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The influence of Late Pleistocene geomorphological inheritance and Holocene hydromorphic regimes on floodwater farming in the Talgar catchment, southeast Kazakhstan, Central Asia

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ABSTRACT

In comparison to Southwest Asia and the Indian subcontinent, the relationship between Holocene river dynamics, climate change and floodwater farming in Central Asia is significantly under researched. To address this, a multi-disciplinary research project was begun in 2011 centred on the Talgar catchment, a south-bank tributary of the Ili River, southeast Kazakhstan. Building on archaeological excavations and surveys conducted over the past 20 years, we have undertaken investigations of Holocene human adaptations to changing hydromorphic regimes in the Tien Shan piedmont region, Central Asia. Fluvial geochronologies have been reconstructed over the last 20,000 years using Optically Stimulated Luminescence and ^{14}C dating, and are compared with human settlement histories from the Eneolithic to the medieval period. Phases of Late Pleistocene and Holocene river aggradation at c. 17,400–6420, 4130–2880 and 910–500 cal. BC and between the mid-18th and early 20th centuries were coeval with cooler and wetter neoglacial episodes. Entrenchment and floodplain soil development (c. 2880–2490 cal. BC and cal. AD 1300–1640) coincided with warmer and drier conditions. Prior to the modern period, floodwater farming in the Talgar River reached its height in the late Iron Age (400 cal. BC – cal. AD 1) with more than 70 settlement sites and 700 burial mounds. This period of agricultural expansion corresponds to a phase of reduced flooding, river stability and glacier retreat in the Tien Shan Mountains. Late Iron age agriculturists appear to have been opportunistic by exploiting a phase of moderate flows within an alluvial fan environment, which contained a series of partially entrenched distributary channels that could be easily 'engineered' to facilitate floodwater farming. Holocene climate change was therefore not a proximate cause for the development and demise of this relatively short-lived (c. 200 years) period of Iron Age farming. River dynamics in the Tien Shan piedmont are, however, strongly coupled with regional hydroclimatic fluctuations, and they have likely acted locally as both 'push' and 'pull' factors for riparian agriculturists.

1. Introduction

The Semirechye (the Land of the Seven Rivers) region of Central Asia (Fig. 1) has emerged as an important area in the long-standing debate concerning the development of farming systems in the

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Fig. 1. Map of study area and catchment of the Talgar River. The Kapchagay Reservoir is located in the former Ili River valley.

Eurasian steppes, particularly Iron Age pastoral nomadism of the first millennium BC (Chang et al., 2003). Traditional views (e.g. Christian, 1998, p. 124), that follow a climate change hypothesis, posit a mixed farming–herding strategy during the Bronze Age (c. 2500–1100 cal. BC) under warm and wet conditions, with a shift to a horse riding pastoral economy in the early Iron Age (c. 800 cal. BC) coinciding with a cold and dry climate. This simple model has been challenged by Chang (2008, 2012) and Koryakova and Epimakhov (2007), and recently Frachetti (2012) and Murphy et al. (2013) have highlighted that strong regional agricultural and cultural trajectories exist in the Eurasian steppes. Although all of these authors have emphasised the possible effects of climate-related change in the phasing and location of human settlement in the region, archaeological and environmental histories have not been effectively integrated in order to evaluate these possible connections. This disconnection has arisen primarily as the result of the limited number of multi-period archaeological surveys, relatively poor chronological precision and, most significantly, because of the absence of research on Holocene river morphodynamics and hydrology in the region.

The Semirechye is located in the southeast margins of the Eurasian steppe, and extends along the northern piedmont of the Tien Shan Mountains northwards to Lake Balkhash. The foothills, alluvial fans and rivers of the Tien Shan constitute near ideal environments for floodwater farming (Lewis, 1966) with spring–summer floods generated by melting glaciers and snow providing a reliable source of water for irrigation. Floodwater farming is still practiced today in southern Kazakhstan and there is good evidence that in the medieval and prehistoric periods it was an important centre for irrigation agriculture (Groshev, 1985; Itina and Yablonskiy, 1997; Oberhänsli et al., 2007). However, while Holocene water-level histories of Lake Balkhash (Shnitnikov, 1980; Endo et al., 2012) and the Aral Sea (Krivonogov et al., 2010) are known in outline, evolution of river valleys in response to Holocene climate change has not been investigated in the Semirechye region, and the impacts of hydroclimatic fluctuations on floodwater farming and human settlement are poorly understood (cf. Blättermann et al., 2012).

Building on Chang and her co-workers (Rosen et al., 2000; Chang et al., 2003) archaeological investigations in southeast Kazakhstan, our research has focused on the alluvial fan and piedmont valley of the River Talgar, which was a major centre of Iron Age and later medieval farming (Chang et al., 2003). The primary objectives of our study were to date major Late Pleistocene and Holocene aggradation and incision episodes, correlate these with regional hydroclimatic records, and to evaluate the influence of changing river dynamics and hydrology on human settlement over the last 5000 years, especially during the apogee of floodwater farming in the area during the Iron Age at c. 400–200 cal. BC.

2. Study region

The River Talgar (length c. 120 km, drainage area c. 440 km^2) is located in the Ili river catchment and drains the Zayiliyskiy Alatau

Range (Fig. 1), in the northern part of the Tien Shan Mountains, whose headwaters reach elevations of just over 5000 m above sea level. Topographic maps made before the construction of the Kapchagay reservoir (completed in 1969), shows the Talgar river splitting into a series of distributary channels that drained into an enclosed wetland and did not connect directly with the Ili river except possibly during floods. The Talgar River has constructed a multi-faceted alluvial fan that is c. 25 km wide and 20 km long, which comprises three lobes that decrease in elevation from west to east (Akiyanova, 1998). The hydrological regime of the Talgar River is dominated by glacier and snow meltwater with high flow between May and September with peak flows in July and August (Fig. 2). Annual rainfall at the town of Talgar located at the apex of the fan is 755 mm (Aubekerov and Gorbunov, 1999) with spring (major) and autumn (minor) peaks, rising to 900 mm on Mount Talgar the highest point in the Talgar catchment at 5020 m above sea level. Presently, the Talgar River catchment includes 92 small glaciers that cover 18% of the watershed, which contribute about 56% to summer runoff (Vilesov and Uvarov, 2001).

Precipitation in the region arises from westerly air masses primarily from the Caspian and Aral Sea areas (Aizen et al., 2006) and the hydroclimatological regime is influenced by the interaction of the Siberian High (SH) and westerly jet stream. The region is shielded by the Tien Shan Mountains from direct effects of the Indian and/or East Asian summer monsoon and its continental climate is controlled by the latitudinal position and strength of the westerlies governed by the SH (Gong and Ho, 2002). Research in the Semirechye and Aral Sea region, and in Amu Darya (Oxus) and Syr Darya (Jaxartes) catchments (Oberhänsli et al., 2011; Sorg et al., 2012), has demonstrated that periods of glacier advance, increased river flow and high-lake level occurred under cooler climatic conditions in the Holocene, most notably during the Little Ice Age (LIA).

3. Methods

Field data on river terrace sedimentology, stratigraphy and geochronology were collected along a 35-km transect stretching from the apex of the Talgar fan downstream to the River Talgar's confluence with the Issyk River (Fig. 1), coming from the neighbouring Issyk alluvial fan to the east. Geomorphological mapping was carried out using satellite imagery (Shuttle Radar Topography Mission: SRTM), topographic maps, and ground survey. Optically Stimulated Luminescence (OSL) and radiocarbon (^{14}C) dating of fluvial units was undertaken at three c. 1-km long reaches located within (i) the apex of the fan centred on the medieval town of Talgar (43°16′41.94″ N, 77°13′06.67″ E), (ii) at Kosmos (43°30′01.11″ N, 77°15′42.58″ E) and (iii) at the Talgar–Issyk confluence (43°35′02.68″ N, 77°17′33.23″ E) (Fig. 1). OSL dating was performed

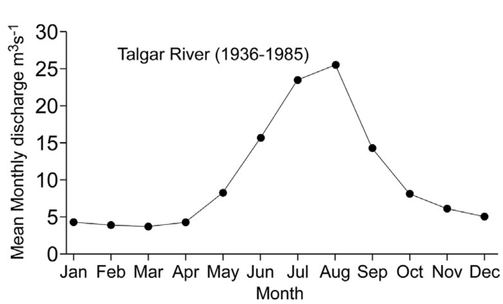

Fig. 2. Mean monthly discharge of the Talgar River observed at the Talgar gauging station (#90255, 43°27′ N and 77°20′ E) for period from 1936 to 1985 (downloaded from http://meteo.ru).

at two laboratories: the Illinois State Geological Survey (ISGS) OSL Dating Laboratory at the University of Illinois and the Aberystwyth University Luminescence Research Laboratory (see Suppl. Mat. for OSL dating protocols). Radiocarbon dating of wood, bone and charcoal samples was undertaken at the NSF-Arizona AMS Facilities, University of Arizona. ^{14}C dates were calibrated using the Calib 7.1 program and the IntCal 13 calibration curve (Reimer et al., 2013).

Grain-size analysis of extensive fine-grained Late Pleistocene and Holocene fluvial units in the Talgar valley, and loess on the Tien Shan foothills, was undertaken using laser diffraction grain-size analysis in order to determine provenance and agent of transport. Samples were taken from units with a clear aeolian, fluvial or glaciofluvial origin to establish characteristic grain-size distributions for wind or water transport in these depositional contexts. Samples from fine-grained units of unknown provenance in dated fluvial terrace sections were compared with these benchmark samples in order to determine the dominant agent of deposition and sediment provenance, either from aeolian processes, fluvial reworking of loess or glacial material, or glacial sources. Samples were measured with a Sympatec HELOS KR particle sizer at the VU University, Amsterdam, following sample treatment procedures from Konert and Vandenberghe (1997).

A GIS database was compiled using data collected by Chang and colleagues (Spengler et al., 2013) as part of the Kazakh-American Talgar Archaeological Project (URL:http://www.cadb.pitt.edu). These differentiated archaeological sites and find-spots were categorised by age and type (settlements, cemeteries, and ceramic scatters) and were plotted on the SRTM satellite imagery (Fig. 3). In order to assess relationships between human settlement, hydrology, and changing river environments in the region, past and present channel networks were delineated using topographic data from SRTM and topographic maps that indicate the position of channels before large-scale landscape modification during the Soviet era and in recent times.

4. Late Pleistocene and Holocene river channel networks and terraces

Three distributary systems (Fig. 3) can be delineated on the Talgar fan, which on the basis of bifurcation points, relative elevation and morphological relationships, decrease in age from west to east. The Taldy Bulak and Tseganka channel networks are developed on the surface of the Late Pleistocene Talgar fan, and originate from bifurcation points located close to the fan apex where the Talgar River emerges from the Tien Shan Mountains (Fig. 3). Most archaeological sites are located along the banks of these channels or engineered distributaries that divert water from larger channels onto local interfluves or islands around which streams divide. Present day river channels are entrenched 1–5 m below the fan surface in small, box-shaped gullies that are up to 50 m wide and are reticulate and anabranching in form (Fig. 4A). Some have perennial flows originating from springs or, more commonly, from water diverted for irrigation from the main Talgar River but the majority are currently ephemeral with no channelized flow. A pit dug into the floor of one of these currently dry valleys revealed that since the Iron Age, (indicated by ceramics directly overlying river pebbles – Fig. 4A′), locally up to 1.5 m of fines has been deposited.

The Talgar River episodically aggraded and incised during the Late Pleistocene and Holocene, producing a series of well-developed terraces that flank the current channel axis (Fig. 5). In the Talgar valley there are also a series of anabranching distributaries, some of which (e.g. west of the present Talgar river between the villages of Alga and Kosmos; Fig. 1) have associated archaeological sites and settlements located on former islands and river terraces. As the result of gravel quarrying, recent channel

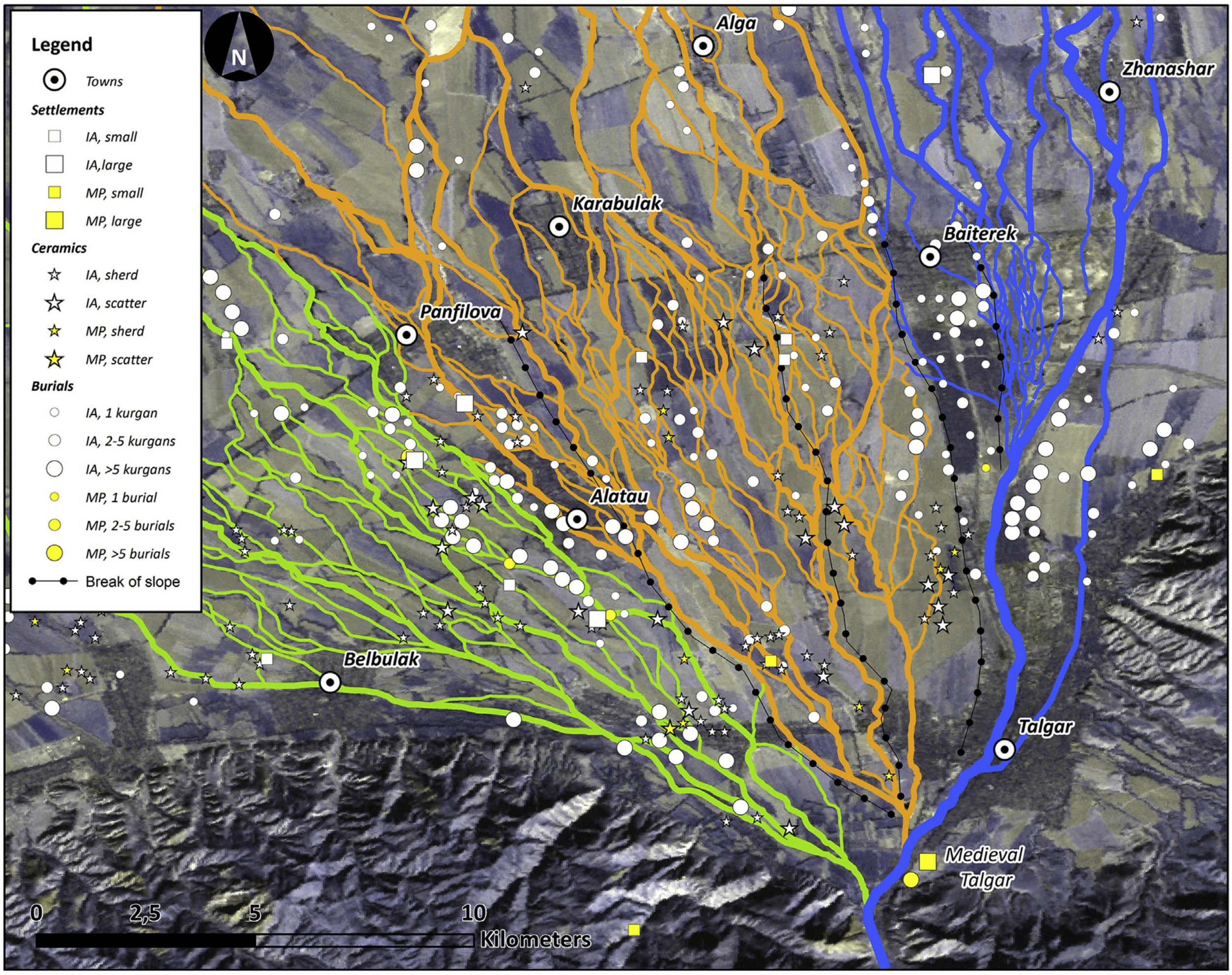

Fig. 3. Distribution of archaeological sites on the Talgar alluvial fan. Iron Age (IA) sites are indicated in white and medieval sites (MP) in yellow. Settlement size was inferred from surface finds (small) and excavations (large). Distributaries of the Talgar River are shown using different colours: Taldy Bulak (green), Tseganka (orange), and the main Talgar River (blue). Breaks of slope separating alluvial fan facets are marked by black dashes and dots (after Akiyanova, 1998). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

entrenchment associated with dam construction, and locally high rates of bank erosion, Late Pleistocene and Holocene fluvial sediments are best exposed in the upper reaches of the Talgar river adjacent to the town of Talgar, in a lower gradient reach centred on the village of Kosmos, and at the confluence of the Talgar and Issyk rivers (Fig. 1).

5. River terrace sedimentology, stratigraphy and geochronologies

5.1. Medieval Talgar town reach

Following Akiyanova's (1998) and our own aerial photographic and ground-based geomorphological surveys, we have identified four terraces in the upper Talgar River valley at c. 13.5 (T1), 9.5 (T2), 4 (T3), and 2.5 m (T4) above the current river-bed (Fig. 5). T1 and T2 comprise of flat-bedded, boulder-to cobble-size gravels (Fig. 4B). The medieval town of Talgar, occupied from 9th to the 13th centuries AD, is located on the surface of T1. On the basis of terrace mapping and morphostratigraphy, T1 in the medieval Talgar town reach is correlated with T1 in the lower Talgar valley (see below), and of Late Pleistocene to middle Holocene age. Channel-forms (with high width–depth ratios and infilled with sandy silts) present in the uppermost 1–2 m of T2 gave an OSL age of 2440 ± 450 BC (Table 1). T3 has a contrasting alluvial architecture to T1 and T2 with cobble-size gravels overlain by finer-grained floodplain sediments that are capped by a c. 1 m thick boulder-rich flood unit. T3 sediments overlie Late Pleistocene glaciofluvial deposits that also crop out in several parts of the lower Talgar Valley (see below). A well-developed soil is present within the middle part of the finer-grained overbank unit and contains 9–13th century AD ceramics as well as abundant bone and charcoal (Fig. 4C). Radiocarbon dating of a pit cut through this soil gave an age of cal. AD 890–1040 and is contemporaneous with the pottery finds. The upper part of the pit is in-filled with well-sorted fine to medium sands that grade upwards into cobble–boulder gravels. These deposits relate to a major period of flooding and channel aggradation that buried the medieval soil. Radiocarbon dating of charcoal within these gravels indicates coarse sediment aggradation at this site until cal. AD 1680–1940. Below T3 there is a low terrace (T4) and a series of partially vegetated boulder berms located up to ~2–3 m above the present river level, which date to flood events over the last 50–100 years.

5.2. Kosmos reach

The Kosmos reach (Fig. 1) is located 20 km downstream of the fan apex and valley width is ~300 m (Fig. 4D). The present river runs

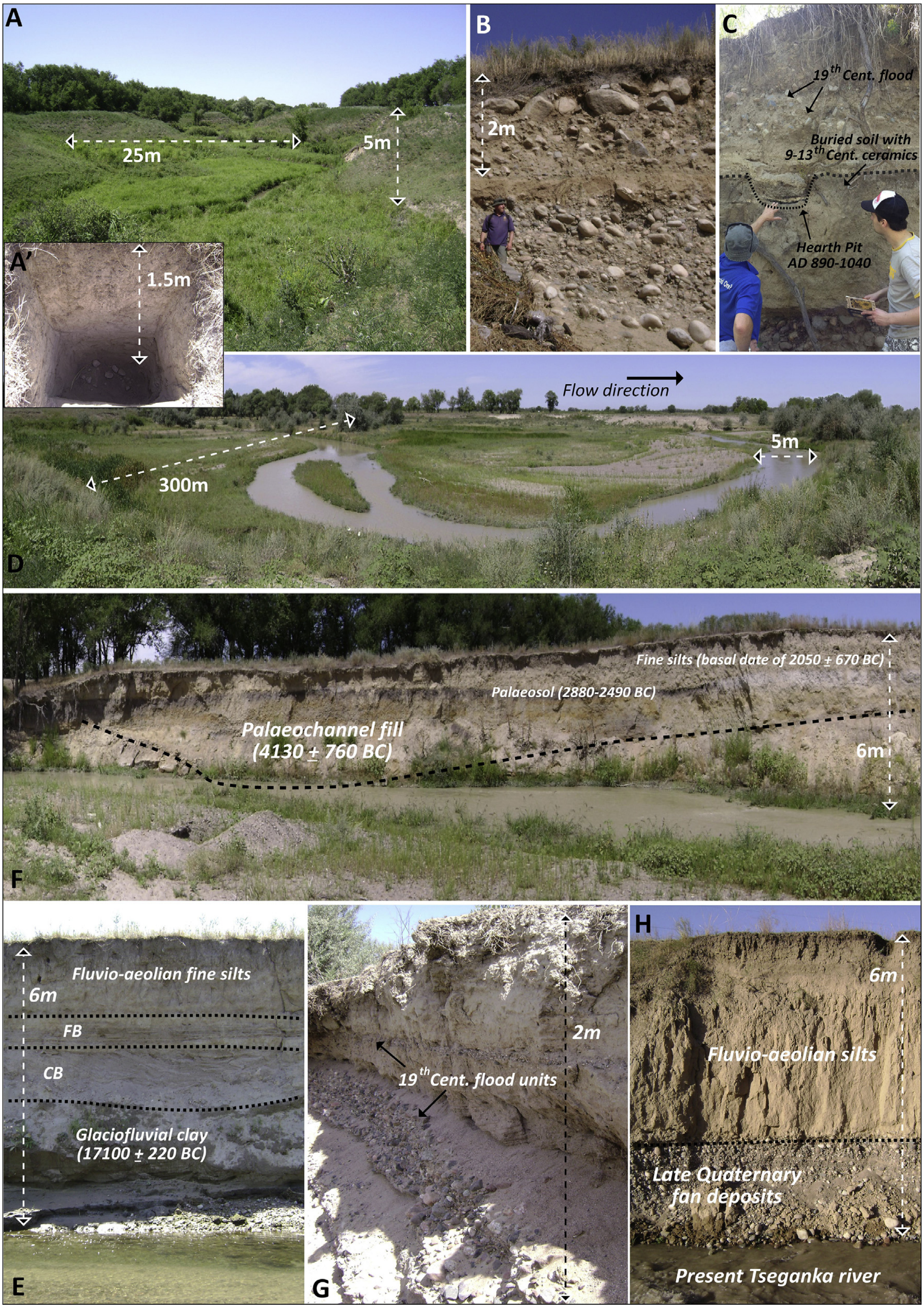

Fig. 4. (A) Typical box-shaped valley on the alluvial fan surface, with fine-grained deposits on the valley floor (A′). (B) Exposure of T1 terrace in the fan apex reach. (C) T3 in the fan apex reach with a buried soil, ceramics, hearth, and flood units at the top of the section. (D) The Talgar River valley in the Kosmos reach. (E) Section of T1 in the Kosmos reach, showing (from bottom to top) glaciofluvial deposits, cross-bedded fluvial sands (CB), flat-bedded fluvial sands (FB), and fluvially redeposited calcified aeolian silts. (F) Section of T2 Kosmos reach showing Holocene channel-fill deposits, and a well developed palaeosol capped by fine-grained fluvial sediments containing reworked loess. (G) Section of T4 in the Kosmos reach showing 19th century AD coarse grained flood units. (H) Incision in the alluvial fan surface caused by recent flow diversion of the Tseganka distributary.

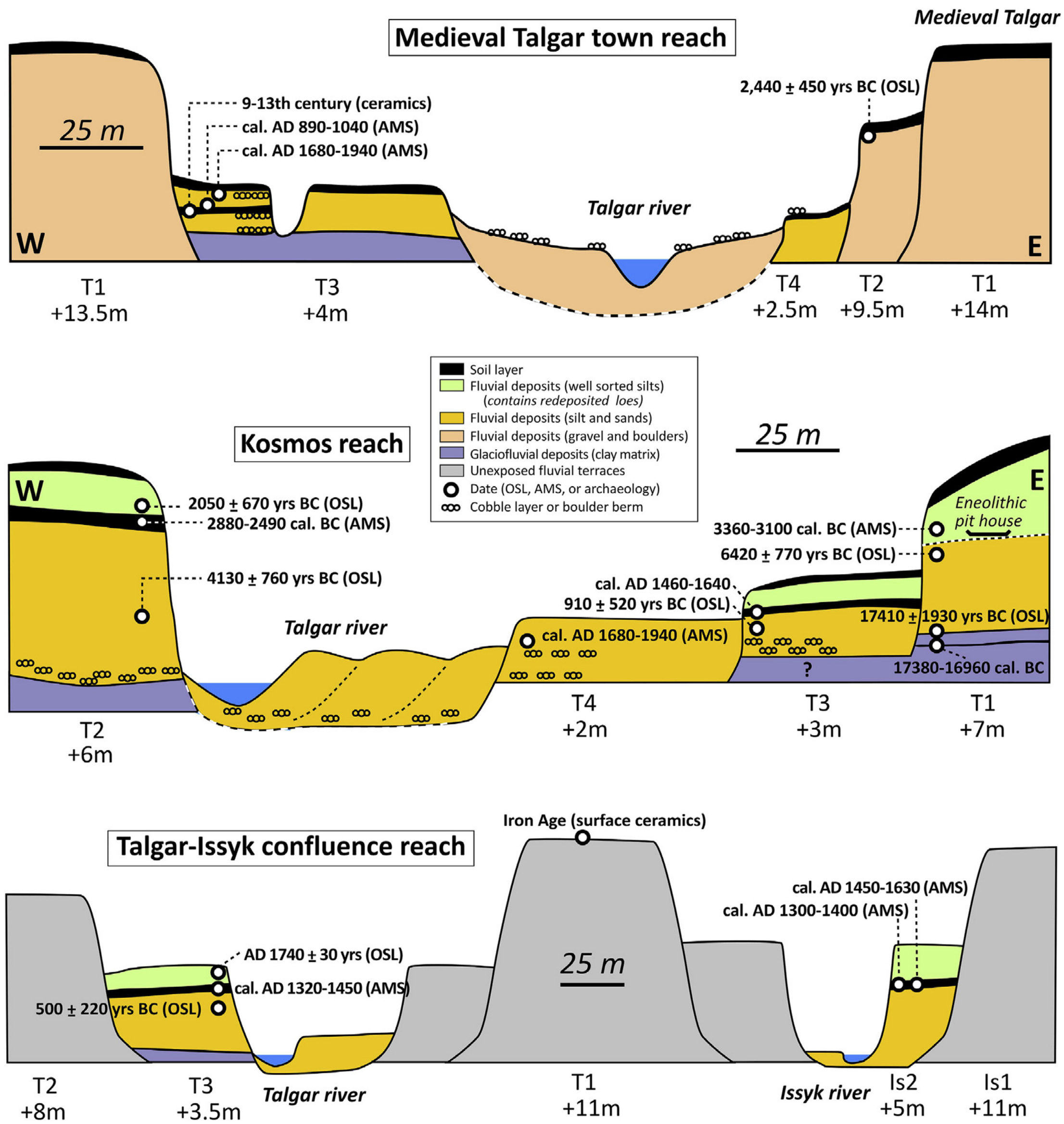

Fig. 5. Schematic stratigraphic cross-profiles of the apex reach near Talgar town, and the Kosmos and Talgar–Issyk confluence study reaches.

in a 100 m wide channel belt, has a high-sinuosity channel and is confined within river terraces of Holocene age 2–7 m above present river level (Fig. 5). Four major terraces are evident at c. 7 (T1), 6 (T2), 3 (T3), and 2 (T4) m above the present river level and can be traced semi-continuously for 15 km northwards towards the Kapchagay Reservoir and 10 km upstream. T1 and T2 are the most extensive terraces and extend 5 km west and east of the current course of the Talgar River and 2 km east where they meet the Issyk River. The basal unit of the T1 comprises massive, poorly sorted glaciofluvial clay to sandy loams intercalated with a palaeosol, overlain by alternating sequences of flat-bedded fluvial sands and calcified silts (Fig. 4E). Grain-size analysis shows that these silt units contain a significant component of loess, (Fig. 6) that has been locally transported and re-deposited by river flow. Radiocarbon dating of a cm-thick organic-rich layer within these glaciofluvial deposits gave an age of 17,380–16,960 cal. BC. Fluvial sands ~1 m above and directly overlying this layer were dated using OSL to 17,410 ± 1930 BC. At a depth of 1.1 m from the surface of T1 a Late Eneolithic/Early Bronze Age pit house floor was discovered and ^{14}C dated to 3360–3100 cal. BC. The floor of this structure was cut into fluvial silts (containing a significant component of fluvial redeposited loess; Fig. 6) and a fluvial sand unit c. 40 cm below the archaeological feature was OSL-dated to 6420 ± 770 BC.

T2 has well developed gravelly lateral-accretion units and associated channels with low-width–depth ratios that erosively truncate clay-rich glaciofluvial sediments exposed at the base of the terrace (Fig. 4F). An OSL-age from sand within one of these lateral accretion units 1.9 m above present river level shows active gravel sedimentation and channel migration at 4130 ± 760 BC (Fig. 6). Channel and floodplain sedimentation continued until sometime before 2880–2490 cal. BC followed by an extended period (c. 700 years) of pedogenesis. The well-developed soil is overlain by 2 m of fluvially redepositied aeolian silts that began to be deposited from 2050 ± 670 BC (Figs. 4F and 6).

T3 comprises basal fluvial gravel and sand unit, which was OSL dated to 910 ± 520 BC. Overlying the upper sandy unit, a palaeosol was ^{14}C dated to cal. AD 1460–1640 and is itself overlain by 0.6 m of fluvial silts. The most recent terrace T4 comprises fluvial gravels

Table 1
Dating results of ^{14}C AMS organic materials (a) and OSL terrace quartz sands (b) from the Talgar River reaches. "Confluence" refers to the Talgar–Issyk River confluence reach. For OSL ages conversions to Yrs BC/AD these are rounded to the nearest decade.

Lab ID	Dating material	^{14}C age BP	Cal yrs BC/AD 2 sigma	Reaches	Sample depth, cm
a) ^{14}C AMS dates					
AA99974	Charcoal	4527±43	3360–3100 BC	Kosmos T1	110
AA99975	Charcoal	4106±61	2880–2490 BC	Kosmos T2	160
AA99976	Charcoal	337±39	AD 1460–1640	Kosmos T3	60
AA99978	Charcoal	121±41	AD 1680–1940	Fan apex T3	150
AA99979	Charcoal	1044±37	AD 890–1040	Fan apex T3	200
AA102902	Charcoal	370±31	AD 1450–1630	Confluence Is2	225
AA102903	Charcoal	612±31	AD 1300–1400	Confluence Is2	223
AA102905	Charcoal	15,851±69	17,380–16,960 BC	Kosmos T1	135
AA102906	Soil	518±37	AD 1320–1450	Confluence T3	120
AA100109	Wood	107±37	AD 1680–1940	Kosmos T4	120

Lab ID	Yrs ka before AD 2013	Yrs BC/AD	Reaches	Sample depth, cm
b) OSL dates				
Aber207Tal12-1	8.43±0.77	6420±770 BC	Kosmos T1	146
Aber207Tal12-2	6.14±0.76	4130±760 BC	Kosmos T1	385
Aber207Tal12-3	2.92±0.52	910±520 BC	Kosmos T3	124
Aber207Tal12-4	2.03±0.31	AD 10±310	Kosmos T3	60
Aber207Tal12-5	1.29±0.26	AD 720±260	Tseganka	165
ISCS 203	4.06±0.67	2050±670 BC	Kosmos T2	145
ISCS 205	4.44±0.45	2440±450 BC	Fan apex T2	70
ISCS 206	19.41±1.93	17,410±1930 BC	Kosmos T1	440
ISCS 207	2.51±0.22	500±220 BC	Confluence T3	210
ISCS 208	0.27±0.03	AD 1740±30	Confluence T3	55

and sands (Fig. 4G), within which an *in situ* tree stump has been ^{14}C dated to cal. AD 1680–1940.

5.3. Talgar–Issyk confluence reach

Three terraces (T1 – 11 m, T2 – 8 m, and T3 – 3.5 m) are present in the Talgar valley immediately upstream of its confluence with the River Issyk (Figs. 1 and 3). The Issyk River has two major terraces (Is1 – 11 m and Is2 – 5 m; Fig. 5). Exposures are available only for T3 and Is2 and both comprise a basal fluvial sand unit on which there is a well-developed soil that is overlain by fluvially redepositied aeolian silts (Fig. 6). The upper part of the basal sand unit in T3 is dated by OSL to 500 ± 220 BC and the buried soil to cal. AD 1320–1450. Fluvial silts that overlie the palaeosol in T3 are OSL dated to AD 1740 ± 30. Charcoal samples collected from the buried soil in Is2 are similar in age to those in T3 and range in age from cal. AD 1300–1400 to 1450–1630.

6. Late Pleistocene and Holocene river dynamics in the Talgar catchment and its relationship to climate change

6.1. Phases of river aggradation and entrenchment, and floodplain pedogenesis

Morphostratigraphic relationships between Talgar fan and valley terraces, in conjunction with 20 ^{14}C (10) and OSL (10) dating assays (Table 1) of Late Pleistocene and Holocene age fluvial deposits and soils, enable the chronology of phases of river aggradation and down-cutting to be reconstructed over the last 20,000 years. Similar height relative relationships between T1 and Is1 suggest that they are coeval, and ^{14}C (17,380–16,960 cal. BC) and OSL (17,410 ± 1930 BC) dates in the Kosmos reach indicate Late Pleistocene glaciofluvial sedimentation in Talgar valley c. 17,400–17,000 cal. BC with river aggradation continuing into the early Holocene until c. 6420 BC (±770) BC. A late Eneolithic/Early Bronze Age pit house floor dated to 3360–3100 cal. BC directly overlies this early Holocene fluvial unit and shows that there was no sedimentation on T1 for c. 3000 years between c. 6420 BC (±770) BC and 3360–3100 cal. BC. This archaeological feature is overlain by just over 1 m of fluvially deposited silts that contain a component of reworked loess (Figs. 4 and 6). To summarise, T1 records channel aggradation from c. 17,400–17,000 cal. BC until c. 6420 BC (±770) BC, a 3000 year long hiatus followed by renewed overbank sedimentation after 3360–3100 cal. BC.

The tread of T2 lies between 4.5 m (medieval Talgar town reach) and 1 m (Kosmos reach) below the surface of T1. On the basis of its alluvial architecture (large asymmetric channels with lateral accretion units that cut into underlying glacial deposits – Fig. 4F) and geochronology, T2 represents a separate and later phase of river sedimentation to T1. River channel entrenchment would appear to have started sometime after c. 6420 (±770) BC (youngest with-channel sediments in T1) and ended before c. 4130 (±760) BC when aggradation was in progress (T2 Kosmos reach; Fig. 5) and river-bed levels were c. 2.5 m higher than those of today. An OSL date from fluvial sands in the upper metre of T2 located within the medieval Talgar town reach shows that sedimentation continued until 2440 (±450) BC. This is confirmed by a buried soil in the Kosmos reach ^{14}C dated to 2880–2490 cal. BC developed in the upper part of T2 and an Infrared Stimulated Luminescence age of 2600 (±300) BC marking the end of sedimentation on the adjacent Issyk alluvial fan (Blättermann et al., 2012). This was followed by a period of very limited overbank sedimentation that lasted between 450 and 800 years until the floodplain soil was buried by fine-grained fluvial deposits at c. 2050 (±670) BC, which contain a significant component of reworked loess.

T3 and Is2 – its age equivalent in the Issyk valley – is well constrained by OSL and ^{14}C dating in all three study reaches. River entrenchment in the Talgar catchment (and formation of T2) began c. 2880–2490 cal. BC with valley floor re-filling re-commencing sometime before c. 910 (±520) BC (Kosmos reach, Fig. 5) and continuing until c. 500 (±220) BC (Talgar–Issyk confluence reach, Fig. 5). A well-developed buried soil within T3 and Is2 is dated to cal. AD 890–1040 in the medieval Talgar town reach, cal. AD 1460–1640 in the Kosmos reach, and cal. AD 1320–1450 (T3) and cal. AD 1300–1400 to 1450–1630 (Is2) in the Talgar and Issyk confluence reach. These dates indicate a prolonged, 400–700 year

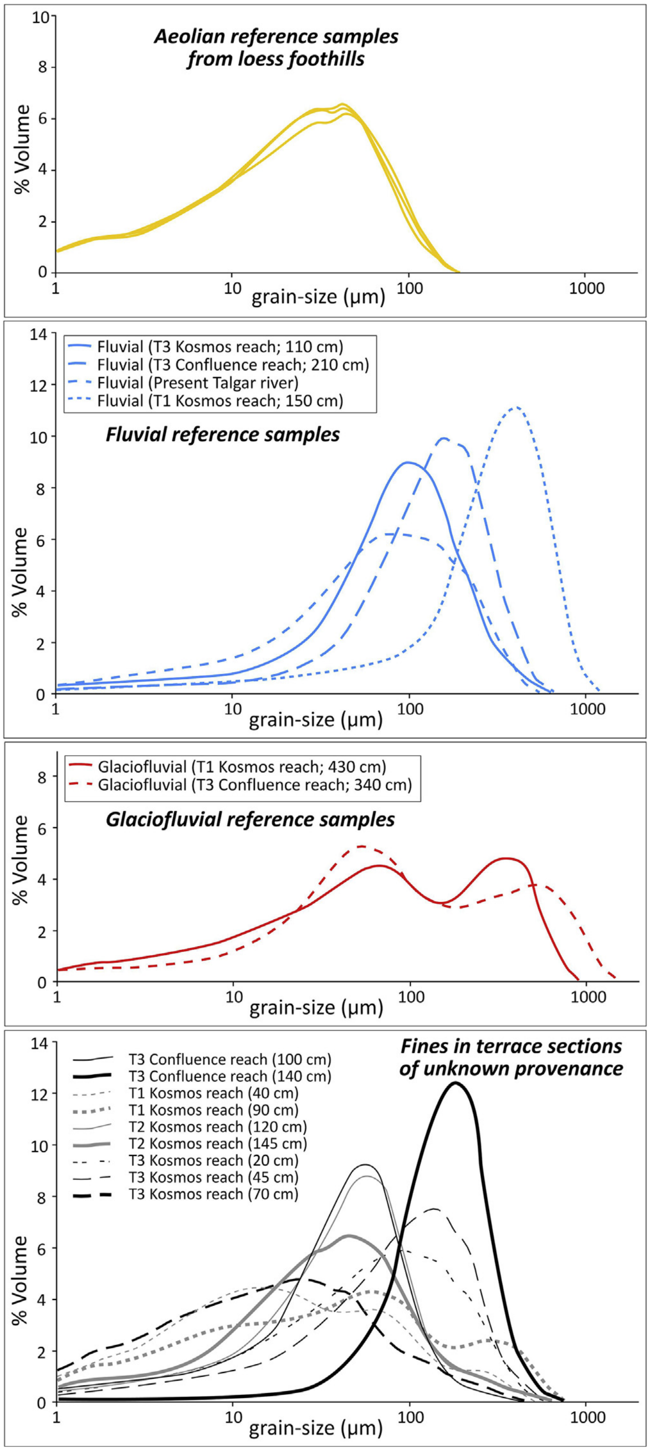

Fig. 6. Grain-size distributions of fluvial (blue), aeolian (orange), and glaciofluvial (red) reference samples in the Talgar catchment; location and sample depth (cm below local ground level) are shown. Black and grey coloured grain-size distributions in the bottom panel of the figure are of fine-grained units within Late Pleistocene and Holocene terraces in the Talgar Valley; location and sample depth (cm below local ground level) are shown. Fluvial reference samples were collected from the surface of gravel bars in the present river and from terrace units with clear fluvial sedimentary structures (e.g. cross-bedding). Aeolian samples were collected from loess units in the foothills the Talgar catchment and material of glaciofluvial origin was sampled from Late Pleistocene deposits located in the Kosmos and confluence reaches (Fig. 5). Comparison of the grain-size distribution of fine-grained units within Late Pleistocene and Holocene river terraces in the Talgar Valley with the reference samples enables the principal transport agent (based on the shape of the grain-size distribution) and the main sediment source (related their uni- or bi-modal nature) to be determined. The majority of Late Pleistocene and Holocene fine-grained fluvial units analysed in the Talgar Valley had a significant loess component, particularly those units sampled in the upper parts of river terraces located in the Kosmos and Talgar–Issyk confluence reaches (coloured green in Fig. 5). However, many of these samples were significantly coarser than loess indicating that they had been transported by flowing water. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

long episode of valley floor stability between the late 9th and early 17th century AD with little overbank sedimentation in the Talgar and Issyk rivers. A phase of channel sedimentation is evident at c. AD 720 (±260) within the Tseganka distributary (Fig. 3) of the Talgar fan but is not recorded downstream in the Talgar river valley.

Valley floor sedimentation began again sometime during the late 17th century AD (T3 medieval Talgar town reach) with dated fluvial deposits in the Talgar–Issyk confluence reach (T3) at c. AD 1740 (±30), and continued into the 19th and possibly early 20th century. A ^{14}C date of cal. AD 1680–1940 on a tree stump buried by fluvial sands and gravels within T4 (Kosmos reach) provides a *terminus post quem* for the last significant episode of channel aggradation in the Talgar valley.

6.2. River response to Late Pleistocene and Holocene hydroclimatic variability

To explore the relationship between fluvial dynamics in the Talgar catchment over the last 20,000 years, river aggradation and incision phases are compared with: (i) periods of glacier advance within the Tien Shan mountains (Savoskul and Solomina, 1996; Sorg et al., 2012; Takeuchi et al., 2014); (ii) water level records in the Aral Sea (Krivonogov et al., 2010, 2014) and Lake Balkhash (Endo et al., 2012; Sala et al., 2015); (iii) regional episodes of soil development (Sun, 2002; Solomina and Alverson, 2004; Blättermann et al., 2012; this paper); and strength of the Siberian High (SH) as inferred by K^+ fluctuations of the GISP2 ice core (Mayewski et al., 2004). Although there are quite a wide range of proxy climate records available for southern Kazakhstan, only water levels in the Aral Sea and glacier advances in the Tien Shan span the entire Holocene and have, for some periods, centennial-scale resolution. In Fig. 7 these higher resolution Holocene hydroclimatic records for the Aral Sea and Tien Shan mountains, together with periods of regionally significant soil formation are plotted with river aggradation and entrenchment phases in the Talgar catchment.

Late Pleistocene glaciofluvial sedimentation in the Talgar valley at c. 17,400–17,100 cal. BC matches high water levels in Lake Balkhash (c. 13 m above mean present level – Endo et al., 2012; Sala et al., 2015) and glacier expansion in the Tien Shan mountains between 21 and 15 ka (Zech, 2012). Similarly, early Holocene river aggradation up to c. 6420 (±770) BC corresponds with a high-stand in Lake Balkhash (Endo et al., 2012; Sala et al., 2015) and renewed glaciation in the Tien Shan mountains between c. 12.5 and 8 ka (Takeuchi et al., 2014). The first major phase of Holocene channel entrenchment in Talgar River (c. 6420–4130 BC) is likely to have begun shortly after 6420 (±770) BC and parallels falling water levels in Lake Balkhash, including an abrupt drop at 6200 cal. BC (Sala et al., 2015) and significant glacier shrinkage at 6070–6020 cal. BC with very low rates of ice accumulation until 4220–3970 cal. BC (Takeuchi et al., 2014). A major regression in the Aral Sea is also recorded between 5050 and 4650 cal. BC (Krivonogov et al., 2014). Early-middle Holocene river incision in the Talgar valley appears to be a response to a warming climate and higher temperatures under a weaker SH between c. 6000–4000 cal. BC (Fig. 7).

Renewed channel and floodplain aggradation occurred in Talgar valley between 4130 (±760) and 2880–2490 cal. BC coinciding with

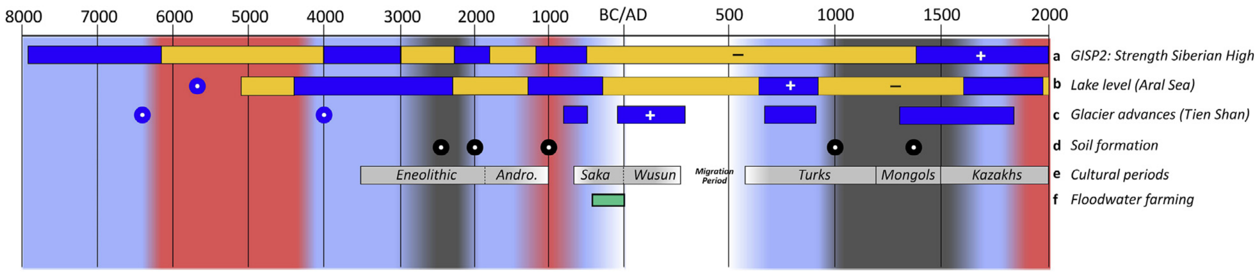

Fig. 7. Correlation of Holocene Talgar river entrenchment (red), aggradation (blue) and soil formation (grey) with regional hydroclimatic proxies: Siberian High (Mayewski et al., 2004), Aral Sea level (Krivonogov et al., 2010, 2014), Tien Shan glacial advances (Savoskul and Solomina, 1996; Aubekerov and Gorbunov, 1999), soil formation in Central Asia (Sun, 2002; Solomina and Alverson, 2004; Blättermann et al., 2012), and cultural periodization (Andro = Andronovo culture complex). Dated periods of floodwater farming on the Talgar fan in the Iron Age and medieval periods are shown. Phases are depicted by bars and shorter episodes with a dot. Yellow and blue denote, respectively, strong and weak Siberian High, or low and high water levels in the Aral Sea. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

cooler conditions and glacier expansion in the Tien Shan (Takeuchi et al., 2014), a period of strong SH (Mayewski et al., 2004), and high water levels in the Aral Sea (Krivonogov et al., 2014) and Lake Balkhash (Endo et al., 2012; Sala et al., 2015).

The second and most prominent phase of Holocene river downcutting occurred in the Talgar catchment shortly after 2880–2490 cal. BC and before 910 (±520) BC. Similar to the early-middle Holocene entrenchment phase, it coincided with a shift to a drier and probably warmer (weaker SH) climate. This is recorded by a pronounced dry interval between c. 3000–1950 cal. BC in Lake Son Kol, Central Kyrgyzstan (Lauterbach et al., 2014), a regression in the Aral Sea between c. 2250–1250 cal. BC (Krivonogov et al., 2014) and a major period of local and regional soil development (Sun, 2002; Solomina and Alverson, 2004; Blättermann et al., 2012; this paper).

River aggradation was again taking place in the Talgar valley between 910 (±520) and 500 (±220) BC, although these dates come from the upper part of this unit and valley floor refilling must have begun sometime earlier. This aggradation phase coincides with a strong SH, glacier advances in the Tien Shan Mountains and high water levels in the Aral Sea (Fig. 7). With the exception of a sedimentation episode in the Tseganka distributary on the Talgar fan at c. AD 720 (±260), which coincided with a brief high-stand of the Aral Sea cal. AD 500–600 and cal. AD 850–950 as well as glacier re-advance in the Tien Shan, the period between c. 500 BC and c. AD 1740 was one of reduced geomorphic activity in the Talgar catchment. It coincided with a weakening of the SH between the second half of the 1st Millennium BC and the end of the 14th AD, as well as with major regressions in the Aral Sea between 150 cal. BC – cal. AD 600–650 and again between cal. AD 850–950 and 1600–1700 (Krivonogov et al., 2010, 2014). Extensive floodplain soil development in the region between cal. AD 1300–1640 indicates significantly reduced flooding and relatively dry conditions. It also coincides with a major regression of the Aral Sea documented in the late Middle Ages (Krivonogov et al., 2010, 2014).

The last phase of river aggradation in the Talgar catchment is dated to c. AD 1740 (±30) or a little earlier based on ^{14}C dating, and may have continued until the early part of the 20th century. It matches high-water levels in the Aral Sea until a drop to modern levels since AD 1960 and a stronger SH.

Late Pleistocene and Holocene river dynamics in the Talgar catchment have been controlled by fluctuations in regional hydroclimate and by glaciation in the Tien Shan Mountains. Phases of Late Pleistocene and Holocene channel aggradation and floodplain sedimentation in the Talgar River at c. 17,400–6420, 4130–2880 and 910–500 cal. BC, and between the mid-18th and early 20th centuries correspond with periods of cooler and wetter climate as reflected by high-water levels in the Aral Sea and Lake Balkhash, glacier advances in the Tien Shan and a stronger SH (Fig. 7). River entrenchment between these dates, and soil development between c. 2880–2490 cal. BC and cal. AD 1300–1640, correlate with low-water levels in the Aral Sea and Lake Balkhash, and glacier retreat associated with a warmer and drier climate. This model of lower river discharge and sediment delivery in the Tien Shan piedmont associated with warmer conditions and declining glacier and snow extent is supported by observations by Aizen et al. (1997) in the second half of the 20th century.

7. Holocene hydroclimatic change and its effects on human settlement and floodwater farming

The earliest Late Eneolithic/Early Bronze Age site in the Talgar valley is a pit house within TI in the Kosmos reach and is dated to c. 3360–3100 cal. BC. It is buried by 1 m of fine-grained fluvial deposits and its occupation coincides with river aggradation and cooler conditions, as recorded by a strong SH and high water-levels in the Aral Sea (Fig. 7). No artefacts were recovered during its excavation and on the basis of a single site no meaningful and wider archaeological inferences can be drawn other than that similar age sites may lay concealed below alluvium elsewhere in the region. Its preservation reflects its position on an upstanding floodplain surface and a period of relatively rapid but low energy sedimentation.

Dated mid-Bronze Age or Andronovo period sites are recorded in the upland headwaters of the Talgar (Panyushkina et al., 2012), but no sites of this age have so far been identified in the Talgar valley or on the Talgar fan (Fig. 3). The Andronovo period c. 1800–1550 cal. BC was a time of channel incision in the Talgar River and occurred under regionally dry and warm climatic conditions as shown by a major regression in the Aral Sea and a weaker SH (Fig. 7).

Iron Age settlement and floodwater farming on the Talgar fan and along the Talgar River are ^{14}C dated at three settlements to between 760 cal. BC and cal. AD 10 with nearly 62% of the dates on archaeological charcoal falling in the period of 400–200 cal. BC (Chang, 2008). This period of intense floodwater farming, the most significant before the modern period, immediately follows a major phase of aggradation in the River Talgar at c. 910–500 BC that coincides very precisely with a strong SH, glacier advances in the Tien Shan Mountains and high water levels the Aral Sea (Fig. 7).

From a hydroclimatic and geomorphological perspective, this period of late extensive Iron Age settlement and floodwater farming occurs during a period of stable channel bed levels in the Talgar River, a weakening SH at 500 cal. BC and a major regression in the Aral Sea at c. 150 cal. BC (Fig. 7). The apogee of Iron Age agriculture on the Talgar fan is also bracketed between two major glacier advances in the Tien Shan Mountains that ended at c. 500

cal. BC and began again around 50 cal. BC. Taken together these records indicate a period of warm climate in the late Iron Age with reduced river flow from c. 150 cal. BC as evidenced by a lowered Aral Sea water level. Nevertheless, given the elevation of the Tien Shan Mountains, late spring and early summer glacier and snow melt floods, would have still produced adequate water flow for irrigation on the Talgar fan as can be seen today with glacier shrinkage under a warming climate.

The focus of Iron Age settlement and burial on the Talgar fan was along the Taldy Bulak and Tseganka distributary stream networks, located in the middle reaches of these systems 5–10 km downstream of the fan apex (Fig. 3). Major settlements and burial sites, as well as concentrations of surface finds, are preferentially located along a series of anabranching distributaries, many of which would have needed to have been engineered in order to enable water from channels to be diverted onto adjacent terraces. It appears that the key to floodwater farming during the late Iron Age, similar to modern irrigation, was the control and management of water flow from the Tseganka and Taldy Bulak channel systems. For the current Taldy Bulak stream water is still diverted by a simple lateral outlet (that has a much smaller gradient than the main channel), which uses the force of flow from the main river to ‘push’ water onto the higher terrace. This simple technique could very well also have been used by farmers in the Iron Age. OSL and ^{14}C dating shows that Talgar River bed levels during the early Iron Age were c. 2 m higher than at present. However, on the basis of sedimentological studies of fine alluvial sediments infilling the floor of the Tseganka channel (Fig. 4A′), flow was not high enough to naturally maintain these distributaries as perennial or seasonal channels. The diffluence point of the Taldy Bulak system is roughly 1 km upstream and 5 m above the level where the Tseganka channel leaves the present day Talgar River and Iron Age farmers must therefore have constructed flow control structures to lead water across the fan surface. However, careful management of these systems would have been required to ensure that water flow down the Tseganka and Taldy Bulak channels was not too large to cause channel incision, making it difficult and eventually impossible to direct flow into smaller irrigation canals that would have fed fields on the fan surface. Indeed, in the Soviet period this is exactly what happened through the inadvertent leakage of flow from concrete irrigation canals. Fig. 4H shows an example of the Tseganka channel, which locally incised 6 m after artificial redirection of flow. Large floods in these distributary systems have always been a significant hazard to floodwater farming because of the highly erodible nature of their channel banks.

In southeast Kazakhstan, and most probably in the southern Tien Shan and Pamir piedmont as a whole, high river flow and the maximum *potential* for water resources to support floodwater farming in both prehistoric and historical times is likely to have been associated with cold and wet conditions and glacier expansion. Counterintuitively, however, the development of extensive late Iron Age settlement in the Talgar region, supported at least in part by floodwater farming, occurred during a phase of relatively warm and dry climate associated with a period of channel stability. This would suggest that hydroclimate and hydrology, at least locally, were not a constraint to the establishment of Iron Age farming on the Talgar fan, nor were they the only factors in its demise. The key to the success of the late Iron Age (and medieval) agriculturists appears instead to have been a period of moderate main channel river flows confined within a Late Pleistocene age alluvial fan that as a consequence of having small, partially entrenched distributary channels was naturally configured to facilitate floodwater farming. We therefore do not need to evoke hydroclimate change as the proximate cause for this relatively short-lived (c. 200 years) period of late Iron Age floodwater farming in the Talgar region. Instead we should develop explanatory models that emphasise the skill of these Iron Age societies in choosing and exploiting particular river environments and hydromorphic regimes that facilitated successful and long-lived farming practices (cf. Macklin and Lewin, 2015). Nevertheless, considering the large Ili, Syr Darya, and Amu Darya dryland rivers downstream of, and fed by, the Tien Shan and Pamir piedmont, conjecture might suggest that wet Holocene neoglacial periods with higher river flow would have been more conducive to floodplain irrigation agriculturists. This may explain the great expansion of irrigation in the region during the first half of the 1st Millennium BC as originally noted by Lewis (1966) nearly 50 years ago. New research on Holocene river dynamics, underpinned by robust geochronologies is urgently required on Central Asia's main rivers – the Syr Darya, and Amu Darya – in order to evaluate long-term society-river environment interactions.

8. Conclusions

Fluvial geochronologies have been reconstructed over the past 20,000 years in the Talgar catchment, southeast Kazakhstan, and related to human settlement from the late Eneolithic/early Bronze Age to the medieval period. Phases of Late Pleistocene and Holocene river aggradation at c. 17,400–6420, 4130–2880 and 910–500 cal. BC, and between the mid-18th and early 20th centuries were coeval with cooler and wetter conditions, marked by high water levels in Lake Balkhash and the Aral Sea, and glacier advances in the Tien Shan Mountains. River entrenchment between these periods, and floodplain soil development at 2880–2490 cal. BC and cal. AD 1300–1640 were associated with warmer and drier conditions.

Floodwater farming on the Talgar fan reached its height in the late Iron Age (400–200 cal. BC) with more than 70 settlement sites and 700 burial mounds. This period of agricultural expansion corresponds with a period of reduced flood flows, river stability and glacier retreat in the Tien Shan Mountains. Late Iron Age agriculturists appear to have been opportunistic by exploiting a period of moderate flows within an alluvial fan environment, which contained a series of partially entrenched distributary channels that could be easily ‘engineered’ to facilitate floodwater farming. Holocene climate change was therefore not a proximate cause for the development and demise of this relatively short-lived (c. 200 years) period of Iron Age farming. River dynamics in the Tien Shan piedmont are however strongly coupled with regional hydroclimatic fluctuations, and they have likely acted locally as ‘push’ and ‘pull’ factors for riparian agriculturists in both upstream and downstream directions (cf. Giosan et al., 2012; Macklin and Lewin, 2015).

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Appendix A. Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.quascirev.2015.10.020.

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