650		0.47 to 0.51	27

Note: Total excludes Kal'makyr low grade mineralisation. The range of grades and tonnages are the limits of available estimates.

which comprises more than 1000 m of andesitic and dacitic lavas, and pyroclastic rocks. ii). The unconformably overlying Nadak Formation, which has been divided into ten units and commences with a basal volcani-mictic conglomerate and sandstone, overlain by andesitic and dacitic lavas and tuffs. The relatively thick units of lava and tuff are separated by thin interlayers of tuffite, sandstone and siltstone. iii). The Upper Carboniferous Oyasai and Upper Permian to Lower Triassic Kyzylnura formations which comprise rhyolitic lava and pyroclastics confined to the southern part of the caldera (Islamov *et al.,* 1999).

The volcanic succession of the caldera, which represents a calc-alkaline to sub-alkaline, high potassic latite series, is cut by dykes, sub-volcanic intrusions and associated extrusives. The sequence is also cut by Middle Carboniferous pre-mineral granodiorite and monzodiorite porphyry which are comagmatic with the Akcha Formation at the base of the caldera, and by minor rhyolite intrusions related to the Oyasai Formation. Pre-mineral basic dykes of Early Permian age are widespread, while rhyolite, granosyenite, syenite, monzodiorite porphyry and late basic dykes are post-mineral (Islamov *et al.,* 1999).

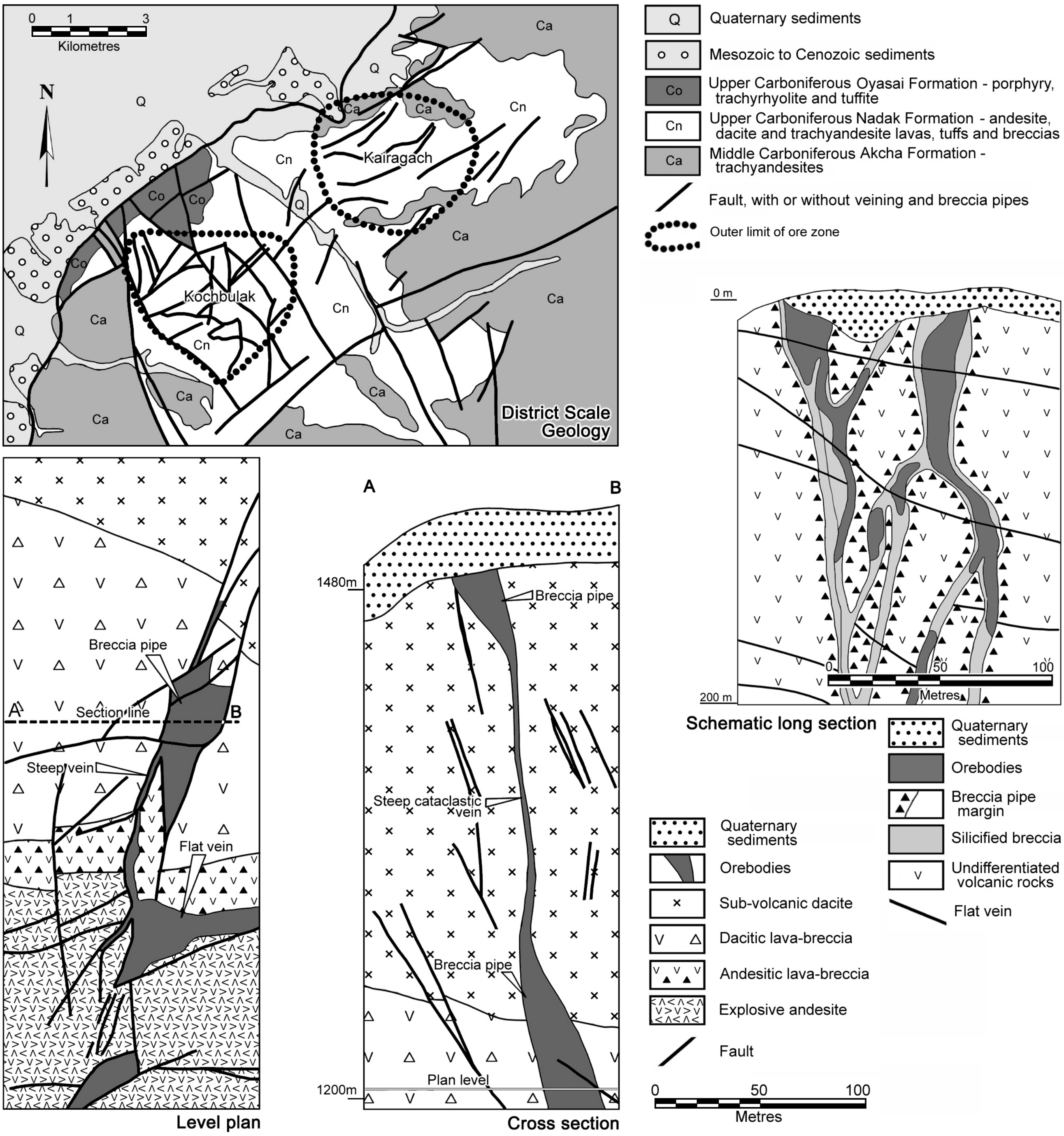


Figure 12: ***Geology, alteration and mineralisation at the Kochbulak epithermal Au deposit, Uzbekistan.*** The district scale geology plan (top left) shows the location of both the Kochbulak and neighbouring Kairagach deposits and the structural elements that control the distribution of mineralisation. A representative level plan and coincident cross section (bottom left) illustrate the relationship between structure and the distribution of steep and flat vein, and breccia pipe mineralisation, while a schematic long section (centre right) shows the morphology of the breccia pipe mineralisation and alteration. After Islamov *et al.,* (1999) and references cited therein.

The deposit area is cut by four large, near north-south trending faults which dip steeply to the west and southwest. Further sets of intervening fractures parallel to the main trend are found in the deposit area, as are intra-formational detachments along the contacts between massive lava units (Islamov *et al.,* 1999).

The Kochbulak mineralisation is restricted to volcanics of the Middle to Upper Carboniferous Nadak Formation on the northern flank of the caldera, close to the Shaugaz Fault. The setting corresponds to the near vent facies of a strato-volcano which was rimmed by sub-volcanic intrusives. Approximately 120 orebodies have been tested, controlled by 32 mineralised structures within a volume of some 4500 x 3000 x 550 m (Kovalenker *et al.,* 1997; Islamov *et al.,* 1999; Yakubchuk *et al.,* 2002).

Alteration and Mineralisation

Three types of orebody are recognised, as follows: i). Steeply dipping, north to northeast aligned veins (40% of the reserve) controlled by the major and intervening faults described above. Some 45 of these steep veins are recognised; ii). Moderately dipping, (20 to 40°) near east-west veins (20% of reserves) which are concentrated where the north-south fault set intersects the intraformational detachments, also mentioned above, and iii). Pipe-like orebodies (40% of the reserves), which are composed of mineralised explosion breccia and which terminate the steeply dipping vein set. There are some 14 pipes, each with a small diameter, but high grade (Islamov *et al.,* 1999).

Mineralisation occurs as massive, banded, brecciated and breccia like textures, with festoon and incrustate structures. Quartz is the dominant gangue mineral, varying from coarse-grained to meta-colloidal to drusy, chalcedonic and amethyst, accompanied by subordinate carbonates and barite. The sulphide content of the two vein types is generally <10%, while in the breccia pipes it may reach 20%. Gold is mainly present as microscopic inclusions, occurring as sheeted, dendritic and cloddy grains in the upper levels and as spongy and drusy gold lower in the deposit. The finest gold is within meta-colloidal quartz, calaverite, sylvanite and altaite, while that in goldfieldite, chalcopyrite and galena is of lower fineness. Electrum accompanies sulphosalts and sulphostannites (Islamov *et al.,* 1999).

The gold mineralisation is present in three associations, namely: i). *Gold-telluride,* which occurs as calaverite, petzite, sylvanite, hessite, stutzite, empessite, goldfieldite and a wide range of other tellurides, and is particularly well developed in the upper level veins and in shallow-formed breccia pipes. ii). *Gold polysulphide* comprises the association of native gold with sulphides of Cu, Pb, Zn, Bi and Sb, and is most frequently found in the upper levels of both the steep and flat veins. iii). *Gold-pyrite,* which is found to varying degrees throughout the system, but is best developed and mineralised with increasing depth. It predominantly occurs as disseminated, uneconomic mineralisation with finely dispersed gold in pyrite, generally only averaging 4 g/t Au (Islamov *et al.,* 1999). In general, the explosive breccia pipes are found in the upper levels of the deposit, passing through a transition zone to steeply dipping mesothermal veins at depth. Mineralisation is known to extend a depth of more than 2000 m.

The pattern of development of the three gold mineralisation associations is zoned both vertically (as described above), and laterally, with the gold-telluride association being the most proximal, within and immediately adjacent to the veins, flanked by the gold-polysulphides, passing out into the lower grade quartz-sulphide association. The distribution is also complicated by the telescoping and resultant superposition of the three zones from different episodes of mineralisation as the deposit evolved (Islamov *et al.,* 1999).

The host volcanics underwent a mild propylitic alteration forming chlorite-carbonate and epidote prior to mineralisation. Alteration related to mineralisation within both the steeply dipping and shallow veins is evident as a regular zonation, with a progressive outward gradation from the ore vein to i). hydrosericite; ii). adularia-sericite; and iii). chlorite-carbonate, to iv). the 'unaltered' country rock. All of the altered rock contains pyrite, which decreases from around 30% in the hydrosericite to 10% in the chlorite-carbonate zone. Pervasive sericite-hydromica dominates in the exploited parts of the deposit, while the chlorite facies was only penetrated in drilling at depths of >1200 m. The breccia-pipe bodies are accompanied by an intense silicification of the hosts, accompanied by variable amounts of sericite, alunite and diaspore (Islamov *et al.,* 1999).

The Kairagach gold deposit is hosted by similar rocks within the same caldera, some 3.5 km to the northeast of Kochbulak. It has a potential resource of 50 t of Au and 150 t of Ag at a comparable grade to Kochbulak and is similar in many aspects, but with variations in detail (Islamov *et al.,* 1999).

Benqala, Kazakhstan

Benqala North and South represent a small to medium sized porphyry Cu-Au system in northern Kazakhstan, approximately 450 km north of the Aral Sea, and 300 km southeast of Magnitogorsk in the Russian Urals. They were emplaced within the Carboniferous Valerianov-Beltau-Kurama magmatic arc (Fig. 3) and are believed to contain around 30 tonnes of contained gold at an average grade of 0.3 g/t, which would equate with approximately 100 Mt of ore. The hypogene Cu grade has been quoted at 0.42% Cu, with 0.55% Cu in the oxide zone.

Mineralisation is associated with Lower to Middle Carboniferous intrusions and dykes of the Sokolov-Sarbai diorite-granite complex which intrude a middle to upper Visean (Lower Carboniferous) volcano-sedimentary sequence. In the western part of the district, the latter is predominantly volcanic, comprising dacites, andesites, andesitic-basalt and basalt porphyrite, while to the east it is largely tuffs and sediments, including tuffites, tuffaceous sandstones, tuffaceous siltstones, and tuffaceous argillites, with thin interbeds of effusives and other sedimentary rocks. The mineralised intrusive comprises an early porphyritic quartz diorite and later associated granodiorite and plagiogranite porphyries. Pre-ore dykes of granite porphyry and post ore micro-dolerite, dolerite and lamprophyre are widespread.

Mineralisation is present as a stockwork which is restricted to the northwestern margin of the host porphyry. The main ore zone has dimensions of more than 1200 x 700 m and extends to a depth of 700 m. It has been subjected to oxidation to 110 m below surface, which is thickest over the immediate ore deposit and its altered hosts. Alteration comprises an early alkaline phase characterised by albite, K feldspar, biotite, silica and tourmaline, accompanied by a propylitic halo of chlorite, epidote and prehnite. This was overprinted by an acid quartz-sericite phase and the development of chlorite and carbonate alteration. The principal metallic minerals are pyrite, chalcopyrite and magnetite, with minor molybdenite, bornite, chalcocite, digenite and rutile (Seltmann *et al.,* 2004).

Tuwu-Yandong, Xinjiang - China

The Tuwu, Yandong (6 km west of Tuwu), Chichu (30 km ENE of Tuwu) and Linglong porphyry Cu-Au deposits are located within eastern Xinjiang in western China, some 500 km ESE of the provincial capital of Urumqi and 80 km directly southwest of the city of Hami. They were deposited at 330 Ma during the Carboniferous, within the Kazakh-Mongol magmatic arc. They occur immediately to the north of the major Kangguer Fault which marks the northern margin of the broad, transitional suture zone between the arc and the Tarim micro-continent to the south. To the south of this fault, a 10 km wide belt is characterised by an ophiolite bearing ductile shear deformed melange. The Carboniferous island arc succession that hosts the deposits is bounded to the north by a Devonian arc assemblage (Wang *et al.,* 2001a; 2001b, Mao *et al.,* 2003).

The Tuwu-Yandong cluster of deposit is quoted as containing 7.5 Mt of Cu metal (Kirkham and Dunne*,* 2000). Han *et al.,* (2003), quote a resource at the main Tuwu deposit alone of 144.5 Mt @ 0.72% Cu, 0.16 g/t Au at a 0.5% Cu cut-off, or 292 Mt @ 0.49% Cu at a 0.2% Cu cut-off.

Geology

The arc and overlying sequence north of the Kangguer Fault comprises the Carboniferous (Han *et al.,* 2003; Wang *et al.,* 2001a, 2001ba), or Devonian (Qin *et al.,* 2002) Qi'eshan Group, which has been subdivided into the following units, from the base: i). Unit 1 - light grey-brown, grey and grey-green medium to coarse-grained schistose greywacke - >100 m thick; ii). Unit 2 - purple-red andesitic volcanic breccia and grey-green tuff - 100 m thick; iii). Unit 3 - grey-green amygdaloidal basalt - 130 m thick; iv). Unit 4 - grey-green and light grey to grey-white pebbly-lithic sandstone, locally grading into polymictic conglomerate, lithic sandstone and bedded tuff, with intercalated basalt, andesite and dacite flows - 170 m thick; v). Unit 5 - grey-green amygdaloidal spilite-keratophyre lavas and brecciated flows, including intercalated trachy-basalt, basaltic trachy-andesite, trachy-andesite, dacite and rhyolite. This unit is the principal wall rock and host to the mineralised intrusives of the Tuwu porphyry Cu-Au deposit - 200 m thick; vi). Unit 6 - grey-green polymict conglomerate with granite, basalt and felsic porphyry clasts, with intercalated fine-grained lithic sandstone - 25 m thick.

The Qi'eshan Group is unconformably overlain by Middle Triassic sandstone and conglomerate of the Xishanyao Formation and by Quaternary sand and gravel cover (Han *et al.,* 2003).

Diorite porphyry and at least 23 individual small stocks of plagiogranite porphyry have been intruded into the Qi'eshan Group in the Tuwu district. The plagiogranite intrusives are massive in appearance and have a porphyritic texture with phenocrysts of quartz, plagioclase and biotite in a subhedral matrix and comprise the mineralised porphyries of the district hosting the Tuwu, Yandong, Linglong and Chichu porphyry Cu-Au deposits (Han *et al.,* 2003).

While Han *et al.,* (2003) describe the deposit as lying within a consistent south dipping succession as described above, Wang *et al.,* (2001a; 2001b) concluded that the mineralised diorite and plagiogranite porphyries have intruded the core of an east-west trending anticline of Qi'eshan Group sediments and volcanics, the limbs of which comprise an outward succession of siltstones, to tuffs and then basalt. This would imply a thinner host succession with only four units. Wang *et al.,* (2001a; 2001b) also observe that the intersection of east-west strike slip faulting and cross trending NNW structures control the localisation of mineralisation. The diorite porphyry, which trends ENE and covers an area of 4 km^2, precedes the less extensive plagiogranite porphyry.

Alteration and Mineralisation

The main Tuwu porphyry Cu-Au deposit is a steeply dipping, east-west elongated body with a surface length of 1400 m, a maximum width of 175 m (20 m at surface, thickening with depth) and down-dip extent of more than 600 m. Its hangingwall and footwall both dip south at 60 to 65° and 65 to 80° respectively, while the orebody tends to plunge to the east. A lower grade deposit, Tuwu East, which is 1300 m long and varies from 32 to 85 m in width, occurs 200 m to the east of the main Tuwu orebody (Han *et al.,* 2003; Wang *et al.,* 2001a; 2001b).

Mineralisation occurs as veinlet, disseminated and less commonly nodular sulphides, principally chalcopyrite and pyrite, with minor bornite, sphalerite, magnetite and rickardite. Molybdenite is also present at Tuwu East. Chalcocite and digenite are found in the supergene enriched ore, while malachite occurs in the oxide zone. Gangue minerals within, and as selvages to veinlets, are quartz, plagioclase, sericite, chlorite and biotite with minor pyroxene, epidote, zoisite and calcite. Mineralisation is hosted by plagiogranite porphyry which occurs in the deposit area as large dykes, in the adjacent diorite porphyry and in basaltic wall rocks. Within the plagiogranite, sulphides are predominantly disseminated, with the principal copper sulphide being medium- to coarse-grained chalcopyrite (or chalcopyrite aggregates) while in the volcanics and diorite porphyry, mineralisation takes the form of well-developed disseminations, veinlets and aggregates of chalcopyrite with associated disseminated bornite (Han *et al.,* 2003).

A number of hypogene mineralised stages are recognised, as follows: i). Stage 1 is characterised by biotite alteration, accompanied by albite and K feldspar, with disseminated chalcopyrite + bornite mineralisation; ii). Stage 2 comprises phyllic alteration with associated quartz + pyrite + chalcopyrite assemblages occurring as veins; iii). Stage 3 is represented by quartz-molybdenite veining and molybdenite disseminations; iv). Stage 4 is composed of sulphates (gypsum and anhydrite) with some accompanying sulphide veinlets; v). Stage 5, late stage carbonate (calcite), laumontite and minor sulphides. The hypogene mineralisation has been subjected to oxidation at surface with the formation of malachite and limonite with brochantite and black copper-wad, underlain by some supergene enrichment to produce chalcocite and digenite (Han *et al.,* 2003). There is an outward alteration zonation of alteration as follows: i). siliceous core; ii). biotite; iii). phyllic; iv). argillic; and v). propylitic outer halo (Fig. 13). In practice however, only three alteration styles are recognised. Phyllic alteration (including an intensely siliceous zone) predominates in the plagiogranite porphyry in the core of the deposit, and is associated with the main orebody, comprising quartz-sericite (muscovite and hydro-muscovite), with minor albite and chlorite. The chlorite-biotite zone is found in the more extensive diorite porphyries (and basalts ?) into which the plagiogranite porphyry dykes were intruded, and as such is on either side of the phyllic zone. It accompanies the outer sections of the main orebody and is characterised by mafic biotite with minor accompanying K feldspar. The outer propylitic zone is mainly composed of chlorite, epidote and albite and is only accompanied by low grade mineralisation on the periphery of the orebody (Han *et al.,* 2003; Wang *et al.,* 2001a; 2001b).

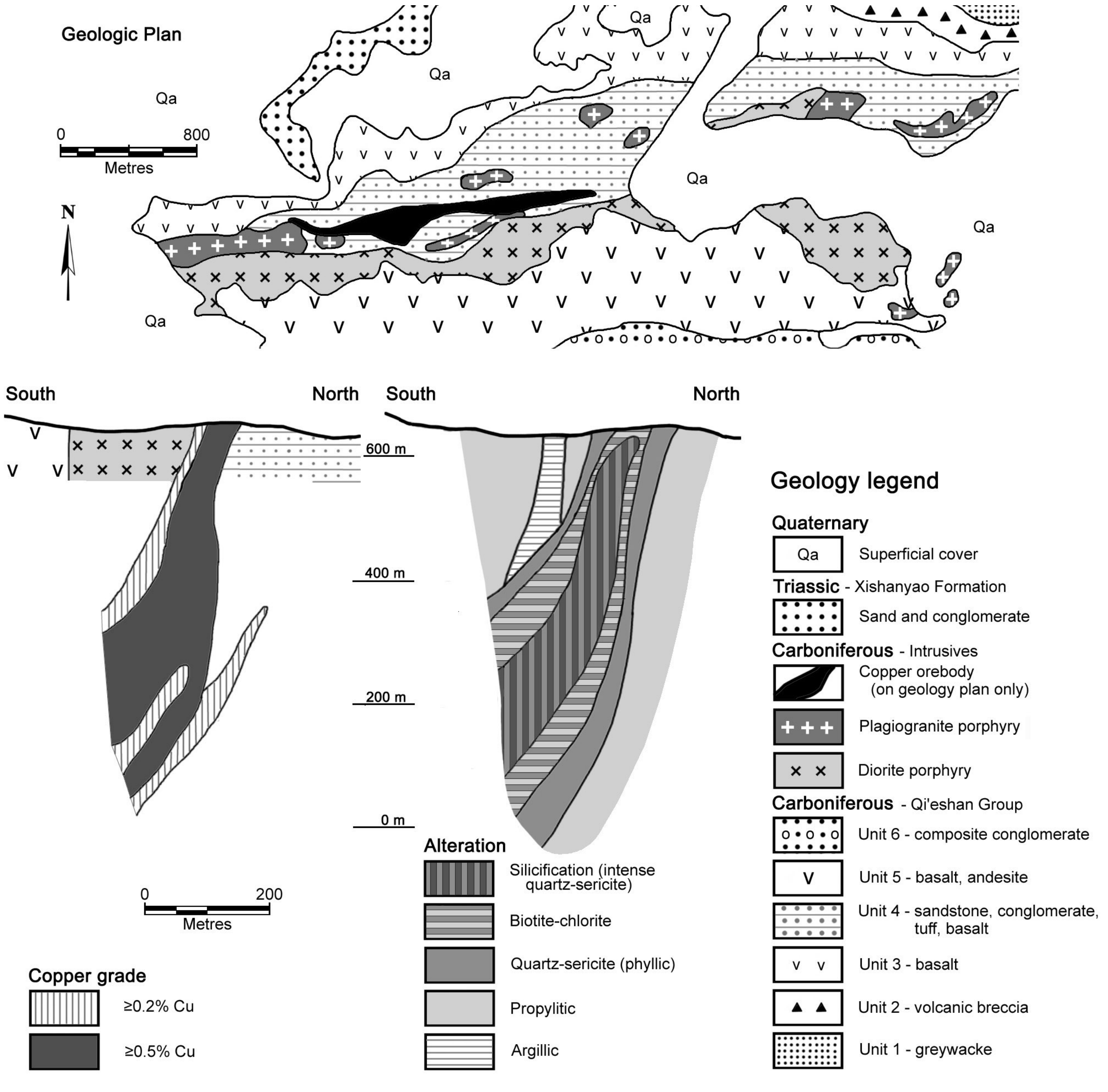


Figure 13: ***Geologic plan (top), and grade (bottom left) and alteration zoning (bottom centre) cross sections through the Tuwu porphyry Cu-Au deposit, Xinjiang, China.*** After Han *et al.,* (2003) and Wang *et al.,* (2001a; 2001b).

Oyu Tolgoi, Mongolia

The Oyu Tolgoi porphyry Cu-Au deposit is located approximately 550 km due south of Ulaanbaatar in southern Mongolia, and 80 km north of the Chinese-Mongolian border. It was formed at 370 Ma (Late Devonian) in the Kazakh-Mongol magmatic arc, and is among the largest and richest known hypogene porphyry Cu-Au deposit in the world.

During the 1980s, a joint Mongolian and Russian regional geochemical survey of the region reported a molybdenum anomaly over what is now the Central Oyu deposit (Fig. 14). Follow-up work noted evidence of copper mineralisation and alteration at South Oyu in the form of sub-cropping malachite, chrysocolla and copper wad. In addition, a number of small, circular pits and minor copper-bearing slag were evident at South Oyu, probably relating to Bronze age activity. A subsequent inspection in 1996 by Magma Copper geologists recognised outcrops of stockwork quartz veining at Central Oyu which were identified as the leached cap of a porphyry copper deposit. Subsequent testing by BHP Minerals after their acquisition of Magma Copper indicated 438 Mt @ 0.52% Cu and 0.25 g/t Au at South and Central Oyu (Perello *et al.,* 2001; Kirwin *et al.,* 2005). The project was farmed out to Ivanhoe Mines in 1999 who have continued exploration to the present. For details of its discovery and delineation see Kirwin *et al.,* (2003).

Declared resources in April 2005 (Ivanhoe Mines press release, May 2005) were:

- At a 0.6% Cu equivalent cut-off, the Measured + Indicated resource = 1.149 Gt @ 1.30% Cu, 0.47 g/t Au, or 1.54% Cu equivalent; plus an Inferred resource = 1.160 Gt @ 1.02% Cu, 0.23 g/t Au, or 1.16% Cu equivalent. The total Measured + Indicated + Inferred resource = 2.309 Gt @ 1.16% Cu, 0.35 g/t Au, or 1.35% Cu equivalent, comprising 26.8 Mt of contained Cu and 810 tonnes (26 Moz) of contained Au.
- At a 1% Cu equivalent cut-off, the Measured + Indicated resource = 0.647 Gt @ 1.82% Cu, 0.58 g/t Au, or 2.13% Cu equivalent; plus an Inferred resource = 0.602 Gt @ 1.35% Cu, 0.28 g/t Au, or 1.54% Cu equivalent. The total Measured + Indicated + Inferred resource = 1.249 Gt @ 1.59% Cu, 0.44 g/t Au, or 1.36% Cu equivalent, comprising 19.8 Mt of contained Cu and 550 tonnes (17.5 Moz) of contained Au.

The extent of economic mineralisation is currently only partially tested, and is open to the north and at depth, with potential for the current drilled resource to be substantially increased. Step-out drilling 200 and 450 m to the north of the 3.5 km long Hugo Dummett deposit intersected 608 m @ 3.24% Cu, 0.82 g/t Au (including 322 m @ 4.59% Cu, 1.07 g/t Au) and 324 m @ 2.45% Cu, 1.23 g/t Au respectively. This drilling is progressively following a 3 km long extension of the induced polarisation anomaly that follows the known mineralisation (Ivanhoe Mines press release, June 2005).

Regional Setting

The Oyu Tolgoi deposit lies within the Middle Palaeozoic Kazakh-Mongol magmatic arc, represented by a 100 to 250 km wide arcuate swathe of arc-related terranes in southern Mongolia (Fig. 14). This swathe of terranes, which has been variously referred to as the Southern Magmatic Belt (Gerel, 1998), the South Mongolian and South Gobi tectonic units (Perello *et al.,* 2001 and references cited therein), follows the southern border between Mongolia and China, with a trend that curves from northeast in the east of Mongolia, to WNW where it passes into western China. The individual terranes are predominantly composed of island arc volcanic rocks and are extensively intruded by voluminous Permo-Carboniferous granites.

To both the north and south, the magmatic arc is bounded by tectonically complex suites of 'basement' terranes composed of Lower to Middle Palaeozoic back- and fore-arc sequences, volcanic rocks of the late Neoproterozoic to Lower Palaeozoic Tuva-Mongol magmatic arc and slivers of basement Meso- to Neoproterozoic metamorphics, separated by intra-arc suture related accretionary wedge sequences which include Late Neoproterozoic (Vendian) to Early Cambrian ophiolites (Figs. 3 and 14) (Yakubchuk *et al.,* 2002; Yakubchuk, 2005; Zonenshain *et al.,* 1990; Lamb *et al.,* 1999; Wainwright *et al.,* 2004, and references quoted therein).

Oyu Tolgoi is within the Gurvansayhan Terrane of Badarch *et al.,* (2002), which is located in the central-southern section of the magmatic arc where it trends roughly east west. The geology of the 600 x 200 km triangular shaped terrane is predominantly composed of Silurian to Carboniferous terrigenous sediments, carbonates, volcani-sediments and intermediate to felsic volcanics, all cut by extensive Devonian granitoids and by Permo-Carboniferous diorite, monzodiorite, granite, granodiorite and syenite bodies, ranging in size from dykes to batholiths that are tens of kilometres across (Perello *et al.,* 2001; Wainwright *et al.,* 2004).

The original architecture of the sequence and the magmatic arc has been masked by alluvium on a mature surface, disrupted by intrusive masses and modified by both mid- to late-Palaeozoic accretion and Mesozoic thrust and sinistral strike-slip faulting. This has resulted in a complex of imbricate thrust sheets, dismembered blocks, mélanges and high strain zones (Badarch *et al.,* 2002). The abundant Permo-Carboniferous intrusive complexes of the terrane appear to be closely related to a major northeast-trending fault zone known as the East Mongolian or Zuunbayan fault zone which cuts obliquely across the arc and forms the southeastern boundary of the Gurvansayhan terrane (Lamb and Badarch, 2001).

The sequence within a 20 km radius surrounding the Oyu Tolgoi deposit (Fig. 14) is predominantly composed of Devonian basaltic to intermediate volcanic and volcaniclastic rocks, overlain by layered pyroclastics and sedimentary rocks with andesitic sills. Layered Carboniferous pyroclastic and sedimentary rocks, cut by andesitic sills overlie and are in fault contact with the Devonian hosts. Several large masses of granitic rocks surround the deposit, the largest being the 287±2 Ma (K-Ar) Hanbogd Mountain peralkaline granite 5 km to the east, while the 308±2 Ma (U-Pb zircon) Javhalant Mountain

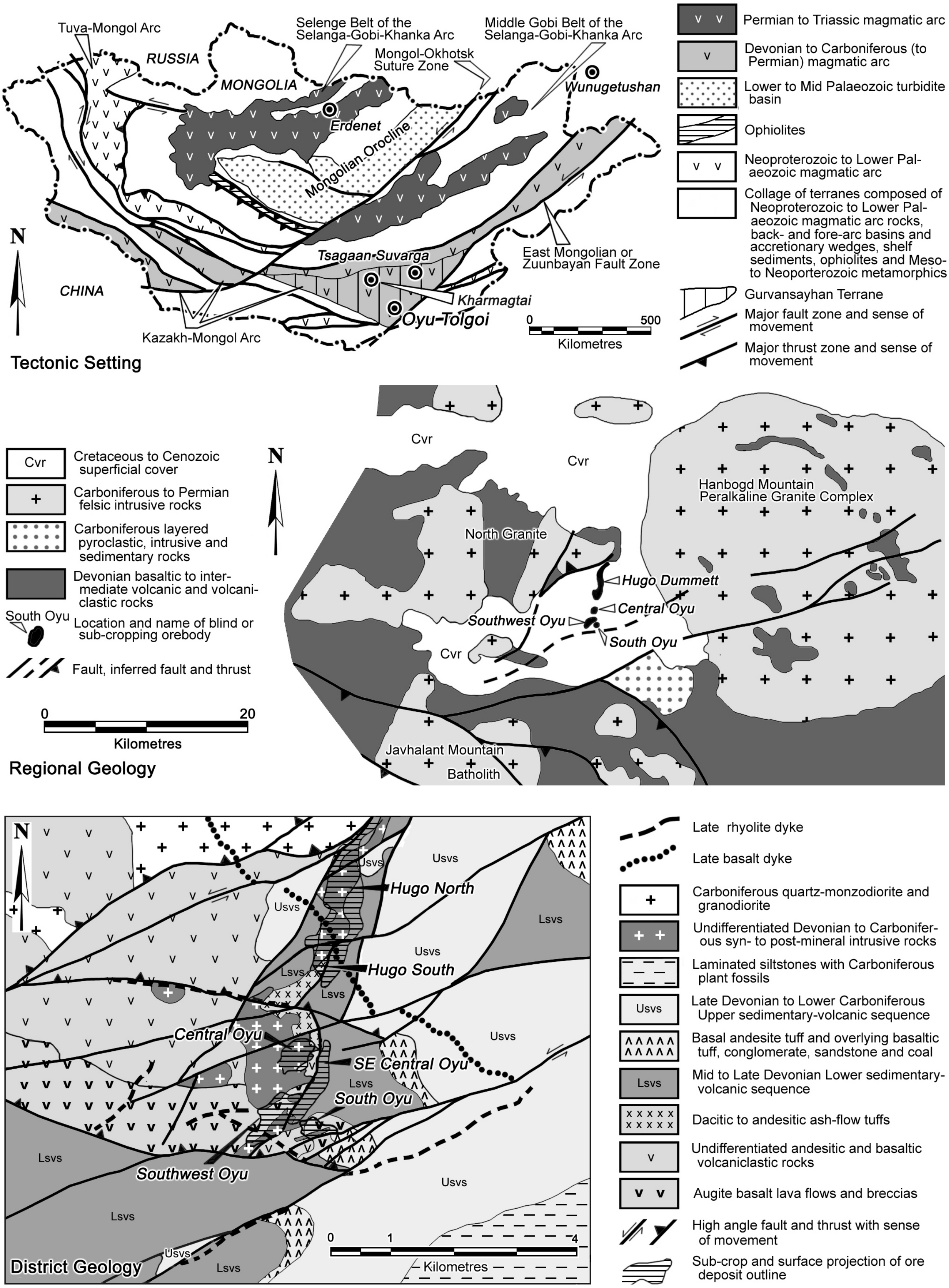


Figure 14: ***Tectonic, regional and district scale geological setting of the Oyu Tolgoi porphyry Cu-Au deposits, Mongolia.*** The upper diagram illustrates the location of the Oyu Tolgoi deposit and the Gurvansayhan Terrane within the tectonic framework of Mongolia. The middle figure represents the outcrop geology surrounding the Oyu Tolgoi group of deposits, while the lower plan shows the interpretted solid sub-crop geology in the immediate vicinity of the deposits. After Kirwin *et al.,* (2005); Ivanhoe Mines, (2005); Wainwright *et al.,* (2004) and references cited therein; Perello *et al.,* (2001) and references cited therein.

Batholith is a similar distance to the south and the 348±2 Ma (U-Pb zircon) North Granite is closer to the north and west (Wainwright *et al.,* 2004).

At the end of the Palaeozoic, the area was subjected to Basin and Range style rifting, with associated bimodal volcanism. This was followed during the early Mesozoic, by widespread uplift and associated thrusting which unroofed the magmatic arcs. Terrigenous sediments were deposited during both the basin and range and uplift/ thrusting episodes in fault controlled basins. By the Late Cretaceous, the region had become increasingly arid, similar to the present day Central Asian basins (Ivanhoe Mines, 2005).

Deposit Geology

The Oyu Tolgoi porphyry Cu-Au deposit comprises four discrete zones namely: i). Hugo Dummett (divided into South and North Hugo, previously Far North Oyu); ii). Central Oyu; iii). South-West Oyu; and iv). South Oyu. These zones are hosted at different stratigraphic levels within a sequence of pre-ore tholeiitic basaltic volcanic and dacitic pyroclastic rocks overlain disconformably by clastic sedimentary and volcaniclastic rocks, and by basalt to dacite lava flows that are locally peperitic. The Cu-Au mineralisation is associated with intermediate- to high-K granitoids emplaced as structurally controlled dykes and small plugs (Ivanhoe Mines, 2005; Kirwin *et al.,* 2005).

Outcrop is generally strongly weathered, and is sparse and subdued, amounting to less than 20% of the deposit area. The host sequence and intrusives are largely masked by a flat to gently south dipping, NNW trending terrace of Neogene(?) piedmont outwash deposits, occurring as a 40 m thick layer of red clay and gravel, in the centre of the deposit area. Two major SSE drainages which incise this terrace are filled by Quaternary sands and gravels (Ivanhoe Mines, 2005).

The host succession within the deposit area , from the lowest to highest stratigraphic level, is as follows (Ivanhoe Mines pers. comm.; Ivanhoe Mines, 2005; Kirwin *et al.,* 2005; Wainwright *et al.,* 2004):

i) *Laminated, andesitic volcaniclastic rocks* are the lowest unit encountered in the deposit area.
ii) *Augite Basalt* lava flows and related breccias which are altered to chlorite/biotite with augite phenocrysts, and total around 800 m in thickness.
iii) *Dacitic to Andesitic Tuffs,* comprising an upper thin block-ash tuff and the underlying ash flow tuff, which represents the bulk of the unit. This unit varies from 80 to 400 m in thickness. It disconformably overlies the Augite Basalt.
iv) *Lower Sedimentary-Volcanic Sequence,* which is approximately 350 m thick, and disconformably overlies the dacitic tuffs. It is composed of red to green-brown siltstone and fine sandstone, with minor conglomerate and carbonaceous shale, and intercalated auto-brecciated basaltic lava and tuff. Some basalt flows in the upper parts of sedimentary sequence are strikingly similar to the lowermost porphyritic augite basalt, and therefore suggest that all the basaltic volcanics are co-magmatic. The lowest 50 m of this unit is a laminated siltstone with carbonaceous shale and coal.
v) A 250 m thick unit comprising an upper sequence of coal, conglomerate, sandstone and a thin green tuff, which overlies a slightly thicker andesitic ignimbrite pile. The last four units (v to viii herein) are also referred to as the *Upper Sedimentary-Volcanic Sequence.*
vi) *Basaltic volcaniclastic unit,* comprising polymictic, subrounded, lapilli-sized clasts in a plagioclase-bearing to silty matrix intercalated with locally peperitic basalt. This unit is up to 400 m thick, and has a thin andesitic lava flow at the base.
vii) *Basaltic lava flows* with minor intercalated breccia and tuff, up to 200 m thick.
viii) *Dacite flow,* possibly a flow or dome facies, up to 200 m thick.

A wide variety of felsic to mafic dykes have been encountered in drill holes throughout the deposit area. The orientations of these intrusives are largely controlled by the dominant structural fabric of the area, which from satellite imagery and geophysical interpretation, trend at both 35° and 70°. The mineralisation is apparently genetically associated with a suite of variably altered and mineralised porphyritic quartz monzodiorite dykes that cut the Augite Basalt and Dacitic to Andesitic Tuff units in the lower part of the host sequence. Post mineral dykes include basalt, rhyolite, hornblende-biotite andesite, and biotite granodiorite intrusive rocks. The closest, large outcropping felsic intrusive mass, is approximately 3 km to the northwest of the deposit area (Fig. 14). Gravity data suggests additional large granitoid intrusives to the west of the deposit area (Ivanhoe Mines, 2005; Kirwin *et al.,* 2005; Wainwright *et al.,* 2004).

The intrusive history of the deposit area can be summarised as follows, from oldest to youngest (Wainwright *et al.,* 2004; Ivanhoe Mines, 2005; Kirwin *et al.,* 2005):

i) Early mineralised and altered quartz monzodiorite, mainly found at South Oyu;
ii) Late mineralised quartz monzodiorite, which only intrudes to the top of the Dacitic to Andesitic Tuff. This phase varies from moderately- to un-mineralised.
iii) Biotite Granodiorite which is largely unaltered, and intrudes the Lower Sedimentary-Volcanic Sequence and into the base of the overlying andesite ignimbrites. This phase is locally altered and mineralised in the Hugo Dummett deposit.
v) Hornblende-biotite andesite dykes which persist into the Basaltic volcaniclastic unit.
vi) Rhyolite dykes, which are found to the top of the sequence.
vii) Basalt dykes, occurring throughout the full sequence.
viii) Dolerite dykes, which were the latest intrusive phase.

Mineralisation and Alteration

The Oyu Tolgoi deposit comprises four main mineralised centres, Hugo Dummett, Central Oyu, South-West Oyu and South Oyu, distributed over an interval of approximately 6.5 km in a NNW trending, 1 to 1.5 km wide corridor of alteration and mineralisation. Each represents a porphyry copper-gold centre with an associated late high sulphidation system, which occurs above, and is partially telescoped onto the underlying porphyry mineralisation. The corridor appears to have been tilted to the north, such that erosion has removed much of the high sulphidation system at South and South-West Oyu, exposing the roots and mid levels of the porphyry system. In contrast, at Hugo Dummett North, the entire high sulphidation system and underlying and over printed porphyry mineralisation is preserved and plunges north at depth, below poorly mineralised hosts (Ivanhoe Mines, 2005; Kirwin *et al.,* 2005).

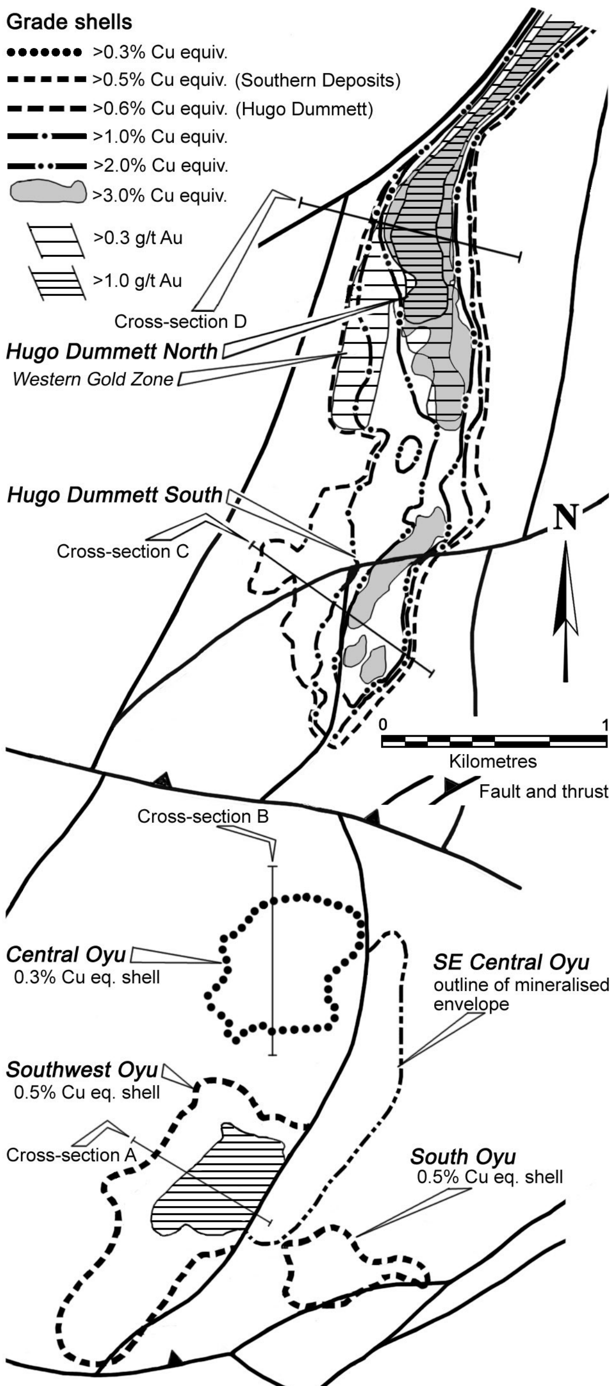


Figure 15: ***Distribution of mineralisation and grade within the Oyu Tolgoi porphyry Cu-Au deposits, Mongolia.*** The grade shells illustrated represent widths along the axis of the deposit projected to surface. The location of sections on Figs. 16 and 17 are also indicated. After Ivanhoe Mines, (2005).

South-West Oyu is centred on a cluster of small 10 to 30 m wide syn- to late-mineral porphyritic quartz monzodiorite dykes (Fig. 16). Mineralisation extends for more than 100 m into the adjacent basaltic volcanic hosts from each dyke. The higher-grade core of the centre, within a >1 g/t Au zone, has a 250 m diameter and extends down plunge to the southwest over a vertical interval of more than 800 m. The grade of mineralisation within the broader 0.3% Cu equivalent shell at South-West Oyu averages 0.41% Cu, 0.47 g/t Au, while at a 1% Cu equivalent cut-off it increases to 0.77% Cu, 1.44 g/t Au.

The main mineralisation is represented by early, relatively high temperature, milky white quartz veins, which cut both the quartz monzodiorite and in the basaltic wall rocks. These veins occur as contorted, sinuous networks, rather than as planar veinlets. Chalcopyrite and subordinate pyrite and bornite are found as disseminations and as late fracture fillings within both the quartz veins and the adjacent host rocks. Gold is very fine, ranging from 1 to 120 µm, and is intergrown with chalcopyrite as veinlet infill, healing hydro-fracturing of pyrite crystals and as inclusions within, or on grain boundaries of chalcopyrite and bornite or gangue minerals. It increases in grade with depth, from an Au (g/t):Cu (%) ratio of 2:1 near surface, to 3:1 at depth, while low grade propylitic basalts surrounding the main high grade core maintain a ratio of 1:1 over an area of 600 x 2000 m (Ivanhoe Mines, 2005; Kirwin *et al.,* 2005).

The dominant alteration in the quartz monzodiorite at South-West Oyu comprises early pervasive albite, overprinted by quartz sericite and minor tourmaline and fluorite, while biotite-magnetite and late chlorite-sericite is the principal alteration facies in the surrounding basalts. Pervasive biotite alteration is found in the core of the deposit, but further outward is only present as selvages to the mineralised veinlets. A quartz monzodiorite dyke which forms the southeastern margin of the South-West Oyu deposit is altered to sericite in its upper levels with weak disseminated pyrite and chalcopyrite. This mineralisation is not characteristic of the porphyry style at South-West Oyu and is believed to represent the root zone of an eroded high sulphidation system (Ivanhoe Mines, 2005; Kirwin *et al.,* 2005).

Central Oyu comprises a high sulphidation systems developed above, and partly telescoped onto, an underlying centre of porphyry mineralisation (Fig. 16). Covellite and pyrite are developed within an upwardly flared zone of intense quartz-muscovite alteration with subordinate minamite, dickite and pyrophyllite, while primary apatite has been altered to secondary phosphates (crandellite, svanbergite and woodhousite). In addition, a supergene-enriched chalcocite blanket several tens of metres thick has been superimposed on the high sulphidation covellite-pyrite mineralisation. This has produced sooty chalcocite coatings on pyrite and as fracture fillings below a 20 to 60 m thick hematite and goethite rich leached cap. Minor exotic copper mineralisation has been encountered in some drill adjacent to the main prospect. The grade of mineralisation at Central Oyu within the 0.3% Cu equivalent shell averages 0.62% Cu, 0.17 g/t Au (Ivanhoe Mines, 2005; Kirwin *et al.,* 2005).

South Oyu has similarities to South-West Oyu and at a 0.3% Cu equivalent cut-off has an average grade of 0.46% Cu, 0.11 g/t Au (Ivanhoe Mines, 2005).

The *Southern deposits* at Oyu Tolgoi, namely Central, South-East Central, South and South-West Oyu, were estimated at April 2005, to contain a Measured + Indicated + Inferred resource of 995.4 Mt @ 0.49% Cu, 0.37 g/t Au at a 0.3% Cu equivalent cut-off, or 655.7 Mt @ 0.60% Cu, 0.64 g/t Au at a 0.6% Cu equivalent cut-off, or 176.7 Mt @ 0.80% Cu, 1.08 g/t Au at a 1% Cu equivalent cut-off (Ivanhoe Mines press release, May 2005). Fig. 15 illustrates the location of these segments of the deposit.

Hugo Dummett also represents a high sulphidation system that has been telescoped onto porphyry-style mineralisation formed at an earlier stage in the evolution of the hydrothermal centre. High grade copper mineralisation extends over a distance of more than 3.5 km in two connected segments, Hugo Dummett South and North. Mineralisation dominantly occurs as bornite, chalcocite and chalcopyrite, with subordinate amounts of pyrite, enargite and tetrahedrite-tennantite. The sulphides that are formed relate directly to the associated alteration assemblage, which in turn is partially dependent upon the lithology of the host rock, but also the position in the outward zonation from the core of the high-grade shell ellipse. The outward zonation from high to low grade Cu ore corresponds with the progression from bornite + chalcocite, to chalcopyrite (±tetrahedrite-tennantite) to pyrite (±enargite) (Ivanhoe Mines, 2005; Kirwin *et al.,* 2005).

A large part of the ***Hugo Dummett South*** deposit is hosted by dacitic to andesitic ash flow tuff, in contrast to Hugo Dummett North which is predominantly within augite basalt and quartz monzodiorite (Fig. 16). This difference in host lithology has a strong influence on both the alteration and sulphide species that are developed. Advanced argillic alteration within the ash flow tuffs is characterised by alunite, pyrophyllite, diaspore, dickite, topaz, zunyite, minor fluorite and rare dumortierite. Enargite, bornite+pyrite, and locally covellite are common sulphide minerals in the ash flow tuff. The observed mineralisation

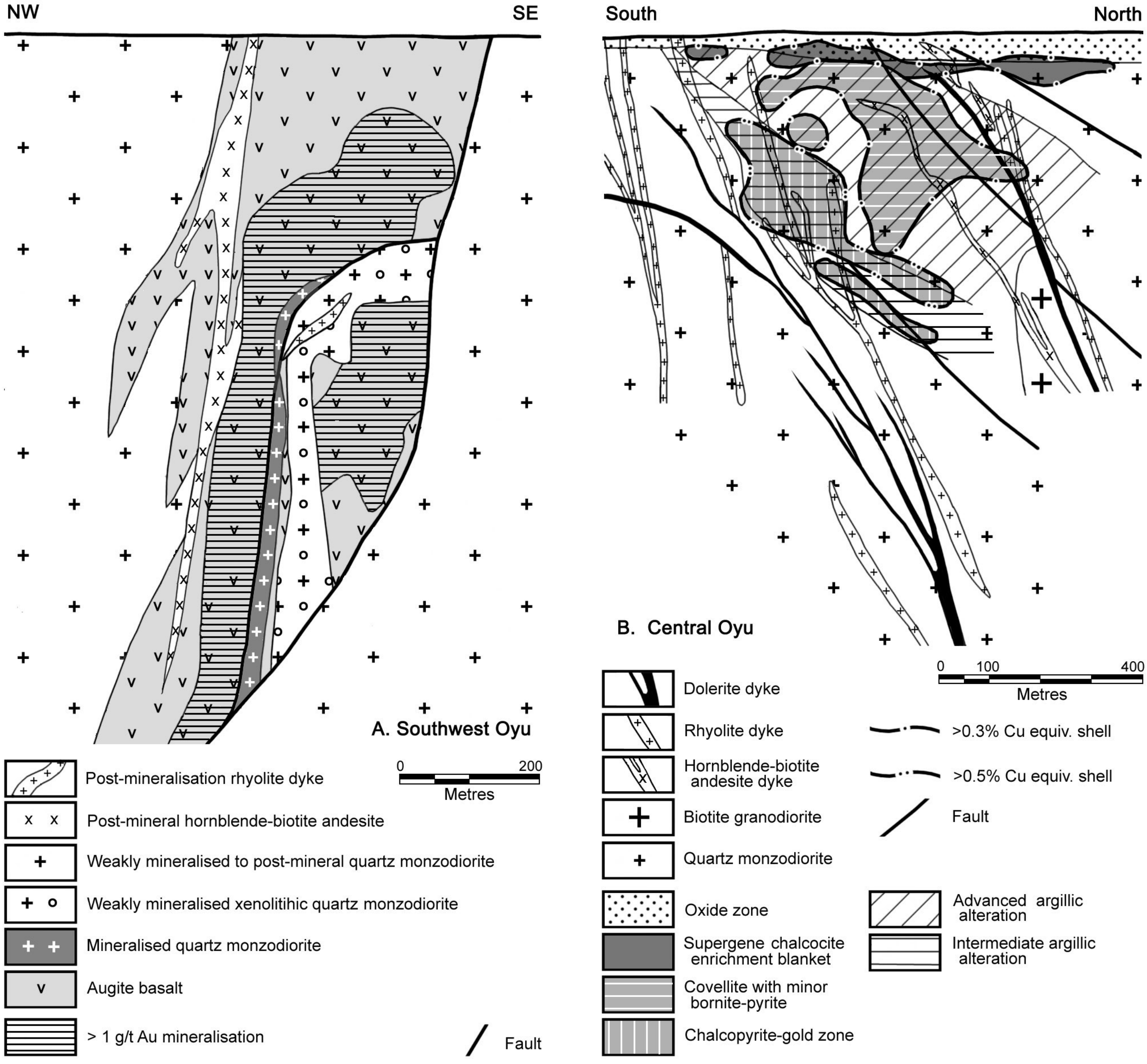


Figure 16: ***Geological cross sections through two of the Southern deposits, Southwest and Central Oyu, of the Oyu Tolgoi porphyry Cu-Au system, Mongolia.*** See Fig. 15 for the location of sections. After Ivanhoe Mines, (2005) and Kirwin *et al.,* (2005).

is related, both vertically and laterally to a series of porphyritic monzodiorite apophyses and to a deeper-seated porphyry-style intrusive core. Magnetite and chalcopyrite veining in biotite and chlorite altered porphyritic augite basalt, similar to South-West Oyu, has been encountered in deep drilling. Exceptional copper grades (locally as high as 10% Cu over 2 m sample intervals) have been intersected at Hugo South, occurring as bornite, chalcopyrite and chalcocite (Ivanhoe Mines, 2005; Kirwin *et al.,* 2005 and references quoted therein).

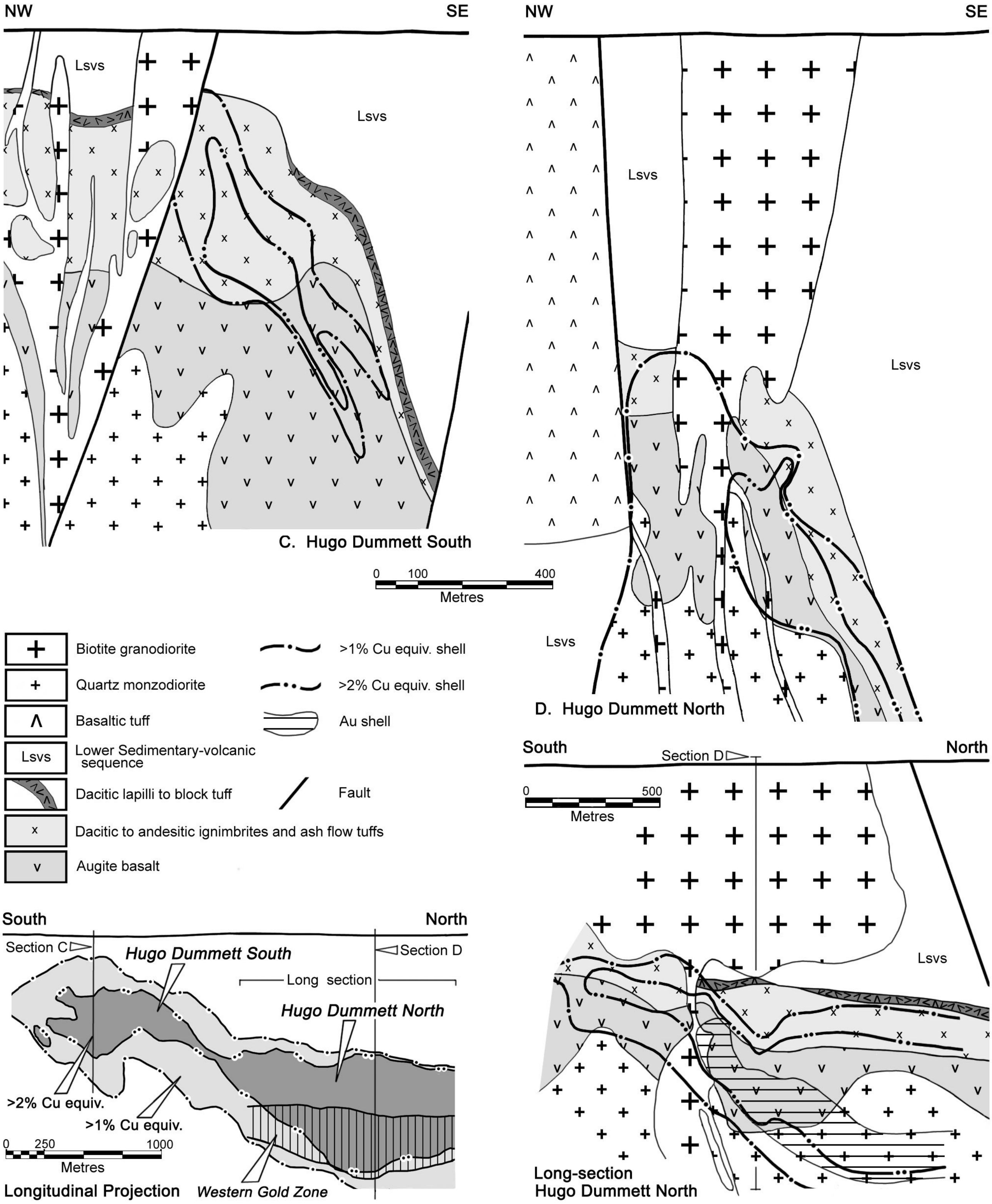


Figure 17: ***Representative geological cross and long sections through the Hugo Dummett deposits of the Oyu Tolgoi porphyry Cu-Au system, Mongolia.*** Cross-section C (top left) is the NE6200 section through the Hugo Dummett South deposit ; Cross-section D (top right) is the N4767200 section at Hugo Dummett North. The longitudinal section (bottom right) through part of the Hugo Dummett deposit is a diagrammatic representation of the geology and grade distribution of the ore deposit. The longitudinal projection (bottom left) is a representation of the outline of the ore grade shells at both the Hugo Dummett South and section of the Hugo Dummett North deposit. See Fig. 15 for the location of cross-sections C and D also. After Ivanhoe Mines, (2005) and Kirwin *et al.,* (2005).

Hugo Dummett North is predominantly within basalt and quartz monzodiorite (Fig. 17), which are characterised by sulphide assemblages of bornite+chalcocite and chalcopyrite with minor, enargite and tetrahedrite-tennantite. This section of the deposit has a continuous high-grade bornite dominant core which extends for at least 1.6 kilometres to the NNE from South Hugo. This core corresponds to a zone containing around 90% vein quartz. It has a vertical extent that varies from 100 m in the neck connecting Hugo Dummett South and North, but expands to more than 700 m on the northern most section drilled (but unclosed) in 2005. The corresponding horizontal width of the high grade core ranges from 150 to 180 metres up to approximately 200 m in the south and north respectively and is entirely enveloped by the greater than 1% Cu grade shell which reaches a maximum horizontal thickness of 450 m at zero RL (1160 m below surface). Maximum gold grades are associated with bornite with Au g/t:Cu% ratios varying from 1:10 to as high as 1:1 in the northern part of the deposit (Ivanhoe Mines, 2005; Kirwin *et al.,* 2005 and references quoted therein).

The main Hugo Dummett North orebody is limited to the west by a thick dyke of late- to post-ore biotite granodiorite. It redevelops again on the western side of this dyke, hosted by quartz monzodiorite to form the gold and bornite rich Hugo *Western Gold* orebody which is up to 100 m thick, with a vertical extent of 300 m and a strike length in excess of 1 km, open to the north, south. In May 2004 it was estimated to contain a minimum of 57.6 Mt @ 0.96% Cu, 0.85 g/t Au (Ivanhoe Mines press release, May 2004).

Molybdenite occurs locally in all rock types. A Re-Os determination from molybdenite in the orebody gave an age for the ore of 372 ±1.2 Ma (Kirwin *et al.,* 2005 and references quoted therein; Wainwright *et al.,* 2004).

The Hugo Dummett deposits, were estimated at April 2005, to contain an Indicated + Inferred resource of 1.071 Gt @ 1.07% Cu, 0.21 g/t Au at a 0.6% Cu equivalent cut-off, or 595.7 Mt @ 1.36% Cu, 0.28 g/t Au at a 1% Cu equivalent cut-off. In addition, the same resource classifications for the high-grade core were estimated to contain 335.4 Mt @ 2.84% Cu, 0.49 g/t Au at a 2% cut-off. This resource is still open to the north and at depth (Ivanhoe Mines press release, May 2005) with substantial potential to be expanded. Fig. 15 illustrates the location and geometry of these segments of the deposit.

Tsagaan-Suvarga, Mongolia

The Tsagaan-Suvarga porphyry copper-molybdenum deposit is located approximately 150 km to the northeast of Oyu Tolgoi in southern Mongolia (Fig. 14) and also lies within the Gurvansayhan Terrane (*see* Oyu Tolgoi description above). Like Oyu Tolgoi, it was formed within the Southern Mongolian Magmatic Belt segment of the Upper Palaeozoic Kazakh-Mongol magmatic arc, and has been dated at approximately 365 Ma (Lamb and Cox, 1998). The published resource at the deposit is 240 Mt @ 0.53% Cu, 0.018% Mo.

Arc magmatism within the Southern Mongolian Magmatic Belt was intermittent through the Late Palaeozoic to the Permian and was predominantly of calc-alkaline to potassic calc-alkaline composition, with a minor alkaline component. The main activity within the arc persisted to at least 370 Ma before shifting south during the Carboniferous. The deposit lies within the Late Devonian to early Carboniferous Tsagaan-Suvarga intrusive complex, which comprises gabbro, diorite, syenite, syenogranite and subordinate granodiorite, and is fringed by Carboniferous and Jurassic to Cretaceous volcanic and sedimentary rocks. The final stages of the Tsagaan-Suvarga complex are represented by a series of intrusive stocks and dykes in its north and northwest, composed of granite, granite porphyry and syenogranite porphyry. Mineralisation within the complex and at Tsagaan-Suvarga is associated with these late stage intrusives. Both the intrusive complex and the overlying Carboniferous volcano-sedimentary sequence are cut by hornblende syenite and monzonite porphyries (Lamb and Cox, 1998; Watanabe and Stein, 2000).

The Tsagaan-Suvarga deposit comprises quartz-chalcopyrite stockwork mineralisation which is developed over an area of 1000 x 300 m, and has been traced by drilling to a depth of 600m. K silicates (mainly K feldspar) are the dominant alteration, overprinted by sulphide bearing ‘bands’ of sericite reaching tens of centimetres in width. The major ore minerals are chalcopyrite, bornite, molybdenite and pyrite, which are concentrated in the sericitic bands. A supergene chalcocite blanket has also been developed over the deposit (Lamb and Cox, 1998; Watanabe and Stein, 2000).

Kharmagtai, Mongolia

The Kharmagtai Au-Cu porphyry district is located in the southern Gobi desert of Mongolia, 120 km north of the Oyu Tolgoi porphyry Cu-Au deposit and 500 km south of the capital Ulaan Baatar. Like Oyu Tolgoi and Tsagaan-Suvarga, described previously, it lies within the Late Palaeozoic Gurvansayhan Terrane which is characterised by calc-alkaline to potassic-calc-alkaline igneous complexes, and comprises section of the Mid- to Late-Palaeozoic Kazakh-Mongol magmatic arc (Fig. 14).

Outcrop throughout the district is sparse, although available exposure indicates large areas are underlain by a Devonian silty clastic sedimentary package which includes arenaceous volcaniclastic rocks with andesitic lava fragments, and plagioclase and hornblende crystals, as well as lesser felsic ash crystal tuffs, reworked tuffaceous sediments and locally, limited exposures of basaltic to andesitic volcanics. All of these lithologies have been intruded by monzodiorite, monzonite and diorite porphyry stocks. The magmatic arc has been eroded and unroofed in the district, with little evidence of comagmatic volcanic equivalents of the intrusive complex, although abundant sediment roof pendants within the stocks imply they are exposed at their upper-most levels. Preliminary Re-Os dates of 330.2 ± 1.0 Ma in the Carboniferous have been determined from samples of these intrusives at Kharmagtai.

While the majority of the intrusive rocks encountered to date have been altered, studies of drill core reveal that the diorite has phenocrysts of plagioclase, hornblende and apatite in a fine grained groundmass of plagioclase, hornblende, quartz, magnetite and zircon, consistent with a potassic-calc-alkaline magmatic association. Numerous tourmaline breccia pipes are scattered throughout the district, the largest of which has a diameter of 500 m, while local, linear, structurally controlled, silicified zones contain abundant tourmaline. Quaternary to Recent sands and loess form a thin cover over most of the district.

Exploration has identified at least four significant zones of IP anomalism and coincident centres of porphyry related gold-copper mineralisation and alteration within an area of around 7x3 km. Some 10 km to the west, distal gold-base metal-bearing breccia pipes has been recognised and several kilometres to the southwest again, complex, structurally controlled, gold bearing silicified zones occur within the volcano-sedimentary pile.

A representative example (see Fig. 18 for location and cross section) of one of these centres of porphyry related gold-copper mineralisation and alteration is represented by a 200 m diameter sub-cropping zone that was oxidised to depths of approximately 60 metres below surface. The oxide zone contains fracture controlled goethite, malachite, copper-wad, minor chalcocite and occasionally native copper. Drilling of the hypogene zone encountered chalcopyrite and subordinate pyrite associated with up to 10% stockwork quartz veins, mostly hosted in microdiorite, with lesser late chalcopyrite-rich sulphide veins (<5% sulphides) containing minor bornite. Rare molybdenite occurs as fracture coating and within milky quartz veins in the stockwork zone. Native gold is present as small inclusions in chalcopyrite grains and to a lesser extent in pyrite and as minor Au tellurides. In high-grade zones the Au g/t:Cu% ratios frequently exceeds 2:1. Narrow zones (normally less than 10 metres in width) of hydrothermal tourmaline breccias contain quartz-veined microdiorite clasts in a matrix of quartz, tourmaline, sericite, pyrite and minor chalcopyrite. Magnetite is a major accessory mineral in this and all of the Kharmagtai mineralised porphyries, occurring within pre-mineral quartz veins and in sulphide-rich veins. Planar "centre-line" and "railroad textured" quartz - sulphide ± magnetite veins are characteristic of the Kharmagtai porphyry mineralisation. Drill intersections across this zone are generally of 80 to 100 m @ 0.5 to 0.8% Cu, 0.7 to 1.25g/t Au and define a 60° south dipping stockwork zone that has been traced to a depth in excess of 250 m below surface.

nitial potassic alteration affected both intrusives and sediments, represented by an assemblage of variably developed albite + biotite + K-feldspar + minor magnetite + quartz + pyrite with veinlets of quartz, magnetite, chalcopyrite, pyrite, apatite, epidote and chlorite. Propylitic (chlorite ± calcite ± pyrite) and phyllic (sericite + pyrite + quartz ± chlorite ± tourmaline ± chalcopyrite ± gold) alteration commonly overprints the potassic assemblages. Some 1.5 km to the north, within another of the mineralised stockwork zones, the early potassic phase is overprinted by quartz-carbonate-sulphide veins and breccias with quartz, calcite, tourmaline, chlorite, sericite, pyrite, chalcopyrite, sphalerite, galena and tennantite-tetrahedrite enclosed by selvages of high-intensity texture-destructive phyllic type alteration in the form of quartz + sericite + pyrite + Ti-phase (rutile, leucoxene and anatase) minerals. Younger tourmaline breccias contain mostly pyrite. Late calcite - zeolite fracture fillings are also recorded, with trace pyrite, hematite, quartz and chalcopyrite.

The individual centres of copper-gold bearing porphyry related quartz stockwork mineralisation identified in the Kharmagtai district are all quite similar. Some occurs as broad planar zones, which in some cases are focused on narrow quartz diorite dykes within the diorite to quartz-diorite hosts, while others are more diffuse and irregular. It is considered possible that the individual stockwork zones may amalgamate at depth to form a single large porphyry deposit The section on Kharmagtai has been drawn from Kirwin *et al.,* (2005a) and references cited therein

Duobaoshan, Inner Mongolia - China

The Duobaoshan Cu-Au-Mo deposit and Tongshan Cu-Mo immediately to the south, both lie within the Xinganling block of Inner Mongolia (Heilongjiang Province) in northeastern China. Duobaoshan is associated with Late Carboniferous to Early Permian granodioritic intrusives of the Kazakh-Mongol magmatic arc, intruding Lower Palaeozoic arc volcanics of the extinct Tuva-Mongol arc. These deposits were emplaced in the waning stages of the

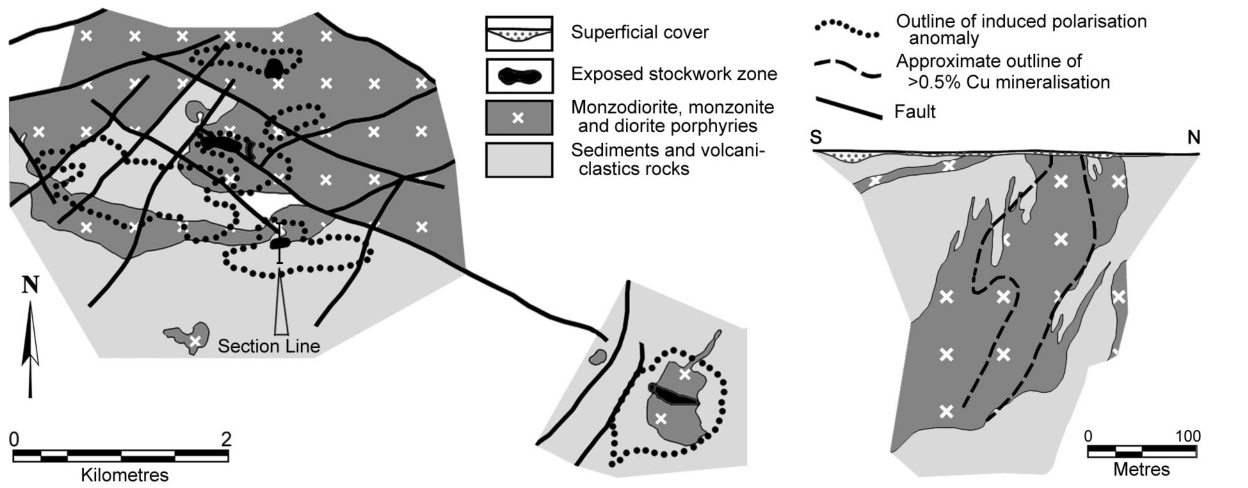


Figure 18: ***Simplified interpretive geological plan of the Kharmagtai district showing the main centres of porphyry style Au-Cu mineralisation and a representative section through one of those mineralised centres .*** After Kirwin, *et al.,* (2005a).

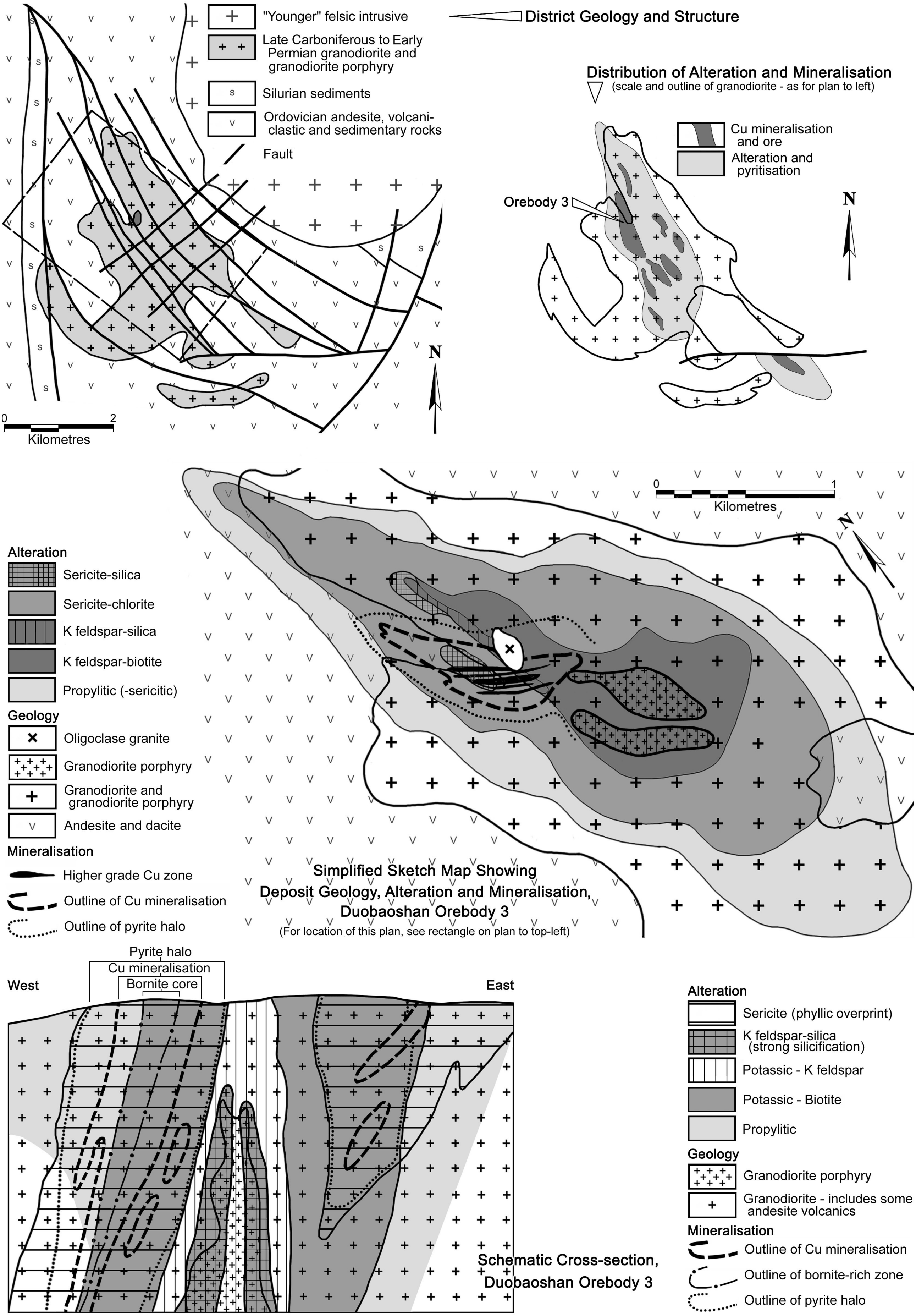


Figure 19: ***Geology, mineralisation and alteration of the Duobaoshan porphyry Cu deposit in Inner Mongolia, northeastern China.*** After Zhao, *et al.,* (1995, 2005), Qi (2004).

Kazakh-Mongol arc, near its overlap with the Selanga-Gobi-Khanka arc of the Palaeo-Pacific Ocean margin. Duobaoshan is reported to have a resource of 508 Mt @ 0.47% Cu, 0.2 g/t Au, 2 g/t Ag, 0.02% Mo, while Tongshan is believed to contain 180 Mt @ 0.47% Cu, 0.023% Mo (Zhao *et al.,* 2005, Mutschler *et al.,* 2000).

The country rock at Duobaoshan comprises a Caledonide sequence of andesitic to dacitic arc-related volcanic and volcaniclastic rocks of the Ordovician Duobaoshan Formation, overlain by Silurian sediments. The volcanic rocks of the Duobaoshan Formation show an alkalic to calc-alkalic trend and were intruded by a composite granodioritic complex predominantly composed of granodiorite and granodiorite porphyry. This intrusive mass covers an exposed area of 8 km^2 within an arcuate, northwest-southeast trending structual zone (Fig. 19). Two strongly altered, lens-like, northwest striking and southwest dipping granodiorite porphyry bodies with exposed areas of 0.08 and 0.09 km^2 respectively are located within the centre of the granodiorite. The granodiorite and granodiorite porphyry have been dated by K-Ar isotopes at 292 and 283 Ma respectively (Zhao *et al.,* 2005).

Mineralisation is associated with a northwest-southeast corridor of alteration that extends across the granodiorite mass over a length in excess of 6 km (Fig. 19) and comprise a large number of lenticular mineralised zones that define the orebodies. The largest of these is Orebody No. 3 which occurs in the hangingwall of the granodiorite porphyry and is associated with an episode of phyllic sericite and quartz-sericite alteration that overprints an earlier potassic phase characterised by intense silicification of the granodiorite porphyry margin, surrounded progressively outwards by K feldspar and then biotite alteration which grades to a periphery that was subjected to propylitic alteration. The phyllic phase overprints the potassic zone near its transition to the propylitic zone. The bulk of the mineralisation was emplaced outside of the granodiorite porphyry, predominantly within the granodiorite mass, but also partially within the Ordovician volcanic wall rock. The core of Orebody No. 3 is occupied by a bornite rich core which passes outwards into chalcopyrite and a pyritic halo. The accompanying ore minerals include pyrite, cuprite and covellite (Zhao *et al.,* 2005; 1995; Yin *et al.,* 1997; Du, 2004).

Fig. 19 summarises the setting, and the distribution of mineralisation and alteration at the Duobaoshan porphyry Cu-Au-Mo system. These diagrams are sketches and comprise the combination of different pieces of information from the range of sources quoted above.

Erdenet, Mongolia

The Erdenet porphyry Cu-Mo deposit is located in northern Mongolia, some 240 km northwest of the capital, Ulaanbaatar. It was emplaced within the Late Palaeozoic to Early Mesozoic Selanga-Gobi-Khanka magmatic arc on the margin of the Siberian Craton at 240 Ma in response to the closing of the Mongol-Okhotsk Sea and subduction of the palaeo-Pacific ocean below the Siberian craton. Erdenet is described in detail in Gerel, (2005), in this volume. See Table 1 for details.

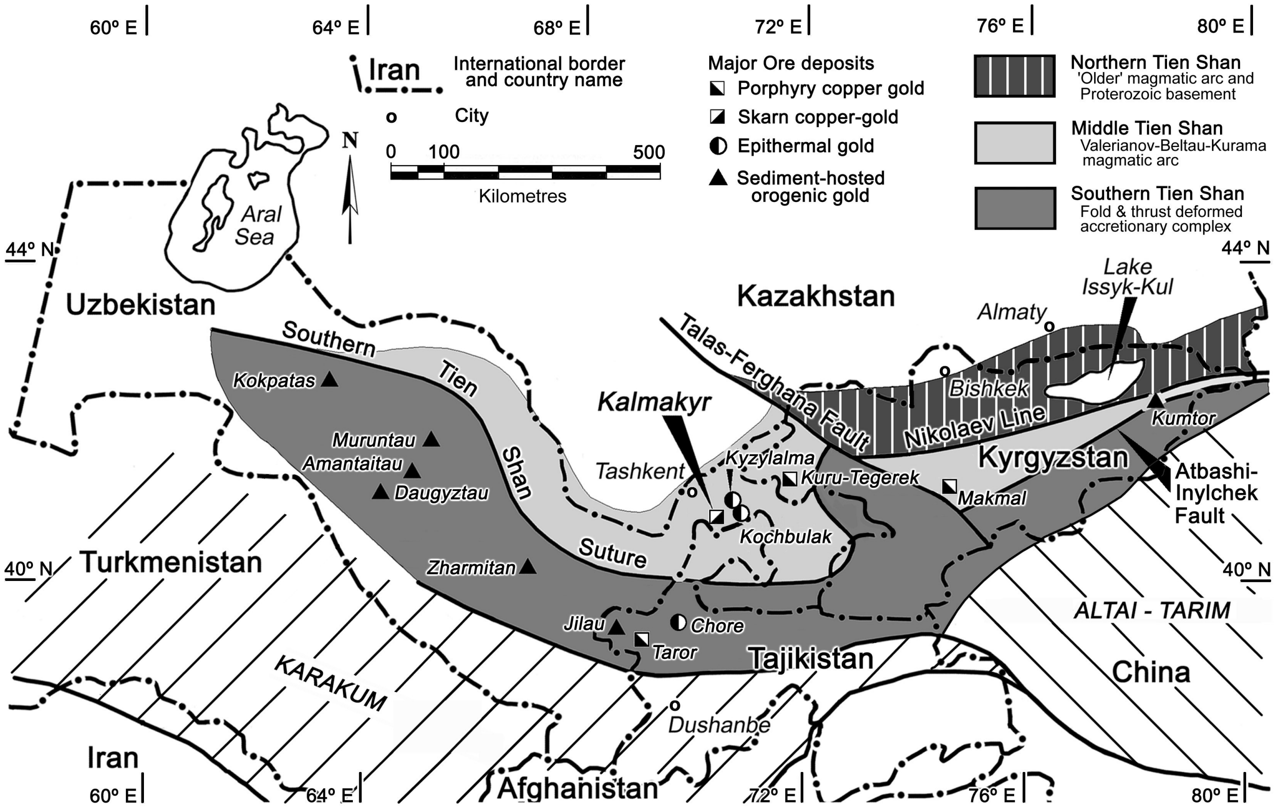


Figure 20: ***Tectonic framework and and distribution of gold ore deposits in the southwestern section of the Tien Shan Mineral Belt.*** After Yakubchuk, *et al.,* (2002); Mao *et al.,* (2004) and others.

Wunugetushan (Wushan), Inner Mongolia - China

The Wunugetushan (abbreviated to Wushan) porphyry Cu-Mo deposit is located in Inner Mongolia, China within 70 km of the border with northeastern Mongolia and 30 km south of the Russian frontier. It was emplaced at 184 Ma (Early Jurassic) within the late stages of the Selanga-Gobi-Khanka magmatic arc and lies on the southern limb of the Mongolian Orocline (Fig. 2). The deposit is quoted as containing 495 Mt @ 0.45% Cu, 0.09% Mo (Mutschler *et al.,* 2000). The host terrane is predominantly composed of Mesozoic calc-alkaline volcanic rocks of the Selanga-Gobi-Khanka magmatic arc, which are bounded by metamorphosed Permian volcanic rocks and older Palaeozoic sequences of the basement to the magmatic arc. Granitic rocks belonging to the Triassic Indo-Sinian, Jurassic Early Yanshanian and Cretaceous Late Yanshanian orogenic episodes intrude all of the basement rocks (Qin *et al.,* 1997).

The immediate wall rocks to the deposit are biotite monzogranite of a 120 km^2 diameter Indo-Sinian batholith dated at between 177 and 201.6 Ma (K-Ar), and 212.85±6.76 Ma (Rb-Sr). The monzogranite batholith is intruded by a monzogranite porphyry stock (188.3±0.6 Ma by U-Pb in zircon) which is associated with the mineralisation. Three alteration zones are recorded, namely an inner quartz-K feldspar zone, a surrounding quartz-sericite phase and an outer illite-hydromuscovite periphery. The Cu orebody is hosted in the outer sections of quartz-K feldspar zone, while the peak Mo mineralisation is in the inner sections of the quartz-sericite annulus. The sericite alteration associated with mineralisation has been dated at 182.3 to 184.7 Ma (Qin *et al.,* 1997).

Orogenic Gold Deposits

Gold mineralisation occurs in two principal settings within the central part of the Altaids, the Tien Shan Mineral Belt, namely as i). *porphyry and epithermal* systems developed within magmatic arcs, as described in the bulk of this paper, and ii). *orogenic-type* gold deposits that are structurally controlled, and temporally and spatially associated with late Palaeozoic, syntectonic to early post-collisional, highly evolved, I-type granodioritic to monzonitic intrusives in fore- and back-arc terranes (Cole and Seltmann, 2000; Yakubchuk *et al.,* 2002; Mao *et al.,* 2004).

While these orogenic-type gold deposits are not directly related to porphyry systems, they are a product of the same larger scale metallogenic evolution and set of tectonic processes as the gold rich porphyry and epithermal deposits of the belt, and hence are briefly discussed herein.

Moreover, although belonging to two different terrane settings, the giant Cu-Au porphyries of the Chatkal-Kurama range (Almalyk district, in the Valerianov-Beltau-Kurama magmatic arc, of the Middle Tien Shan) and the giant orogenic Au mineralisation hosted by the black-shale series of the Central Kyzylkum slate belt (Southern Tien Shan, Khanty-Mansi accretionary complex) have some striking similarities. These hint at crust-mantle interaction and dominance of a deep-seated regime during emplacement, referred to as the "Chatkal-Kurama hot spot" (I.M. Golovanov, pers. comm.; Dalimov *et al.,* 2003). They are temporally close (315 to 285 Ma, Seltmann *et al.,* 2004), their isotope signatures reveal the incorporation of a moderate mantle component (Chiaradia *et al.,* 2005), and geophysical patterns from the middle crust in the region exhibit zones of low reflection indicating the existence of extended mafic bodies just beneath both giant ore-magma systems (S. Cherkasov, pers. comm.). Focused studies are required to provide evidence that may substantiate this controversial discussion.

The orogenic gold deposits of the Tien Shan Mineral Belt include some of the largest economic gold accumulations in the world, e.g. Muruntau in Uzbekistan which contains over 5400 tonnes (175 Moz) of gold at an open pit recovered grade of 3.4 g/t Au. These deposits are spread across the belt in Russia, Uzbekistan, Tajikistan, Kyrgyzstan, Kazakhstan and western China, and span the time scale from Lower to Late Palaeozoic. The greatest concentration of significant orogenic gold deposits however, is in the southwestern part of the belt, in the South and Middle Tien Shan of Uzbekistan and Kyrgyzstan. These deposits are associated with Permian magmatism emplaced during the final- to early post-collisional stages of orogenesis, within a sutured back-arc setting containing carbon-rich sedimentary sequences (Cole and Seltmann, 2000; Yakubchuk *et al.,* 2002; Mao *et al.,* 2004).

The orogenic gold deposits of the South Tien Shan are controlled by structures related to the Southern Tien Shan Suture Zone that separates the Carboniferous Valerianov-Beltau-Kurama magmatic arc to the north, and the Altai-Tarim-Karakum micro-continent to the south. They are hosted by the back arc accretionary complex deposited in the basin that had separated these two tectonic elements (Fig. 20). The suture zone is defined by ophiolites and borders the strongly deformed fold and thrust belt of the Southern Tien Shan that has been extensively intruded by Permian granitoids and hosts most of the significant orogenic-style gold deposits (Mao *et al.,* 2004).

Most of the orogenic-gold deposits within the Tien Shan are located at mesozonal crustal levels, within Late Palaeozoic granitoid intrusives, or their contact metamorphic aureoles, and yield radiometric dates of mineralisation coincident with the magmatism. However, few can be shown to have a direct genetic link with the associated intrusives. Never-the-less, geochemical, isotope and fluid-structural models have implicated highly evolved Late Palaeozoic, syntectonic I-type granitoids as the source of metals and/or fluids for spatially associated orogenic gold deposits within the belt. The gold-quartz vein systems produced appear to represent only part of a larger magmatic-hydrothermal system that often includes earlier scheelite (±Au) skarn mineralisation (e.g. Zharmitan in Uzbekistan and Jilau in Tajikistan, while Muruntau, also in Uzbekistan, exhibits some similarities). In these examples, Au and W occur together with characteristic enrichments of As, Bi, Mo and Te deposited from CO_2-rich fluids at temperatures of up to 400°C and pressures of approximately 2 Kbar (Cole and Seltmann, 2000).

The distribution of the granitoids and the associated gold deposits are both controlled by the same regional deep seated faults and shear zones that were the primary focus of regional fluid flow and of deformation. Mineralisation appears to have been formed by CO_2-rich fluids of deep crustal origin that episodically escaped from geopressured reservoirs along major high angle reverse faults and deposited gold in zones of local structurally enhanced permeability (Cole, 1998; 2002).

Cole and Seltmann, (2000) note that a general trend can be recognised in these granitoid related systems, where W, in the form of scheelite, dominates in mesozonal, more reduced settings, whereas Cu substitutes for W in the paragenesis of epizonal, more oxidised systems. They also observe that these same Late Palaeozoic (Variscan-Hercynian) granitoids are temporally, mineralogically, compositionally and isotopically similar, whether related to orogenic-style Au-W veins and associated skarn systems in the South Tien Shan fore-arc accretionary complex, or, related to shallower porphyry Cu-Au systems in the magmatic arc of the Middle Tien Shan. They suggest a continuum which would encompass classic Cu-Mo-Au porphyry, Cu-Au skarn and Au-Ag epithermal deposits in epizonal crustal environments/levels, passing down into W-Mo-Au with associated Bi-As-Te associations in skarn, lode and stockwork deposits (i.e. orogenic-style Au) at mesozonal depths.

Acknowledgments

This paper merges the professional experience of TMP in mineral exploration and synthesis of information with the results of almost 15 years of collaborative applied research by RS in the framework of a series of international academic network projects. The latter studies were coordinated by RS and funded initially through the INTAS 93-1783 project "Anatomy and magmatic-hydrothermal mechanisms of ore deposition" (1993-1996), followed by the IUGS-UNESCO funded projects IGCP-373 “Ore-bearing granites of Eurasia” (1997-2002) and IGCP-473 “GIS metallogeny of Central Asia” (2002-2006). The resulting output was supplemented and enhanced by advanced mineral deposit case studies combining the development of regional-scale GIS packages and focused petrochemical and geochronological research along selected geodynamic-metallogenic geotraverses. Since 2002, this approach has been initiated and coordinated through NHM's Centre for Russian and Central Asian Mineral Studies (CERCAMS) and has led to new insights and additional information. The long-term research benefited from the scientific contributions of several dozen teams in the countries of the former Soviet Union, Mongolia and China, representing the knowledge input of several hundreds of regional and local specialists of various specialisation. Without their continuous support and stable cooperation over more than a decade, providing access to unpublished data and key samples, inspiring discussions, field support, their papers, maps and reports used for the CERCAMS database, facilitating this compilation would not have been possible. The remarkable input and collaboration of all those friends and colleagues is highly appreciated. Among all those involved, the cooperation and fruitful discussions especially with Igor Golovanov, Rustam Koneev, Ochir Gerel, Rosalia Jenchuraeva, Olga Plotinskaya, Victor Popov, Andy Cole, Vertrees M. Canby, Dmitry Konopelko, Vjacheslav Serykh, Vladimir Dolgopolov and Alla Dolgopolova are highly appreciated. Special thanks is owed to Vitaly Shatov and Alexander Yakubchuk for their cooperation, specifically for their assistance in developing the CERCAMS mineral deposits maps and databases on Central Asia, Mongolia and the Urals. Deep appreciation is due to Douglas Kirwin for a thorough review of an earlier version of this paper, for his comments and suggestions that improved the paper and the valuable information he provided on ore deposits in Mongolia and China. This CERCAMS publication is simultaneously a contribution to the IGCP-473 project.

References

Allen, M.B., Windley, B.F. and Zhang, C., 1992 - Palaleozoic collisional tectonics and magmatism of the Chinese Tien Shan, Central Asia. *Tectonophysics*, v. 220, pp. 89-115.

Badarch, G., Cunningham, W.D. and Windley, B.F., 2002 - A new terrane subdivision for Mongolia: implications for the Phanerozoic crustal growth of Central Asia; *Journal of Asian Earth Sciences,* v. 21, pp. 87-110.

Bespaev, Kh.A. and Miroshnichenko, L.A., (Eds.), 2004 - Atlas of Mineral Deposit Models of the Republic of Kazakhstan. Almaty, Kazakhstan; English edition by Halls, C., Seltmann, R., Dolgopolova, A., *CERCAMS NHM,* London, 2004, 142p.

Central Asia Gold Ltd, 2005 – Web-site at http://www.cagl.com.au.

Chiaradia, M., Konopelko, D., Seltmann, R. and Cliff, R., 2005 - Lead sources in ore deposits and magmatic rocks of the Tien Shan and Chinese Altay; *in* Mao, J.W., *et al.,* (Eds.), Mineral Deposit Research: Meeting the Global Challenge, Proceedings of the Eighth Biennial SGA Meeting, Beijing, China, 18-21 August, 2005; *Springer,* pp. 1301-1304.

Chisholm, J.M., 2003 - Independent Geologist’s Report; Continental Resource Management Pty Ltd, attached to Central Asia Gold Limited Prospectus, submitted to ASX, Australia.

Cole, A., 1998 - Gold mineralisation in the southern Tien Shan, Central Asia: tectonic setting, characteristics and regional exploration criteria; (Abstract) *in Geological Society of London,* Mineral Deposits Studies Group Annual Meeting, Programs and Abstracts, v. 22. p. 27.

Cole, A., 2000 - Genesis of granitoid-hosted gold-tungsten mineralization, Jilau, Tajikistan: Unpublished Ph.D. thesis, UK, *University of London,* 240 p.

Cole, A. 2002 - The Great Silk Road paved with gold. *International Mining and Minerals,* No. 48, pp. 13-15.

Cole, A. and Seltmann, R., 2000 - The role of granitoids during Variscan orogenic gold mineralization in the Tien Shan and Ural mountain belts of central Eurasia; *in* Bouchot, V. and Moritz, R. (Eds.), Orogenic Gold Deposits in Europe, *Editions BRGM,* v. 297, pp. 110-111.

Corbett, G., 2004 - Epithermal and Porphyry Gold - Geological Models; *in* Hi Tech and World Competitive Mineral Success Stories Around the Pacific Rim, Proc. PACRIM 2004 Conference, Adelaide, 19-22 September, 2004, *AusIMM,* Melbourne, pp. 115-125.

Dalimov, T.N., Ganiev, I.N. and Ishbaev, Kh..D., 2003 - The Chatkal-Kurama "hot spot" and history of magmatic evolution.- *Geologiya i Mineral'nyie Resursy* (Geology and Mineral Resources), Tashkent, v. 5 (5), pp. 3-14 *(in Russian).*

Du Qi, 2004 - The alteration and mineralization features of the Duobaoshan porphyry copper deposit; Bulletin of the Geological Survey of Japan, v. 33, pp. 469-477.

Gerel, O., 1998 – Phanerozoic felsic magmatism and related mineralization in Mongolia; *Bulletin of the Geological Survey of Japan*, v. 49, pp. 239-248.

Gerel, O. and Munkhtsengel, B., 2005 - Erdenetiin Ovoo Porphyry Copper-Molybdenum Deposit in Northern Mongolia; in Porter, T.M. (Ed.), Super Porphyry Copper & Gold Deposits: A Global Perspective; *PGC Publishing,* Adelaide, v. 2, pp. 525-543.

Golovanov, I.M., Seltmann, R. and Kremenetsky, A.A., 2005 - The Porphyry Cu-Au/Mo Deposits of Central Eurasia: 2. The Almalyk (Kal'makyr-Dalnee) and Saukbulak Cu-Au Porphyry Systems, Uzbekistan; *in* Porter, T.M. (Ed.), Super Porphyry Copper & Gold Deposits: A Global Perspective; *PGC Publishing,* Adelaide, v. 2, pp. 513-523.

Han, C., Rui, Z., Mao, J., Yang, J., Wang, Z. and Yuan, W., 2003 – Geological characteristics of the Tuwu copper deposit, Hami, Xianjiang; in Mao, Goldfarb, Seltmann, Wang, Xiao and Hart, (Eds.), 2003 – Tectonic Evolution and Metallogenesis of the Chinese Altay and Tianshan, Proceedings Volume of the International Symposium of the IGCI – 473 Project in Urumqi and Guidebook of the Field Excursion in Xinjiang, China: August 9-21, 2003. *IAGOD Guidebook Series 10: CERCAMS/NHM,* London, pp. 249-260.

Hedenquist, J.W., Arribas, A. Jr. and Reynolds, T.J., 1998 - Evolution of an intrusion-centered hydrothermal system: Far Southeast-Lepanto porphyry and epithermal Cu-Au deposits, Philippines; *Economic Geology,* v. 93, pp. 373-404.

Hedenquist, J.W. and Daneshfar, B., 2003 - Mineral potential of Central and East Asia. Basis for mining investment in transition economy countries; The World Bank Group, Mining Department; *Mining Journal Books Ltd.,* London. 105p. PDF document on CD-ROM.

Heinhorst, J., Lehmann, B., Ermolov, P., Serykh, V. and Zhurutin, S., 2000 - Paleozoic crustal growth and metallogeny of Central Asia: evidence from magmatic-hydrothermal ore systems of Central Kazakhstan, *Tectonophysics* v. 328, pp. 69-87.

Herrington, R.J., Puchkov, V.N. and Yakubchuk, A.S., 2005 - A reassessment of the tectonic zonation of the Uralides: implications for metallogeny; *in* McDonald, I., Boyce, A.J., Butler, I.B., Herrington, R.J. and Polya, D.A., (Eds.), Mineral Deposits and Earth Evolution. *Geological Society,* London, Special Publications, v. 248. pp. 153-166.

Islamov, F., Kremenetsky, A., Minzer, E. and Koneev, R., 1999 - The Kochbulak - Kairagach ore field; *in* Shayakubov, T., Islamov, F., Krementsky, A. and Seltmann, R., (Eds.), Au, Ag, and Cu deposits of Uzbekistan. Excursion guidebook to the International Field Conference of IGCP-373, Excursion B6 of the Joint SGA-IAGOD symposium, London/Tashkent, 27/28 August - 4 September 1999, Chapter 5, pp. 91-108.

Ivanhoe Mines, 2004-2005 – Web-site at http://www.ivanhoe-mines.com/s/OyuTolgoi.asp.

Jahn, B.-M., 2004 - The Central Asian Orogenic Belt and growth of the continental crust in the Phanerozoic; *in* Malpas, J., Fletcher, C.J.N., Ali, J.R. and Aitchison, J.C., (Eds.), Aspects of the Tectonic Evolution of China, *Geological Society,* London, Special Publications, v. 226. pp. 73-100.

Jahn, B.-M., Wu, F. and Chen, B., 2000 - Granitoids of the Central Asian Orogenic Belt and continental growth in the Phanerozoic: *Transactions of the Royal Society of Edinburgh,* Earth Sciences, v. 91, pp. 181-193.

Jenchuraeva, R.J., 1997 - Tectonic setting of porphyry-type mineralization and hydrothermal alteration in Paleozoic island arcs and active continental margins, Kyrghyz Range, (Tien Shan) Kyrghyzstan, *Mineralium Deposita,* v. 32, pp. 434-440.

Jenchuraeva, R.D., Nikonorov, V.V. and Karaev, Yu.V., 2005 - Atlas of Economic Types of Ore Deposits in Kyrgyzstan; State Agency on Geology and Mineral Resources under the Government of the Kyrgyz Republic and Institute of Geology, National Academy of Sciences, Kyrgyz Republic, Bishkek. English edition by *CERCAMS, NHM,* London (in press).

Jun, G., Maosong, L, Xuchang, X., Yaoqing, T. and Guoqi, H., 1998 - Paleozoic tectonic evolution of the Tienshan Orogen, northwestern China, *Tectonophysics*, v. 287, pp. 213-231.

Kamitani, M. and Naito, K, (Eds.), 1998 - Mineral resources map of Asia, Metal Mining Agency of Japan, Scale 1:10,000,000, accompanied by one booklet of tables and an html CD-ROM; http://www.mmaj.go.jp/mric_web/deposit/index.htm

Kidd, R.P. and Robinson, J.R., 2004 - A Review of the Kapit Orebody, Lihir Island Group, Papua New Guinea; *in* Hi Tech and World Competitive Mineral Success Stories Around the Pacific Rim, Proc. PACRIM 2004 Conference, Adelaide, 19-22 September, 2004, *AusIMM,* Melbourne, pp. 323-331.

Kirkham, R.V. and Dunne, K.P.E., (compilers), 2000, World distribution of porphyry, porphyry associated skarn and bulk-tonnage epithermal deposits and occurrences; *Geological Survey of Canada,* Open File 3792, Scale 1:35,000,000, accompanied by one diskette.

Kirwin, D.J., Forster, C.N. and Garamjav, D., 2003 - The discovery history of the Oyu Tolgoi porphyry copper-gold deposit, South Gobi, Mongolia; *in Proceedings of the NewGenGold 2003 Conference*, Perth, WA, pp. 130-146.

Kirwin, D.J., Forster, C.N., Kavalieris, I., Crane, D., Orssich, C., Panther, C., Garamjav, D., Munkhbat, T.O. and Niislelkhuu, G., 2005 - The Oyu Tolgoi Copper-Gold Porphyry Deposits, South Gobi, Mongolia; *in* Seltmann, R., Gerel, O. and Kirwin, D.J., (Eds.), Geodynamics and Metallogeny of Mongolia with a Special Emphasis on Copper and Gold Deposits: SEG-IAGOD Field Trip, 14-16 August 2005, 8th Biennial SGA Meeting. IAGOD Guidebook Series 11: *CERCAMS/NHM,* London. pp. 155-168.

Kirwin, D.J., Wilson, C.C., Turmagnai, D. and Wolfe, R., 2005a - Exploration History, Geology, and Mineralisation of the Kharmagtai Gold-Copper Porphyry District, South Gobi Region, Mongolia; in, Seltmann, R., Gerel, O. and Kirwin, D.J., (Eds.), Geodynamics and Metallogeny of Mongolia with a Special Emphasis on Copper and Gold Deposits: SEG-IAGOD Field Trip, 14-16 August 2005, 8th Biennial SGA Meeting. IAGOD Guidebook Series 11: *CERCAMS/NHM,* London, pp. 175-191.

Kovalenker, V.A., Safonov, Yu.G., Naumov, V.B. and Rusinov, V.L., 1997 - The Epithermal Gold-Telluride Kochbulak Deposit,Uzbekistan.- *Geology of Ore Deposits,* v. 39, N2, March-April 1997, pp. 107-128.

Kudrin, V.S., Solov'yev, V.A., Stavinskiy, V.A. and Karabdin, L.L., 1990 - The gold-copper-molybdenum-tungsten ore belt of the Tien Shan: *International Geology Review,* v. 32, pp. 930-941.

Kudryavtsev, Yu.K., 1996 - The Cu-Mo deposits of Central Kazakhstan; *in* Shatov, Seltmann, Kremenetsky, Lehmann, Popov and Ermolov, (Eds.) - Granite-Related Ore Deposits of Central Kazakhstan and Adjacent Areas; INTAS-93-1783 Project, *GLAGOL Publishing House,* St. Petersburg, pp. 119-144.

Lamb, M.A. and Badarch, G., 2001 - Paleozoic sedimentary basins and volcanic arc systems of southern Mongolia: New geochemical and petrographic constraints; *in* Davis, G.A. and Hendrix, M.S., (Eds.), Paleozoic and Mesozoic Tectonic Evolution of Central Asia from Continental Assembly to Intracontinental Deformation, *Geological Society of America,* Memoir 194, pp. 117-149.

Lamb, M.A. and Cox. D., 1998 - New $^{40}Ar/^{39}Ar$ age data and implications for porphyry copper deposits of Mongolia; *Economic Geology,* v93, pp. 524-529.

Lamb, M.A., Hanson, A.D., Graham, S.A., Webb, L.E. and Badarch, G., 1999 - Left-lateral sense offset of Upper Proterozoic to Palaeozoic features across the Gobi Onon, Tost and Zuunbayan faults in southern Mongolia and implications for other central Asian faults; *Earth and Planetary Science Letters,* v. 173, pp. 183-194.

Malyukova, N.N., 2001 - The Taldybulak Levoberezhny gold deposit; *in* Seltmann, R. and Jenchuraeva, R., (Eds.), Palaeozoic Geodynamics and Gold Deposits in the Kyrgyz Tien Shan; IGCP-373 Field Conference in Bishkek and the Kyrgyz Tien Shan; 16-25 August, 2001 & Pre-meeting Field Trip A5 of the Joint 6th Biennial SGA Meeting in Krakow, Poland, Excursion Guidebook, pp. 97-110.

Mao, J., Goldfarb, R., Seltmann, R., Wang, D., Xiao, W. and Hart, C., (Eds.), 2003 - Tectonic evolution and metallogeny of the Chinese Altay and Tianshan. International Association on the Genesis of Ore Deposits (IAGOD), London, Guidebook Series 10, *CERCAMS NHM,* London, 286p.

Mao, J., Konopelko, D., Seltmann, R., Lehmann, B., Wen Chen, Yitian Wang, Eklund, O. and Usubaliev, T., 2004 - Postcollisional age of the Kumtor gold deposit and timing of Hercynian events in the Tien Shan, Kyrgyzstan; *Economic Geology,* v. 99, pp. 1771-1780.

Mossakovskiy, A.A., Ruzhentsev, S.V., Samygin, S.G. and Kheraskova, T.N., 1993 - Central Asian fold belt: geodynamic evolution and history of formation; *Geotektonika*, no. 6, pp. 3-33 *(in Russian)*.

Mutschler, F.E., Ludington, S. and Bookstrom, A.A., 2000 - Giant porphyry-related metal camps of the world - a database; *U.S. Geological Survey* Open-File Report 99-556, Online Version 1.0, http://geopubs.wr.usgs.gov/open-file/of99-556/world_ppy.xls

Nie Fengjun, Jiang Sihong, Zhang Yi, Liu Yan and Hu Peng, 2004 - Geological features and origin of porphyry copper deposits in China-Mongolian border region and its neighbouring areas; *Mineral Deposits,* v. 23, No. 2, pp. 176-189 *(in Chinese, English abstract).*

Nikonorov, V.V., Karaev, J.V., Zamaletdinov, T.S., Borisov, F.I., Tolskiy, V.I., Larina, T.V., Gorbaneva, T.V., 2000 - Explanatory Notes and Catalogue of mineral deposits shown on the Map of Mineral Resources of the Kyrgyz Republic, Scale 1 : 1 000 000, Bishkek, 75p.

Perello, J., Cox, D., Garamjav, D., Sanjdorj, S., Diakov, S., Schissel, D., Munkhbat, T.-O. and Oyun, G., 2001 - Oyu Tolgoi, Mongolia: Siluro-Devonian Porphyry Cu-Au-(Mo) and high-sulfidation Cu mineralization with a Cretaceous chalcocite blanket; *Economic Geology,* v. 96, pp. 1407-1428.

Pokalov, V.T., 1977 - Deposits of molybdenum, *in* Smirnov, V.I., (Ed.), 1977 – Ore Deposits of the USSR; *Pitman Publishing,* v. 3, pp. 125-179.

Qin, K., Li, M. and Ishihara, S., 1997 - Intrusive and mineralization ages of the Wunugetushan porphyry Cu-Mo deposit, NE-China: Evidence from single grain zircon U-Pb, Rb-Sr isochron and

K-Ar ages; *Resource Geology*, v. 47 (6), pp. 293-298.

Qin, K., Sun, S., Li, M. Fang, T., Wang, S. and Liu W., 2002 - Paleozoic epithermal Au and porphyry Cu deposits in north Xinjiang, China: Epochs, features, tectonic linkage and exploration significance; *Resource Geology*, v. 52 (4), pp. 291-300.

Richards, J.P., 2005 - Cumulative Factors in the Generation of Giant Calc-alkaline Porphyry Cu Deposits; *in* Porter, T.M. (Ed.), Super Porphyry Copper & Gold Deposits: A Global Perspective; *PGC Publishing,* Adelaide, v. 1, pp. 7-25.

Samonov, I.Z. and Pozharisky I.F., 1977 - Deposits of copper, *in* Smirnov, V.I., (Ed.), 1977 – Ore Deposits of the USSR; *Pitman Publishing,* v. 2, pp. 106-181.

Seltmann, R. and Jenchuraeva, R., (Eds.), 2001 - Paleozoic geodynamics and gold deposits in the Kyrgyz Tien Shan: IGCP 373 International Field Conference, Bishkek and Kyrgyz Tien Shan, Kyrgyz Republic, 16-25 August 2001, Guidebook Series 9, 183p.

Seltmann, R., Koroteev, V., Fershtater., G. and Smirnov, V., (Eds.), 2000 - The eroded Uralian Paleozoic ocean to continent transition zone: Granitoids and related ore deposits: IGCP 373 International Field Conference, Urals, Russia, 18-30 July 2001, Excursion Guidebook, 102p.

Seltmann, R., Shatov. V. and Yakubchuk, A., 2004 - Mineral Deposits Database and Thematic Maps of Central Asia, Scale 1.5 million: ArcView 3.2 and MapInfo 6.0(7.0) GIS Packages, Explanatory Notes, *CERCAMS, Natural History Museum,* London, UK., 117p.

Sengör, A.M.C., Natal'in, B.A. and Burtman, V.S., 1993 - Evolution of the Altaid tectonic collage and Paleozoic crustal growth in Eurasia: *Nature,* v. 364, pp. 299-307.

Sengör, A.M.C. and Natal'in, B.A., 1996 - Palaeotectonics of Asia: Fragments and synthesis; *in* Yin, A. and Harrison, M., (Eds.), The Tectonic Evolution of Asia: *Cambridge University Press,* pp. 486-640.

Shatov, V.V., Cole, A., Seltmann, R. and Yakubchuk, A., 2001 - Metallogeny of gold in the Tien Shan and Urals Paleozoic fold belts: A GIS-based approach; *in* Piestrzynski, A., *et al.,* (Eds.), Mineral deposits at the beginning of the 21st century: *Lisse, Swets and Zeitlinger,* pp. 489-492.

Shatov V.V., Seltmann R. and Moon C. J., 2003 - The Yubileinoe porphyry Au(-Cu) deposit, the South Urals: Geology and alteration controls of mineralization; *in* Eliopoulos, D.G., *et al.,* (Eds.), Mineral Exploration and Sustainable Development, Proceedings 7th Biennial SGA Meeting, Athens, 24-28 August 2003; *Millpress* Rotterdam, v. 1, pp. 379-382.

Shayakubov, T., Islamov, F., Krementsky, A. and Seltmann, R., (Eds.), 1999 - Au, Ag, and Cu deposits of Uzbekistan: IGCP 373 International Field Conference, Excursion B6 of the Joint SGA-IAGOD Symposium, London-Tashkent, 27 August-4 September 1999, Excursion Guidebook, 112p.

Sokolov, A.L., 1995 - The regional and local controls on giant-scale copper and gold mineralisation, Uzbekistan; *in* Clark, A.H., (Ed.), Giant Ore Deposits II. Controls on the scale of orogenic magmatic-hydrothermal mineralisation; Proceedings of the second giant ore deposits workshop, Kingston, Ontario, Canada, April 25-27, 1995. Department of Geological Sciences, *Queens University,* Kingston Ontario, pp. 450-474.

Wainwright, A.J., Tosdal, R.M., Forster, C., Kavalieris, I., Crane, D., Findlay, A. and Kirwin, D., 2004 - Structure and Stratigraphy of the Oyu Tolgoi Cu-Au porphyry, Mongolia; Poster, Cordilleran Roundup 2004; www.mdru.ubc.ca/home/research/tog-ot-roundup_04_poster.pdf.

Wang Futong, Feng Jing, Hu Jianwei, Wang Lei, Jian Lifeng and Zhang Zheng, 2001a - Characteristics and significance of the Tuwu porphyry copper deposit, Xinjian [J]; *Chinese Geology*, v. 28 (1), pp. 36-39 *(in Chinese)*.

Wang Futong, Zhuang Daoze, Hu Jianwei, Feng Jing, Jian Lifeng, Zhang Zheng and Hu Changan, 2001b - Application of geophysical exploration method in the Tuwu area, Winjiang - On the prospecting model of porphyry copper deposit [J]; *Chinese Geology,* v. 28 (3), pp. 40-46 *(in Chinese).*

Watanabe, Y. and Stein, H.J., 2000 - Re-Os ages for the Erdenet and Tsagaan Suvarga porphyry Cu-Mo deposits, Mongolia, and tectonic implications; *Economic Geology,* v. 95, pp. 1537-1542.

White, N.C., Hedenquist, J.W. and Kirkham, R.V., 2001 - Asia: The waking giant: *Mining Journal* supplement, March 2001, 12p.

Windley, B.F., Allen, M.B., Zhang, C., Zhao, Z.-Y. and Wang, G.-R., 1990 - Paleozoic accretion and Cenozoic redeformation of the Chinese Tien Shan Range, central Asia; *Geology,* v. 18, pp. 128-131.

Yakubchuk, A., 2002 - The Baikalide-Altaid and North Pacific orogenic collages: similarity and diversity of structural patterns and metallogenic zoning; *in* Blundell, D., Neubauer, F. and von Quadt, A., (Eds.), *Geological Society,* London, Special Publications, v. 204. pp. 273-297.

Yakubchuk, A., 2004 - Architecture and mineral deposit settings of the Altaid orogenic collage: a revised model; *Journal of Asian Earth Sciences*, v. 23, pp. 761-779.

Yakubchuk, A.S., 2005 - Geodynamic evolution of accreted terranes of Mongolia against the background of the Altaids and Transbaikal-Mongolian collages; *in,* Seltmann, R., Gerel, O. and Kirwin, D.J., (Eds.), Geodynamics and Metallogeny of Mongolia with a Special Emphasis on Copper and Gold Deposits: SEG-IAGOD Field Trip, 14-16 August 2005, 8th Biennial SGA Meeting; IAGOD Guidebook Series 11: *CERCAMS/NHM,* London; pp. 13-24.

Yakubchuk, A.S., Cole, A., Seltmann, R. and Shatov, V., 2002 - Tectonic setting, characteristics and regional exploration criteria for gold mineralization in central Eurasia: The southern Tien Shan province as a key example; *in* Goldfarb, R. and Nielsen, R., (Eds.), Integrated Methods for Discovery: Global Exploration in Twenty-First Century; *Economic Geology*, Special Publication No. 9, pp. 177-201.

Yin Bingchuan and Ran Qingchang, 1997 - The tectonic environments of metallogenesis of Duobaoshan superlarge copper deposit; *Jilin Geology,* v. 17, no. 2. (*in Chinese, English abstract)*.

Zhao Yuanyi and Zhao Guangjiang, 1995 - Geochemical characteristics of the Duobaoshan copper orefield REE and its genetic model in Heilongjiang Province; *Jilin Geology,* v. 14, no. 2 *(in Chinese, English abstract)*.

Zhao Yuanyi, Ma Zhihong and Zhong Chongxue, 2005 - Ore-forming geochemistry of the Duobaoshan copper deposit, Heilongjiang Province, China; The 8th Biennial SGA Meeting, Beijing, China, Extended Abstract Volume, Chapter 9-65, pp. 1119-1121.

Zonenshain, L.P., Kuzmin, M.I. and Natapov, L.M., 1990 - Mongol-Okhotsk fold belt; *in* Page, B.M., (Ed.), Geology of the USSR: a Plate Tectonic Synthesis; *American Geophysical Union,* Washington, Geodynamic Series, v. 21, pp. 97-108.

Zvezdov, V.S., Migachev, I.F. and Girfanov, M.M, 1993 – Porphyry copper deposits of the CIS and the models of their formation; *Ore Geology Reviews,* v. 7, pp. 511-549.