Sedimentary record of erosion and deformation rates in the northern Tianshan as constrained from magnetostratigraphic sections in the Junggar basin, western China

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Abstract The Junggar flexural basin which flank the Tianshan range to the north, has recorded the history of erosion and overthrusting of the range. We combine detailed magnetostratigraphic section from the fold-and-thrust piemont belts, seismic data on subsurface structures and cooling ages from detrital minerals. These data indicate that the flux of sediment eroded from the Tianshan has increased first about 15 ago and again around 11Myr ago to reach a plateau of ~50 km3/Myr (with correction for sediment compaction). Given the area of the Tianshan presently drained by this basins, the sedimentary flux imply erosion rates of the order of 0.3-0.5 mm/yr over the last 10Myr. The uppermost formation in both forelands, the Xiyu formation, consist of a dark coarse gravel often thought to mark the beginning of the Pliocene. This formation is shown to be highly diachronous: the gravel sheet has prograded over the understhrusting forelands at rates of 2.5mm/yr in the north, suggesting a shortening rate across the Central Tianshan (at 83°E) of at most 2.5mm/yr, comparable to the present 3mm/yr shortening rate. Our study shows that the shortening rate across the central Tianshan probably didn't change much over the last 8Myr and that the present tectonic regime was established between about 10 and 12Ma. There is no indication of an increase in sedimentary flux at 4-2Myr, as proposed in some earlier studies and taken to reflect enhanced erosion rates driven by a global climate change. We conclude that the Tianshan may have been reactivated by about 20-24Ma. The sedimentary flux increased by about 15Ma and again by 11Myr, probably reflecting a coeval increase of tectonic rates which lead to the creation of the topography of the modern Tianshan. The 10Myr time lag between the earliest deformation of the range and the increase in sedimentary flux might reflect the time needed to create sufficient topography to enhance surface processes and for the development of the drainage

Introduction

The growth of a mountain range results primarily from crustal thickening driven by horizontal shortening. As mountain grows surface processes become more active and operate mass transfer from the uplifted zone to the flanking lowlands. This transfer depends on climate and topography. Mountain building is therefore a complex process resulting from coupling between tectonic deformation, surface processes and climate. The redistribution of mass at the surface are key factors determining tectonic deformation. In Central Asia the high Tianshan mountains are flanked by the Tarim and the Junggar that are two large closed intracontinental basins where eroded material is shed from the Tianshan. Folding and thrusting along both the northern and southern piedmont have exposed sections of the sediment fill. This setting is particularly appropriate to quantify sediment flux into the basins and analyze the sedimentary record of thrusting.

(1) Kinematic framework

To describe the evolution of the Tianshan range we used the kinematic frame work of Figure 1.
We thus combine (1) structural model of the piedmont and the foreland basin, (2) chronological constraints on the stratigraphy derived from magnetostratigraphic sections of Neogene sediments and (3) thermochronologicals and cosmonucleid dating respectively of detrital grains and actual river sand, to determine:
- sediment flux history Fe
- timing and rate of deformation Vi of the piedmont thrust fault
- erosion rates
- sediment propagation rates Vpr

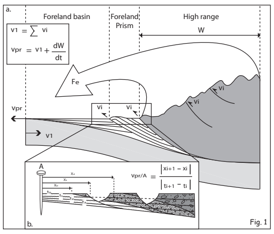
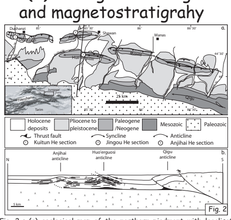


Fig. 1: schematic sketch defining the kinematic framework used in this study; V1 is the underthrusting velocity of the foreland; Vi are the shortenning rates of the various thrust that composed the piedmont and the range; Vpr is the sediment propagation rate in the foreland, Fe is the eroded material flux.

(2) Geological setting and magnetostratigrahy



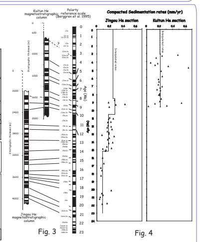
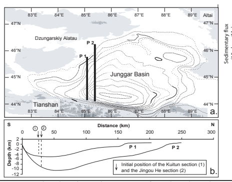


Fig. 2 : (a) geological map of the northern piedmont with localisation of the Kuitun He and the Jingou He section; (b) schematic cross section of the northern piedmont at the Jingou He longitude.
Fig. 3: magnetostratigraphic column of the Jingou He and the Kuitun He section and their correlation to the reference scale.
Fig. 4: Compacted sedimentation rates in the Jingou He and the Kuitun He section deduced from the magnetostratigraphic correlation, 1Tuncertaintie in white.

The Tianshan is a 2500-km-long range with an average altitude of 2500 m with summit up to 7000 m high. The range was originally built during Devonian to Carboniferous. During Oligocene to late Miocene ancient structures were reactivated by the India-Asia collision giving most of the living topography. The main northern Tianshan piedmont is about ~240 km-long from the Urumqi province capital to the Dushanzi city (Fig. 2a). It is constituted by three main rows of thrust fault and fold belt. Folds are mainly fold-bend fault and detachment fold. Folded and faulted sediments in the foreland present a large age span from Permien to Quaternary time and are well exposed along several north-south flowing rivers. But because sediments are mainly continental in origin their ages are poorly constrained. We thus carried out two magnetostratigraphic sections in Neogene sediments in order to better contsraint the sedimentary history related to the reactivation of the range.

(3) Sedimentary flux reconstruction



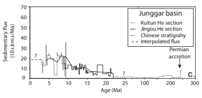
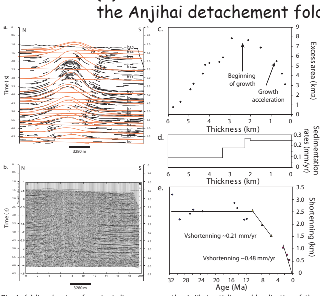
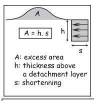


Fig. 5: (a) topographic and isopachs maps of the junggar basin; (b) longitudinal profiles of the Junggar basin at both the Kuitun and the Jingou He longitudes; (c) sedimentary flux evolution reconstructed from our magnetostratigraphic sections and the chinese stratigraphy, 1Tuncertaintie in white.

Assuming that the relative thickness is uniform throughout the basins the volume Vi above a i layer in the whole basin may be expressed as follow: $v_i = v_0 (z_i / z_0)$.
Where z_i is the true depth of the i layer at a given vertical profile, z_0 is the depth of basin basement at the same profile and V_0 is the total volume of the basin. Yet, horizontal section along river in the piedmont may be considered as vertical profiles as drill hole. We thus reconstruct the sediment flux accumulation in the Junggar basin based on the stratigraphy constrained by our magnetostratigraphic dating along the two Kuitun and Jingou He sections (Fig. 6c).
We calculated V_0 of both the Junggar and the Kuche basin by digitalizing isopachs map of the basement (Fig. 6a) and found a total volume of ~430.10³ km3. Z_i is obtained from the magnetostratigraphic thickness (giving the depth of the top of the section) and the necessary compaction correction. z_0 must be estimated giving the initial position of the sedimentary column before shortening and incorporation within the piedmont (Fig. 6b).

(4) Deformation rates across the Anjihai detachement fold

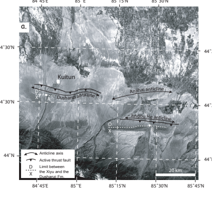


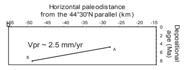


Considering a given deformed horizon of a detachement fold such as the Anjihai anticline (Fig. 6a), one can calculate the 'excess area' (Fig. 6g). between the deformed horizon and its initial geometry obtained by interpolating the horizon linearly across he fold.
Across such detachment fold, in the hypotheses that no bed parallel shear occur, pregrowth strata should be characterized by a linear relationship between excess area and thickness while growth strata should present a non-linear relationship (Fig. 6d).

Fig. 6: (a) line drawing of a seismic line ran arcoss the Anjihai anticline and localisation of the 15 horizons used to calculate the Excess area; (b) original seismic line (from Dengfa et al., 2005); (c) Excess area agianst thikcness of the 15 horizons; (d) sedimentation rates agianst thickness deduced from the magnetostratigraphic correlation; (e) Shortenning across the Anjihai antcline with respect to time, 1Tuncertaintie in white

(5) The conglomerate Xiyu formation and its propagation rates





The Cenozoic stratigraphy is characterized by a gradual coarsening upward with the dark conglomerate Xiyu formation at the top underlying the Dushanzi formation. The Xiyu formation is widely distributed along the margin of the Tianshan and have been assigned to be Plio-Pleistocene in age. From our magnetostratigraphic study we found that the basal age of the Xiyu formation at the Jingou He section is ~8.3 Ma in age while at the Kuitun section it is ~4.8 Ma in age. From these basal ages and satelit images analyses, we calculated a propagation rate of sediments Vpr of ~2.5 mm/yr, providing the initial position of the section before shortenning.
We carried out a similar analyses in the south Tianshan that give a propagation rate Vpr of ~6 mm/yr.

Fig. 7: (a) landsat image of the Dushanzi area with localisation of the Kuitun He and the Jingou He section and the limit between the Dushanzi and the Xiyu formation; (b) plot of the basal ages of the Xiyu formation versus the distance from the 44°30'N parallel

(6) Preliminary results of U-Th/He thermochronology

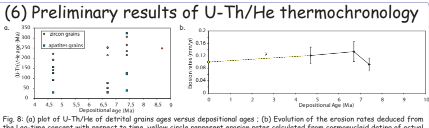


Fig. 8: (a) plot of U-Th/He of detrital grains ages versus depositional ages ; (b) Evolution of the erosion rates deduced from the Lag-time concept with respect to time, yellow circle represent erosion rates calculated from cosmonucleid dating of actual river sand of the Kuitun He river

In order to decipher the late exhumation history of the Tianshan mountains, we carried out U-Th/He dating on both apatite and zircon detrital grains collected in the Kuitun section. Results are summuraized on Figure Xa. From the youngest apatite ages providing the sediment depositional age from our magnetostratigraphic study, we also calculated the erosion rates using the lag-time concept. We found an average rates of ~0.1 mm/yr average

Discussion

From the sediment flux reconstruction we believe that, by ~15 Ma and by ~11 Ma, the Tianshan range may have underwent rapid uplift acceleration with a rising topography that is rapidly stabilized as compensated by heightened erosion rates that give higher sediment fluxes delivered to the basin. These ages are consistent with other previous studies carried out in the Tianshan.
Giving the constant sedimentary flux of ~50.10^3 km^3 during the last ~10 Ma, the geometry of the range probably did not significantly change with an equilibrium between erosion and uplift. Thus the area of the Tianshan presently drained by the Junggar basin remains probably the same over the last 10 Myr giving an average erosion rates of ~0.3-0.4 mm/yr. Moreover as the geometry of the range may have been constant, according to our kinematic model the total shortenning accross the range (V1) was of ~2.5 mm/yr during the last ~8 Myr which is consitent with the present day rates of ~3 mm/yr. This reinforces the idea that that the present tectonic regime was established between about 10 and 12Ma.
Some authors have interpreted the Xiyu formation as reflecting directly tectonic uplift (e.g., Zheng et al, 2000) while others assign it to a global effect of climate change on erosion rates (Peizhen et al, 2001). Our interpretation is that this gravel sheet was prograded over the foreland as it was underthrusting beneath the orogenic wedge. We reject the common assumption that these conglomerates would reflect climate change or a particular episode of thrusting and uplift of the Tian Shan.